The Sparing Is Far From Spurious: Reevaluating Within-Trial Contingency Effects in the Attentional Blink

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The attentional blink is the marked deficit in awareness of a 2nd target (T2) when it is presented shortly after the 1st target (T1) in a stream of distractors. When the distractors between T1 and T2 are replaced by even more targets, the attentional blink is reduced or absent, indicating that the attentional blink results from online selection mechanisms that act in response to distracting input rather than being the result of T1-induced cognitive resource depletion. However, Dell'Acqua, Jolicoeur, Luria, and Pluchino (2009) recently contended that an attentional blink is found in the multiple-target case as long as the appropriate trial context and analyses are used, thus reinstating resource-based explanations of the attentional blink and challenging the selection account. Specifically, an attentional blink reemerges when target performance is analyzed contingent on previous target accuracy. We argue on theoretical and empirical grounds that neither the trial context nor the type of analysis poses a serious problem for selection accounts. We show that the attentional blink and previous target contingency effects can be dissociated, with the latter depending more on low-level, short-range competition. We conclude that selection mechanisms involved in filtering for targets still provide a strong and coherent explanation of the attentional blink.

Keywords: selective attention, attentional blink, working memory, inhibition

The *attentional blink* refers to the marked deficit in awareness of a relevant perceptual event when this event is presented shortly after another relevant perceptual event. It is typically measured using the rapid serial visual presentation (RSVP) paradigm, in

which observers are instructed to report two targets (T1 and T2, often letters), which are embedded in a stream of distractors (e.g., digits), all presented at the same location at a rate of about 10/s. The lag between T1 and T2 is varied systematically. The common finding is that T2 detection or identification accuracy suffers when presented at short lags after T1, but it recovers within about 500 ms. This temporary dip is called the attentional blink (Raymond, Shapiro, & Arnell, 1992).

There has been recent debate on what causes the attentional blink. For the past 20 years, the phenomenon has been taken as one of the seminal pieces of evidence for the capacity limitations of the brain's perceptual systems (see, e.g., Broadbent & Broadbent, 1987). The core model is Duncan's (1980) two-stage theory. According to this theory, target as well as distractor objects are processed in parallel up to the level of representation that allows viewers to distinguish between them. Targets are then selected for a second stage involving higher cognitive processes such as memory consolidation, awareness, and response selection. However, second-stage processing is limited to about one object at a time, and in case of multiple simultaneous targets, one or more are likely to suffer from the capacity limitations. Chun and Potter (1995) have successfully applied this idea to the attentional blink paradigm, in which the targets do not appear simultaneously, but shortly after each other (see also Jolicoeur & Dell'Acqua, 1998;

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Shapiro, Arnell, & Raymond, 1997). The general idea is that T1 occupies the second processing stage for up to 500 ms, therefore denying high-level resources to T2.

The attentional blink is usually deepest when T2 appears at Lag 2 or 3, when one or two distractors are presented between T1 and T2. In contrast, at Lag 1, when T2 immediately follows T1, performance is typically spared. This Lag 1 sparing effect is problematic for a resource-depletion account, but it can be explained by the hypothesis that, under these circumstances, T1 and T2 are combined into a single representation (e.g., Bowman & Wyble, 2007). However, recent findings have been more challenging to the general resource depletion model, most notably the finding that sparing is not limited to Lag 1. The attentional blink has been found to be reduced or absent for targets at later lags when the intervening distractors are replaced by even more targets (Di Lollo, Kawahara, Ghorashi, & Enns, 2005; Olivers, Van der Stigchel, & Hulleman, 2007). For example, in a condition containing three consecutive targets (T1–T2–T3), performance for the last target was much improved over performance for the last target when the middle item was a distractor (T1–D–T2). This happened despite the fact that a T1 had to be processed in both conditions, and despite the fact that the three-target condition contained more targets (which, according to resource-depletion accounts, should lead to a deeper rather than a shallower blink). Di Lollo, Olivers, and their respective colleagues therefore concluded that the attentional blink does not reflect a T1-induced resource depletion, but instead a temporary disruption or inhibition of the perceptual input following the presentation of the post-T1 distractor. The idea is that the attentional blink is not caused by limitations in second-stage processing, but by gating or filtering mechanisms at the *transition* of information from the first to the second stage. In other words, the attentional blink is a selection problem, not a capacity problem. A computational model developed by Olivers and Meeter (2008) demonstrates that such a scenario can account for a large variety of attentional blink findings without having to assume capacity limitations (see also Taatgen, Juvina, Schipper, Borst, & Martens, 2009; Wyble, Bowman, & Nieuwenstein, 2009).

This is not to deny that there are capacity limitations. For example, observers obviously face limitations when having to actively remember things by storing them in visual short-term memory (VSTM). Furthermore, when presented at very close temporal range (i.e., around 100 ms or less), targets appear to compete directly with each other, during the first stage of processing, when sensory and conceptual representations are still feeble (Potter, Staub, & O'Connor, 2002; Wyble et al., 2009). What selection accounts claim, however, is that such limitations are not sufficient or necessary to explain the attentional blink. For instance, VSTM storage capacity is typically around three to four items (Cowan, 2001), which should be sufficient to store the usual number of targets in the attentional blink task. Moreover, the close-range Stage 1 competition between targets cannot account for the 200- to 500-ms deficit that is called the attentional blink.

A Challenge to Selection Accounts

A key finding supporting the selection account over the resource-depletion account is the substantial reduction of the attentional blink for the final target in the three consecutive target case (T1–T2–T3) relative to the intervening distractor case

(T1–D–T2). It is this finding that has recently been challenged by Dell'Acqua et al. (2009). In essence, Dell'Acqua et al. make two claims: (a) Relative accuracy for T3 in the three-target sequence depends on the observer's expectations of how many targets will appear in the stream or at which lags, with more uncertainty leading to worse performance; (b) relative accuracy for T3 depends critically on how one analyzes the data, and the analyses performed by Di Lollo et al. (2005) and Olivers et al. (2007) were not entirely correct. These two claims have important theoretical implications, as they serve to challenge the selection account and to rehabilitate the resource-depletion account of the attentional blink. In the present study, we argue that although the Dell'Acqua et al. study indeed reveals competition between targets—and as such is a relevant and important study—their claims do not present a serious challenge for selection accounts.

Reevaluating Capacity Limitations

Uncertainty Reduction

With regard to the first claim, Dell'Acqua et al. (2009) write that “reducing the level of uncertainty allowed a more efficient processing of contiguous sequential targets, a finding that is consistent with prior work . . . suggesting that subjects' advance knowledge about the structural or temporal organization of RSVP paradigms often results in beneficial effects on post-T1 targets processing,” followed by the statement that this poses a “serious challenge” for selection models because it shows a “subjectively controlled dynamic adjustment of the accessibility of VSTM” (p. 349). Indeed, Experiment 2 of Dell'Acqua et al. shows that knowing the number of targets in advance aids T3 performance: Identification accuracy was higher when target number was blocked than when it was mixed. Experiment 3 also had a fixed number of targets, and again performance was better than in Experiments 1 and 2 (even better than in the fixed condition of the latter). Variability in lag did not appear to matter to overall T3 performance (Experiment 3), although across experiments it appears it may have interacted with the uncertainty about the number of targets because performance was worst when both lag and number of targets were uncertain. These are important findings, and are consistent with earlier indications that mixing the number of targets or lags may indeed have some detrimental effect on final target performance (Di Lollo et al., 2005; Kawahara, Kumada, & Di Lollo, 2006; Olivers et al., 2007). The question is whether they really pose a serious challenge for the selection account. We think not. Indeed, it is to be expected that performance should deteriorate when the number of targets is unknown. Any general theory that allows for top-down, strategic modulations of attention could make this prediction. In fact, selection models are exactly the models that allow for dynamic adjustment of access to VSTM (even online). Naturally, flexible resource models can also account for such effects by assuming a redistribution of resources, but real bottleneck models appear to assume a more structural limitation and as such would have more difficulty.

So, we agree that uncertainty can aggravate the attentional blink, but it is not necessarily the cause of it. Note that in most of their experiments, Di Lollo et al. (2005) and Olivers et al. (2007) compared their three-target condition (T1–T2–T3) with a two-target condition (T1–D–T2) in which both the number of targets

and the lag were fixed. Yet, there was an attentional blink in the two-target case, but not the three-target case. In brief, given that reductions of uncertainty are achieved through goal-directed top-down processes, the improved performance under conditions of reduced uncertainty is at least as aptly explained by selection models as by resource-depletion models. In the remainder of this article, therefore, we focus on the second, potentially more challenging, claim that the good T3 performance was possibly an artifact of the analyses used by Di Lollo et al. (2005) and by Olivers et al. (2007).

Potential Analysis Artifacts

The second claim made by Dell'Acqua et al. (2009) is that whether a T3 benefit is found in contiguous-target triplets depends on the analysis performed on the data. Given that T1 is assumed to be critical for the attentional blink, performance on any subsequent target should be analyzed contingent on T1 being reported correctly. This procedure is commonly adopted in attentional blink experiments on the grounds that, on trials in which T1 is identified incorrectly, the source of the error is unknown, and thus its effect on the processing of subsequent targets cannot be estimated. Dell'Acqua et al. argue that similarly, in the three-target condition, T3 performance should be assessed contingent on both T1 and T2 being reported correctly because only then can we be sure that limited capacity resources are maximally drained. As correctly pointed out by Dell'Acqua et al., Di Lollo et al. (2005) did not analyze T3 performance contingent on T1 or T2 performance. Olivers et al. (2007) did analyze their data contingent on T1, but not on T2 performance. Dell'Acqua et al. claim that this failure to apply the within-trial contingency (WTC) procedure may explain why no attentional blink was found for T3 in the Di Lollo et al. and Olivers et al. experiments. Indeed, when Dell'Acqua et al. analyze their own data with and without applying the WTC procedure, they demonstrate that this makes significant differences: T3 performance shows a greater drop relative to T1 performance when WTC is applied. This drop can be taken as evidence for the presence of an attentional blink, consistent with resource depletion models and against selection models.

In the remainder of this article, we argue that the second claim of Dell'Acqua et al. (2009) is beset by a number of theoretical and empirical issues that need to be addressed first to assess the validity of the argument. At a theoretical level, we note that the rationale for a T2-contingent analysis is questionable. At the empirical level, we show that WTC effects were relatively weak in the original Olivers et al. (2007) and Di Lollo et al. (2005) studies, and even in studies designed to demonstrate a trade-off in resources (Dux, Asplund, & Marois, 2008, 2009). We also report a number of experiments that investigate the source of the WTC effect, and whether it indeed reflects an attentional blink in disguise.

Theoretical Issues

It is important to emphasize that according to resource-depletion models, T1 is the culprit in the standard attentional blink for T2: T1 drains the second-stage resources, leaving few for T2. No attentional blink is found when there is no T1. Thus, the presence of T1 is a necessary but above all a *sufficient* condition to produce

an attentional blink. No additional targets are necessary to create a blink. Dell'Acqua et al. (2009) are thus correct in saying that it makes sense for any analyses to be contingent on T1. By the same token, a T1-contingent analysis is sufficient. Notably, if T1 is the cause of the final target deficit in a T1–D–T2 sequence, it should also be a sufficient cause of the final target deficit in a T1–T2–T3 sequence. They are both in the same temporal relationship to T1. In other words, to test whether T1 processing is the cause of the attentional blink, there is no a priori reason to also analyze performance for T3 contingent on T2.

In fact, as was pointed out by Dell'Acqua et al. (2009, p. 339), in the conventional two-target task there is usually little difference in attentional blink magnitude whether or not T2 accuracy is analyzed contingent on T1 accuracy. This may be because with T1 accuracy often above 90%, the additional 10% of trials does not make that much difference. Furthermore, a large proportion of missed T1 may still have been processed up to a reasonably high level, and thus cause an attentional blink even on those trials. The fact that contingency analysis suddenly matters considerably more for T3 when another target is inserted immediately prior to it suggests that something different may be going on.

Given the above potential problems in interpreting contingency effects, a safer comparison in our view is the one between the final target of the T1–T2–T3 sequence and the final target of the T1–D–T2 sequence (for correct T1 trials, as was done by Olivers et al., 2007). Crucially, selection accounts predict an improvement for T3 in the former sequence, whereas resource accounts predict the exact opposite, namely deterioration. It is this qualitatively different prediction that makes the test so strong. Unfortunately, Dell'Acqua et al. (2009), although including two-target trials, did not include the T1–D–T2 sequence necessary for this comparison.

Despite all this, a case can actually be made for direct competition between multiple targets, as long as these targets are presented very closely in time (Potter et al., 2002; see also Kawahara & Enns, 2009; Olivers, Spalek, Kawahara, & Di Lollo, 2009; Wyble et al., 2009). When analyzing standard attentional blink data (with two targets), it is often found that T2 performance is remarkably accurate at Lag 1 (the aforementioned Lag 1 sparing), but that often this improvement occurs somewhat to the detriment of T1. It seems that at short stimulus onset asynchronies (SOAs) of around 100 ms or less, the T1 and T2 representations compete with each other such that T1 can suffer despite it having a head start. This may even result in order reversals during report. In the three-target case, T2 and T3 may likewise compete with each other. It is questionable, however, whether this type of competition explains the attentional blink. The time range up to about 100 ms is associated with many low-level processes involved in masking, temporal integration, object substitution, direct semantic competition, and the like (Michaels & Turvey, 1979; Kahneman, Treisman, & Burkell, 1983; Potter, Dell'Acqua, Pesciarelli, Job, & Peressotti, 2005; Wyble et al., 2009). For example, in the Olivers and Meeter (2008) model, contiguous targets suffer from more forward and backward masking due to the structural or semantic similarity of the neighboring items. The attentional blink, on the other hand, is often found to be maximal in the range of 200–300 ms and beyond and when dissimilar items (i.e., distractors) intervene.

Empirical Issues

The idea that the results of Di Lollo et al. (2005) and Olivers et al. (2007) may have depended on the failure to apply the WTC procedure can be tested by reanalyzing those data. Table 1 shows an overview of the proportions correct for the various three-target experiments of Di Lollo et al. and Olivers et al. For completeness, we also included the data of Kawahara, Kumada, and Di Lollo (2006), Dux et al. (2008, 2009), and Dell'Acqua et al. (2009). As can be seen from this table, applying the WTC procedure indeed had a negative effect on T3 performance, although in most experiments the effect was rather small and unreliable. In addition to the study by Dell'Acqua et al., the two most notable exceptions were the experiment reported by Kawahara, Kumada, and Di Lollo (2006), in which short and long lags were randomly mixed within blocks, and Experiment 3 of Olivers et al., in which the number of targets, as well as a variety of lags, was randomly mixed within blocks. Taken together, the experiments thus confirm the findings of Dell'Acqua et al. that (a) WTC has some effect; (b) uncertainty about the number of targets is detrimental for T3 relative to T1 (especially when T1 and T2 are reported correctly); and (c) uncertainty about lag does not result in T3 being worse than T1, although it does contribute to the WTC effect.

Another important observation that can be made is the apparent independence of the WTC effect, on the one hand, and the attentional blink (as expressed by the T1–T3 difference) on the other. Di Lollo et al. (2005) and Olivers et al. (2007) found relatively small WTC effects and small attentional blinks. Kawahara, Kumada, and Di Lollo (2006) found large WTC effects but no blink whatsoever. Dux et al. (2008, 2009) found small WTC effects but quite large blinks in some experiments, and finally Dell'Acqua et al. (2009) found both large WTC effects and large blinks. This strongly suggests that different factors may be underlying the two effects, as we argue again later.

The most important observation, however, is that even when WTC is applied, and even under conditions of uncertainty, T3 performance was still considerably *better* than T2 when presented in the equivalent temporal position of the T1–D–T2 sequence in all those experiments that tested this comparison (Di Lollo et al., 2005; Olivers et al., 2007; but also Dux et al., 2008, 2009). Thus, Dell'Acqua et al. (2009) were correct in pointing out that WTC may change the absolute level of T3 accuracy when measured under conditions of uncertainty, but their claim that this poses a serious challenge for selection accounts does not hold. To wit, the relative sparing remained intact, consistent with selection accounts. The question then remains as to what causes the WTC effect, and why it may have been stronger in the Dell'Acqua et al. study than in most other studies. We believe that the short-range competition mentioned earlier may play some role, as we explore next.

Experiment 1: Replicating Dell'Acqua et al. (2009)

Given the large number of conditions, Dell'Acqua et al. (2009) measured at most 14, but typically only 7 data points per cell. When analyzing contingent on T1 and T2 correct, this often left only a handful of data points for the crucial T3 comparisons and occasionally led to empty cells. It deserves pointing out, however, that their WTC effects were reliable and consistent across three

experiments. However, a potentially important limitation of the few trials per cell is that observers receive little opportunity to gain experience with a particular trial type. This may also explain why a larger variety of conditions (i.e., increased uncertainty) may negatively affect performance. Furthermore, because our own previous studies have generated rather weak and inconsistent WTC effects (see Table 1), we thought it prudent to try to replicate the Dell'Acqua et al. results. We followed their Experiment 3 as closely as possible (including their software, timing, luminance values, font). The differences were that we limited the measurements to the contiguous three-target condition (T1–T2–T3) because this is the condition central to the debate, and we measured 100 data points to increase the chances of observers becoming familiar with the target triplet. Furthermore, the on-screen instructions were translated from Italian to Dutch.

Method

Participants. Twelve undergraduate students of the Vrije Universiteit Amsterdam participated in return for course credits or €7 an hour.

Stimuli. The experiment was run in a dimly lit cubicle. The stimuli were 22 letters of the English alphabet (all except the letters *B*, *I*, *O*, and *Z*) and the digits 2–9. These characters were displayed in light gray (34 cd/m²) on a uniform black background (6 cd/m²) on a CRT screen placed about 70 cm from the participant's eyes, using MEL software. All characters fit in a virtual square with a side of 0.95°. An RSVP of mainly letters was used, each of which was displayed for 84 ms at the center of the screen and was immediately replaced by the next item (interstimulus interval [ISI] = 0 ms). The letters were selected randomly without replacement. Three consecutive letters were each replaced with a digit target (T1, T2, and T3). No digit was ever repeated in a given RSVP stream. The number of letters preceding T1 was varied randomly from two to five across trials. Each RSVP stream ended with between two and four distractors following the last target.

Design and procedure. Each trial began with the presentation of a plus (+) sign at the center of the screen. The trial started with a space bar press, which caused the plus sign to disappear. After a fixed blank interval of 800 ms, the RSVP stream was displayed. A question was displayed 800 ms after the end of the RSVP stream, inviting participants to report the digit(s) by pressing the corresponding keys on the numeric keypad of the computer keyboard or 0 if no digit was seen. The instructions mentioned explicitly that the order in which the responses were given (when more than one response was made) was not important. Responses were made without speed pressure, and were followed by feedback on accuracy for each target. There were four blocks of 25 trials, preceded by a single practice block of 10 trials. Thus, in total there were 100 trials available for the analyses.

Results and Discussion

The results are shown in Figure 1. For the sake of simplicity and comparability to the Dell'Acqua et al. (2009) results as presented in their Figure 3, we left out T2 performance here and in the next experiments. Accuracy for T2 typically exceeded that of T1 and T3, in line with our earlier work. Figure 1A shows the results when all trials were analyzed. A clear WTC effect was found: T3

Table 1
Percentage Correct Responses for Target 1, Target 2, and Target 3 in the Various Two- and Three-Target Conditions of the Studies of Di Lollo et al. (2005); Kawahara, Kumada, and Di Lollo (2006); Olivers et al. (2007); Dux et al. (2008, 2009); and Dell'Acqua et al. (2009)

Study	Experiment	Condition	p(T1)	p(T2)	p(T2 T1)	p(T3)	p(T3 T1^T2)	WTC effect: p(T3 T1^T2) - p(T3)	AB effect: p(T3 T1^T2) - p(T1)	Sparing effect: p(T3 T1^T2) for T1-T2-T3 - p(T2 T1) for T1-D-T2
Di Lollo et al. (2005)	1	T1-D-T2	85.5	59.4	55.3	72.9	64.8	-8.1 ($p < .001$)	-7.4 (<i>ns</i>)	9.5 ($p < .005$)
		T1-T2-T3	72.2	87.2	86.4					
	1a	T1-D-T2	91.9	74.6	73.4					
		T1-T2-T3	87.6	91.7	91.2	82.1	80.2	-1.9 (<i>ns</i>)	-7.4 ($p < .01$)	6.8 ($p < .01$)
	2	T1-D-T3	84.3	54.8	51.6					
Kawahara, Kumada, & Di Lollo (2006)		T1-T2-T3	77.1	87.9	87.7	72.1	67.4	-4.7 (<i>ns</i>)	-9.7 ($p < .05$)	15.8 ($p < .005$)
Olivers et al. (2007)	1	T1-T2-T3	64.2	79.4	73.2	75.9	64.1	-11.8 ($p < .001$)	2.2 (<i>ns</i>)	
		T1-D-T2	93.1	64.6	63.5					
		T1-T2-T3	85.8	94.4	94.5	87.5	83.9	-3.6 (<i>ns</i>)	-1.9 (<i>ns</i>)	20.4 ($p < .01$)
	2	T1-D-T2	75.0	57.3	52.9					
		T1-T2-T3	68.1	84.7	82.5	79.2	75.4	-3.8 (<i>ns</i>)	7.3 (<i>ns</i>)	22.5 ($p < .02$)
Dux et al. (2008)	3	T1-D-T2	75.7	40.8	33.2					
		T1-T2-T3	69.7	76.7	72.9	61.5	51.1	-10.4 ($p < .001$)	-18.6 ($p < .001$)	17.9 ($p < .001$)
	1 ^a	White T1-D-T2	91.7	64.9	63.0					
		White T1-T2-T3	81.7	87.6	87.1	76.6	75.4	-1.7 (<i>ns</i>)	-6.3 (<i>ns</i>)	12.5 ($p < .02$)
		Red T1-D-T2	95.9	51.6	47.0					
Dux et al. (2009)	2	Red T1-T2-T3	89.5	80.7	81.4	60.9	58.9	-2.0 (<i>ns</i>)	-30.6 ($p < .01$)	11.4 (<i>ns</i>)
	1 ^b	T1-T2-T3	92.3	85.2	84.7	66.1	64.3	-1.8 (<i>ns</i>)	-28.0 ($p < .01$)	
		T1 rel.; T1-D-T2	84.3	47.4	46.4					
		T1 rel.; T1-T2-T3	75.1	81.9	81.9	63.3	58.2	-5.2 ($p < .0001$)	-16.9 ($p < .001$)	11.8 ($p < .02$)
		T3 rel.; T1-D-T2	80.6	53.9	43.7					
Dell'Acqua et al. (2009)	2a	T3 rel.; T1-T2-T3	65.4	80.1	80.1	73.6	70.3	-3.3 ($p = .06$)	4.9 (<i>ns</i>)	26.6 ($p < .001$)
	2b	T1-T2-T3	84.6	83.4	84.3	68.4	66.6	-1.7 (<i>ns</i>)	-18.0 ($p < .001$)	
	2c	T1-T2-T3	82.9	79.6	79.9	62.9	58.0	-4.9 ($p < .02$)	-24.8 ($p < .001$)	
	1	T1-T2-T3	85.5	86.0	85.7	75.1	72.7	-2.4 (<i>ns</i>)	-12.8 ($p < .02$)	
	2	T1-T2-T3	72.0			68.0	46.0	-22.0 ($p < .05$)	-24.0 ($p < .05$)	
	2	T1-T2-T3	78.0			73.0	61.0	-12.0 ($p < .02$)	-17.0 ($p < .01$)	
	3	T1-T2-T3	76.0			77.0	68.0	-9.0 ($p < .01$)	-8.0 ($p < .05$)	

Note. Performance for T2 and T3 are also given contingent on earlier target performance. The net within-trial contingency (WTC) effect is performance for T3 contingent on T1 and T2 correct minus performance for T3 on all trials. The attentional blink (AB) effect is the measure for the AB as used by Dell'Acqua et al., namely T3 performance minus T1 performance. The sparing effect is the relative benefit for T3 in a three-target condition relative to T2 in the same temporal position in a two-target condition.

^a In this experiment, targets could be all white or all red, in a stream of white items. Dux et al. (2008, 2009) excluded all trials on which none of the targets were reported correctly. We included these trials in our analyses, but this makes only subtle differences. ^b In the instruction of this experiment, either T1 was emphasized as more relevant (T1 rel. condition) or T3 was emphasized as more relevant (T3 rel. condition). All items were white. In the T1-relevant condition, one subject was left out of the analyses as s/he did not produce any trials on which both T1 and T2 were correct. In the T3-relevant condition, two subjects were left out for this reason.

Figure 1. The effect of within-trial contingency (WTC) on third target (T3) performance in Experiment 1, for (A) all experimental trials and (B) only the first 14 experimental trials.

performance was a good 10% worse when analyzed contingent on T1 and T2 being correct, compared with when all trials were included, $t(11) = 3.21$, $p < .01$. This clearly replicates the WTC effect reported by Dell'Acqua et al. However, the results do not replicate the Dell'Acqua et al. finding that when WTC is applied, T3 performance becomes significantly worse than T1 performance (the difference here was only 2%), $t(11) < 0$, $p > .65$. In other words, there was still no sign of an attentional blink. Figure 1B suggests one potential source of this discrepancy: When analyzing only the first 14 trials in each cell, the average performance for T1 remained the same, but average performance for T3 dropped, such that when applying the WTC procedure, it ended up 11% below T1 performance. This difference rose to 14% when only the first seven trials were taken into account (although the now noisier data prevented this difference from being reliable; one participant had to be dropped from the analysis because of an empty cell). We therefore tentatively propose that the more experience observers have with a particular trial type (in this case, the T1–T2–T3 triplets), the more the later targets (in this case, T3) may benefit. Note that this is not unlike what Dell'Acqua et al. suggested with their first claim, namely that T3 performance may benefit from a consistent task context: It may simply take a minimum number of trials to firmly establish this context. We repeat here that such context effects are not particularly damaging to selection accounts.

In all, we conclude that the Dell'Acqua et al. (2009) findings were largely replicated, even though the effects of T1 processing on T3 were not as dramatic here as in their study.

Experiment 2: WTC Effects Are Stronger at Shorter SOAs

With the Dell'Acqua et al. (2009) WTC effect replicated, we set out to further investigate what causes these WTC effects. Although on the surface the paradigms seemed very similar across the different labs, at close inspection there is actually an extensive set of differences (from the way a trial is started to the way responses were entered), each of which may have contributed to the effect. An exhaustive search for potential factors (let alone potential interactions between these factors) is beyond the scope of this article.

As discussed previously, one thing the literature suggests is that when targets are presented at really close temporal succession (i.e., one immediately after the other), an early competition between elements may take place prior to selection for the second (working memory) stage of processing (Potter et al., 2002). Such direct short-range competition may occur at a sensory level (i.e., resulting in masking; Bachmann & Hommuk, 2005) or even at a more conceptual level (i.e., letters suppressing other letters). For example, it is known that when a target is preceded by distractors that share its structural or semantic characteristics, it suffers relatively more from visual masking than when it is preceded by a distractor with different characteristics (Kawahara, Enns, & Di Lollo, 2006, Experiment 3). T3 may then suffer more when T1 and T2 are particularly strong examples of the target class, leading to WTC effects. One prediction from such short-range processes would then be that WTC effects increase with decreasing SOA between items in the RSVP stream. At 84 ms, the SOA used by Dell'Acqua et al. (2009; who found strong WTC effects) was shorter than the 100 ms to 125 ms used by Di Lollo et al. (2005; who found intermediate WTC effects) and Olivers et al. (2007; who found hardly any WTC effects). To test this prediction, we systematically varied the interitem SOA between 50 ms and 150 ms at 25-ms steps for the three-target case.

Method

Participants. Seventeen undergraduate students of the Vrije Universiteit Amsterdam participated in return for course credits or €7 an hour. One participant was omitted from the analyses because of near-chance performance on T1.

Stimuli, design, and procedure. The methods were the same as those in Experiment 1, except for the following changes. The characters were displayed in Courier New font, in black on a gray (40 cd/m²) background, using E-Prime software. They measured approximately 0.8° × 0.8°. The RSVP series was 22 characters long, and between 11 and 15 items preceded T1. Targets were drawn from the set 0 to 9. The trials were not self-paced, but started automatically. It is important to note that the SOAs varied between 50 ms and 150 ms, with steps of 25 ms. The ISI was 25 ms. SOA was blocked. There were 75 trials for each cell.

Results and Discussion

Figure 2 shows the average proportion correct for T3 as a function of WTC and SOA. An analysis of variance (ANOVA) with WTC and SOA as factors revealed a main effect for each, and an interaction, $F(1, 15) = 23.3$, $MSE = 0.0013$, $p < .001$, $\eta_p^2 =$

Figure 2. The effect of within-trial contingency (WTC) on third target (T3) performance in Experiment 2 as a function of interitem stimulus onset asynchrony (SOA). Separate *t* tests revealed significant WTC effects for SOAs of 50 ms ($p < .001$), 75 ms ($p < .01$), and 100 ms ($p < .05$).

.608; $F(4, 60) = 4.22$, $MSE = 0.009$, $p < .01$, $\eta_p^2 = .219$; and $F(4, 60) = 14.14$, $MSE = 0.00090$, $p < .001$, $\eta_p^2 = .485$, respectively. As expected, performance improved with increasing SOA. It is important to note that applying the WTC had a greater effect at short SOAs than at long SOAs, consistent with short-range competition or masking effects.

Experiment 3: The Attentional Blink and WTC Effects Can Be Dissociated

The previous experiment showed that, with three consecutive targets, WTC effects on T3 increased with decreased SOA between the targets. This stands in contrast to what has been found with regard to the attentional blink itself in the standard two-target case. At normal presentation rates of around 10 items per second, the attentional blink for T2 is usually deepest for Lag 2 or 3, and becomes less severe for the shorter lags. This suggests that the attentional blink is most severe at 200 to 300 ms after T1. Several studies have shown that the dip in performance is *time* based rather than *lag* or *item* based, with the trough of the attentional blink remaining at 200 to 300 ms regardless of presentation rate (Bowman & Wyble, 2007; Martens, Munneke, Smid, & Johnson, 2006; Nieuwenhuis, Gilzenrat, Holmes, & Cohen, 2005). For example, Bowman and Wyble (2007) found that the worst performance for T2 shifted from Lag 3 to Lag 6 when they doubled the stream speed from 10 to 20 items per second, whereas performance was now spared at Lag 2.

Thus, it appears that there may be a dissociation between WTC effects (the stronger the closer the targets are spaced in time) and the attentional blink itself (which is strongest for targets spaced at 200 to 300 ms). The present experiment further tested for this potential dissociation. As in the previous experiment, we varied the presentation rate by varying the interitem SOA. However, instead of three targets, there were the standard two targets, separated by a distractor (i.e., T2 followed T1 at Lag 2). By varying the interitem SOA, we could then find the point at which the overall deficit in T2 performance relative to T1 performance was worst—in other words, where the attentional blink was deepest.

On the basis of the earlier work mentioned above, we expected this trough to lie between 200 and 300 ms after T1. With T2 being presented at Lag 2, this would imply an interitem SOA of around 125 ms. At the same time, on the basis of the results of Experiment 3, we expected the WTC effect to be maximal for the shorter SOAs, in line with the direct but short-range competition that occurs between targets presented very closely in time.

To maximize the sensitivity of our test, we increased the number of SOAs. We also changed the stimuli to letter targets among meaningless fantasy characters. These displays were used previously in Experiment 2 of Olivers et al. (2007) and have some advantages for our present purpose. For one, Olivers et al. found the standard attentional blink to be maximal at Lag 3 for these displays, with an interitem SOA of 125 ms. This suggests that the attentional blink is relatively slow to develop for these types of display, potentially allowing for a maximal dissociation with the WTC effect. In addition, these target and distractor stimuli were quite difficult to distinguish, resulting in an average T1 performance of just under 70%. A relatively low T1 performance allows for a more sensitive measure of the WTC effect as it leaves a sufficient number of trials on which T1 is *not* detected. Rather than comparing final target performance when T1 was detected (i.e., $p[T2|T1]$) with performance regardless of whether T1 was detected (i.e., $p[T2]$), one can now directly compare it with performance when T1 was not detected (i.e., $p[T2|\neg T1]$). This comparison is the ultimate measure of what effects full T1 processing has on T2 processing.

Method

Participants. Twelve undergraduate students of the Vrije Universiteit Amsterdam participated in return for course credits or €7 an hour.

Stimuli, design, and procedure. The methods were the same as those in Experiment 2, except for the following changes. There were only two targets, with T2 presented at Lag 2. The targets were now drawn from a set of 23 letters consisting of a particular combination of line segments within a virtual square and its diagonals (similar to the characters often used in LCD displays of electrical appliances). Distractors were now drawn from a set of 23 fantasy characters, which were created by reshuffling the line segments of the letters to form unrecognizable figures that were still somewhat letter-like (e.g., within a character line segments had to be connected). The SOAs now ranged from 50 and 200 ms in steps of 16.7 ms. The ISI was half the SOA. SOAs were randomly mixed within blocks. There were 50 trials for each cell.

Results and Discussion

The top part of Figure 3 shows the average proportion correct T1 and T2 detection as a function of interitem SOA. The performance for T2 is further split according to whether or not T1 was reported correctly. We first assessed the overall attentional blink effect, that is, comparing T1 and T2 performance regardless of whether T1 was correct, in an ANOVA with target and SOA as factors. As expected, overall performance increased with SOA, $F(1, 11) = 112.54$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = .911$, and was overall better for T1 than for T2, $F(1, 11) = 39.82$, $MSE = 0.02$, $p < .001$, $\eta_p^2 = .784$. However, T2 performance was only worse

Figure 3. Top panel: T1 (diamonds) and T2 (squares) performance as a function of stimulus onset asynchrony (SOA) and different within-trial contingencies. Bottom graph: The overall attentional blink effect (T1–T2 performance) and the WTC effect ($T2/(T1-T2/T1)$) as a function of SOA.

for the intermediate SOAs, not for the very short or very long SOAs, resulting in a Target $\times$ SOA interaction, $F(9, 99) = 9.41$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = .461$. The differences between T1 and T2 performance as a function of SOA are plotted in the bottom graph of Figure 3. As can be seen from the graph, this T1–T2 difference peaks at SOAs of 133 to 150 ms, and tapers off toward the extremes. Separate t tests further confirmed that the difference at 134 ms was the most reliable of all differences, $t(11) = 7.08$, $p = 2 \times 10^{-5}$.

We then assessed the WTC effects by comparing T2 performance when T1 was correct ($T2/T1$) versus when T1 was incorrect ($T2/(T1-T2/T1)$) as a function of SOA. The average number of trials in the T1 incorrect condition ranged from 35 at the shortest SOA to seven at the longest SOA.¹ As expected, performance increased with SOA, $F(9, 99) = 30.92$, $MSE = 0.018$, $p < .001$, $\eta_p^2 = .738$. There was a trend toward better T2 performance when T1 was missed, $F(1, 11) = 4.05$, $MSE = 0.132$, $p = .069$, $\eta_p^2 = .269$. Most important was the finding that WTC effects varied as a function of SOA, $F(9, 99) = 4.3$, $MSE = 0.013$, $p < .001$, $\eta_p^2 = .281$. The bottom part of Figure 3 plots the difference on T2 performance between T1 incorrect and T1 correct trials, and shows that the WTC effect tended to be maximal toward the short end of the SOA range. Numerically, it was maximal at an SOA of 100 ms, and statistically it was most reliable at 83 ms, $t(11) = 4.50$, $p < .001$.

Thus, maximal WTC effects appeared to occur earlier than the maximum of the attentional blink itself. To further test for such a difference, we determined the SOAs at which the WTC effect peaked for each participant, and compared this with the SOAs at which the attentional blink effect peaked. The peak WTC effect occurred on average at 94 ms, whereas the peak attentional blink effect occurred on average at 129 ms, a 35-ms difference that was significant, $t(11) = 5.02$, $p < .001$. The same was true when we compared the second largest peak for each of the measures: Across the participants, this averaged to 92 ms for the peak WTC effect and to 125 ms for the peak attentional blink effect, a 33-ms difference that was again significant, $t(11) = 2.86$, $p < .02$. Furthermore, for the shorter SOAs (50 and 66 ms), there was a (close to) reliable WTC effect, $t(11) = 2.05$, $p = .06$, and $t(11) =$

3.07, $p = .01$, but no attentional blink; in fact, at 50 ms, there was a T2 benefit, $t(11) = 2.9$, $p < .02$, and no reliable effect at 66 ms, $t < 1$. In contrast, for SOAs of 133 ms and upwards, there were no reliable WTC effects (at 133 ms, $t < 2$; at 150 ms and beyond, $t < 1$), whereas there were reliable attentional blinks, $t_s > 2.2$, $p_s < 0.04$.²

These results point toward a dissociation between the attentional blink and the WTC effect. If the WTC effect reflects an attentional blink in disguise, then it would be expected that both effects peak at the same point in time. That is, if at a particular time point the cognitive system is maximally sensitive to whatever limitation underlies the attentional blink, it should at the same time be maximally sensitive to the WTC effect. This turned out not to be the case. Overall, the T2 deficit relative to T1 was maximal for an interitem SOA of around 130 ms, which corresponds to an inter-target SOA of around 260 ms. This fits well with the earlier estimates of 200 to 300 ms (e.g., Bowman & Wyble, 2007; Martens et al., 2006). The maximum of the WTC effect, however, occurred significantly earlier, at an average interitem SOA of around 95 ms.

Experiment 4: Low-Level Visual Differences

Experiments 2 and 3 showed that WTC effects were especially apparent at the shorter SOAs, consistent with a short-range competition account. Such competition may at least partly be sensory in nature. The closer stimuli are presented together in time, the more they will suffer from mutual masking or integration. The prediction then is that WTC effects may depend on, among other things, the low-level visual properties of the stimuli such as the complexity of the font used. There is earlier work suggesting a role for feature similarity and pixel density differences between fonts in RSVP processing (Maki, Bussard, Lopez, & Digby, 2003). It is

¹ One participant had an empty cell at the longest SOA in the T1 incorrect condition. For the overall statistics, we replaced this cell with the group average of 82%. The pattern of results did not change when the participant was removed altogether.

² The correlation across participants between the peak WTC SOA (average 94 ms) and the peak attentional blink SOA (average 129 ms) was significant ($r = .58$, $p < .05$). At first glance, this correlation might suggest that the two effects are related, but note that it merely confirms what the t test already tells us, namely that there is a reliable time difference between the two effects. To illustrate, were the difference between the peaks exactly 35 ms for each of the 12 participants, then the correlation would simply be 1. There are other correlational analyses one could perform on the data. For example, we could correlate the WTC effect ($T2/(T1-T2/T1)$) and the attentional blink effect (T1–T2) across participants but separately for each SOA. This results in r values of .283, .598, .093, .061, .001, .283, .170, .427, .206, and .526 for each of the SOAs between 50 and 200 ms. None of these reached significance under a Bonferroni correction. The higher r values of .598 and .526 occur near the ends of the scale, with relatively few data points per cell, and are difficult to interpret theoretically. We conclude that this measure does not reveal a clear correlation between the WTC and attentional blink effects. A final measure might be to take the average WTC performance but only for those SOAs around the peak (SOAs 83 and 100 ms in our case) and relate it to the attentional blink effect around the peak SOA (SOAs 116, 134, and 150 in our case), across participants. This yields $r = .30$, $p = .33$, so again no clear relationship.

important to note that, whereas Olivers et al. (2007, Experiment 1) used the relatively simple Courier font, Dell'Acqua et al. (2009) used a nonaliased, low-resolution Roman Triplex, which is visually more complex (e.g., more serifs, varying line widths, and noisy pixelation). To verify this, we conducted an initial test on 20 observers, asking them to respond as rapidly as possible to the parity (odd or even) of a single target digit presented in a short (four-item) RSVP stream of letters. All other stimulus parameters were as in Experiment 1. When the font was Courier New, average response time was 445 ms (average error rate 10.8%); for the Roman Triplex font, it was 463 ms (error rate 10.2%). The 18-ms difference in response time was significant, $t(19) = 2.34$, $p < .05$ (no reliable difference for the error rates, $t < 1$). Moreover, we asked 15 of the 20 observers to indicate which of the two fonts they found the "most simple," the "most clear," the "most pleasant," and the "most familiar," by pressing one of three buttons (including an "undecided" response option). Eleven of 15 found the Courier font the most simple and the most clear, two found the Roman font most simple and clear, and two were undecided. Thirteen of 15 found the Courier font most pleasant, the other two found the Roman font the most pleasant. Six found the Roman font the most familiar (perhaps because it resembles the familiar Times New Roman font), four the Courier font, and five were undecided on this.

The exact differences between the fonts are not the point here. The point is that, for whatever reason, the short-range sensory competition within one set of visual stimuli may be greater than within another. To test this, we varied the font (between Courier New and Roman Triplex), and assessed whether this affected the WTC effect.

Method

Participants. Fifteen undergraduate students of the Vrije Universiteit Amsterdam participated in return for course credits or €7 an hour. One participant was omitted from the analyses because of very low accuracy on both T1 and T2 (both $< 50\%$).

Stimuli, design, and procedure. The methods were the same as those in Experiment 1, except for the following changes. From block to block (in counterbalanced order, 40 trials per block), we varied the font from Courier New to Roman Triplex. We also varied the foreground/background luminance (light on dark or vice versa; see the values used in Experiment 1 vs. Experiments 2 and 3 here), as this was another difference between the Dell'Acqua et al. (2009) study and ours. This factor turned out to have no effect whatsoever and will not be mentioned further. Trials were no longer self-paced. In the Dell'Acqua et al. study, trials were started by pressing the space bar, whereas in this and our previous experiments, trials started automatically 1 s after the previous response. In a control experiment with 14 participants, we found that pacing (self-paced vs. automatic) made no difference to performance or the WTC effect. There were 80 data points per cell.

Results and Discussion

Identification accuracies for T1 and T3 as a function of WTC and font are shown in Figure 4, collapsed across the factor foreground/background luminance, which showed no effects or interactions. An ANOVA on T3 performance with font (Courier vs.

Figure 4. The effect within-trial contingency (WTC) on third target (T3) performance in Experiment 4 as a function of font (compared with T1 performance, which was virtually identical for both fonts).

Roman) and WTC (not contingent vs. contingent on T1 and T2) revealed a main effect of WTC, $F(1, 13) = 11.72$, $MSE = 0.005$, $p < .01$, $\eta_p^2 = .474$. T3 performance was worse when T1 and T2 were reported correctly. However, WTC interacted with font, $F(1, 13) = 4.70$, $MSE = 0.00034$, $p < .05$, $\eta_p^2 = .265$. As shown in Figure 4, the effect of WTC was greater for the Roman font than for the Courier font, although it deserves mentioning that numerically, the additional effect was not large (2.1%). When WTC was applied, performance for T3 was lower than for T1, but again this was only significant for the Roman font, $t(13) = 2.43$, $p < .05$ (for the Courier font, $t < 1.5$, $p = .18$). We take these data as evidence that some lower level sensory factors may contribute to WTC effects when targets are closely spaced in time. Such sensory competition or masking effects are not the same as the competition for high-level mnemonic resources or response selection mechanisms that have been assumed by resource-depletion theories to be the cause of the attentional blink. Note that there were no differences in T1 performance that could account for the differences in T3 performance. Nor are these low-level sensory influences assumed to be the same as the gating or filter mechanisms proposed by selection accounts. Thus, at least some of the WTC effect appears to have little to do with the attentional blink, regardless of the theoretical framework.

General Discussion

A number of studies have now reported evidence that the attentional blink is reduced or even abolished when the distractor(s) preceding T2 are replaced by even more targets (Di Lollo et al., 2005; Dux et al., 2008, 2009; Kawahara, Kumada, & Di Lollo, 2006; Olivers et al., 2007). This finding goes against resource-depletion accounts of the attentional blink, which state that impairments in processing of later targets are directly due to the still ongoing processing of earlier targets. However, Dell'Acqua et al. (2009) have recently argued that a true attentional blink may have been present, but that it may have been camouflaged by the analyses. Specifically, previous studies did not analyze final target performance contingent on performance for earlier targets.

We have argued that it indeed makes sense to analyze T3 contingent on T1 accuracy, given that, according to resource-depletion theories, T1 is believed to be the target causing the attentional blink. Analyzing contingent on T2 accuracy does not make a priori sense, even under a resource-depletion account. Indeed, T2 may add to any deficit caused by T1, but such modulations would not be directly informative about what caused the attentional blink in the standard two-target case (which in our view remains the core finding that needs explaining). Furthermore, we have argued that additional costs induced by T2 may be of a different nature than the attentional blink. For example, T2 (together with T1) may compete with T3 on a sensory level, or even a semantic level, prior to entry to VSTM (Potter et al., 2002). In addition, T2 occupies an additional memory slot. Thus, we have argued that comparing T3 with T1 under different contingencies is not necessarily a good measure of the attentional blink. A better comparison is between T3 (in the three-target case, T1–T2–T3) and T2 in the equivalent temporal position of the two-target case (T1–D–T2). Indeed, when we analyzed our original data fully contingent on earlier target performance, we found that (a) WTC effects were occasionally reliable but still relatively minor compared with Dell’Acqua et al. (2009), and (b) T3 performance was indeed still better than T2 performance in the equivalent temporal position.

This then raises the question as to what factors may have contributed to any WTC effects. We have identified a few.

Uncertainty. A reanalysis of the Olivers et al. (2007, Experiment 3) data confirmed the Dell’Acqua et al. (2009) finding that uncertainty about the number of targets presented on any given trial increases the influence of WTC. The same appears to go for the uncertainty about lag in Kawahara, Kumada, & Di Lollo (2006). It remains an open question as to why this is the case. It would not be the first time that uncertainty affects performance. It may impose an additional task load on the observer, who now also has to determine how many targets there were or when they may occur. As was proposed earlier by Olivers et al., when observers are unsure about the number of targets, they may occasionally not bother looking for, or remembering, the later targets in the stream. The important finding, however, was that the same uncertainty also reduced performance in the two-target condition such that the three-target benefit remained intact.

Practice. Limiting the experience that observers have with three-target trials may reduce T3 performance. When we limited the analysis of Experiment 1 to the first 14 trials, in accordance with Dell’Acqua et al.’s (2009) limited number of data points, numerically, this led to a relative aggravation of T3 performance.

SOA. Experiment 2 showed that WTC effects increased with decreasing SOA. At short SOAs, overall performance deteriorated, but for T3 more so when analyzed contingent on T1. Such effects are consistent with a short-range competition when targets are presented near simultaneously (Kawahara & Enns, 2009; Olivers et al., 2009; Potter et al., 2002; Wyble et al., 2009), and may thus explain why T1 accuracy and especially T2 accuracy may affect T3 performance. Experiment 3 provided strong indications that such short-range effects should be dissociated from the attentional blink. Using a two-target RSVP to create an attentional blink, we found that the maximum WTC effect occurred earlier than the maximum attentional blink effect.

Visual sensory effects. Experiment 4 suggested that sensory differences, such as those resulting from the type of font used, may

have played a role. Targets and distractors drawn in different fonts may differentially mask each other when presented shortly after each other. A more complex font may also need more attention to be perceptually resolved, thus increasing the competition between targets presented at short range.

Collectively, the evidence suggests that there may indeed be competition between multiple successive targets that are presented closely in time, but that this competition is relatively minor in comparison to the benefits that are achieved relative to the situation in which targets are interspersed with distractors. Furthermore, the competition appears to be of a relatively short range and at least partly sensory in nature, rather than a competition for high-level mnemonic or response selection resources that has been assumed to underlie the attentional blink.

Recent Evidence Against Selection Accounts

The selection accounts of Di Lollo et al. (2005; Kawahara, Kumada, & Di Lollo, 2006) and Olivers and colleagues (Olivers, 2007; Olivers & Meeter, 2008; Olivers et al., 2007) state that the attentional blink is the result of a temporary disruption or inhibition of the perceptual input following the presentation of the post-T1 distractor. Two recent studies appear to speak against this idea, as they reported an attentional blink even though no distractor was presented after T1 (Nieuwenstein, Potter, & Theeuwes, 2009; Visser, 2007). In the first experiment of the Visser (2007) study, participants were asked to judge the size of a rectangle as the T1 task, followed by a letter identification task for T2. The latter task was impaired when closely following T1, even when T1 was not masked. The same was true for T2 letter identification in subsequent experiments, in which the T1 task was a complete visual search task (e.g., search for the *G* in an array of five letters). However, note that in these cases the attentional blink is confounded with a complete task switch. Both the perceptual set and the response set need to change from T1 to T2. We know from work on the psychological refractory period that such task switches result in costs at short SOAs (e.g., Pashler & Johnston, 1998). The attentional blink, on the other hand, occurs independent of task switches (as also argued by Visser, Bischof, & Di Lollo, 1999).

The Nieuwenstein et al. (2009) study has demonstrated an attentional blink-like pattern even when there is no distractor following T1 and there is no task switch between T1 and T2. One could thus interpret this finding as straightforward evidence in favor of the resource-depletion account and against distractor-induced inhibition. However, in their study, T2 was presented only briefly, for about 50 ms, and followed by a very strong mask. With normal presentation rates (100 ms/item) and masking conditions, there was no attentional blink for T2. So, at the very least, other mechanisms than resource depletion are necessary to explain the attentional blink as found for the usual presentation rates. It deserves pointing out that Olivers and Meeter’s (2008) boost and bounce theory does exactly that: It assumes that sudden blanks in the stream are only mildly disruptive, and thus cause weak inhibition that can be picked up with very briefly presented and highly masked second targets, whereas real distractors cause strong inhibition, which is then measured even at longer presentation durations. A more important argument against a resource account here is the final experiment (Experiment 4) reported by Nieuwenstein et

al. In that experiment, the post-T1 blank was filled with multiple targets, reminiscent of the three-target case we have been investigating here. Consistent with Di Lollo et al. (2005) and Olivers et al. (2007), T2 detection again *improved* when the intervening items were targets, compared with the two-target case in which there was a blank in between. This led Nieuwenstein et al. to argue that “these results strongly oppose the notion that the attentional blink for a second target is due to the depletion of working memory resources in encoding preceding items. Instead, they provide compelling support for the hypothesis that the root cause of the attentional blink lies in the temporary discontinuation of target input in the interval separating two target items” (p. 166). Nieuwenstein et al. used the recent eSTST framework (Wyble et al., 2009) as a suitable model to explain their data. The eSTST model combines a high-level tokenization process in working memory with lower level attentional mechanisms that engage onto and from the RSVP stream. It explains the attentional blink not in terms of limited processing capacity at the memory stage but in terms of rapid changes in selective attention as a function of the perceptual input. This is consistent with our account that the attentional blink is due to a disruption of the perceptual input (Di Lollo et al., 2005; Olivers & Meeter, 2008). The accounts differ in what causes the disruption: Whereas we have argued that the presence of a strong distractor signals the disengagement of attention, Nieuwenstein et al. argue that it is the end of the target (or multiple target stream) that signals that attention should be disengaged. A blank can be such a signal. Whatever the signal to disengage, the Nieuwenstein et al. studies, together with ours, argue for an explanation of the attentional blink in terms of selection rather than resource depletion.

A final piece of evidence against the selection account comes from Dux et al. (2008, 2009). They used the T1–T2–T3 configurations as used by Di Lollo et al. (2005) and Olivers et al. (2007), but they manipulated the amount of attention devoted to T1 by either making T1 more or less salient (e.g., by coloring the triplets red when distractors were white) or by changing the task so that T1 became more or less relevant to the observer. These manipulations modulated the relative performance of T3, consistent with a trade-off in resources between T1 and T3 (see also Table 1 here). As we have argued elsewhere (Olivers et al., 2009), some of these trade-offs may be better explained through sensory differences resulting in changes in discriminability of the different targets. Moreover, as our reanalysis of the Dux et al. data in Table 1 reveals, any WTC effects in their studies were at most only modest, and therefore show little evidence for a direct trade-off between T1 and T2. But even when the T1–T3 differences do reflect some trade-off in resources, it remains doubtful whether this explains the attentional blink. For example, Dux et al. (2009, Experiment 1), in their reply to Olivers et al. (2009), have shown that T3 suffers more when the importance of T1 is emphasized than when the importance of T3 is emphasized, in line with a trade-off between the two targets. Regardless of such emphasis, however, when compared with the T1–D–T2 condition, Dux et al. found better performance for T3 in the three-target triplet than for T2 in the two-target case (again see Table 1). This is the difficult finding for resource accounts: How can processing three targets lead to more resources than having to process only two?

More Evidence for Selection Accounts

The RSVP tasks featuring more than the usual two targets have generated more evidence in favor of selection accounts for the attentional blink. One piece of evidence is that the attentional blink, when fully triggered, can be rapidly reversed (Kawahara, Kumada, & Di Lollo, 2006; Olivers et al., 2007; see also Nieuwenstein, Chun, Lubbe, & Hooge, 2005). Consider the three-target sequence T1–D–T2–T3. In this condition, a clear attentional blink is found for T2, but not for T3 (compared with a T1–D–D–T2 sequence). If T2 is missed because T1 uses up vital resources, then T3 should have been missed too, especially because the preceding T2 should use additional resources. The fact that this does not happen is more consistent with selection accounts: T2, even when missed on a conscious level, is registered as a target (i.e., it matches the attentional set), resulting in an opening up of the attentional gate or filter, allowing T3 to pass.

The selection account also predicts that even after T1 has been presented, the attentional blink itself can be postponed. This is because the attentional blink is not directly caused by T1, but by the following distractor(s). As long as no clear distractor is presented, an attentional blink should not be induced. This has recently been confirmed by Olivers and Meeter (2008), who found that the attentional blink is postponed when the post-T1 distractor highly resembles a target.

Another piece of evidence suggesting that inhibition of the post-T1 distractor causes the attentional blink comes from a recent study by Kihara, Yagi, Takeda, and Kawahara (in press), using the *distractor devaluation effect* as a tool. This effect refers to the negative affective ratings that observers assign to visual objects that have to be suppressed (Fenske & Raymond, 2006; Raymond, Fenske, & Tavassoli, 2003). Kihara et al. showed that when T2 is missed, the post-T1 distractor is rated more negatively, compared with when T2 is reported and compared with the pre-T1 distractor, thus providing a direct link between inhibition of the post-T1 distractor and the attentional blink.

Finally, selection accounts predict that the attentional blink is ameliorated when selection settings are less stringently applied, as when the distractors are deemed less disruptive by the system. Evidence for this comes from studies showing a reduced blink when observers are engaged in additional perceptual or cognitive activities (Arend, Johnston, & Shapiro, 2006; Olivers & Nieuwenhuis, 2005, 2006; Taatgen et al., 2009) or when observers are not required to select a specific target (Nieuwenstein & Potter, 2006; however, see Dell’Acqua et al., 2009, for the argument that task switches may underlie the Nieuwenstein and Potter results). Resource theories have difficulties explaining such findings.

Conclusion

Taken together, the evidence leads us to believe that resource limitations, be it in terms of low-level sensory competition or high-level competition for scarce memory slots, may certainly contribute to target detection deficits in the attentional blink paradigm. In this respect, selection models may have been too restrictive in claiming that there is no competition between targets whatsoever. There are often modest but consistent trade-offs be-

tween targets when presented at close range. However, given that such trade-offs appear to occur with a different time course than the attentional blink itself, and given that even with such trade-offs present, three-target performance still exceeds two-target performance, we also believe that the core explanation of the attentional blink still has to be one in terms of selection mechanisms, and not resource depletion.

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