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Lag-1 sparing in the attentional blink: Benefits and costs of integrating two events into a single episode

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When people monitor a visual stream of rapidly presented stimuli for two targets (T1 and T2), they often miss T2 if it falls into a time window of about half a second after T1 onset—the attentional blink. However, if T2 immediately follows T1, performance is often reported being as good as that at long lags—the so-called Lag-1 sparing effect. Two experiments investigated the mechanisms underlying this effect. Experiment 1 showed that, at Lag 1, requiring subjects to correctly report both identity and temporal order of targets produces relatively good performance on T2 but relatively bad performance on T1. Experiment 2 confirmed that subjects often confuse target order at short lags, especially if the two targets are equally easy to discriminate. Results suggest that, if two targets appear in close succession, they compete for attentional resources. If the two competitors are of unequal strength the stronger one is more likely to win and be reported at the expense of the other. If the two are equally strong, however, they will often be integrated into the same attentional episode and thus get both access to attentional resources. But this comes with a cost, as it eliminates information about the targets' temporal order.

A major issue in the study of human visual attention concerns the number of elements that can be processed at a time. One aspect of this issue has to do with limitations in space—that is, with the question of whether more than one location, or more than one event at a given location, can be concurrently attended. Another aspect that has been addressed more recently (see Shapiro, 2001), has to do with temporal limitations—that is, with the question of how quickly we can attend an event after just having attended another event. Research on these latter, temporal limitations has revealed a striking phenomenon: When people monitor a visual stream of rapidly presented stimuli for two targets (T1 and T2), the second target (T2) is often missed if it falls into a time window of about 100–600 ms after onset of

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T1 (e.g., Broadbent & Broadbent, 1987; Raymond, Shapiro, & Arnell, 1992). In analogy to an overt blink of the eyes, Raymond et al. (1992) have called this temporal blindness to the second of two sequential targets the *attentional blink* (AB).

Several accounts of the AB have been suggested thus far (Chun & Potter, 1995; Duncan, Ward, & Shapiro, 1994; Enns & Di Lollo, 1997; Jolicœur, Dell'Acqua, & Crebolder, 2000; Shapiro, Raymond, & Arnell, 1994). However, as Shapiro, Arnell, and Raymond (1997) pointed out, ignoring differences in terminology allows one to extract three widely shared assumptions: (a) as T1 is masked by the item(s) following it, increased attention is required to create and consolidate its cognitive representation; (b) with increasing attentional demands of T1 processing less attentional capacity is left to consolidate T2, which makes its codes sensitive to inhibition, competition, and/or decay; and (c) this problem is enhanced with increasing response requirements, such as the need to perform a speeded response to T1.

One way to investigate the causes underlying these temporal attentional limitations in more detail is to study exceptional cases—that is, conditions under which the AB does not occur (e.g., Sheppard, Duncan, Shapiro, & Hillstrom, 2002). Arguably, the best established exception of that sort is the so-called *Lag-1 sparing effect* (Potter, Chun, Banks, & Muckenhoupt, 1998). It refers to the frequent observation that AB is more or less absent if T2 appears immediately after T1, hence in the ordinal position Lag 1. In a comprehensive meta-analysis of studies in which Lag-1 sparing was or was not obtained, Visser, Bischof, and Di Lollo (1999) were able to identify three conditions that need to be met to produce the sparing effect: Both targets need to appear at the same location in space; the interval between them must not exceed the effective temporal integration window; and the two targets, or the features defining them, must not differ to a degree that would require a switch of the attentional set (cf. Potter et al., 1998).

So far the mechanisms underlying Lag-1 sparing have not attracted a lot of attention, which led Visser et al. (1999, p. 464) to this, rather pessimistic, sketch of the state of affairs: "It is fair to say that Lag-1 Sparing has been treated with the theoretical equivalent of benign neglect. When mention is made of Lag-1 Sparing, it is usually to ascribe it to a sluggish attentional gate and to say no more about it." The sluggish-gate idea (see Chun & Potter, 1995; Shapiro & Raymond, 1994) assumes that an attentional gate is opened on presentation of T1. Processing T1 starts immediately but the gate is closed rather sluggishly, so that the next (i.e., Lag-1) item can "slip in" and access attentional resources as well. As a consequence, both items will be processed together and may become part of the same attentional episode (Sperling & Weichselgartner, 1995; Visser et al., 1999) or object file (Sheppard et al., 2002). Based on their meta-analysis, Visser et al. extended this hypothesis by assuming that Lag-1 items can slip in only if T1 and T2 are presented at the same location and if their identification does not require switching between different attentional sets.

Although attractive at first sight, the sluggish-gate idea is still largely underdeveloped and faces some empirical problems. Consider the situation that T2 appears immediately after T1 under conditions that according to Visser et al. (1999) allow Lag-1 sparing to occur. The gate is opened to process T1 and, as it is sluggish, T2 slips in. A major question that arises is whether it slips in for free—that is, whether the fact that it does slip in and, therefore, gains access to attentional resources, has any consequences for T1. The very term of *sparing* suggests a positive answer, suggesting that T1 is processed and consolidated under (almost) all circumstances, and, at least in most cases, T2 is processed and consolidated as well.

Theoretically, this would imply that processing and consolidating T2 either need no additional attentional capacity or need no more than what is left by T1-related processing anyway. Hence, there is more performance for the same cognitive price. Empirically, this would imply that performance on T1 is independent of performance on T2. However, findings of Broadbent and Broadbent (1987) let one doubt whether this is the case. In their Experiment 1, these authors presented participants with streams of words: target words presented in uppercase, nontargets in lowercase. Although T1 performance was not analysed as a function of T2 performance, there are several indications that performance on the two targets was negatively correlated: While correct T1 report was much worse for Lag 1 than for Lag 2 (46% vs. 60%), T2 performance showed the opposite pattern (35% vs. 15%). Also, T2 performance was much better if T1 could not be reported than if it could (58% vs. 20%). A very similar error pattern was obtained by Chun and Potter (1995), who had participants identify two letters among digits. Chun (1997) investigated temporal binding errors in a rapid serial visual presentation (RSVP) paradigm, finding that these are influenced by the attentional blink and observing that T1 report suffers at Lag 1. Unfortunately, neither the specific type of errors nor the performance on T1, given that T2 was correct, was reported. More recently, Potter, Staub, and O'Connor (2002) provided further evidence for a negative correlation between T1 and T2 performances in experiments using very short T1–T2 intervals: Gains in T2 report at intervals below 100 ms were accompanied by comparable losses in T1 report. Thus, all in all, there are a number of hints suggesting that T1 processing suffers from processing T2, especially at short lags. This also fits with the general observation that, in many single target tasks using RSVP, people often tend to report the item following the actual target (for an overview, see Botella, Barriopedro, & Suero, 2001)—a tendency that also occurs in the standard AB task (Raymond et al., 1992).

Another reason to ask what is actually spared at Lag 1 has to do with the implications of being processed in the same integration window or of being integrated into a single episode. Assume that a sluggishly closing gate actually allowed T2 to slip in, and that this leads to the joint integration of T1 and T2 into a common cognitive episode. Even if it were possible to create a single episodic trace representing both a target and the item following it, it is not obvious in which way this might improve overall performance. Consider the version of the AB task employed by Raymond et al. (1992), where T1 is a white letter among black letter distractors, and T2 is a black X. If T2 appears in Lag 1 one could imagine that both targets are integrated into the *same* episodic trace and then, at report, retrieved together. If so, some information would necessarily get lost: one being the order of the two items (after all, they are treated as *one* event), another the fact that it was T1 that was white but not the X. True, these losses do not create any problem because the participant knows that the X always follows, but never precedes, T1 and that T1 is always white while the X is always black. But what if any other item appears at Lag 1? In the case of Raymond et al.'s (1992) design this would be a black letter, which then would be integrated with T1 into the same episode. How does the participant know which letter was white and which was first? Considering the number of possible errors a participant could make in this situation it would be no trivial achievement to still reach an accuracy level of 80% or more correctly reported T1 (e.g., Raymond et al., 1992). Indeed, when Raymond et al. required participants to report a single target as well as the three (distractor) letters following it, it became apparent that Lag 1 posttarget intrusions occurred fairly often (on 16% of trials).

The evidence for an exchange relation between T1 and T2 performance with short intervals between them has led Potter et al. (2002) to challenge the sluggish-gate idea in its original form. In particular, they doubt that it is only the actual moment in time when coding takes place that decides about whether a target gets access to the attentional gate or not—one of the major implications of the sluggish-gate metaphor. Instead, T1 and T2 are assumed to compete for access. Clearly, T1 will often win the competition and get exclusive access. However, at very short intervals T2 may sometimes prevail because it benefits from the previous detection of T1: T1 triggers the mobilization of attentional resources but is overwritten by T2 so quickly that the resources are eventually allocated to the second target (an idea very similar to Müsseler & Neumann's, 1992, account of the tandem effect).

This more dynamic, competitive scenario suggested by Potter et al. (2002) fits nicely with the discussed negative relationship between T1 and T2 performance at short lags. However, there are reasons to doubt whether the evidence Potter et al. provide is sufficient to justify their claims. One problem is that only one of their six experiments used the standard AB design with a single visual stream—that is, without spatial uncertainty—while the other experiments employed two streams. This means that most of their results may tell us more about limitations of spatial attention than about the purely temporal limitations reflected in the AB. A second problem is that they only report unconditional accuracy on T1 and T2, so that it remains unclear whether and how often their subjects were able to report both targets. As most experiments yielded a mean accuracy of 50–60% it may even be that subjects mostly or always failed to report more than one target per trial. If so, one may doubt whether the findings can be compared to findings from standard AB experiments, where the rate of full reports at short lags is commonly substantial. Third, and even more worrisome, given that conditional accuracy for T2 (i.e., T2 given T1 correct) is not specified, is that we do not know whether Potter et al. were able to demonstrate Lag-1 sparing—which is commonly defined as better performance on T2 *conditional* accuracy than at subsequent lags—at all. This is the more problematic, as the two-stream design that they used in most of their experiments does not meet the criteria that Visser et al. (1999) considered to be necessary for Lag-1 sparing to occur. Finally, it is far from obvious how a competitive approach accounts for full reports at Lag 1. If there is insufficient capacity for processing more than one target, how is it possible that both targets can be reported in a commonly substantial number of trials? One possibility is that competition between targets can have two outcomes: Sometimes one target may win and exclude the other—the cases the competitive approach focuses at—and sometimes both may be integrated—the cases the sluggish gate metaphor aims at.

In sum, then, the competitive approach of Lag-1 sparing suggested by Potter et al. (2002) provides an attractive account of a number of observations that do not seem to fit naturally with the original sluggish-gate metaphor. At the same time, the additional evidence Potter et al. present does not yet seem to represent a sufficiently solid backbone of their own approach and does not seem to rule out the possibility of integration altogether. Accordingly, the aim of our study was to test some further implications of a competitive account, vis-à-vis the sluggish gate account, by using a standard AB task with a single visual stream—that is, without spatial uncertainty—and by analysing performance in terms of conditional accuracy. Given the emphasis a competitive account puts on T2-related effects on T1, we included analyses of conditional accuracy for both T1 (i.e., T1 given T2 correct) and T2 (T2 given T1 correct). Moreover, to tap into the possible common integration of

T1 and T2, and the loss of order information this might imply, we also had an eye on order errors—that is, on cases where subjects correctly reported the identity of the two targets but confused their order.

EXPERIMENT 1

As a first step, we carried out an AB task fulfilling the following criteria: First, conditions should be optimal for Lag-1 sparing to occur. Accordingly, we presented all stimuli at the same spatial location, used a reasonably short stimulus–onset asynchrony, and defined the two targets in such a way that a shift of task or attentional set was not necessary (Visser et al., 1999). Second, we wanted to compare performance on T1 and T2 under conditions in which confusion of target order matters and conditions in which it does not. Accordingly, we presented participants with two digit targets among letter distractors, and asked them to identify the two targets *in the correct order*. Obviously, we expected conditional T2 performance to be comparatively good at the shortest lag (Lag-1 sparing), decrease then to show the standard AB, and get back to baseline at the longer lags. Along the lines of the competitive approach and its prediction of a negative relationship between T1 and T2 performance, we also expected T1 performance to be particularly bad at Lag 1. Finally, taking up the joint-integration idea, we expected order errors to be particularly pronounced at Lag 1.

Method

Participants

A total of 16 students from Leiden University volunteered to participate for pay in single sessions of about one hour.

Apparatus and stimuli

Display and timing were controlled to the nearest millisecond by a standard PC. A white asterisk served as fixation mark, appearing at the centre of the black screen. Target stimuli were the digits 1, 2, 3, 4, 6, 7, 8, and 9, and distractors were the 26 letters of the alphabet, all appearing in white at screen centre. All stimuli were presented in text mode; from a viewing distance of about 60 cm, each symbol measured about 0.3° in width and 0.4° in height. Participants were to identify the two targets and to type the corresponding numbers in the correct order in the computer keyboard.

Procedure and design

After an intertrial interval of 2,000 ms, each trial began with the presentation of the fixation mark for 1,000 ms, followed by a blank interval of 250 ms. Then a stream of 15 symbols appeared, each symbol being replaced by the next after 98 ms. Each stream consisted of two digits (T1 and T2) and 13 randomly drawn letters (without replacement). T1 could appear in stream position 2, 3, or 4 (randomly determined), and T2 1, 2, 3, 4, 5, 6, 7, or 8 positions later (Lags 1–8). T1 and T2 were always different. Participants were to identify T1 and T2 at leisure at the end of the trial. They were presented with the prompt "First digit:" (in Dutch) and pressed the number key that they considered correct, and then the procedure was repeated for the second digit. Feedback was provided by briefly (1,000 ms) presenting a pair of plus (correct) and/or minus (incorrect) symbols, one for each response. Each participant worked through 10 randomly determined practice trials and 10 experimental blocks. Each block was composed of 32 randomly ordered trials: the possible combinations of eight lags and four randomly determined pairs of (always different) targets per lag.

Results and discussion

A significance level of 5% was adopted for all analyses. Degrees of freedom were adjusted according to Greenhouse–Geisser, if applicable (i.e., in the case of a significant test on sphericity). The data from one participant were excluded from analyses because of extraordinarily high overall error rates.

We first checked whether a standard AB with Lag-1 sparing was obtained. To do that, we computed, for each participant, the conditional percentage of T2 report given that T1 was reported (T2|T1), separately for each lag. These data served as input into an analysis of variance (ANOVA) with lag (1–8) as within-participant factors. The lag effect was reliable, $F(3.5, 49.1) = 9.91$, $MSE = 0.02$, $p < .001$. As shown in Figure 1 (filled symbols), performance on T2 was very good at Lag 1 and then dropped by more than 20% in absolute report accuracy, to recover around Lag 5, where an asymptotic level of about 70% was reached. Given this performance level at lags that clearly extend beyond the interval that entails the attentional blink, it is in our view reasonable to accept this as a baseline for two-target performance. A paired samples *t* test confirmed that performance at Lag 3 differed significantly from that at Lag 8, $t = -3.40$, $p < .005$. That is, we were able to produce both an AB and a Lag-1 sparing effect that satisfies the criteria suggested by Visser et al. (1999)—namely, performance at Lag 1 that exceeds the lowest level of performance by more than 5% in absolute terms.

The next step was to see whether Lag 1 would really be spared or whether good T2 report at Lag 1 came at the expense of T1 performance. To do so, we reversed the logic underlying the previous analysis and computed the conditional percentage of T1 report given that T2 was reported (T1|T2), over all eight lags (see Figure 1, unfilled symbols). Interestingly, an ANOVA on these data did not reveal any lag effect, $F(3.9, 54.2) < 2$ (see unfilled symbols). Even if we

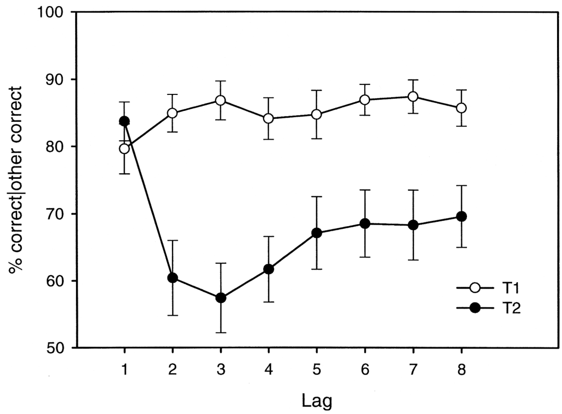

Figure 1. Percentage correct conditional report of the second target given the first target (T2|T1), and of the first target given the second (T1|T2), as a function of lag in Experiment 1. Error bars represent standard error.

consider the small numerical drop at the shortest lag, it seems clear that T2 sparing cannot be fully accounted for by a trade-off with T1—a finding that is at variance with the competition account of Potter et al. (2002). Yet, Lag-1 sparing did not come for free either, as more detailed analyses revealed. Figure 2 provides an overview of the unconditional report accuracy for T1 (unfilled symbols) and T2 (filled symbols), as a function of lag. Circles show percentages of trials in which a target was correctly reported in terms of both identity (which digit) and temporal position (e.g., T1 was reported as first target), a stricter criterion than that applied to the data in the conditional analyses previously. Clearly, T1 report is dramatically impaired at Lag 1 but relatively stable across the remaining lags, $F(3.7, 51.2) = 26$, $MSE = 0.009$, $p < .001$, which fits with the observations of Potter et al. (2002). T2 performance, on the other hand, is relatively bad (though still way above chance) at the first three lags and increases from Lag 4 to Lag 5, where it reaches an asymptote, $F(7, 98) = 7.72$, $MSE = 0.008$, $p < .001$. Obviously, there is nothing special in T2 performance to Lag 1; nothing is spared here or at the two subsequent lags. However, as computing the conditional T2 report rate relates the report of both targets to the report of T1 alone, (T1&T2)/(T1&T2 + T1), the large drop of T1 performance at Lag 1 increases the relative size of the additional contribution from T2 and, thus, makes conditional T2 performance look better.

Yet, something is spared, as the other two lines in Figure 2 reveal (see diamond-shaped symbols). They show again unconditional performance on T1 and T2 but with a laxer accuracy criterion. Here, we considered as correct all reports of the correct digit identities, irrespective of whether the order was correct or not. Not surprisingly, overall performance is somewhat better than that according to the stricter criterion, which shows that the loss of item-order information is a general problem in an AB task. Moreover, the fact that performance is better across all lags suggest that this problem is not (only) due to the temporal proximity of the two targets; rather, it seems that order or temporal-position information is either difficult to code or difficult to bind to stimuli belonging to the same stream of events. Similar to the strict unconditional analyses, both T1 and T2 performance showed a significant lag

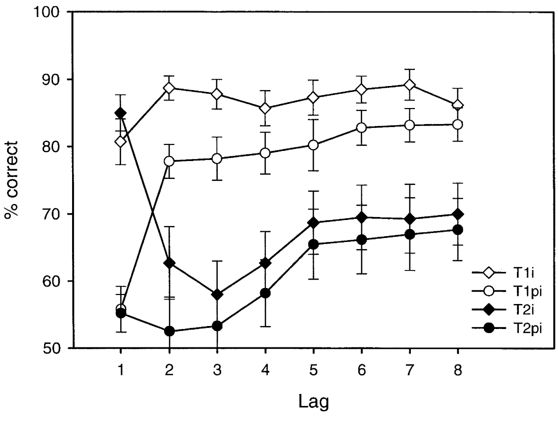

Figure 2. Percentage correct unconditional report (+/− 1 *SE*) of the second target, where "p" denotes the position criterion and "i" the identity criterion (identity only, T2i; identity and temporal position, T2pi) and of the first target (identity only, T1i; identity and temporal position, T1pi) as a function of lag in Experiment 1.

effect, *F*(3.9, 55.2) = 2.83, *MSE* = 0.007, $p < .05$, and *F*(3.8, 52.5) = 10.24, *MSE* = 0.018, $p < .001$, respectively.

Apart from the general difference in performance level the shapes of the curves with strict versus lenient accuracy criteria are relatively similar, but there are two interesting exceptions. First, T1 performance no longer drops at Lag 1. This suggests that the drop obtained with the strict criterion does not reflect that T1 was not encoded or stored. Indeed, the identity of T1 is maintained rather well, but it does not seem to be bound to the correct temporal position if the two targets appear in close succession. The second exception is that T2 performance shows a Lag-1-sparing-type function with particularly good performance (here in absolute, unconditional terms) at the shortest lag. Thus, the loss of order information for T1 goes along with equally strong increase in reports of correct T2 identity. In fact, identity information for both targets is retained better at Lag 1 than at any other lag, which suggests that temporal proximity of to-be-processed stimuli does provide some extra benefit. However, this benefit comes at the expense of order information.

Finally, we analysed the different types of error or, more precisely, partial report. If we adopt the strict accuracy criterion, we can distinguish between six types of partial report: trials in which no target was reported correctly (none), reports of correct T1 identity in incorrect position (and no correct T2 identity), reports of correct T1 identity and position, reports of correct T2 identity in incorrect position (and no correct T1 identity), reports of correct T2 identity and position, and reports of correct T1 and T2 identities in the wrong order. Figure 3 provides an overview of the distribution of these types of error across lags. Reliable lag effects were obtained for T1 identity, *F*(2.6, 36.1) = 11.71, *MSE* = 0.002, $p < .001$, T1 identity and position, *F*(7, 98) = 8.55, *MSE* = 0.01, $p < .001$, T2 identity, *F*(7, 98) = 2.57, *MSE* = 0.002, $p < .05$, and T1 and T2 identity, *F*(2.3, 31.6) = 59.54, *MSE* = 0.004, $p < .001$, but no effects were obtained for the categories none, *F*(3.1, 44.6) < 1.93, and T2 identity and position, *F*(3.4, 47.5) < 1.09.

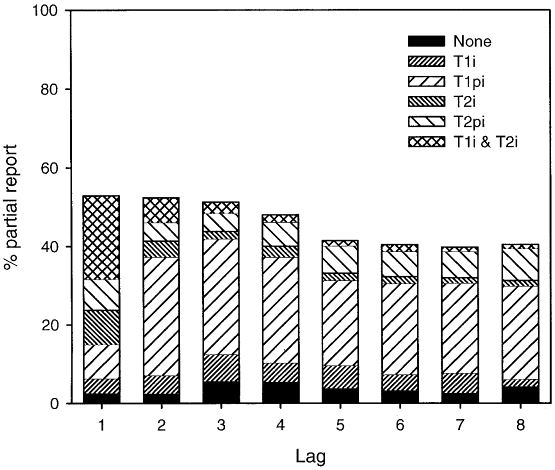

Figure 3. Percentage partial reports as a function of lag in Experiment 1 (none correct, None; T1 identity only, T1i; T1 identity and temporal position, T1pi; T2 identity only, T2i; T2 identity and temporal position, T2pi; both targets in wrong order, T1i & T2i).

Overall, by far the strongest contribution to partial reports comes from full T1 reports (i.e., of both identity and correct temporal position) accompanied by the absence of any T2 report. This is particularly true for Lags 3 to 8 where, apart from some T1-identity-only reports, other types of partial report play a negligible role. Things change, however, at the two shortest lags. This is particularly true for Lag 1, where full reports of T1 show a pronounced decrease and even together with partial T1 reports do not reach the frequency of full T1 reports at longer lags. Thus, short lags lead to a loss of T1-related information, especially to the loss of position information. Interestingly, T2-only reports do not change much across lags: Full T2 reports are not reliably affected at all, and identity-only reports show just a slight increase at Lag 1. That is, the most dramatic effect of lag concerns the reports of correct identities of both targets in the wrong order. This category is negligible across the longer lags but it provides by far the strongest contribution at Lag 1. This pattern has two implications: that Lag 1 facilitates the report of both target identities and that it does so at the expense of order information.

To summarize, Experiment 1 does not provide evidence in support of a competitive account as in Potter et al. (2002)—that is, good performance on T2 at Lag 1 cannot be (fully) explained by a trade-off against T1. In contrast, more than one identity can be processed at the shortest lag, a possibility that seems to be gone as soon as the first distractor arrives. However, it is also true that this particularly good performance does not come for free: Processing two targets at the same time is accompanied by, or leads to, the loss of information about the temporal order in which these targets appeared. Together with the similar observations in the literature, we take that as converging evidence in favour of an integration account as implied by the sluggish-gate metaphor.

EXPERIMENT 2

The first experiment provides some evidence for target integration at Lag 1, whereas hints towards a mere trade-off between T1 and T2 were lacking. One possible interpretation of the latter outcome is that for some reason competition between the two targets did not take place in our particular set up. However, it is also possible that competition did take place but to a degree that was insufficient to result in the exclusion of one target or the other from processing. Experiment 2 was designed to explore this possibility by manipulating the degree of conflict between the two targets by varying their (relative) visual discriminability. Reducing the discriminability of one target is likely to lengthen the time needed to complete its identification, which according to Potter et al. (2002) should reduce the odds of that target winning the competition for access to attentional resources. In other words, the less the discriminability of a target the more likely it will miss the open attentional gate. Accordingly, performance on T1 should increase with decreasing discriminability of T2, and performance on T2 should increase with decreasing discriminability of T1, particularly at Lag 1.

Method

Participants

Another 20 students (17 female, 3 male; mean age 19.1 years) from Leiden University volunteered to participate for pay or course credit in single sessions of about one hour.

Apparatus and stimuli

The experiment was controlled by the E-Prime© experimental software package. Each self-initiated RSVP stream was preceded by a black plus sign ("+"), presented for 200 ms on a grey background (RGB 128, 128, 128). Target digits were the same as those in Experiment 1, but varied in intensity, depending on the discriminability condition. On the basis of pilot testing, white (220, 220, 220) targets were considered to be *easy* to discriminate, black (0, 0, 0) targets of *medium* difficulty, and grey (60, 60, 60) targets as *difficult*, based on the contrast with the grey background.[1] Distractors were as those in Experiment 1, presented in black on a grey background at screen centre.

Procedure and design

After the self-paced initiation of each trial an 800-ms pause was followed by the fixation mark, in turn followed by the first RSVP stimulus. The total stream consisted of 20 stimuli, presented for about 59 ms each and with an interstimulus interval of about 35 ms. Each RSVP contained two random target digits and 18 random letters. T1 was presented as the 7th, 8th, or 9th item in the stream. T2 followed at Lag 1, 3, 5, or 8. No letter or digit was repeated within any trial. At the end of the RSVP a 200-ms pause ensued. Then the two targets were to be identified in the correct order as in Experiment 1. No feedback was provided. Each session entailed one practice block of 32 trials and three randomly mixed experimental blocks of 144 trials each.

Results and discussion

T2|T1 performance was analysed by using a $3 \times 3 \times 4$ repeated measures design, with T1 discriminability (easy, medium, or difficult), T2 discriminability, and lag (1, 3, 5, or 8) as independent variables. Significant main effects were obtained for T1 discriminability, $F(2, 38) = 9.7$, $MSE = 0.01$, $p < .001$, T2 discriminability, $F(1.3, 24.2) = 36.11$, $MSE = 0.088$, $p < .001$, and lag, $F(1.9, 36.1) = 39.06$, $MSE = 0.051$, $p < .001$. Reliable two-way interactions were obtained for T1 Discriminability × Lag, $F(6, 114) = 3.28$, $MSE = 0.012$, $p < .005$, T2 Discriminability × Lag, $F(6, 114) = 18.76$, $MSE = 0.01$, $p < .001$, and T1 Discriminability × T1 Discriminability, $F(4, 76) = 4.48$, $MSE = 0.008$, $p < .005$. The three-way interaction of these variables was marginally significant, $F(5.9, 112.5) = 2.17$, $MSE = 0.017$, $p < .052$. The main effects indicated (a) that performance was much better with an easy-to-discriminate T2 (98%) than with medium (84%) or difficult (80%) T2s, (b) that a typical AB was obtained (which was also confirmed by a reliable difference between Lag 3 and Lag 8, our baseline, $t = -7.5$, $p < .001$), including Lag-1 sparing (see Figure 4, filled symbols), and (c) that T1 discriminability was a mirror image of its T2 counterpart: Performance on T2 tended to be worse if T1 was easy to discriminate (85%) than if it was of medium (88%) or high (88%) difficulty.

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[1] Note that we do not claim that our discriminability manipulation reflects variations on a single physical scale or dimension. On the contrary, the three types of target differed in a number of respects: White targets were the most intense, the most unique, and the least well masked stimuli (the letter stream was black); black targets were the least intense, the least unique (same colour as letter stream) and best masked stimuli, which, however, were easy to see on the grey background; grey targets, however, were of medium intensity, relatively unique, not well masked, but very similar to the background. However, the results show that this mix of characteristics was successful in creating three conditions of sufficiently differing difficulty and "competitiveness" with respect to the hypothesized race for access to attentional resources. None of our conclusions depend on how these differences were achieved.

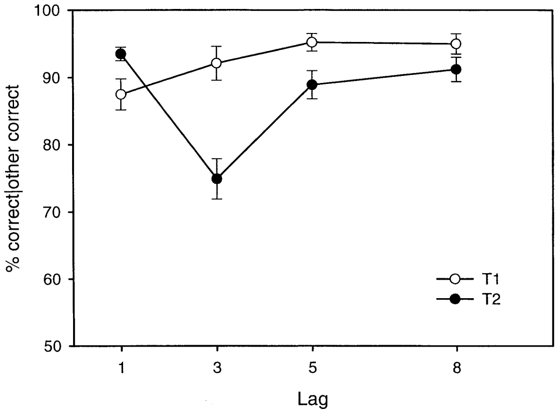

Figure 4. Percentage correct conditional report (+/− 1 *SE*) of the second target given the first target (T2|T1), and of the first target given the second (T1|T2), as a function of lag in Experiment 2.

The interaction effects reflected two relationships: First, in contrast to the other T2 conditions, performance on T2 was unaffected by T1 and T2 discriminability and lag if T2 was easy to discriminate; this interpretation was supported by the fact that dropping the easy-T2 conditions eliminated the three-way interaction, $p > .4$, as well as the other interactions with T2 discriminability, *p*s > .5. We see a similar pattern in T1 performance, where the easy-discrimination condition was also the least affected. These observations are direct reflections of the experimental manipulation and indicate little more than the fact that black letters are not particularly good masks for white targets. Second, and more importantly, in the medium and difficult T2 conditions, T1 discriminability had an effect on the two shortest lags but not on the longer lags (see Figure 5). This interaction was entirely due to the

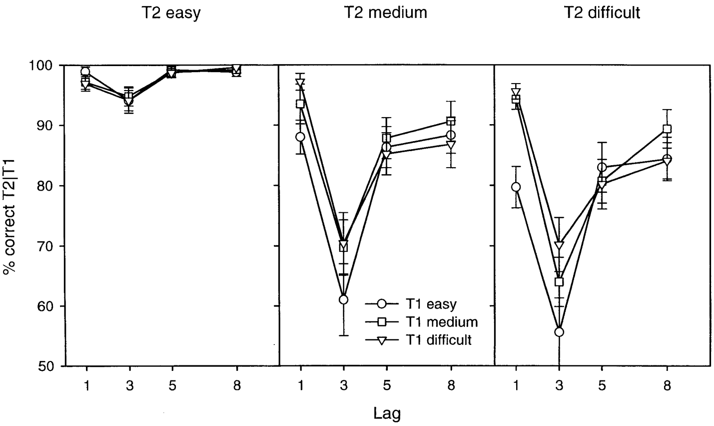

Figure 5. Percentage correct conditional report (+/− 1 *SE*) of the second target given the first target (T2 | T1) as a function of T1 discriminability and lag in Experiment 2. Separate panels represent different T2 discriminability conditions.

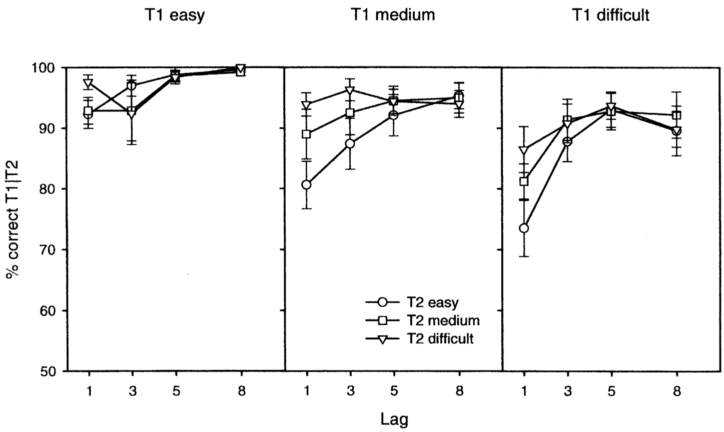

Figure 6. Experiment 2: Percentage correct conditional report (+/− 1 *SE*) of the first target given the second target (T1 | T2) as a function of T2 discriminability and lag in Experiment 2. Separate panels represent different T1 discriminability conditions.

easy T1 condition, as dropping that condition eliminated the effect, $p > .3$. Such an outcome provides strong support for a competitive account of Lag-1 sparing, according to which an easy-to-discriminate T1 is a particularly strong competitor that reduces the chances for T2 to get access to attentional resources.

An ANOVA on T1|T2 yielded main effects of T1 discriminability, $F(1.2, 23.5) = 9.9$, $MSE = 0.065$, $p < .005$, T2 discriminability, $F(2, 38) = 7.19$, $MSE = 0.01$, $p < .005$, and lag, $F(2.1, 40.8) = 17.63$, $MSE = 0.018$, $p < .001$. Lag interacted with both T1 discriminability, $F(3.4, 65.1) = 4.14$, $MSE = 0.013$, $p < .01$, and T2 discriminability, $F(3.1, 58.1) = 4.62$, $MSE = 0.015$ $p < .005$. The overall effect of lag is shown in Figure 4: Performance on T1 was worse than on T2 at Lag 1 and then gradually improved until Lag 5, a pattern that is consistent with the Potter et al. (2002) study. As shown in Figure 6, T1 performance at short lags was better when T1 discrimination was easier and T2 discrimination was more difficult.[2] The fact that the ease of identifying T2 affects T1 performance at all is difficult to combine with, and certainly not predicted from, the sluggish-gate account. In contrast, both interactions are exactly as predicted from a competitive account in showing that performance on T1

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[2] Note that although Lag 1 is most strongly affected by our discriminability manipulation the AB-critical period still shows an effect. In other words, making the processing of the targets easier or more difficult has an impact on the size of the AB. This observation is consistent with a number of other studies (Chun & Potter, 1995; Grandison, Ghirardelli, & Egeth, 1997; Seiffert & Di Lollo, 1997, who also provide an overview) but inconsistent with McLaughlin, Shore, and Klein's (2001) failure to find a relation between target difficulty and the AB. This is somewhat paradoxical because McLaughlin et al.'s design can considered to be the most similar to ours in attempting to manipulate the perceptual quality of the targets and avoiding a task switch between them. However, in contrast to the present study, McLaughlin et al. manipulated the discriminability of T1 and of T2 in different experiments and by using the skeletal target–mask–target–mask task version introduced by Duncan, Ward, and Shapiro (1994). In the absence of more systematic research on this issue we are unable to offer an interpretation of how these procedural differences might explain the divergent outcomes. What seems clear, however, is that McLaughlin and colleagues' conclusion that data-limiting difficulty manipulations do not affect the AB is too general.

is a direct reflection of the relative competitiveness of both T1 and T2: better performance with stronger T1 and weaker T2.

To compare these outcomes with those from Experiment 1 we also ran ANOVAs on unconditional T1 and T2 performances, separately for the two scoring criteria (lax = identity only, strict = identity & order). As Figure 7 shows, the results were comparable; for the sake of brevity, all significant effects are listed in the Appendix.

Partial reports were classified as in Experiment 1; Figure 8 provides an overview. The emerging pattern is very similar to that obtained in Experiment 1. First, the three longer lags and Lag 3 in particular are dominated by reports of correct T1 identity and position in the

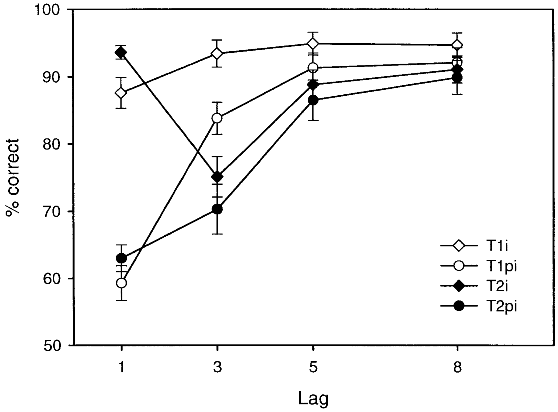

Figure 7. Percentage correct unconditional report (+/− 1 *SE*) of the second target, where "p" denotes the position criterion and "i" the identity criterion (identity only, T2i; identity and temporal position, T2pi) and of the first target (identity only, T1i; identity and temporal position, T1pi) as a function of lag in Experiment 2.

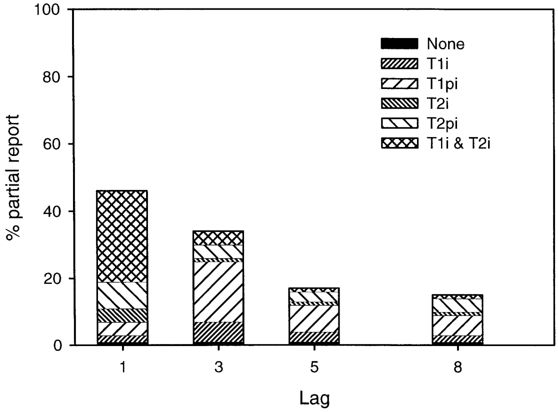

Figure 8. Percentage partial reports as a function of lag in Experiment 2 (none correct, None; T1 identity only, T1i; T1 identity and temporal position, T1pi; T2 identity only, T2i; T2 identity and temporal position, T2pi; both targets in wrong order, T1i & T2i).

absence of T2—the sign of a standard AB. Second, by far the largest contribution to Lag 1 comes again from reports of correct T1 and T2 identities in the wrong order. Separate analyses of the error types yielded reliable lag effects for T1 identity, $F(1.8, 34.3) = 12.40$, $MSE = 0.009$, $p < .001$, T1 identity and position, $F(1.8, 34) = 37.92$, $MSE = 0.023$, $p < .001$, T2 identity, $F(1.4, 26.6) = 19.41$, $MSE = 0.004$, $p < .001$, T2 identity and position, $F(1.8, 34.3) = 10.14$, $MSE = 0.015$, $p < .001$, and T1 and T2 identity, $F(1.2, 23.6) = 181.56$, $MSE = 0.038$, $p < .001$, while no effect was obtained for category none.

Figure 9 shows how error types are distributed at Lag 1. Even though the pattern looks complex it tells a rather coherent story. First consider the three conditions with an easy T1—hence, the three left-most bars. If T2 is easy as well—that is, if the two targets are equally strong competitors—identity-related performance is excellent but subjects often commit order errors, accompanied by a smaller but still considerable tendency to report only T2. As T2 gets less discriminable, order errors and T2-only reports become less frequent and give way to an increasingly strong tendency to report T1 only. Next, consider the three medium-T1 conditions. The tendency to report T2 only is even stronger if T2 is easy to discriminate but is replaced by an increasing contribution from order confusions and T1-only reports as T2 discriminability decreases. Finally, consider the three difficult-T1 conditions, where we see the same trends as with medium T1s but on a higher overall level for almost all error types involved. These error patterns suggest at least two important conclusions. First, big differences in discriminability between the two targets strongly increase exclusive reports of one—namely, the better—discriminable target. This observation is consistent with Potter et al.'s (2002) claim that targets compete for access to attentional resources and that the time needed to complete target identification is a crucial determinant of competitive strength. Second, small discriminability differences between the two targets seem to induce mainly order confusions, which is particularly obvious from the opposite effect of T2 discriminability on the error confusions (T1i & T2i) with easy T1s (where easy T2s create the most confusions) and with difficult T1s (where difficult T2s create the most confusions). As subjects were able to

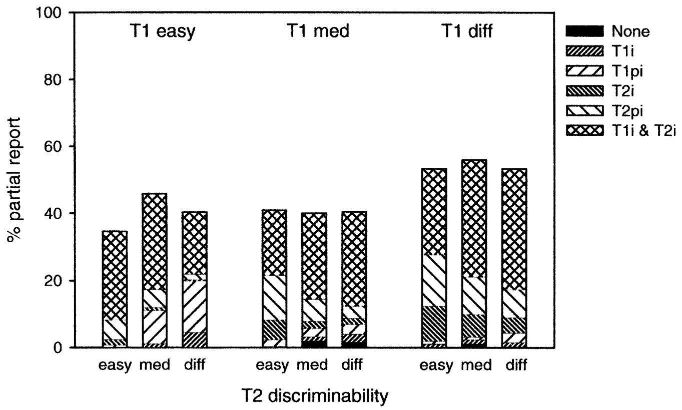

Figure 9. Percentage partial reports for Lag 1 as a function of T1 discriminability and T2 discriminability in Experiment 2 (T1 identity only, T1i; T1 identity and temporal position, T1pi; T2 identity only, T2i; T2 identity and temporal position, T2pi; both targets in wrong order, T1i & T2i).

correctly report both target identities both targets must have gained access to attentional resources. According to the sluggish-gate account this would mean that T1 and T2 became part of the same attentional episode, which necessarily eliminated information about the sequence of the two stimuli.

All in all, Experiment 2 shows that performance at Lag 1 of an AB task is systematically affected by the discriminability of the two targets. Assuming that absolute and, more important, relative discriminability of the targets determines their competitive strength when trying to get access to attentional resources our findings provide direct evidence that T1 and T2 do indeed compete for access to the next processing stage and that this competition is particularly pronounced at Lag 1. However, we also found strong evidence for integration, especially in cases where the two targets were likely to be competitors of equal strength. Thus, there are reasons to assume that competition and integration accounts do not provide alternative interpretations of the same phenomenon but, rather, refer to the different possible outcomes of concurrent target processing.

GENERAL CONCLUSIONS

Our study aimed at investigating the mechanisms underlying the so-called Lag-1 sparing in the AB task. In particular, we asked two questions: One was whether T1 performance would be affected by lag, which would support Potter et al.'s (2002) suggestion that T1 and T2 compete for access to attentional resources. The second was whether Lag 1 would be associated with an increase of order errors in target reports, which would support the idea that the two targets may be processed in or integrated into a common attentional episode. Both questions can be answered affirmatively.

T1 report was strongly affected by lag, at least in Experiment 2. As in the study of Potter et al. (2002), the probability of correctly reporting T1 was reduced at Lag 1 to a degree that varied with the amount of "sparing" observed for T2. The fact that we were able to replicate this effect shows that Potter et al.'s observations are not restricted to the RSVP tasks with spatial uncertainty that they used but generalize to standard AB tasks. Moreover, we were able to demonstrate the exchange relation between T1 and T2 in conditionalized accuracy data, vis-à-vis a standard AB and a Lag-1 sparing effect that both satisfy the criteria of Visser et al. (1999). Thus, we can be sure that T1 performance is affected by the temporal distance between T1 and T2—which fits well with previous observations of Broadbent and Broadbent (1987) and Chun and Potter (1995)—and that at least part of the Lag-1 sparing of T2 performance is due to a trade-off with T1—supporting the conclusions of Potter et al. (2002). With regard to our second question about target-order errors the outcome is also clear. In Experiment 1 we saw that subjects often reported the right target identities in the wrong order when T1 and T2 were presented in direct succession. Experiment 2 confirmed this impression and showed that the frequency of order errors depends on the relative discriminability of the two targets, which we take to determine the targets' competitive strength.

Taken together, our findings underscore Potter et al.'s (2002) point that some qualifications are in order of both the term "Lag-1 sparing" and assumptions about the mechanisms underlying it. Regarding the term it seems clear by now that whether one can consider something is spared or not strongly depends on one's performance criteria. This is obvious from Figure 10, where we present, for Experiments 1 and 2, the unconditional, lag-related performance on both targets (i.e., the percentage of trials in which both targets were reported correctly) as a function of two different criteria of what counts as "correct report". The unfilled symbols represent the rather lenient criterion that is commonly used in AB studies—namely, the requirement to report correct identities irrespective of order (e.g., Chun & Potter, 1995). Clearly, what we see here can be characterized as "sparing", inasmuch as Lag 1 shows better performance than other lags. The filled symbols represent the stricter requirement to report both identity and order correctly. Here we see no evidence of any special role of Lag 1, which in fact produces the numerically worst performance.

In our view, the very fact that Lag-1 sparing depends on whether target order is to be reported or not points to the mechanism underlying it. A strong interpretation of a competitive account along the lines of Potter et al. (2002) holds that targets compete for access to attentional resources and that only one target can win; hence, no more than one stimulus at a time can enter the first stage of processing in an AB task. (Potter et al. rightly point out that their findings do not require this conclusion but they do seem to have a strong preference

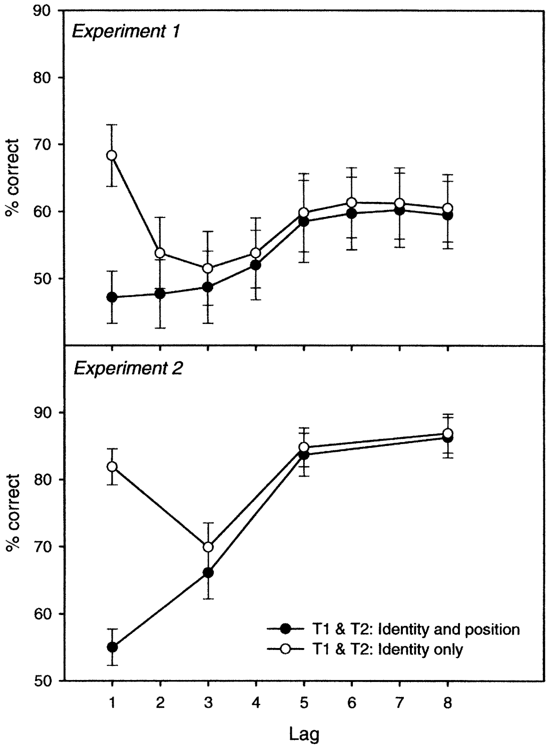

Figure 10. Percentage correct report (+/− 1 *SE*) of the identity or of identity and order of both targets as a function of lag in Experiment 1 (upper panel) and experiment 2 (lower panel).

for it.) However, we find it difficult to see how such an account may explain the pattern presented in Figure 10: Why, through competition between temporally close T1 and T2, would identity-related performance benefit but order information get lost? This does not mean that competition does not take place at all—in fact, we have seen several reasons to assume that it does—but competition as such does not seem to readily account for the patterns in our error data.

A better account for this particular pattern seems to us to be the suggested interpretation of the sluggish-gate metaphor discussed by Chun and Potter (1995), Shapiro and Raymond (1994), Visser et al. (1999), and others, that presenting two targets in close temporal succession may lead to the joint integration of both events into a single episodic trace. If so, T2 codes can kind of parasitize T1 and enjoy the same prioritized attentional treatment as the first target. This comes with a cost, however: As both targets now belong to the same represented episode information about their temporal relation is lost, as witnessed by the excessive increase of order errors we observed in our two experiments. If these errors count, temporal proximity can be said to impair (or have no impact on) performance, but if they do not count temporal proximity has a positive effect—Lag-1 sparing. The consideration that integrating both targets into a common episodic trace may benefit performance (as long as order is not an issue) is also consistent with recent demonstrations of Sheppard and colleagues (2002). By using a morphing technique they showed that the AB is eliminated if T2 is a visual continuation of T1 and, hence, is presumably perceived as a mere change of T1 but not as a new object. Moreover, the suggestion that identity information may often be retained while order information is lost fits well with observations of Kessler and colleagues in a recent MEG study of the AB (Kessler et al., 2005a, 2005b). The activation patterns obtained in this study suggest that, in the AB task, a left-temporo-parietal network is coding the identity of the targets and their match with the maintained target template while a dissociable, slightly time-lagging, right-temporo-parietal network is responsible for binding identities to temporal positions. That is, identifying the targets may well be independent from, and briefly precede, the assigning of temporal order. If so, the identification network may (often) treat temporally close targets as one single stimulus, which then receives a single time tag (or two distorted tags) from the temporal-binding network—thereby effectively eliminating or distorting order information. Indeed, Kessler et al. (2005a) found distinct M300 (the magnetoencephalographic equivalent of the P300) components for the two targets in prefrontal and right-temporo-parietal areas but only a single component in left-temporo-parietal areas.

The findings from Experiment 2 further suggest that, if two target stimuli are presented sufficiently close in time, they compete for attentional resources. One possible outcome of this competition is that one target wins at the expense of the other(s)—which will not be retained for later report. The easier a target can be discriminated relative to its competitor the better its chances of winning and the less likely the competitor will be recalled. If two competitors are equally strong, however, they will often be treated as one single event, and both get access to attentional resources. But this comes with a cost, as order information will be lost. While the joint integration of targets and its associated loss of order information can be better explained by the sluggish-gate metaphor, the trade-off of identification performance observed in Experiment 2 seems to be better accommodated by the competition account.

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APPENDIX

Comparison of performances between Experiments 1 and 2

Variable	*df*	*F*	*MSE*	*sig.*
	T1 unconditional, strict			
T1 discriminability	1.1, 20.9	6.29	.173	.05
Lag	1.8, 35	145.58	.047	.001
T1 discr. × Lag	3.8, 72.3	8.43	.019	.001
	T2 unconditional, strict			
T2 discriminability	1.5, 28	48.76	.058	.001
Lag	2, 38.9	54.34	.08	.001
T1 discr. × Lag	6, 114	4.68	.014	.001
T2 discr. × Lag	3.9, 73.4	10.95	.027	.001
T1 discr. × T2 discr.	4, 76	2.69	.018	.05
	T1 unconditional, lax			
T1 discriminability	1.1, 21.1	7.86	.109	.01
T2 discriminability	1.5, 29.3	13.42	.007	.001
Lag	2.1, 40.2	25.51	.012	.001
T1 discr. × Lag	6, 114	6.44	.004	.001
T2 discr. × Lag	6, 114	7.56	.004	.001
T1 discr. × T2 discr.	4, 76	2.94	.003	.05
	T2 unconditional, lax			
T1 discriminability	1.5, 27.9	9.67	.014	.005
T2 discriminability	1.3, 24.3	37.12	.087	.001
Lag	2, 37.3	36.98	.051	.001
T1 discr. × Lag	3.9, 74.1	3.4	.017	.05
T2 discr. × Lag	6, 114	19.48	.009	.001
T1 discr. × T2 discr.	4, 76	4.68	.007	.05
T1 discr. × T2 discr. × Lag	5.5, 103.8	2.24	.017	.05