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Adaptive Control of Event Integration

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Identifying 2 target stimuli in a rapid stream of visual symbols is much easier if the 2nd target appears immediately after the 1st target (i.e., at Lag 1) than if distractor stimuli intervene. As this phenomenon comes with a strong tendency to confuse the order of the targets, it seems to be due to the integration of both targets into the same attentional episode or object file. The authors investigated the degree to which people can control the temporal extension of their (episodic) integration windows by manipulating the expectations participants had with regard to the time available for target processing. As predicted, expecting more time to process increased the number of order confusions at Lag 1. This was true for between-subjects and within-subjects (trial-to-trial) manipulations, suggesting that integration windows can be adapted actively and rather quickly.

Keywords: Lag 1 sparing, control of event integration, attentional blink

Selecting one or more predefined target objects from a rapidly changing stream of visual information is a difficult task (Schneider & Shiffrin, 1977). Such rapid serial visual presentation (RSVP) tasks are known to generate the so-called attentional blink (AB): the second of two targets to be reported (T2) is often missed if it appears briefly after the first (T1; Raymond, Shapiro, & Arnell, 1992). The AB has been attributed to competition between target codes for access to short-term memory (Chun & Potter, 1995), competition within short-term memory (Shapiro, Raymond, & Arnell, 1994), and capacity limitations associated with consolidation into short-term memory (Jolicœur & Dell'Acqua, 1998). Under certain circumstances, however, these limitations do not seem to come into play. When T2 immediately follows T1—that is, at Lag 1—and when there is no task switch between targets, identification accuracy on T2 is much higher than at the following lags and as good as, or even better than, performance at long lags outside of the AB interval. This phenomenon has been called *Lag 1 sparing* (Potter, Chun, Banks, & Muckenhoupt, 1998). Lag 1 sparing and the AB are logically intertwined, because Lag 1 sparing is an escape from the dual task deficit evidenced by the AB. Yet the sizes of the two effects are often uncorrelated and can be dissociated by appropriate experimental manipulations, which suggests that they have different origins (Visser, Bischof, & Di Lollo, 1999). In the present study, we focused on mechanisms underlying Lag 1 sparing rather than those specific to the AB.

Sparing seems to reflect at least two different and not mutually exclusive processes. First, targets appearing close in time apparently compete for attentional resources, so that gains with respect to T2 come with losses regarding T1 (Potter, Staub, & O'Connor, 2002). Indeed, a trade-off between the two targets at Lag 1 has been observed in several studies (Broadbent & Broadbent, 1987; Chun & Potter, 1995; Hommel & Akyürek, 2005; Potter et al., 2002), suggesting that competition does play a role. In particular, at Lag 1, the competition seems to be biased toward the identity of T2, whereas T1 is favored during the AB. However, biased competition cannot be the whole story. As found by Hommel and Akyürek (2005) and others (e.g., Shih, 2000), Lag 1 sparing is accompanied by a substantial increase of order errors—that is, people are able to report both targets in a substantial number of trials, but they often do so in the wrong order. This suggests temporally close targets may, under particular circumstances, be integrated into the same episodic representation or object file in the sense described by Kahneman, Treisman, and Gibbs (1992; cf. Raymond, 2003; Sheppard, Duncan, Shapiro, & Hillstrom, 2002). Integration of two targets into one representation would, on the one hand, help to recall the identity of more than one target but, on the other, lead to the loss of information about their relative timing and temporal order (Hommel & Akyürek, 2005; Kessler et al., 2005). The increase of order errors and its associated improvement of identity report are typical of the Lag 1 condition and have no parallel in "blinked" lags.

In the present study, we investigated whether people can exert control over this hypothetical integration process. Lupiañez, Milliken, and colleagues (Lupiañez & Milliken, 1999; Lupiañez, Milliken, Solano, Weaver, & Tipper, 2001) provided evidence that people may be able to adjust the time window during which

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information about a given visual object is collected and thus when the object file holding this collection is closed. For instance, Lupiañez et al. (2001) have shown that the transition from priming by location repetition to inhibition of return occurs earlier in time when interfering distractors are present than when they are not. Although alternative interpretations of this observation are viable (Klein, 2000), it seems possible that the mere expectation of the presence or absence of a distractor can affect the time taken to integrate information about a target. In other words, people may be able to control the temporal extension of the integration window used to construct object files.

The present study aimed at providing direct evidence for the adaptive control of event integration by modulation of the temporal extension of the integration window in particular. Our diagnostic measure was not Lag 1 sparing as such, as this is likely to reflect both gains from integration into the same object file and losses (distributed across T1 and T2) from competition within this file (Hommel & Akyürek, 2005). Instead, we used order confusions between T1 and T2. Order confusions can occur only if both targets are reported, which means that this measure at least minimizes the impact of target competition. Moreover, we were not interested in order errors as such, as some of them may merely reflect memory processes (forgetting), but in order errors that are restricted to Lag 1.

We attempted to induce longer or shorter integration windows by manipulating the expectations of our participants with regard to the time available for target processing. Consider how encouraging participants to use a long integration window would affect the integration of the two targets at Lag 1. When encountering T1, the corresponding object file would be left open and information would be collected for a longer time, so that T2 would have greater chance to be included and integrated together with T1. Because of the creation of a unitary episode containing both targets, an increased probability of joint integration should be accompanied by an increase in the frequency of order confusions. That is, the likelihood of reporting both targets in the wrong order would increase.

Experiment 1

In Experiment 1, we presented two groups of participants with standard RSVP trials that we expected to produce Lag 1 sparing, as defined by Visser et al. (1999); that is, performance at Lag 1 exceeding the lowest level of performance at any other lag by more than 5%. In one group, we mixed a large proportion of RSVP trials in which stimuli had an apparently fast presentation rate with a small portion of apparently slow trials. In the other group, we employed the reverse distribution of trials so that the slow trials were in the majority. The high frequency of trials in which there was (seemingly) more time to process the targets was meant to encourage participants to use a relatively long integration window, persisting even in the few fast trials. As a consequence, the frequency of order errors in trials at Lag 1 should be increased in this *slow expectancy* group as compared to the first, *fast expectancy* group.

We used a procedure similar in character to that used by McLaughlin, Shore, and Klein (2001) to realize the appearance of different trial speeds: Within an interval of 100 ms, stimulus and blank duration were varied. In the fast trials, the stimuli stayed on screen for 30 ms, each followed by a 70-ms blank interval (i.e., nothing visible on the standard background). In the slow trials, the stimulus lasted for 70 ms, with a 30-ms blank interval. To the observer, the first type of trial appears to be considerably faster than the second.[1] However, because the stimulus onset asynchrony between stimuli was in fact constant, the design was comparable to traditional RSVP-based AB studies, because all trials were paced such that an AB could be elicited.[2]

Method

Participants. Thirty-two students (25 female, 7 male) at the University of Reading participated in this experiment for course credit or monetary compensation. None of them were aware of the purpose of the experiment and all reported having normal or corrected vision. Mean age was 21.9 years.

Apparatus and stimuli. The experiment was designed using the E-Prime (Version 1.2) software package; stimuli were presented on a standard PC using a 17-in. monitor refreshing at 100 Hz, with a resolution of 800 × 600 pixels (16-bit color depth). Participants were seated in a lab behind a computer screen at a viewing distance of about 60 cm. A red plus sign (+) presented at the center of the light gray screen served as fixation mark. Target digits were *1, 2, 3, 4, 6, 7, 8*, and *9*, and distractors were chosen from the 26 letters of the alphabet. All characters were set in 18-point Courier New font and presented in black. Participants were to respond to successive prompts (first, then second target) after RSVP offset by pressing the corresponding numeric keys on the keyboard.

Procedure and design. Participants initiated each trial by pressing the spacebar, followed 200 ms later by a fixation mark that was presented in red for 250 ms. The RSVP stream that followed consisted of 19 items with either 30 ms stimulus duration and 70 ms blank duration or the reverse. Finally, two identification prompts were presented for the unspeeded responses to T1 and T2. Target and distractor items were randomly drawn from their sets (see above) but were never repeated within a trial. Each participant completed 20 practice trials and 480 experimental trials. Each session lasted from 50 to 60 min, depending on the participant's response speed.

The experimental design featured two within-subjects factors. The first one was a T1–T2 lag that varied between T2 being the first, third, or eighth stimulus shown after T1. The second was stimulus duration, which was either short (creating the impression of fast presentation rate) or long (resulting in a seemingly slow presentation rate). There was furthermore a single between-subjects factor, which was expected speed—being either fast or slow. Expected speed was varied by manipulating the frequency of short and long presentation durations in an experimental session.

[1] Note that if this method of creating an appearance of trial speed were ineffective, this would work against our hypothesis, not for it.

[2] We initially implemented the trial speed manipulation by varying stimulus durations between 80 and 240 ms per item. This produced results that were virtually identical to those presented here (regarding the order errors in particular), with the exception of a failure of T2 performance to recover at longer lags in some conditions. Because of this somewhat atypical performance pattern, we did not report this study, although the data were otherwise consistent with our present findings.

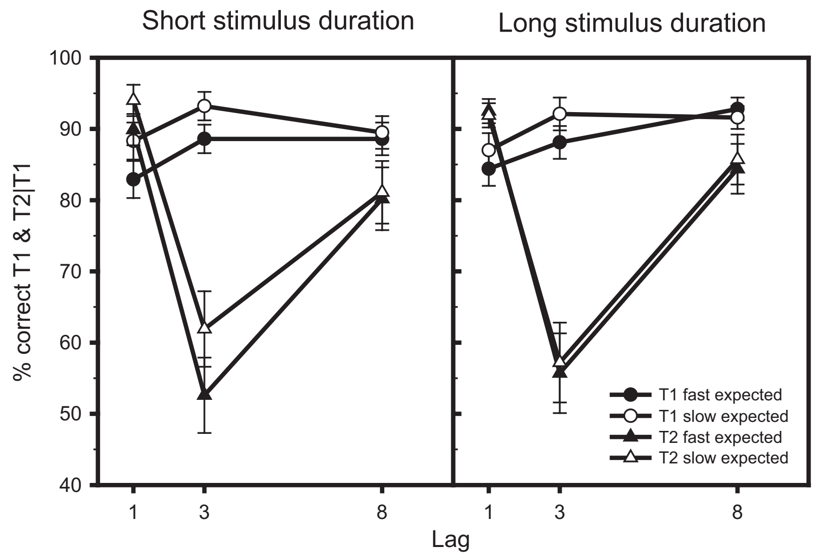

Figure 1. Identification accuracy (% correct) of Target 1 (T1) and Target 2 (T2), given T1 correct for fast and slow speed expectations in Experiment 1. The left panel shows results for trials with short stimulus duration, and the right panel shows results for trials with long stimulus duration. Error bars represent ± one standard error of the mean.

In the fast group, the stimuli were presented for a short duration in 80% of the trials and for a long duration in 20% of the trials, whereas in the slow group the stimuli appeared for a short duration in 20% of the trials and for a long duration in 80% of the trials. The occurrence of long and short stimulus durations was a matter of chance within these distributions. T1 was presented randomly at either the fifth or the seventh position in the stream.

Results and Discussion

The analysis of T1 identification accuracy showed a main effect of lag, $F(2, 60) = 18.58$, $MSE = 27.94$, $p < .001$; $\eta^2 = .38$.[3] As can be seen from Figure 1, this reflected a drop in performance from 90.6% at Lag 8, and 90.5% at Lag 3, to 85.6% at Lag 1. The drop at Lag 1 was accompanied by particularly good performance on T2 (see Figure 1), which indicated a trade-off and thus competition between the two targets. There were no differences between slow and fast expectation groups ($F < 1$), nor between long and short stimulus durations ($F < 1.8$). There was a significant interaction between lag and expected speed, $F(2, 60) = 3.60$, $MSE = 27.94$, $p < .05$; $\eta^2 = .11$. This seemed to reflect better performance in the slow expectancy group at Lags 1 (4.0%) and 3 (4.4%) but not at Lag 8 (−0.2%). Furthermore, lag and stimulus duration interacted as well, $F(2, 60) = 3.59$, $MSE = 18.79$, $p < .05$; $\eta^2 = .11$, reflecting better performance with long stimulus duration at Lag 8 (3.2%) but not on the other lags. Because lag effects on T1 cannot be interpreted without the confounding issue of its delayed response (i.e., the response to T1 is given after the stream has ended and T2 has also been shown), we opted to not offer a detailed explanation of these interactions here, but rather take them into account when discussing T2 performance below. Lastly, the interaction between stimulus duration and expected speed was not reliable ($F < 2.1$) and neither was the three-way term ($F < 1$).

As expected, an AB manifested itself: Conditional T2 performance (T2|T1) was lowest at Lag 3 (56.8%), whereas it was quite good at Lag 1 (92.1%) and Lag 8 (82.9%), $F(2, 50) = 85.51$, $MSE = 298.98$, $p < .001$; $\eta^2 = .74$. As before on T1 performance, expectation of speed had no reliable bearing on the means ($F < 1$). The same was true for stimulus duration ($F < 2.2$). Similar to the analysis of T1 performance, lag interacted with stimulus duration, $F(2, 48) = 3.65$, $MSE = 41.71$, $p < .05$; $\eta^2 = .11$. At Lag 8, performance with long stimulus duration was better than it was with short duration (4.4%), which was not the case for Lag 3 (−0.8%) and Lag 1 (0.3%). A virtually opposite pattern of means was observed for T1 performance; this seemed to suggest that the long stimulus duration might have led to a trade-off between targets, which only benefited T2 to the extent that it had an effect when attention was not taxed, that is, outside of the AB interval. The interaction between stimulus duration and expected speed was also significant, $F(1, 30) = 5.33$, $MSE = 36.12$, $p < .05$; $\eta^2 = .15$. No further effects were reliable (all Fs < 2). Although there was not much difference between expected speeds with long stimulus duration (0.8%), this was not the case for short stimulus duration. On trials with short stimulus duration, a slow expectancy actually

[3] To maintain consistency with the classic method of assessing identification performance, while allowing a more detailed look at committed errors, we adopted the following procedure. Trials were classified as (a) none correct; (b) T1 identity reported, but at T2 position, T2 incorrect; (c) T1 identity reported at T1 position, T2 incorrect; (d) T2 identity reported, but at T1 position, T1 incorrect; (e) T2 identity reported at T2 position, T1 incorrect; (f) T1 identity reported at T2 position, and T2 identity reported at T1 position; or (g) both correct. For analyses of T1 accuracy, all trials in categories b, c, f, and g are counted as T1 correct. For T2, the standard method to assess the AB is to exclude trials on which T1 was incorrect, and therefore only categories f and g were used. For analyses of order errors, trials in category f were used exclusively.

improved T2 performance compared to the fast expectancy (79.0% and 74.2%, respectively). We attribute this performance benefit to the beneficial effect on the AB associated with a more relaxed state of mind (Olivers & Nieuwenhuis, 2005, 2006). When participants expect to face a relatively easy trial, they are not as prone to overinvest in the processing of T1 as they would be when trying harder, which would increase the difficulty of processing T2.

The analysis of order errors showed a large effect of lag (see Figure 2). Order errors were very common at Lag 1 (28.1% of all trials) yet much less so at Lag 3 (5.2%) and Lag 8 (1.0%), $F(1, 41) = 231.13$, $MSE = 86.24$, $p < .001$; $\eta^2 = .89$. Neither stimulus duration nor expected speed had an effect on the number of order errors (Fs < 1). The interactions between lag and stimulus duration ($F < 1$) and between lag and expected speed ($F < 2.2$) were not reliable, and the interaction term for stimulus duration and expected speed did not quite reach significance either, $F(1, 30) = 3.33$, $MSE = 9.93$, $p < .08$; $\eta^2 = .10$. This indicated that the increase in order errors in the slow expectancy group was stronger with short stimulus duration than with long stimulus duration. This trend was supported by the three-way interaction between lag, stimulus duration, and expected speed, which was significant, $F(2, 60) = 3.63$, $MSE = 9.62$, $p < .05$; $\eta^2 = .11$. As can be seen from Figure 2, Lag 1 was crucial. When participants expected a slow trial speed, they made more order errors than when they were not, and this was strongest with short stimulus duration. When they were expecting a fast trial speed, more order errors were committed with long stimulus duration.

These results support the idea that the attentional window of integration can be adjusted on the basis of global task expectations. This process seems furthermore to be modulated by stimulus duration. If it is assumed that integration is most likely to be successful when both stimuli are perceived fully from onset to offset, then this would be slightly more likely on fast trials. On these trials, the time between the onset of T1 and the offset of T2 is 130 ms (30 ms for T1, 70 ms for the blank, and 30 ms for T2), whereas it is 170 ms on slow trials (70 ms T1, 30 ms blank, 70 ms T2). Therefore, on fast trials, an increase in integration time would be sufficient for joint integration to occur sooner than it would be on slow trials.

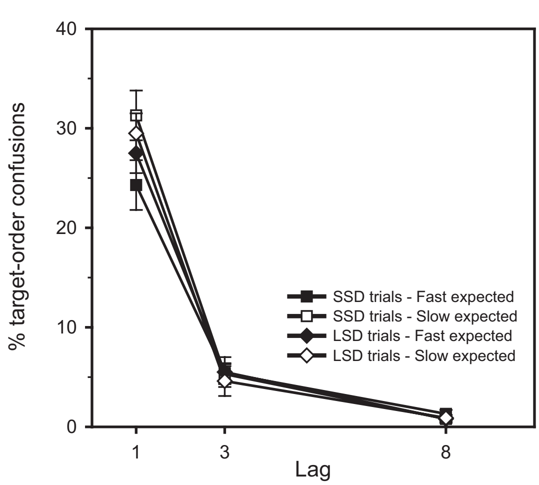

Figure 2. Percentage of target-order confusions of the total number of trials for fast and slow speed expectations in Experiment 1. Error bars represent ± one standard error of the mean. SSD = short stimulus duration; LSD = long stimulus duration.

In essence, Lag 1 sparing seems to be due to the extension of a single attentional episode, whereas the AB itself reflects the interplay between two episodes. This account is compatible with studies in which a task or location switch prevents Lag 1 sparing, because that creates a discrepancy between targets. When information that conflicts with the T1 template enters the visual system, it triggers closure of the current attentional episode (Di Lollo, Kawahara, Ghorashi, & Enns, 2005). Perception of T2 then requires initiation of another episode, resulting in the attentional deficit.

Experiment 2

Experiment 2 was conducted to test whether an alternative effort-based interpretation of the results of Experiment 1 was feasible. Rather than pointing to context-sensitive integration strategies, the outcome pattern may reflect that people tend to make fewer order errors in the fast expectancy group because they are trying harder to deal with the perceived difficulty of the task. Although one may object that T1 and T2 performance were actually lower in the fast expectancy group, this could be because the physical stimulation conditions differed between the groups. We put this account to the test by examining whether manipulating difficulty alone would lead to comparable results. In Experiment 2, all participants were again confronted with short and long stimulus durations, which, however, were presented in two separate homogeneous blocks. If participants were merely putting more effort into the trials on which stimulus duration was short, then order errors should be fewer in the fast block, relative to the slow block. From the perspective of the joint integration account, however, no difference in the number of order errors should be evident, as all trials would match expectations and thus meet integration strategies that would be perfectly tailored to them. This should eliminate the possibility that a T2 appears "too early" and thus gets the opportunity to "slip into" the attentional gate opened to process T1.

Method

Participants. Sixteen students (11 female, 5 male) at the University of Reading participated in the experiment for course credit or monetary compensation. They answered to the same criteria as in Experiment 1. Mean age was 19.9 years.

Stimuli, procedure, and design. The experiment was an exact replication of Experiment 1 with the following exceptions. There were two blocks of trials with either only short stimulus duration or only long stimulus duration (30-ms stimulus with 70-ms blank, and vice versa). The order of these blocks was counterbalanced between subjects. There were 192 fast trials and 192 slow ones (384 total) and another 18 practice trials that were not considered for analysis. The design consisted of two within-subjects variables: T1–T2 lag (1, 3, and 8) and stimulus duration (short or long).

Results and Discussion

T1 performance was affected by lag, $F(2, 30) = 28.36$, $MSE = 31.90$, $p < .001$; $\eta^2 = .65$. As observed in Experiment 1, performance was lowest at Lag 1 (74.3%), whereas it leveled off at 84.3% and 82.5% at Lags 3 and 8, respectively. No other effects were significant (Fs < 1). T1 performance is plotted in Figure 3.

On T2 performance, lag had an effect as well, $F(1, 19) = 72.78$, $MSE = 281.68$, $p < .001$; $\eta^2 = .83$. T2 was most often correctly recognized at Lag 1 (87.3%), and performance dropped dramatically at Lag 3 (47.9%) before recovering again at Lag 8 (76.4%). Stimulus duration was close to being significant, $F(1, 15) = 3.77$, $MSE = 24.26$, $p < .07$; $\eta^2 = .20$. This trend indicated that T2 performance was slightly higher with long stimulus duration (71.5%) than with short stimulus duration (69.6%), which was reminiscent of the pattern observed in Experiment 1. The interaction term was not significant ($F < 2$).

The analysis of order errors showed that these were far more frequent at Lag 1 than at the other lags, $F(1, 18) = 107.05$, $MSE = 87.87$, $p < .001$; $\eta^2 = .88$. Order errors were committed on 25.1% of trials at Lag 1, on 3.7% of trials at Lag 3, and on 1.2% of trials on Lag 8. There was no effect of stimulus duration ($F < 1$), nor of its interaction with lag ($F < 1$). As can be seen from Figure 4, the means of trials with short and long stimulus duration overlap each other almost perfectly. This result was virtually mirrored in Experiment 1, when the data were collapsed over expectancy (which was absent in Experiment 2). In Experiment 1, the number of order errors with short stimulus duration was 27.8%, and 28.5% with long duration. In other words, we observed almost no difference between stimulus durations, similar to the presently observed means (25.0% and 25.2% for short and long duration, respectively). On average, slightly more errors were made in Experiment 1, which was obviously due to the additional difficulty associated with the task uncertainty in that experiment. The absence of any detectable difference between short and long stimulus durations when there was no task uncertainty rules out a difficulty interpretation of the effects observed in Experiment 1.

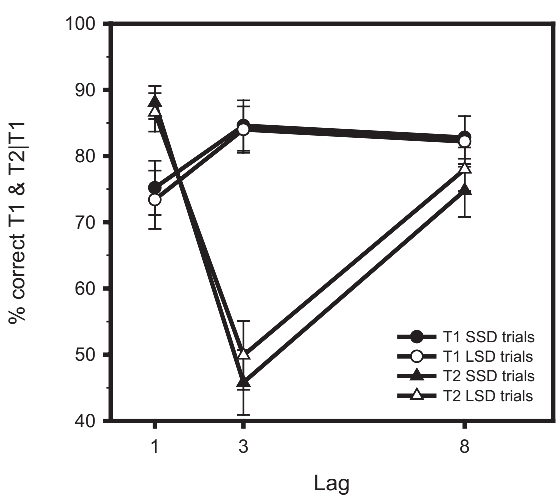

Figure 3. Identification accuracy (% correct) of Target 1 (T1) and Target 2 (T2), given T1 correct for short and long stimulus duration trials in Experiment 2. Error bars represent ± one standard error of the mean. SSD = short stimulus duration; LSD = long stimulus duration.

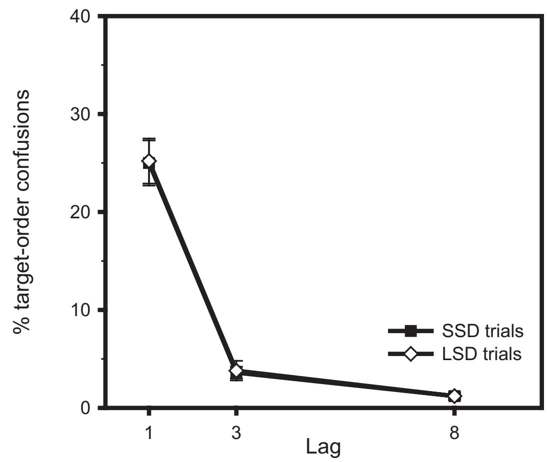

Figure 4. Percentage of target-order confusions of the total number of trials for short and long stimulus duration trials in Experiment 2. Error bars represent ± one standard error of the mean. SSD = short stimulus duration; LSD = long stimulus duration.

Experiment 3

Experiment 1 suggested that it is possible to adapt to (perceived) presentation speed on the basis of global task expectations by adjusting attentional integration timing. Although this represents a form of adaptive endogenous control over fairly subtle cognitive processes (i.e., adjusting integration time on a 100-ms level), it may still be taken to be a rather passive form of adaptation. In particular, participants might have settled on their supposedly optimal approach over the course of their session, which may reflect rather general learning. Thus, we carried out Experiment 3 to see whether a more active mode of control can be employed to adapt attentional integration from trial to trial. In this experiment, RSVP speed was cued on a trial-by-trial basis. Invalid cues were furthermore introduced as a conservative compensation for the degree of uncertainty regarding the expectation of stimulus duration in Experiment 1 (75% valid and 25% invalid cues). The logic of this design was as follows: If participants are able to act directly on the cue, a slow cue should induce a longer integration window than a fast cue. If so, slow cues should be associated with more order errors. Conversely, the absence of any impact of the cued speed on order errors would suggest a more passive, learning-like form of adaptive control.

Method

Participants. Twenty students (15 female, 5 male) of the University of Reading participated in this experiment for course credit or monetary compensation. Mean age was 21.5 years.

Stimuli, procedure, and design. The experiment was again identical to Experiment 1, with the following changes. A symbolic speed cue, either > (slow) or >>> (fast), was presented 200 ms after the participant had initiated the trial. The cue lasted for 500 ms and was set in red and in the same font and size as the other stimuli. Because the cuing procedure was done within subjects, there was no need for a between-subjects variable in this design. The experimental design therefore had three within-subjects vari-

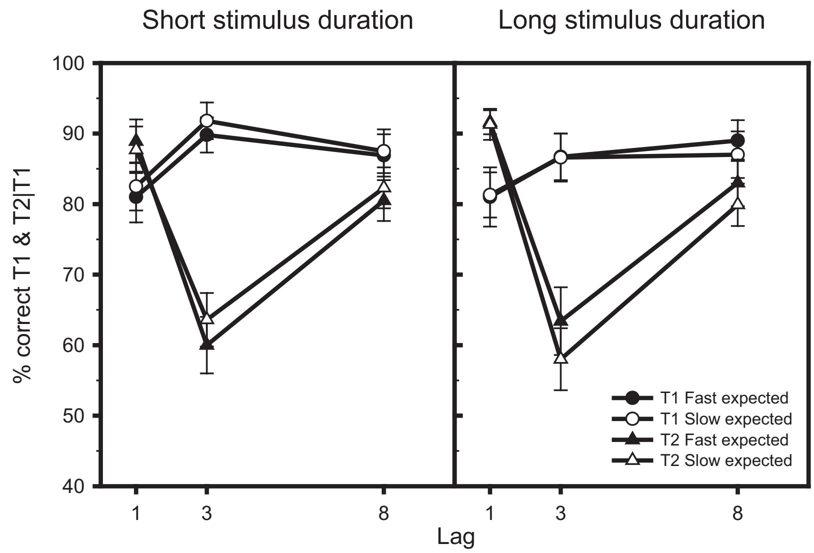

Figure 5. Identification accuracy (% correct) of Target 1 (T1) and Target 2 (T2), given T1 correct for fast and slow speed cues on trials with short stimulus duration (left panel) and on trials with long stimulus duration (right panel) in Experiment 3. Error bars represent ± one standard error of the mean.

ables only. The first one was T1–T2 lag (1, 3, and 8), the second one was the cued (expected) speed (slow or fast), and the third one was stimulus duration (again, short or long). There were 504 trials in total, 24 of which were practice trials and not considered for analysis.

Results and Discussion

Figure 5 shows T1 and T2 performance, with separate lines representing fast and slow cues, for short (left panel) and long (right panel) stimulus durations. T1 identification accuracy was 81.4% at Lag 1, which was the lowest point, and improved to 88.7% at Lag 3 and 87.6% at Lag 8, $F(2, 38) = 24.41$, $MSE = 50.32$, $p < .001$; $\eta^2 = .56$. Whereas cued speed was nonsignificant, $F(1, 19) = 4.07$, $MSE = 25.12$, $p < .058$; $\eta^2 = .18$, its interaction with lag did reach a reliable level, $F(2, 38) = 6.00$, $MSE = 20.96$, $p < .01$; $\eta^2 = .24$. The principal difference seemed to occur at Lag 3, where a fast cue improved T1 performance to 90.8%, from 86.7%. This might show a beneficial side effect of having a brief window of integration: Under circumstances where attention is limited (i.e., at Lag 3 during the blink), and when more than one attentional episode is created, interference from competing items is reduced, leading to higher identification accuracy. No further effects were significant (all Fs < 1.3).

Conditional T2 performance was high at Lag 1 (89.9%) and Lag 8 (81.4%), and low at Lag 3 (61.2%), $F(2, 38) = 60.09$, $MSE = 288.30$, $p < .001$; $\eta^2 = .76$. Both T1 and T2 performance was as expected over lag, with T1 dropping slightly at the shortest lag and T2 showing low performance at Lag 3, characteristic of an AB. In contrast to what happened with T1, there was no effect of cued speed on T2 performance ($F < 1$). Instead, there was an interaction between cued speed and stimulus duration, $F(1, 19) = 4.99$, $MSE = 57.78$, $p < .05$; $\eta^2 = .21$. Performance on T2 was slightly better when stimulus duration did not match the cued speed. With short stimulus duration, performance improved from 76.4% to 79.3%, and with long duration it went from 76.4% to 77.9%. This was a relatively small effect, which might have been due to increased vigilance when a disparity between cued speed and actual stimulus duration was detected.

The analysis of order errors showed a large effect of T2 lag, $F(1, 23) = 124.26$, $MSE = 182.77$, $p < .001$; $\eta^2 = .87$, with errors again much more frequent at Lag 1 (26.6%) than at Lag 3 (6.2%) or Lag 8 (1.8%). Cued speed did not have a reliable effect ($F < 2.3$), and neither did stimulus duration ($F < 1$). However, lag and cued speed did interact, $F(2, 38) = 15.92$, $MSE = 11.79$, $p < .001$; $\eta^2 = .46$. A slow cue resulted in more errors at Lag 1 (28.6%) than a fast cue (24.6%), as shown in Figure 6. This finding was

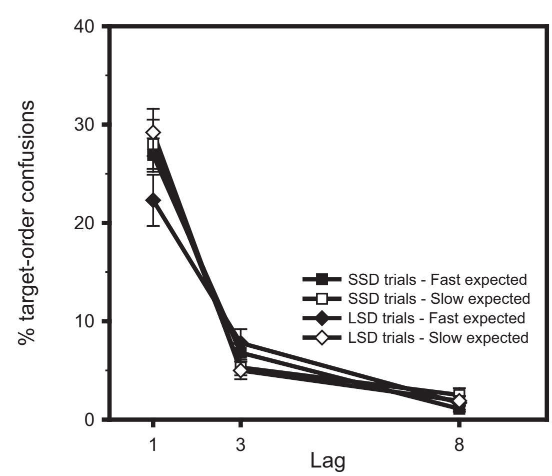

Figure 6. Percentage of target-order confusions of the total number of trials for fast and slow speed cues in Experiment 3. Error bars represent ± one standard error of the mean. SSD = short stimulus duration; LSD = long stimulus duration.

consistent with the active control hypothesis; participants were changing their integration window on perception of the cue, thereby incurring more order errors. The other two- and three-way interactions did not approach significance (all Fs < 2.9).

Interestingly, although the three-way interaction was not significant, it seemed that the increase in order errors due to a slow expectation was weaker with short stimulus duration, when compared to Experiment 1. This was most likely due to the more dynamic cuing procedure used in this experiment. In Experiment 1, the induced expectation of trial speed presumably engaged a cumulative adaptation mode, during which small adjustments to the integration window were made from trial to trial over the course of the session. Trials on which the stimulus duration did not match the expectation would moderate the adjustment (i.e., push it in the opposite direction), but this would be a limited effect as it is weighed against the cumulative evidence of the majority of congruent trials. In Experiment 3, however, integration had to be done from trial to trial, resulting in relatively large fluctuations in integration time. In this case, no cumulative evidence was collected and the process necessarily focused on the current trial alone. A fast trial appearing after a slow cue may therefore have caused a rapid mismatch response, as participants perceived the risk of having a long window that takes in quickly following distractor stimuli, which causes interference. The mismatch response results in a reduction of the length of the integration window and a decrease in order errors. However, the results also show that this mismatch adjustment is imperfect, as order errors are still more likely after a slow cue in the fast trials.

Finally, the difference in order errors between fast and slow expectations (cued speeds) was slightly smaller in Experiment 3 than it was in Experiment 1. This need not be surprising, considering the necessarily much more fragile nature of the induced expectation. While a stable task expectation could be formed in Experiment 1, the present experiment presented no such opportunity and required an active adaptation whenever the next new trial cue required it. This allows a number of factors to limit the impact of cues: Mismatch responses may become more likely, people may sometimes ignore the cue or forget to act upon it (De Jong, 2000), the efficiency of their control operations may vary, and the previous control setting may linger on and interfere with the new setting (Allport, Styles, & Hsieh, 1994). Hence, there are a number of reasons why the variable nature of control demands resulted in a somewhat less efficient adaptation. However, despite the rapidly changing and random nature of the task, participants were still able to tune their attentional integration to the task characteristics on demand.

General Discussion

We hypothesized that expecting a slow presentation rate of stimulus sequences might encourage our participants to use a rather broad temporal integration window for collecting information into a given object file. If so, these participants should be more likely to produce order confusions, that is, to report the two targets in the reversed order, because of the increased likelihood of perceiving two successive target stimuli in one attentional episode. This is indeed what we found: Participants expecting a slow presentation rate produced more order confusions at Lag 1 than participants expecting a fast presentation rate. This suggests that people have control over the size of their integration window, and that decisions about the size are affected by expectations about the time available for interference-free processing of the relevant information, as claimed by Lupiañez and Milliken (1999; Lupiañez et al., 2001). This is an instance of cognitive control that allows minimization of interference by irrelevant stimuli, even when attentional load is high (cf. Lavie, 2005).

The present experiments showed that even relatively small apparent changes in speed, without actual changes in the SOA of the RSVP, resulted in an expectation-modulated increase in order errors. This was especially noteworthy since the change in presentation speed was mostly only apparent, which meant that no great benefit was to be had from extending integration time: The next stimulus in the stream arrived at the same time in all conditions. In spite of this, participants kept trying and used the illusion of speed changes to adjust integration. The adaptation process was furthermore shown to be active and online, capable of operating on a per-trial basis, rather than reflecting slow incremental learning.

As pointed out in the introduction, Lag 1 sparing is presumably associated with two logically related but nevertheless different processes: integration into the same episodic file and competition within this file. Accordingly, our findings should not be taken to mean that the preservation of target identity by joint integration is the only factor that plays a role in Lag 1 sparing. Given the consistently observed drop in T1 performance at Lag 1, it seems obvious that the two targets also competed for selection in a number of cases (cf. Hommel & Akyürek, 2005; Potter et al., 2002). It is furthermore likely that time-related expectation is not the only endogenous factor that can affect the integration window. The AB has been observed to be reduced or even disappear if participants are encouraged to relax (Olivers & Nieuwenhuis, 2005, 2006) and if they manage to reduce their level of cortical activation in response to T1 (Shapiro, Schmitz, Martens, Hommel, & Schnitzler, 2006). Although this does not necessarily mean that these factors also affect Lag 1 sparing, such an impact is at least possible and seems worthwhile to investigate.

Finding that endogenous factors, such as temporal expectation, can affect the time an object file stays open does not exclude possible contributions from exogenous factors. One promising candidate seems to be the perceptual relation between the targets and/or the elements of the whole RSVP stream. If these relations create a perceptual gestalt, the AB has been found to be dramatically reduced or even eliminated (Kellie & Shapiro, 2004; Raymond, 2003; Sheppard et al., 2002), and it may well be that perceptual relations between the two targets affect the likelihood that they are integrated into the same object file. It may also be that the mere presence of a distractor, whether it is expected or not, triggers the closing of an object file automatically (cf. Akyürek & Hommel, 2005). In support of this, Di Lollo et al. (2005) and Olivers, van der Stigchel, and Hulleman (2007) found that the blink does not take effect when up to four target items are chained without intervening distractors. Note that these results also support the idea that the blink occurs when new event episodes have to be created, and that when only one event file is made it can contain multiple successive items without incurring the blink.

Converging evidence supporting the joint integration account of order errors at Lag 1 has recently been obtained by Akyürek, Riddell, Toffanin, and Hommel (2007), who studied event-related potentials in conditions where joint integration was likely and in those where it was not. In a paradigm very similar to our present study, they found N2- and P3-related modulations evoked by T2 in the fast expectancy group (in which joint integration was unlikely). Crucially, these modulations were absent in the slow group. By definition, joint integration means that both targets are being represented in one event episode. When joint integration does not take place, two events have to be created, one for each target stimulus. Akyürek et al. argued that these observed modulations reflect the creation of the second event episode.

The onset of these event-related potential components (at about 200 and 390 ms post-T2 for N2 and P3, respectively) offers an intriguing way to incorporate the mechanism of joint integration with existing theories of the AB. The predominant model of the blink is that the processing of targets takes place in two stages (Chun & Potter, 1995). During the first stage rapid detection and visual processing take place, while full target identification and memory consolidation are done in the second stage. It is thought that the second stage is capacity limited: When it is occupied by T1, it is not able to process T2 at the same time. Left waiting in Stage 1, the representation of T2 is vulnerable to interference and decay, which ultimately leads to the failure to report it. Previous studies have shown that Lag 1 is an exception to the above scenario (Hommel & Akyürek, 2005; Potter et al., 2002). The explanation of its occurrence has so far been based on exogenous factors. The rapid detection stage is assumed to match according to a target template, at which point the attentional process is set in motion and incoming (visual) information is passed on. This flow of information is delimited by the onset of target-conflicting sensory sensation. The mismatch of target template and distractor stimulus causes the attentional gate to close. In the case of Lag 1 sparing, there is no conflicting information between targets and so both are allowed in.

The present results add to this account of the blink and Lag 1 sparing in the following ways. First, the adaptation of the integration window (or the time during which the attentional gate is open) showed that Stage 1 processing is not a fully automatic "fire and forget" process. Global task expectations, even when presented in cue form less than a second in advance of trial, can affect the timing of the integration window. In other words, it is possible to exert cognitive control over attentional integration. This finding may be just one instance in which deliberate control over relatively early detection processes during the blink is possible. One prediction could be that the same sort of control is possible for other aspects of the integration process, such as the visual detection parameters, as well. For instance, if targets are expected to be relatively hard to distinguish from distractors, this may result in a very strict detection criterion—possibly reducing joint integration at Lag 1 and decreasing T2 identification performance, which would mean a less successful escape from the blink.

Second, when a unitary representation of targets is created in the early stage of processing, it can be passed on as a whole to the second stage, yet the properties reflecting the moment of perception of the individual targets are often lost. Crucially, the most dire limit on Stage 2 processing seems to be the number of integrated events (i.e., it seems to concern only one event at a time), rather than the number of individual target items or the complexity of their representations. In memory studies, the items to be retained behave in a similar way, as coherent chunks of information can often be retained just as well as individual items (Miller, 1956). Interestingly, the "chunking" observed in the present study for targets in the RSVP was taking place at an early attentional stage, and does not seem to be a property emerging from the organization of consolidated information (i.e., post-Stage 2 processing). This suggests that attention can have a fairly immediate and early effect on the representation of information, and can be a decisive factor in its eventual consolidation.

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