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Acta Psychologica 119 (2005) 305–314

acta psychologica

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Target integration and the attentional blink

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Received 31 October 2004; received in revised form 16 February 2005; accepted 19 February 2005
Available online 14 April 2005

Abstract

If people monitor a visual stimulus stream for targets they often miss the second (T2) if it appears soon after the first (T1)—the attentional blink. There is one exception: T2 is often not missed if it appears right after T1, i.e., at lag 1. This lag-1 sparing is commonly attributed to the possibility that T1 processing opens an attentional gate, which may be so sluggish that an early T2 can slip in before it closes. We investigated why the gate may close and exclude further stimuli from processing. We compared a control approach, which assumes that gate closing is exogenously triggered by the appearance of nontargets, and an integration approach, which assumes that gate closing is under endogenous control. As predicted by the latter but not the former, T2 performance and target reversals were strongly affected by the temporal distance between T1 and T2, whereas the presence or the absence of a nontarget intervening between T1 and T2 had little impact.

PsycINFO classification: 2323; 2346

Keywords: Selective attention; Attentional blink; Lag-1 sparing

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0001-6918/$ - see front matter
doi:10.1016/j.actpsy.2005.02.006

1. Introduction

Human attention is limited with regard to space and time. An impressive example for a temporal limitation is the so-called attentional blink (AB), which occurs if people monitor a stream of perceptual events for particular target events: If the second of two targets (T2) occurs in an interval of about half a second after the first (T1), it will often be missed (Broadbent & Broadbent, 1987; Raymond, Shapiro, & Arnell, 1992). An interesting exception is observed at lag 1, that is, if T2 appears right after T1. In this condition performance on T2 is often as good as at very long lags: the so-called lag-1 sparing phenomenon (Visser, Bischof, & Di Lollo, 1999). The present study aimed at investigating why lag-1 sparing occurs and which mechanisms are responsible for it.

A key characteristic of lag-1 sparing is that it comes with a cost: First, relative increases in lag-1 performance on T2 are sometimes accompanied by drops in performance on T1 (Hommel & Akyürek, in press; Potter, Staub, & O'Connor, 2002), at least if the time interval between the two targets is short. Thus, not all benefits associated with T2 are due to true "sparing"; instead, short lags may simply increase the probability that the two targets compete for attentional resources, a competition that T2 sometimes wins. Second, there is evidence that most if not all of the relative increase in performance on T2 stems from trials in which both targets are reported correctly but in the wrong order (Hommel & Akyürek, in press). This suggests that, even in the trials in which report of T2 does not go at the expense of T1, "sparing" identity information leads to the loss of temporal order information.

A possible explanation for this trade-off between identity and order information is motivated by the idea that registering T1 leads to the opening of an attentional gate or integration window, which closes after sufficient information has been gathered to identify the first target. This gate may be sluggish, so that T2 will get the opportunity to "slip in" if it appears soon enough (cf., Raymond et al., 1992)—which is more likely the shorter the lag. Integrating the two targets into the same attentional episode would certainly be beneficial for T2, which then could enjoy the same privileged processing as T1. However, if the two targets are processed "as one event" or at least concurrently there would be no way to determine their temporal sequence. Accordingly, people can only guess which of the two remembered targets came first, which will produce numerous order errors. In support of this possibility, Kessler et al. (in press) observed clearly separable M300 (the magneto-encephalographic equivalent of the better-known P300) peaks for two successive targets in frontal cortical regions and right-parietal areas (which, among other things, may be involved in sequencing), while temporal sources (presumably related to identification) showed only a single, merged M300. This suggests that stimuli that appear while the attentional gate is open get parallel access to attentional resources and are identified in parallel, and even their temporal positions may be properly registered. However, the temporal overlap of the identification processes may make the binding of identities to relative positions difficult and error prone.

Given the apparently very beneficial consequences of opening and leaving open an attentional gate, the question arises why people do not leave this gate open until T2 is processed, irrespective of the lag. The answer to this question is likely to be related to the many nontargets a typical AB stream includes. The most important of these may be the one directly following T1. In a study by Seiffert and Di Lollo (1997), the presence of this nontarget (or mask), was directly investigated. The authors concluded that a clear negative relation between the occurrence of the mask (which in their view degraded the perception of T1) and the attentional blink existed. Yet, the existence of this relation was challenged by McLaughlin, Shore, and Klein (2001), who (using a variable mask-target duration paradigm) observed no relation between T1 accuracy and the severity of the blink. At the same time, an additive effect was found for the same manipulation on T2 and its mask (but see Giesbrecht, Bischof, & Kingstone, 2003). If it can at least be assumed that a nontarget following T1 can have an effect on T1 and T2 performance, then there are at least two ways of how the presence of such a nontarget may affect the opening and, more important for present purposes, the closing of integration windows.

First, the occurrence of a nontarget may automatically trigger the closing of the gate. As suggested by Di Lollo, Kawahara, Ghorashi, and Enns (2005), the first nontarget that appears after T1 may hamper the proper maintenance of the target-related task set and induce a temporal loss of control. If T2 appears before control is reestablished, it will be missed. If it appears before the first nontarget, however, as is the case for lag 1, T2 can escape that problem and will be reported as often as T1. Note that the size of the integration window, that is, the time the attentional gate is open, plays no role in this approach. What matters is only whether a nontarget is or is not inserted between T1 and T2—performance on T2 should be bad if it is but excellent if it is not, irrespective of the time between the two targets.

Second, people may be able to control the size of their integration windows. As a typical AB stream consists of numerous distracting stimuli presented in fast succession, it would make sense to tailor the integration window to the rhythm of the stimulus sequence, that is, to choose integration windows that approximate the presentation time of the targets (cf., Lupiáñez, Milliken, Solano, Weaver, & Tipper, 2001). Consistent with this idea, Toffanin, Akyürek, and Hommel (submitted for publication) found more target reversals at lag 1 if subjects were led to expect a very slow presentation rate than if they expected a very fast presentation rate. According to this approach, time may be more important for order reversals than the presence of nontargets, at least with respect to a given trial. On the one hand, it is true that the presence and timing of nontargets will affect the size of the integration window chosen. On the other hand, however, once the experience with the relevant stimulus events has led to the implementation of a particular size, the likelihood that T2 falls into the integration window should only depend on how quickly T2 appears after T1 has been registered and the window opened.

To gain more insight into the processes underlying target integration, and the role of time and nontargets in particular, we varied the duration of T1 on the one hand and the presence or the absence of a nontarget at lag 1 on the other. Fig. 1 shows the relevant manipulations for the shortest and therefore theoretically most important lags. The first and the third rows show the two most standard conditions: T2 appears at the second lag after T1 and lag 1 is either filled with a nontarget (third row) or

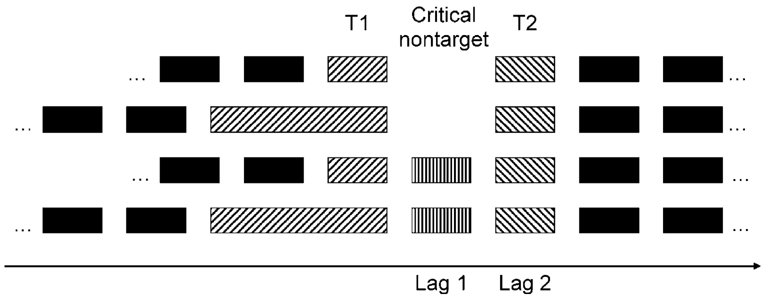

Fig. 1. Sequence of events. T1 was either short (first and third row from top) or long (second and fourth row) and a nontarget either did (third and fourth row) or did not (first and second row) appear in the otherwise constant interval between T1 offset and T2 onset. Note that our counting of lags refers to temporal positions (from T1 offset on) but not events.

unfilled (first row). To manipulate the temporal distance between T1 and T2, we could have increased the unfilled interval in the condition without an intervening nontarget and increased the interval between either T1 and the nontarget or between the nontarget and T2 in the condition with an intervening nontarget. Unfortunately, however, this would have introduced a couple of confounding factors, such as breaking the rhythm of the whole stimulus stream if the empty gap becomes too large (Sheppard, Duncan, Shapiro, & Hillstrom, 2002) and changing the amount of backward or forward masking provided by the intervening nontarget. To avoid these kinds of effects, we decided to keep the interval between T1 *offset* and T2 onset constant but manipulate the interval between T1 onset and T2 onset by varying the duration of T1 (see second and fourth rows).

Given that some combinations of our experimental factors create rather trivial demands on target processing proper (e.g., performance is likely to be excellent if T1 and T2 are widely spaced and not separated by a nontarget), we focused on the apparently most sensitive measure of T1–T2 integration, namely, target-order reversals. In particular, we looked into whether order reversals at the shortest lag (lag 2 in our case) would be more likely if the two targets appear in close succession (irrespective of whether or not a nontarget appears in between) or whether order reversals would only occur in the absence of a nontarget stimulus in between (irrespective of the temporal distance between the two targets).

2. Method

2.1. Participants

Twenty Leiden University students (18 female and 2 male) participated in the experiment in exchange for monetary compensation or course credit. They were unaware of the purpose of the experiment and reported normal vision and concentration span. Mean age was 20.6 years.

2.2. Apparatus and stimuli

The experiment was run by the E-Prime© 1.1 SP3 runtime component on a standard Pentium© III class PC. A 17 in. flat-screen CRT running at 800 by 600 pixel resolution in 16 bit color and refreshing at 100 Hz was used for all presentations. The viewing distance was approximately 50 cm, but not strictly controlled. The fixation point at the start of each trial was a black plus sign ("+") presented in the center of the display on a uniform gray background (RGB 128, 128, 128). The target digits were randomly picked (without repetition) from the digits 1–9, with the exception of 5. The nontargets were selected in the same way from the complete alphabet. All visual stimuli were set in 16 pt. Times New Roman font in black on the aforementioned gray background. Participants responded at leisure by pressing the appropriate digit keys on a standard USB keyboard.

2.3. Procedure and design

The completely within-subject design had three independent variables: lag, the temporal position of T2 with respect to T1, which varied between lags 2, 3, and 8; the duration of T1, which was either short (70 ms) or long (210 ms); and the presence or the absence of a nontarget at lag 1. Participants initiated each trial by pressing the spacebar, which triggered the presentation of the 200-ms fixation mark after a delay of 800 ms. Then the 20-item stream started. It was presented centrally to exclude spatial factors such as location switching costs. Each item lasted for 70 ms, with a pause of 30 ms in between items, except in the T1 long condition where T1 lasted for 210 ms (see Fig. 1). Two hundred milliseconds after the offset of the last item two successive unspeeded response screens for T1 and T2 identity ensued. A complete session consisted of two blocks of 288 experimental trials and 16 practice trials. All experimental variables were presented intermixed, so that participants would not be able to adapt to specific conditions. The total of 592 trials took about 60 min to work through, depending on individual response speed.

3. Results

Analyses were run on accuracy (percentage correct) on T1 (absolute) and on T2 (conditional, i.e., T2 given T1 correct), and on the percentage of T1–T2 order reversals (i.e., the trials in which both targets were reported but in the wrong order), as a function of T1 duration, the presence or the absence of a nontarget at lag 1, and the lag between T1 and T2. ANOVAs for dependent measures were used and degrees of freedom were Greenhouse–Geisser adjusted and rounded to one decimal whenever appropriate. The correct order of report was not required in the analyses of T1 and T2 performance.

T1 performance was affected by the three main effects of T1 duration, $F(1,19) = 25.56$, $\mathrm{MSE} = .002$, $p < .001$, the presence of a mask, $F(1,19) = 26.54$, $\mathrm{MSE} = .001$, $p < .001$, and lag, $F(2,38) = 4.92$, $\mathrm{MSE} = .001$, $p < .013$. The latter indicated that lag 2 was slightly more difficult than lags 3 and 8 (97.0% vs. 97.9% and 97.6%, respectively). Duration and nontarget were also involved in an interaction, $F(1,19) = 36.27$, MSE = .001, $p < .001$, that indicated that the combination of short T1 presentation and an intervening nontarget produced a worse performance than the remaining conditions, which were all close to ceiling (see Fig. 2, left panel).

Performance on T2 was similarly affected by main effects of duration, $F(1,19) = 69.17$, MSE = .002, $p < .001$, intervening nontarget, $F(1,19) = 25.84$, MSE = .004, $p < .001$, and lag, $F(2,38) = 12.36$, MSE = .004, $p < .001$. In addition, the interaction of nontarget and lag was significant, $F(2,38) = 5.86$, MSE = .003, $p < .006$. The duration and nontarget effects were rather straightforward: performance was worse if T1 was short than if it was long, and worse if a nontarget stimulus appeared in between the two targets. The lag effect showed a lower performance on lags 2 and 3 than on lag 8, that is, we obtained an AB. The size of this AB may seem fairly modest, but this is largely due to the inclusion of the not commonly used gap and long-T1 conditions. Without the trials from these conditions the difference between lags 2 (79%) and 3 (78.1%) on one side and lag 8 (88.5%) on the other is about twice as big, indicating a healthy 10%-AB. As shown in the center panel of Fig. 2, the interaction is due to the gap conditions being virtually unaffected by lag, whereas performance on trials with a nontarget at lag 1 drops at lags 2 and 3. Given previous reports that the AB is absent if T1 is not masked (Raymond et al., 1992), this observation does not come as a big surprise.

The most interesting analysis referred to the frequency of T1–T2 order reversals (see Fig. 2, right panel). These decreased with increasing duration (3.4% and 1.0%,

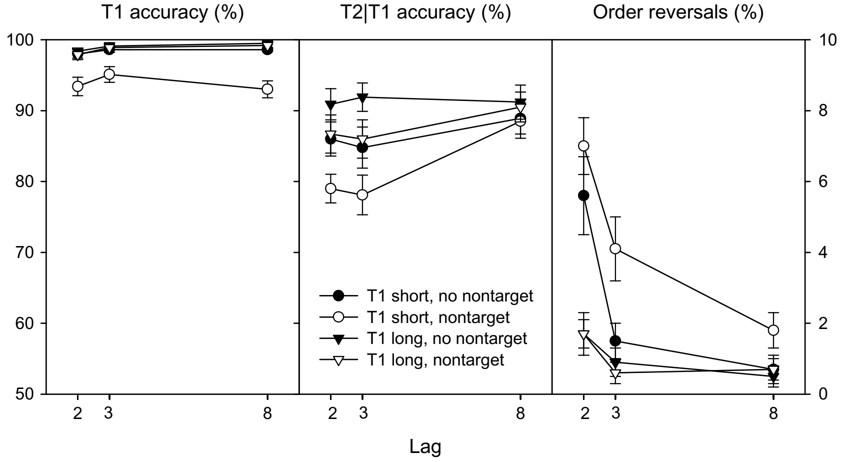

Fig. 2. Performance on T1 (left panel, percent correct), conditional performance on T2 (center panel, percent correct), and T1–T2 order reversals (right panel, percent of the total number of trials) as a function of lag between T1 and T2, T1 duration, and the presence or the absence of a nontarget between T1 offset and T2 onset.

respectively; $F(1,19) = 67.25$, MSE = .001, $p < .001$), were more likely in the presence than the absence of a nontarget (2.6% vs. 1.8%), $F(1,19) = 9.18$, MSE = .001, $p < .007$, and steadily decreased as lag increased (4.0%, 1.8%, and 0.9%, respectively), $F(1.4,32.7) = 24.37$, MSE = .001, $p < .001$. The interactions of duration and lag, $F(2,38) = 18.86$, MSE = .001, $p < .001$, and of duration and nontarget, $F(1,19) = 13.34$, MSE = .001, $p < .001$, were also significant. The former indicated that the increase of reversals at the shortest lag was more pronounced for brief T1 presentations. The latter showed that an intervening nontarget impaired order recall if T1 was brief but had no impact if T1 was long. Interestingly, there was no interaction relating the presence of an intervening nontarget and lag, $p > .27$.

Comparison of the middle and right panels of Fig. 2 showed that while there was virtually no difference between the short T1 without intervening nontarget and the long T1 with nontarget conditions in the analysis of T2 accuracy, there was a remarkable difference between them in the reversal analysis. Separate ANOVA's on these conditions confirmed this interpretation. On the accuracy analysis, T2 lag affected both conditions, $F(1.4,27.1) = 8.21$, MSE = .003, $p < .004$, but no other difference existed between them, $p > .26$. On the reversal analysis, a pronounced difference between conditions did exist, $F(1,19) = 19.29$, MSE = .001, $p < .001$. T2 lag also affected both conditions, $F(1.3,24.3) = 16.84$, MSE = .001, $p < .001$. Finally, the interaction was significant, $F(1.5,28) = 15.13$, MSE = .006, $p < .001$, indicating that the difference was largest at lag 2.

4. Discussion

The purpose of the present study was to compare the impact of the temporal distance between T1 and T2 on performance in an AB task with the impact of a nontarget intervening between the two targets. Performance on T2 is partly consistent with the findings of Di Lollo et al. (2005): T2 is reported more often if it is not separated from T1 by a nontarget. According to Di Lollo et al., this may indicate that the stimulus not matching the current input filter or search template creates an exogenously triggered attentional control problem, e.g., by activating a task set that is incompatible with what is needed for the current task. Accordingly, T2 appears at a point in time when the system is not optimally prepared and, thus, is more often missed. However, two observations do not seem to fit with the control approach of Di Lollo et al.

First, an intervening nontarget impaired performance equally at lags 2 and 3. If T2 appeared at lag 3, it was always preceded by at least one nontarget (at lag 2), irrespective of the presence or the absence of another nontarget at lag 1. Should not this nontarget at lag 2 have triggered a control problem even in the conditions without an intervening nontarget at lag 1? If so, should not the effect of the lag-1 nontarget be restricted to T2s appearing at lag 2? Not necessarily. The control approach assumes that nontargets can exert their damaging effects only while the system is occupied with T1 processing, so that the necessary control signals to input filters cannot be issued. This would suggest that nontarget-induced costs are only to be expected if the triggering stimulus appears soon after T1 is presented, that is, if the nontarget appears at lag 1. More problematic for the control approach is the finding that an intervening nontarget impaired performance even when T1 appeared for 210 ms. In view of the excellent performance on T1 it seems unreasonable to assume that (at least) the visual perception of the first target required longer than 210 ms, which means that in this condition a nontarget at lag 1 would not meet a system that is too busy to issue control signals. Accordingly, this nontarget should have been as unable to trigger a competing task set as nontargets appearing at lag 2.

An alternative account for the obtained pattern in T2 performance in terms of temporal integration windows is viable. Consider that the integration windows used in a particular situation are tailored to match the expected length of the respective target stimuli (Toffanin et al., submitted for publication). As T1 was often very long in our experiment, the respective integration window was likely to be somewhat larger than normal, that is, larger as one would expect if T1 is always very brief. This would have opened the possibility that distractor information fell into the T1-related window and enjoyed prioritized processing to some degree, which again would make it a strong competitor in short-term memory. This should have been more likely the shorter T1 was presented (as that implied sooner appearance of a nontarget) and the earlier the respective nontarget appeared, that is, if one appeared at lag 1. Accordingly, one would expect main effects of T1 duration and the presence of an intervening nontarget at lag 1, just as observed. To account for the (rather mild) decrease of the nontarget effect at lag 8, one may either assume that this is a ceiling effect or speculate that the impact of the stored distractor can be counteracted in some way while waiting for the late T2. For instance, distractors may be less strongly consolidated, so that their codes decay more quickly and a later arriving T2 meets less resistance.

Our main interest was whether and how target-order reversals would be affected by our experimental variables. As expected, reversals were most likely at the shortest lag, which replicates the observations of Hommel and Akyürek (in press) and others. However, the lag effect only occurred for short T1 presentation. This provides strong evidence in favor of an integration approach: If we assume that the sizes of integration windows are not changed from trial to trial and, even more important, within a trial, an integration window opened upon the registration of T1 was more likely to allow for parallel processing of T2 the sooner T2 appeared. As processing the two targets in parallel made the binding between computed target identities and their temporal positions difficult and error prone, order reversals increased as the temporal distance between T1 onset and T2 onset decreased, hence, if T1 was brief and lag was short. The consequences for T2 to fall into a still open integration window (i.e., the T1-duration effect) would not depend on the presence or the absence of a nontarget, which explains why the impact of an intervening nontarget does not modulate the interaction between duration and lag. Some caution has to be taken with this account, as there was some indication in the reversal analysis that the difference between the effect of the nontarget for T1 short and long durations was largest at lag 3. An explanation for this phenomenon could be that the attentional gate is not always shut perfectly and that additional intervening items increasingly contribute to the shutting down process, which would promote reversals at lag 3 when an extra (i.e., at lag 1) nontarget is presented.

Nontargets at lag 1 do have an impact on performance, but only if T1 is short. The fact that this impact is independent of lag suggests that it is unrelated to attentional selection and target integration. Along the lines of our account of the T2 performance pattern, we assume that a short T1 increases the likelihood that a distractor at lag 1 falls into the open integration window and thus gains access to attentional resources. Once processed and consolidated to some degree, this nontarget will compete with the other items stored in short-term memory. This competition may further hamper the maintenance of order information, which then gets lost until target report. Consequently, subjects have to guess, which leads to order reversals.

To summarize, our findings do not support the control account of Di Lollo et al. (2005). Given the many differences between the design these authors used and the one we employed in the present study, we hesitate to draw strong conclusions from the failure of the control approach to account for our findings. It may well be that nontargets do challenge the current attentional set if the system is busy, but that the conditions under which they do are less general than Di Lollo et al. assumed. What seems clear, however, is that our present findings are not predicted by and do not require such an account.

Instead, an integration approach seems to have some promise in capturing the main observations with respect to T2 performance and order reversals. The assumption that processing target-related information is associated with establishing an integration window of a particular temporal extension has also been successfully applied to the interpretation of varying patterns of inhibition of return (IOR) effects. These effects are obtained if spatially varying target stimuli are preceded by noninformative spatial cues. If the interval between cue and target is short, the spatial correspondence between them facilitates performance on the target. With longer intervals, however, correspondence yields a disadvantage: IOR. Interestingly, the point in time (i.e., the interval) when facilitation turns into interference changes from study to study. Lupiáñez et al. (2001) have pointed out that this variability may not be accidental but reflect different sizes of integration windows suggested by the task and the difficulty to identify the target. Making a target more difficult to identify may induce longer integration windows, because more information needs to be gathered before a decision about target identity can be made. This may increase chances that a temporally close cue falls into the integration window, which in the case of cue-target correspondence produces a benefit. In support of their account, Lupiáñez et al. were able to show that, indeed, increasing identification difficulty extends the cue-target interval during which facilitation is observed, while the presence of distractors reduces this interval. Given Toffanin et al.'s (submitted for publication) observation that order reversals in an AB task are affected by the expectation of a slow vs. fast stimulus presentation rate, it makes sense to assume that a very similar integration mechanism is at work in processing more extended streams of visual information, such as in the present experiment. The indications that the size of this integration window seems to be variable and sensitive to task constraints open new, interesting venues for further research.

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