TEMPORAL TARGET INTEGRATION UNDERLIES PERFORMANCE AT LAG 1 IN THE ATTENTIONAL BLINK

Elkan G. Akyürek, [1] Sander A. H. Eshuis, [1] Mark R. Nieuwenstein, [1] Jefta D. Saija, [1] Deniz Başkent, [2] & Bernhard Hommel [3]

[1] University of Groningen, The Netherlands

[2] University Medical Center Groningen, The Netherlands

[3] Leiden University, The Netherlands

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Address correspondence to:
Elkan Akyürek
Department of Psychology, Experimental Psychology, University of Groningen
Grote Kruisstraat 2/1, 9712 TS Groningen, The Netherlands
Email: e.g.akyurek@rug.nl
Telephone: +31 (0)50 3636406
Fax: +31 (0)50 3636304

ABSTRACT

When two targets follow each other directly in rapid serial visual presentation (RSVP) they are often identified correctly but reported in the wrong order. These order reversals are commonly explained in terms of the rate at which the two targets are processed, the idea being that the second target can sometimes overtake the first in the race towards conscious awareness. The present study examined whether some of these order reversals might alternatively be due to a mechanism of temporal integration whereby targets appearing closely in time may be merged into a single representation. To test this integration account, we used an attentional blink task in which the two targets could be combined perceptually in a meaningful way such that the conjunction of the two target elements constituted a possible target stimulus itself. The results showed that when targets appeared at Lag 1, observers frequently reported seeing only a single merged target stimulus, and these reports occurred up to approximately three times as often as (real) order reversals. When the possibility to report the integrated percept was removed, order reversals consequently tripled. These results suggest that integration may actually be the primary cause of order reversals in dual-target RSVP tasks.

Keywords: attentional blink, temporal integration, Lag 1, order reversals

Our visual world is highly dynamic and we are exposed to a continuous stream of visual information whatever we are watching and wherever we are moving. This poses high demands on the processes underlying visual perception, which need to segregate the continuous stream of information into discrete events and discriminate between relevant events and those that can be neglected. These kinds of processes have been extensively studied by means of rapid serial visual presentation (RSVP) tasks, in which observers are to identify or detect visual targets appearing within a rapidly presented sequence of distractors.

Research using this paradigm has yielded several phenomena that provide important insight into the temporal dynamics and the limitations of mental operations underlying conscious visual perception. A key phenomenon in this domain is the attentional blink (AB) – the finding that observers frequently miss the second of two targets if the second target is masked and presented at a stimulus-onset asynchrony (SOA) of about 150-500 ms (Broadbent & Broadbent, 1987; Raymond, Shapiro, & Arnell, 1992). Countless studies have been conducted to investigate this “blink of the mind” and several models have been suggested to explain it (for a review, see Dux & Marois, 2009). The present study, however, was devoted to a condition under which the AB may *fail* to occur: The second target is often not missed if it appears within less than about 150 ms from the first, which is an aspect of the attentional blink phenomenon that has been referred to as “sparing”. [1] It is most commonly observed in the so-called Lag 1 condition, in which the two targets follow each other directly without intervening distractors, at an SOA of around 100 ms (for a review, see Visser, Bischof, & Di Lollo, 1999).

Sparing itself is not a unitary phenomenon, as it may perhaps seem at first glance. Sparing has been defined more or less formally as an increase of at least 5% in identification accuracy of the second target (T2), relative to blinked lags (Visser et al., 1999). However, this increase is often obtained only if participants are to report the identity of the two targets, while less or no sparing is observed if the correct target order also needs to be reported (Hommel & Akyürek, 2005). In other words, what looks like sparing seems more like trading order information for identity information. The loss of order information is especially severe at short target stimulus-onset asynchronies and the report of the first target (T1) is equally affected by the resulting order confusions (i.e., it is reported as the second target; Hommel & Akyürek, 2005). Indeed, in a broader sense, Lag 1 performance can also be decomposed in multiple types of responses, and even when the identity of the second target is preserved, differences may exist in other aspects. For instance, T2 may be reported (incorrectly) as the first target, and T1 may then be reported as the second, or T1 may not be reported at all.

The aim of the present study was to investigate the origin of this order-for-identity trade-off by contrasting two explanations of order reversals. The first concerns a set of explanations that derive from the precedence account first proposed by Reeves and Sperling (1986; Olivers, Hilkenmeier, & Scharlau, 2011; Wyble, Bowman, & Nieuwenstein, 2009). These accounts will be contrasted to the temporal integration account proposed by Hommel and Akyürek (2005; Akyürek & Hommel, 2005; Akyürek, Riddell, Toffanin, & Hommel, 2007; Akyürek, Toffanin, & Hommel, 2008; see also, Bowman & Wyble, 2007; Treisman, 1996). In the following sections, we will describe these accounts in further detail.

Precedence-based accounts

The precedence account was developed by Reeves and Sperling (1986) in an attempt to model report order in a task that required report of several successive items in an RSVP stream. More specifically, the task involved two simultaneous RSVP streams shown to the left and to the right of a central fixation cross. Upon detecting a pre-specified target stimulus in the left stream, participants had to shift their attention to the right-hand stream as quickly as possible in order to encode the first four items occurring in that stream. The results showed a bell-shaped distribution of reported items that peaked at an interval of about 400 ms following the target. Analyses of the order in which the items from this distribution were reported showed that the item occurring approximately 400 ms after the target, that is, the item reported most often, was also the item that was most often reported first by the participants, with earlier items being reported later. In other words, there was a relationship between identification accuracy and report order, such that the item that could be identified most easily also tended to be the one that was reported first.

In constructing a model that could accommodate these results, Reeves and Sperling (1986) proposed an account in which order of report is determined by the strength of an item’s representation in visual short-term memory (VSTM), with the strength of representation being a function of the amount of attention an item receives. More specifically, Reeves and Sperling proposed that following the detection of the target in the left-hand stream an attentional gate was opened to allow items from the right-hand stream to enter VSTM. This opening of an attentional gate was proposed to involve a location-specific attentional enhancement effect that reached its maximal efficacy about 400 ms after the onset of the target in the left-hand stream. The strength of an item’s representation in VSTM derived from this attentional enhancement function, the idea being that items that appeared at the time of maximal enhancement also achieved the greatest strength of representation in VSTM. With these assumptions, Reeves and Sperling were able to provide an accurate simulation of the results obtained across a number of variants of the task.

In recent years, the notion that report order can be explained in terms of a precedence effect that is driven by attention allocation has been incorporated into models of the attentional blink and sparing. For instance, in the episodic simultaneous type – serial token model proposed by Wyble, Bowman, and Nieuwenstein (2009), report order is derived from a combination of Reeves and Sperling’s notion of attention-driven precedence and assumptions regarding the time course of working memory consolidation. More specifically, the eSTST model assumes that consolidating a representation in working memory is a time consuming process that will take longer for stimuli that are more complex, or represented more weakly. The model further assumes that the order of report reflects the order in which the items complete the consolidation stage. At this point an item's representation is bound to a token through the establishment of binding links between the token and the item's type representation. By assuming that report order is determined by the order in which items complete the consolidation stage, the predictions of the eSTST model entail that report order depends not only on the amount of attention an item receives (more attention results in a stronger representation trace that can be consolidated more rapidly) but also on factors that affect the rate of consolidation, such as the intrinsic strength of the item and the extent of competition between simultaneously activated target representations. With these assumptions, eSTST was shown to be capable of providing accurate simulations of identification accuracy and report order in various RSVP tasks, including tasks similar to the task used by Reeves and Sperling (1986), and the dual-target partial report tasks typically used in studies of the attentional blink.

Another variant of the precedence account was recently proposed by Olivers and colleagues (2011) who suggested that report order could be explained in terms of the law of prior entry (Titchener, 1908; for a review see Spence & Parise, 2009). In accordance with both eSTST (Wyble et al., 2009) and the precedence account proposed by Reeves and Sperling (1986), the prior entry account holds that order of report is determined by the amount of attention an item receives. The account differs from the eSTST model, however, in that it ascribes no role to the time that is needed to consolidate an item's representation in working memory. Instead, the prior entry hypothesis follows Olivers and Meeter's (2008) Boost and Bounce model of the attentional blink in assuming that consolidation in working memory does not involve a time consuming process, and therefore has no effects on report order. In other words, while eSTST can be said to assume that report order reflects the order in which items complete the consolidation stage, the prior entry hypothesis can be said to assume that report order reflects the order in which items enter the consolidation stage.

Integration accounts

The alternative to precedence-based accounts of report order can be found in the integration account proposed by Hommel and Akyürek (2005). This account stems from considerations that relate to the difficulty of segregating a continuous, rapid stream of visual information into discrete events (see also Zacks & Swallow, 2007). The presumably most reliable criterion to parse information and integrate it into the same cognitive episode is time: The closer in time two pieces of information appear, the more likely they are part of the same event. Accordingly, if T1 and T2 appear very close in time, as is the case in the Lag 1 condition, it could be that they are integrated into the same episodic trace (Akyürek et al., 2007; 2008; Bowman & Wyble, 2007; Hommel & Akyürek, 2005). This would help to retain T2-identity information but eliminate order information, exactly as was found at Lag 1. Furthermore, the resultant order errors were shown to vary as a function of the visible persistence of the stimuli, as would be expected if they were related to temporal integration (Hommel & Akyürek, 2005; Figure 9).

Visual temporal integration is in fact a rather universal perceptual process when stimuli appear within intervals of about 200 ms or less. Across the shortest of these (<20 ms), the limited temporal resolution of the visual system likely plays a role (which might be referred to as fusion rather than true integration). At longer intervals, however, this resolution is not a factor, and the perception of multiple stimuli is often maintained to some degree (i.e., it is seen as a flicker), but the resulting percept is nevertheless one of an integrated whole of the stimuli. Early accounts conceptualized the phenomenon as a consequence of a travelling perceptual moment (Allport, 1968), in which a perceptual sample is built up across a running-average interval of fixed duration (as opposed to discrete successive intervals as previously proposed by Stroud; 1956). Experimentally, some support for such an interval has come from so-called missing element tasks (MET), and conceptually similar letter-based form-part integration tasks. In MET tasks, a regular grid (e.g., 5x5) of dots or squares is presented across two successive displays (e.g., 12 dots each), with a single empty position remaining that is for the observer to find. Thus, the missing element is only apparent from the combined percept, rather than from either of the two individual displays (Di Lollo, 1977; Di Lollo, 1980; Hogben & Di Lollo, 1974). Similarly, performance in letter-based integration task depends on the ability to combine two visual noise displays, in order to reveal letter shapes (Eriksen & Collins, 1967; 1968; Fraisse, 1966). The principal finding from tasks like these is that integration is inversely correlated with the total duration of the stimuli; shorter durations lead to increased integration (and increasing simultaneity reports). The integration process operates comparably across meaningless and meaningful stimuli such as dots and letters, and acts even when the task requires combining two distinct entities in time, such as a string of letters and a delayed circle or bar indicating one of them as the target (Averbach & Coriell, 1961).

This is not to say that temporal integration is automatic and thereby inflexible, such as would result from so-called “intrinsic persistence” of visual stimuli. As proposed by Dixon and Di Lollo (1994), the data may be interpreted best in the framework of a temporal coding process, in which the perceptual system attempts to maintain perceptual continuity (integration) but also needs to be able to detect rapid changes (segregation). Temporal coding is thought to operate on the correlation in time of successive stimuli, a comparison that could also, in principle, be biased by the observer, to accommodate task demands (i.e., to favor or suppress integration in general). In line with this idea, Visser and Enns (2001) provided some evidence that temporal integration is modulated by the availability of attention, which affords a substantial measure of endogenous control. A recent electrophysiological study of the MET furthermore showed that the N1, N2, and P3 components of the event-related potential (ERP) are implicated in temporal integration, all of which are also modulated by attention (Akyürek, Schubö, & Hommel, 2010). Although the involvement of the P3 may suggest that working memory processes could also affect temporal integration, there is some evidence to suggest this is not the case (Jiang, Kumar, & Vickery, 2005; see also Brockmole, Wang, & Irwin, 2002). Thus, modulations of the P3 in the MET may reflect differences in the consolidation of integrated percepts rather than changes in ongoing integration, similar to P3 effects seen in the AB, which may be seen as a consequence of earlier, attentional modulations, such as the N2pc (e.g., Dell'Acqua, Sessa, Jolicœur, & Robitaille, 2006).

How might these findings be related to RSVP? One possibility as to how integration might occur in RSVP tasks can be found in the simultaneous type – serial token model proposed by Bowman and Wyble (2007), the predecessor to the eSTST model proposed by Wyble et al. (2009). Like eSTST, the STST model assumes that report order is determined by a combination of how much attention an item receives and how long it takes to consolidate the item's representation in working memory. A crucial difference between the two models lies in the fact that in STST, the consolidation mechanism allows for two items to be merged in a single episodic memory representation, a possibility abandoned in the eSTST model (see below for a discussion of why this change was implemented). In STST, integration occurs when there is a sufficient degree of temporal overlap between the activation of the type representations of the two target representations. In this case, both activated types can be bound to a single token instead of to two separate tokens, resulting in a loss of order information.

Integration versus precedence: Evaluation based on previous research

As alluded to above in the discussion of the STST and eSTST models, there has been a change of opinion with regard to the possible role of integration in the order reversals that occur in conditions of sparing, with the original STST model (Bowman & Wyble, 2007) proposing a mechanism of integration to explain reversals while the more recently proposed eSTST model (Wyble et al., 2009) abandoned this possibility. There are three main reasons for this change of opinion. Firstly, studies examining order reversals in sparing showed that the rate of reversals is lower than what might be expected based on a strong version of the integration account. Notably, several researchers have argued that the integration account predicts a complete loss of order in case of sparing, thus allowing them to argue against the integration account because report order is more frequently correct than it is incorrect in the case of sparing. In our view, however, this does not present a compelling argument against integration because it presumes that integration occurs on every trial in which sparing occurs and this need not be the case. Instead, it seems plausible to assume that integration constitutes one of several possible outcomes for trials in which sparing occurs, with the outcome being dependent on how close the race between consolidation of T1 and T2 is, and who wins in case the race is not so close (cf. STST). That is, trials with very close finishes might yield order reversals due to integration while trials with less close finishes may yield either a reversal due to prior entry or a correctly ordered report in case T1 wins the race. Suffice it to say, the finding that the accuracy of order of report does not reach chance levels does not logically preclude the possibility that integration plays a role in the occurrence of order reversals.

The second argument against the integration account derives from findings that show that the occurrence of order reversals varies as a function of manipulations that influence how much attention is allocated to T1 and T2. For instance, it has been shown that increasing attention for T1 by means of a precuing manipulation leads to a decrease in reversals while precuing T2 leads to an increase in reversals (Hilkenmeier, Olivers, & Scharlau, in press; Hilkenmeier, Scharlau, Weiß, & Olivers, in press; Olivers, Hilkenmeier, & Scharlau, 2011). While we agree that these findings demonstrate that order reversals depend on the amount of attention allocated to the two targets, we disagree that they provide a solid argument against the integration account. To wit, if we assume that the occurrence of integration depends on whether or not there is a sufficient degree of temporal overlap between the activation of the type representations of the two targets (cf. STST), it follows that any manipulation that increases this temporal overlap will increase the occurrence of integration and resulting order reversals while the converse would be true for manipulations that decrease temporal overlap. According to this view, precuing T1 reduces temporal overlap by giving T1 more of a head start while precuing T2 increases the probability that there will be sufficient temporal overlap for integration to occur because precuing T2 will increase the rate at which activation of the T2 type will accumulate.

Finally, the third reason for abandoning the STST integration in the eSTST model was the observation that when longer successive target sequences are considered, order report (at least in whole report) follows an U-shaped function; order is lost most frequently for the second and third target, in a series of four (Wyble, Bowman, & Nieuwenstein, 2009). If one assumes that integration starts at the first target, and then ends at some point in time (e.g., 200 ms) afterwards, a more bi-modal pattern might be expected, in which T1 and T2 are exchanged most frequently, as well as T3 and T4, in two successive integrated episodes. Whether such ‘default’ integration behavior should be expected in these circumstances is not entirely clear, however. Adaptive control of integration does occur (Akyürek, Toffanin, & Hommel, 2008), and if participants expect to see series of successive targets, they may change their behavior accordingly. Observers might decide to focus on the most recently viewed targets, for instance, as these are most easily committed to and maintained in memory, which could lead to a ‘late start’ of integration. Similarly, participants may extend the interval across which they integrate, so that the bi-modal pattern might be obscured by trials on which events do not contain two targets each, but perhaps three and one. It may furthermore be argued that with extended target sequences such as these, memory-related factors will start to affect recall, and indeed the order reports seen here follow a typical serial position pattern. Without these primacy and recency effects, the underlying pattern of reversals is more diffuse, but nonetheless still shows that targets are most often confused with their temporal neighbors, which is compatible with an integration account.

Taken together, although the considerations mentioned above cast some doubt on the possibility that integration plays a role in order reversals, they do not logically preclude that possibility. The available literature furthermore provides some indications that buttress the plausibility of the integration account. Firstly, as commented upon by some researchers, the phenomenology of the Lag 1 condition is that the two targets seem to overlap, as if superimposed (e.g., Taatgen, Juvina, Schipper, Borst, & Martens, 2009). Importantly, however, this observation has not yet been verified in a direct empirical test as all AB studies conducted thus far did not allow for reports of an integrated percept due to the fact that these studies required separate responses for the T1 and T2 identities. Secondly, visual temporal integration has been shown to occur at the temporal intervals used in RSVP in a range of different tasks, such as form-part integration and MET, which were mentioned previously. There seems to be little reason to assume integration should not occur in RSVP, when its temporal dynamics are comparable. Indeed, as SOA increases in the MET, the ability to integrate its two displays decreases and the probability of perceiving two distinct stimuli increases, which mirrors the time course of order reversals across lags seen in studies of the attentional blink and sparing.

The present study

As will be clear from the discussion above, the findings that have been used to argue against the integration account and in favor of the precedence account do not rule out the possibility that integration plays a role in order reversals. The goal of the present study was to conduct a more critical test of these accounts by examining a prediction that is unique to the integration account. This prediction relates to the phenomenological aspects of the Lag 1 condition, where the integration account predicts that participants will often perceive the two targets as being superimposed, that is, perceptually integrated. If so, it follows that participants should have difficulty distinguishing between the presentation of two successive targets and the presentation of a single target consisting of a combination of the two target stimuli. To test this prediction, we modified the standard attentional blink task in two regards. Firstly, we used targets that could be combined in a meaningful way such that the compound of the two targets constituted a possible target itself. For instance, in one of the experiments, the targets included the symbols “/”, “\”, as well as the conjunction of these symbols “X”. The primary issue of interest was what participants would report in case of a Lag 1 trial in which the former two targets were used as T1 and T2; would participants report the two targets separately, or would they report the integrated percept of the two targets instead? To ensure that participants would consider report of a single target a viable response, we also included a small portion of trials with only a single target. Taken together, these features of the design enable dissociation between correctly ordered reports of the two target identities, reports of the ‘illusory’ integrated percept, and reports of the two targets in the incorrect order (i.e., a non-integration based order reversal).

EXPERIMENT 1

In Experiment 1, the targets consisted of one or more corners of a square (see Figure 1). As these corners were never repeated between the targets, and because the targets could consist of a variable number of corners, this design allowed the ‘perceptual summation’ of the two targets. In other words, if participants really integrated the two targets, this integrated percept constituted a valid and reportable target identity itself. To ensure that reporting a single target also constituted a viable response, we also included trials on which only a single target was present and participants were informed of this possibility before the experiment began. This design permitted us to separate correct responses, integrations, order reversals, and other kinds of errors. Importantly, the precedence account and the integration account make different predictions for the report of integrations: While the integration account would predict a substantial number of such reports, the precedence account would have no obvious mechanism to explain their existence.

Method

Participants

Twenty students of psychology (all female) at the University of Groningen participated in the experiment for course credit. Informed consent was obtained in writing and the study was conducted in accordance with the Declaration of Helsinki. Participants were unaware of the purpose of the experiment and reported normal or corrected-to-normal vision. Data from two participants were removed from the analyses because T1 performance was below 30% correct overall, indicating that the task was not properly executed. Mean age was 19 years (range 18-22 years).

Apparatus and stimuli

Participants were individually seated in a dimly lit testing chamber at a distance of approximately 50 cm from the screen. The 22” CRT screen was driven by a standard personal computer running the Microsoft Windows XP operating system, and refreshed at 100 Hz with a resolution of 1024 by 768 pixels in 16 bit color. The experiment was programmed in E-Prime Professional 2.0 (Psychology Software Tools). Responses were logged on a standard keyboard. A light gray background (RGB 192, 192, 192) was maintained during the experiment, and all stimuli were presented in black (RGB 0, 0, 0). Distractor stimuli consisted of capital letters, drawn in bold 52 pt. Courier New font. They were drawn randomly without replacement from the full alphabet for each trial. The fixation cross consisted of a small plus sign (“+”) and was drawn in the same font.

As shown in Figure 1, the targets consisted of one or more corners of a square that was 54x54 pixels in size. The horizontal and vertical sides of the corners were each 23 pixels long, and 7 pixels wide, so that the corners were separated by a gap of 8 pixels. Overall, the area within which the target stimuli appeared was comparable to that of the distractors. The targets were chosen in such a way that their features did not overlap with each other (i.e., the same corner was never shown for both T1 and T2). This was also a prerequisite to be able to distinguish correct, incorrect, and integration responses (see Figure 1 for an example). With this constraint in place, all resulting possible combinations of T1 and T2 (including different numbers of corners; e.g., the upper left corner for T1 and both lower corners for T2) were used equally often and presented in a random sequence.

insert Figure 1 about here

Procedure

The experiment comprised of a total of 688 self-paced experimental trials with an optional pause half-way, and started with a short block of practice trials that were excluded from analysis. The experimental session lasted for approximately 70 minutes. At 100 ms after the initiation of each trial, the fixation cross was displayed for 200 ms. Then the RSVP sequence of 19 stimuli commenced, all of which were on screen for 70 ms and followed by a 10 ms blank screen each (80 ms SOA). On most trials, two of these stimuli were targets (i.e., T1 and T2), while the others were distractors. T1 appeared as either the 5th or the 7th item in the stream and T2 followed T1 with either 0, 2, or 7 distractors in-between, referred to as Lag 1, 3, or 8 (31.2% of trials each). There was no T2 on a small portion of trials (just below 6.4%), and a distractor took its place instead. These trials were also excluded from analysis.

Participants were asked to identify the targets, and were told that there would usually be two in the stream. At the end of the stream, a 100 ms blank delay ensued before participants were successively prompted to first enter the identity of T1 and then that of T2. Each response was given on a labeled section of the numeric keypad. The upper left corner corresponded to the 4 key, the upper right corner to the 5 key, the lower left corner to the 1 key, and the lower right corner to the 2 key. Thus, when a target consisted of multiple corners, it required multiple key presses to identify it. When they had completed entering the identity of a target, they had to finish by pressing the Enter key. Although participants were encouraged to guess they were not forced to as they were informed they could press Enter without entering a response.

Design

Repeated measures analyses of variance (ANOVA) with the single variable of T1-T2 Lag (1, 3, and 8) were conducted first to assess task performance. Analyses were performed on mean T1 and T2 accuracy, where T2 accuracy was computed as the percentage of correctly identified stimuli given that T1 was correct (T2|T1). For the main analyses of both measures, a response was only considered correct if both the identity and the temporal position (order) were reported correctly. The frequency of integrations (i.e., reports of the integrated percept) and the frequency of order reversal errors (i.e., trials in which T1 was reported as T2 and vice versa) were also analyzed. Note that a response was only categorized as an integrated percept if its features matched the combination of T1 and T2 exactly. Partial migrations of individual features were not considered, even though they might well be indicative for integrative processes. The primary reason for excluding partial migrations was that they become increasingly prone to chance reports and are therefore difficult to interpret. Furthermore, only responses in which the integrated percept was the sole response (i.e., no second response was entered at all), were counted. This reduces the number of trials on which integration was considered to occur, for instance excluding trials on which the integrated percept was reported twice, but the remaining trials are those on which the observer most clearly indicated having seen but one (integrated) target. For the analyses and line graphs of integrations and order reversals, their frequency was computed relative to the total number of trials on which both target identities were reported (cf. Chun & Potter, 1995). To also allow for an accurate assessment of the entire response pattern at each lag, the absolute frequencies (i.e., relative to the total number of trials) are shown in separate cumulative bar graphs (cf. Hommel & Akyürek, 2005). In all ANOVA's, degrees of freedom were adjusted using the Greenhouse-Geisser epsilon correction in case there was significant heterogeneity of variance between conditions.

Results and Discussion

Accuracy on T1 was strongly affected by Lag, $F(1.4, 23.6) = 188.19$, $MSE = .008$, $p < .001$. Performance averaged 37% at Lag 1, compared to 76% at Lag 3, and 81.1% at Lag 8. The relatively low performance at Lag 1 was partially due to the increased frequency of integrations and order errors, which are analyzed in detail below. If integrations and order reversals were counted as correct reports of T1 identity, and if trials on which only T1 was reported as the second target were treated likewise (i.e., ignoring report order and using a relaxed report criterion, as in Hommel & Akyürek, 2005, and the large majority of AB studies), performance at Lag 1 rose to 67.8%. The increased frequency of cases in which T1 identity was lost altogether and 'superseded' by the report of T2 identity as the first target; (i.e., T2 identity-only reports, as shown in Figure 3) suggests some form of competition between targets at Lag 1, which likely included factors such as the strength of backward (meta-contrast) masking by T2 (see e.g., Enns & Di Lollo, 2000; McLaughlin, Shore, & Klein, 2001). Furthermore, the spatial discrepancy between target elements might have played a role. Performance on T1 as a function of Lag is shown in the left panel of Figure 2.

insert Figure 2 about here

T2|T1 performance was affected by Lag, *F*(1.5, 25.7) = 29.61, *MSE* = .02, *p* < .001. Identification accuracy averaged 56.8% at Lag 1, 75.9% at Lag 3, and 88.1% at Lag 8. As expected, the attentional blink was evident at the short lags. At Lag 1, T2 performance was reduced by integrations and order reversals, just as T1 performance was. If report order was ignored, performance at Lag 1 rose to 76.2%. The right panel of Figure 2 shows average performance on T2, given that T1 was correct, plotted across Lag.

In many studies, the increased contribution of order reversals (and, hypothetically, integrations) at Lag 1 correlates with sparing, that is, performance at Lag 1 is elevated over blinked lags, but this was not the case here. The results showed a steep decrease from Lag 8 and Lag 3 to Lag 1 in the number of trials on which both targets were identified correctly, thus lowering overall performance at Lag 1. An additional ANOVA on the frequency of this type of trial confirmed this pattern, *F*(2, 34) = 101.52, *MSE* = .012, *p* < .001. Trials on which both targets were identified correctly averaged 23.4% at Lag 1, compared to 60.1% at Lag 3 and 72.6% at Lag 8.

Like T1 performance, the drop in T2|T1 performance at Lag 1 might be attributed to the nature of the target stimuli, which were presented centrally but nonetheless at different spatial locations. Location switches are also known to prevent, or at least severely impair the occurrence of sparing, presumably due to the time required to shift attention from one location to the next (Breitmeyer, Ehrenstein, Pritchard, Hiscock, & Crisan, 1999; Visser et al., 1999; for evidence that this may require a spatially narrow focus of attention, see Jefferies

& Di Lollo, 2009; Kawahara & Yamada, 2006; Lunau & Olivers, 2010; Shih, 2000). The target stimuli were also somewhat complimentary masks of each other—something that may have produced meta-contrast masking, which is known to affect T2 performance when the targets are presented in direct succession (Seiffert & Di Lollo, 1997). Importantly, however, no model would predict that the presence of increased competition between targets should lead to increased integration at Lag 1.

The primary research question of the present study was whether integration occurred at Lag 1. An analysis of the frequency of reports of integrated percepts showed a significant effect of Lag, $F(1, 17.2) = 29.86$, $MSE = .043$, $p < .001$.[2] Integration was frequent at Lag 1, occurring on 34.2% of identity-correct trials, compared to 2.2% at Lag 3, and .6% at Lag 8. The frequency of order reversals was also affected by Lag, $F(1.4, 24.6) = 34.72$, $MSE = .002$, $p < .001$. However, at Lag 1 reversal errors were clearly less frequent than integrations, averaging 12.8% at Lag 1 (compared to 5% at Lag 3, and 1.5% at Lag 8). The left panel of Figure 3 shows the relative frequency of integrations and order reversals as a function of lag.

insert Figure 3 about here

The right panel of Figure 3 shows the distribution of reports at each lag (in absolute numbers, i.e., relative to the total number of trials); trials on which both targets were correctly identified, integrations, order reversals, and trials on which the identity of one target only was reported (but at the wrong temporal position). Trials on which nothing was correct, and trials on which either only T1 or T2 was identified correctly (at the correct temporal position) are not shown to increase clarity. This distribution of responses gives a comprehensive overview of performance at Lag 1, and illustrates the need to go beyond the notion of absence or presence of sparing as an arbitrary rise of performance compared to other lags.

The results of Experiment 1 thus provided clear evidence: Integration played a major role at Lag 1, occurring on a considerable number of trials. One caveat has to be made, however, namely that the targets in the present task together formed a recognizable shape outline, which may be suspected to lead to effects due to Gestalt grouping. The possibility thus exists that the Gestalt aspect of the present task was solely responsible for integration. If so, integration might not occur in typical AB task that do not feature Gestalt perception. Experiment 2 was conducted to address this concern.

EXPERIMENT 2

As mentioned, Experiment 2 was conducted to investigate the possible contribution of the Gestalt principle of visual completion to the occurrence of integration. In Experiment 1, this may have played a role since the stimuli used as targets in this experiment may have formed a distinct, recognizable shape in case they were integrated. In Experiment 2, the potential contribution of visual completion was excluded by replacing the square corners by digits that would not form a familiar visual shape in case they were integrated, thus removing the Gestalt that might have been elicited by the square outline in Experiment 1.

Method

Participants

Twenty-eight new participants (21 female, 7 male) were recruited using the same procedures and criteria as in Experiment 1. Data from two female participants were removed from the analyses, using the same exclusion criterion as in Experiment 1. Mean age was 19.7 years (range 18-24 years).

Apparatus and stimuli

The experimental setup and stimuli were identical to those of Experiment 1, with the sole exception that the targets now consisted of the digits 4, 5, 2, and 1, drawn in Courier 36 pt. bold font. Compared to the corners used for T1 and T2 in Experiment 1, these digits were displaced slightly towards the center of the screen (by nature), but still appeared in their respective locations, similar to the corners in Experiment 1. They mapped directly to their response keys (cf. Experiment 1).

Procedure and design

The experimental procedure and analyses were identical to those of Experiment 1.

Results and discussion

T1 accuracy was affected by Lag, $F(1.4, 34.6) = 295.76$, $MSE = .008$, $p < .001$. Performance was 41.1% at Lag 1, and improved to 82% at Lag 3 and 88.1% at Lag 8. If T1 performance was assessed using the relaxed criterion (ignoring order), performance at Lag 1 increased to 74.2%. Performance on T1 as a function of Lag is shown in the left panel of Figure 4.

insert Figure 4 about here

Predictably, T2|T1 performance was also affected by Lag, $F(1.3, 32.6) = 35.75$, $MSE = .019$, $p < .001$. Identification averaged 66.2% correct at Lag 1, 84.4% at Lag 3, and 91.9% at Lag 8. Performance at Lag 1 averaged 81.5% if report order was ignored. As in Experiment 1, the frequency of trials in which both targets were reported correctly was lowest of all at Lag 1 (29% compared to 70.8% at Lag 3 and 81.6% at Lag 8), $F(2, 50) = 226.39$, $MSE = .009$, $p < .001$. The right panel of Figure 4 shows T2|T1 performance plotted over Lag.

As in Experiment 1, integration occurred more frequently at Lag 1 than at later lags, $F(1, 25.6) = 43.94$, $MSE = .045$, $p < .001$. At Lag 1 the report frequency of the integrated percept averaged 37.1%, compared to 4.1% at Lag 3, and 1.6% at Lag 8. The frequency of order reversals also showed a significant effect of Lag, $F(1.2, 29.5) = 51.62$, $MSE = .003$, $p < .001$, with 11.5% of the responses being reversals at Lag 1, compared to 2.2% at Lag 3, and

.4% at Lag 8. The left panel of Figure 5 shows the relative frequency of integrations and order reversals as a function of lag, and the right panel of Figure 5 shows the distribution of partial reports at each lag.

insert Figure 5 about here

Taken together, the results of Experiment 2 were clear-cut, and they represented a virtually perfect replication of Experiment 1: Integration was equally frequent at Lag 1 as it was in the previous experiment indicating no clear influence of Gestalt grouping on task performance in Experiment 1. If anything, the task used in Experiment 2 seemed slightly easier, although this might also have reflected group differences (see e.g., Martens, Munneke, Smid, & Johnson, 2006).

EXPERIMENT 3A

The experiments reported so far all included a spatial component. In Experiment 1, the spatial layout of the corners was closely tied to the identification task for the participants. The spatial discrepancy between the targets might have modulated performance at Lag 1, or it might have created unusual target masking conditions. Experiment 2 did change the visual appearance of the stimuli, thereby removing the perceptual Gestalt, but the task was still rather spatial in nature as the targets still occupied distinct locations in the display. Moreover, although the participants were asked to identify the digits, these did not vary in position, so that localizing the stimuli may have been sufficient to accomplish the task. The possibility thus exists that temporal integration requires such a spatial component to occur, even though the combined frequency of order reversals and integrations observed in Experiments 1 and 2 seemed largely consistent with the frequency of order reversals seen in previous reports (see also the General Discussion below). To examine whether the occurrence of integration generalizes to conditions more typical of those used in other AB studies, Experiment 3 used an RSVP paradigm in which all stimuli appeared in the same spatial location.

Method

Participants

Sixteen new participants (13 female, 3 male) were recruited using the same procedures and criteria as in Experiment 1. Mean age was 20.6 years (range 18-24 years).

Apparatus and stimuli

The experimental setup and stimuli remained mostly identical to those of Experiment 1. The targets now consisted of all possible combinations of the capital letter O and the forward and backward slash ("/" and "\") symbols, as shown in Figure 6A. These were presented in black, in the same font and size as the distractors. To avoid undue confusion with the distractors, the letters O and X were removed from the distractor set. Participants could identify the target symbols by means of labeled keys on the numeric keypad (keys 2, 4-9 underneath the labels).

insert Figure 6 about here

Procedure and design

Because of the new target items, and the corresponding change in the number of response alternatives, the number of trials now totaled 608 (31.6% for each lag). The percentage of trials on which no T2 was shown also changed slightly to 5.3% (previously 6.4%). The design and analysis were otherwise identical to those of Experiment 1.

Results and discussion

T1 performance was affected by Lag, $F(1.4, 20.4) = 27.22$, $MSE = .006$, $p < .001$. Performance was 41.9% at Lag 1, 54.6% at Lag 3, and 57.7% at Lag 8. If order was ignored, T1 performance increased most strongly at Lag 1, to 64.7%, but performance at Lags 3 and 8 also seemed to improve (to 66.1% and 67.8%, respectively). Performance on T1 as a function of Lag is shown in the left panel of Figure 7.

insert Figure 7 about here

T2|T1 performance was also affected by Lag, *F*(1.4, 21.3) = 21.54, *MSE* = .015, *p* < .001. Performance was 22.5% at Lag 1, 22.6% at Lag 3, and highest at Lag 8 with 43.4%. Interestingly, when order was ignored, performance at Lag 1 increased greatly to 48.6%. At Lag 3 (34.7%) and Lag 8 (52.2%) the increase was more modest. Lag 1 sparing was thus clearly obtained with this paradigm. T2|T1 performance as a function of Lag is shown in the right panel of Figure 7.

Integration frequency showed the same pattern as was observed in the earlier experiments. There was a significant effect of Lag, *F*(1.4, 20.9) = 33.25, *MSE* = .02, *p* < .001, with integration being more frequent at Lag 1 (43%) than at Lag 3 (22.7%) and Lag 8 (9%). It seemed that this task elicited a higher ‘baseline’ of integration responses than observed previously. However, this can be attributed to the increased difficulty of the task, which resulted in fewer trials in which the identities of both targets were correctly reported. As can be seen from comparing the relative frequencies with the absolute reports (see the right panel of Figure 8), the relatively high level of the former could be attributed to the somewhat artificial inflation caused by task difficulty. The reason for this increase in difficulty may have been the removal of the spatial aspect of the task, or increased power of the distractors to induce erroneous responses. Although the most confusable letters were removed from the task (X and O), others remained that might also have had some effect (e.g., Q or K). In any case, the most important result was that the number of integrations at Lag 1 remained substantial, and was clearly elevated above the baseline level. The number of order reversals was also affected by Lag, *F*(2, 30) = 10.6 *MSE* = .004, *p* < .001. Order reversals averaged

18.5% at Lag 1, 10.8% at Lag 3, and 8% at Lag 8, all of which seemed to be slightly inflated by task difficulty as well. Integration and reversal frequency as a function of Lag is shown in the left panel of Figure 8.

insert Figure 8 about here

There were furthermore some changes in the distribution of errors other than integrations and reversals (see below for the analysis of these). As can be seen from the right panel of Figure 8, there were relatively many trials on which only the identity of T2 was retrieved (i.e., reported as T1, and the identity of T1 was not reported as T2), across all lags. The same was true, to a lesser degree, for T1 identity-only reports. These might also be explained by the increased difficulty of the task. In this experiment, the targets were more similar to the distractors, which likely constituted an additional source of difficulty. Importantly, there was no meaningful change over lag apparent for these errors ($F < 2.1$ for T1 identity, and $F < 2.9$ for T2 identity). Another aspect of interest emerging from the right panel of Figure 8 was the more modest increase of trials on which both targets were reported correctly from Lag 1 to Lag 3 (from 9.7% to 12.7%).

EXPERIMENT 3B

Experiment 3B was conducted to more directly investigate the possible effects of task difficulty on the different performance measures. Since Experiment 3A seemed to be more difficult overall than Experiments 1 and 2, Experiment 3B was designed to make the task easier. To this end, the targets received a unique color.

Method

Participants

Fifteen new participants (10 female, 5 male) were recruited using the same procedures and criteria as in Experiment 1. Mean age was 19.2 years (range 18-22 years).

Apparatus and stimuli

The experiment was a replication of Experiment 3A, except that the target stimuli now appeared in blue (RGB 0, 0, 255). The distractors remained black.

Procedure and design

The procedure and design were identical to those of Experiment 3A.

Results and discussion

T1 performance was strongly affected by Lag, *F*(1.2, 16.3) = 98.87, *MSE* = .014, *p* < .001. Performance was low at Lag 1 (45.3%), but it improved at Lag 3 (82.6%), and remained high at Lag 8 (86.8%). If report order was ignored, performance was 75% at Lag 1, 89.5% at Lag 3, and 91.6% at Lag 8, again clearly showing the most substantial increase at the shortest lag. The left panel of Figure 9 shows T1 performance as a function of Lag.

insert Figure 9 about here

T2|T1 performance was also significantly affected by Lag, *F*(2, 28) = 27.31, *MSE* = .026, *p* < .001. Performance at Lag 1 was 37.4%, compared to 57.3% at Lag 3, and 80.9% at Lag 8. As was consistently the case before, ignoring report order improved performance most at Lag 1 (63.3%, 65.3%, and 85%, at Lags 1, 3, and 8). The right panel of Figure 9 shows T2|T1 performance as a function of Lag.

Crucially, integration frequency was once again dependent on Lag, *F*(1, 14.3) = 25.98, *MSE* = .045, *p* < .001. Reports of the integrated percept were frequent at Lag 1, averaging 36.3%, but not at Lag 3 (3.2%) and Lag 8 (.5%). As before, order reversals followed the same pattern, *F*(1.3, 17.8) = 44.66, *MSE* = .003, *p* < .001, though at lower rates overall. Order reversals averaged 17.3% at Lag 1, 5.5% at Lag 3, and 2.1% at Lag 8. The left panel of Figure 10 shows integrations and order reversals as a function of Lag.

insert Figure 10 about here

As shown in the right panel of Figure 10, there was one salient change compared to Experiment 3A: The number of trials on which both targets were identified correctly was relatively high at Lag 3 (48.8%). Because attentional blink magnitude was comparable between Experiment 3A and 3B (computed as T2|T1 performance at Lag 8 minus Lag 3, blink magnitude was 20.8% in Experiment 3A, and 23.6% in 3B), this change must be attributed to other factors that affected the overall level of performance, which did indeed differ substantially between these experiments. It seemed that the blue color of the targets set them apart from the distractors, which made them easier to discern from the distractors (but not necessarily from each other).

Most importantly, Experiment 3B thus replicated the primary result of the other experiments; integration took place frequently at Lag 1. The induced change in the overall level of performance did not seem to cause meaningful changes in the frequency of integrations nor that of order reversals.

EXPERIMENT 4

Experiment 4 was conducted to further support the generalization of the present results to ‘classic’ attentional blink studies that use RSVP paradigms in which targets typically consist of letters or digits. First, with such targets, there is more visual overlap between targets, and one might suspect that increasing overlap could decrease integration frequency: Overlapping parts do not neatly complement each other, which may be a cue for the perceptual system to avoid integration. If overlap were an issue indeed, then the present results might not well account for Lag 1 performance in more traditional RSVP paradigms, because they were obtained with stimuli that either did not overlap at all (Experiments 1 and 2), or only with regard to intersections (Experiments 3A and 3B). Second, the targets used in classic RSVP paradigms are typically meaningful; a letter is recognized as such, and may not be treated as an arbitrary symbol. It is conceivable that a meaningful target is less likely to be integrated with another, as its identity is already a coherent, single item. If this were the case, the use of less well identifiable targets in the present study may again cause an overestimation of integration frequency. To address these issues, the target stimuli used in Experiment 4 consisted of identifiable ‘LED’ letters (in digital alarm clock font, see Figure 6B; cf. Dux & Coltheart, 2005), which furthermore had a large degree of overlap between targets (up to 3 out of 7 line segments). If the previous experiments are indeed indicative of integration in more classic RSVP paradigms also, integration should also be observed in this design.

Method

Participants

Twenty-four new participants (20 female, 4 male) were recruited using the same procedures and criteria as in Experiment 1. Mean age was 19.7 years (range 18-25 years).

Apparatus and stimuli

The experiment was a replication of Experiment 3B, except that the target stimuli now consisted of the LED symbols shown in Figure 6B. Analogous to the previous experiments, these symbols could be combined to form viable integrated responses. For instance, “l” and “o” could combine to form “b”, an example in which one of the LED line segments was shared between targets. Similarly, “q” and “d” could be integrated together to form a “B”, an example of a trial in which 3 line segments overlapped. T1-T2 combinations that would not form a feasible integrated percept (e.g., “d” and “b”) were not shown.

Procedure and design

The procedure and design were mostly identical to those of Experiment 3B. The total number and distribution of trials was changed slightly to accommodate the different integration possibilities resulting from the new target stimuli. The total number of trials was 604 (31.8% for each lag), and the percentage of trials on which no T2 was shown was 4.6%.

To test whether the new design caused a different pattern of integration, an additional analysis was added. Integration was examined as a function of lag, and compared between Experiment 3B and 4.

Results and discussion

Lag had a pronounced effect on T1 performance, *F*(1.4, 31.1) = 165.5, *MSE* = .006, *p* < .001. As before, performance at Lag 1 (42.1%) was lower than at Lag 3 (67.1%) and Lag 8 (73.6%). Predictably, ignoring report order mainly improved Lag 1 performance (to 71.8%), but performance also improved at Lag 3 (81.4%) and Lag 8 (84.6%). The left panel of Figure 11 shows T1 performance as a function of Lag.

insert Figure 11 about here

Lag also influenced T2|T1 performance, *F*(2, 46) = 26.99, *MSE* = .013, *p* < .001. At Lag 1, identification accuracy averaged 39.2%, compared to 46% at Lag 3, and 62.7% at Lag 8. Interestingly, ignoring report order produced sparing, as was the case in Experiment 3A before. Performance came to 73.7% at Lag 1, clearly elevated over the 63.2% at Lag 3, and comparable to the 73.1% at Lag 8. The right panel of Figure 11 shows T2|T1 performance as a function of Lag.

Integration frequency was also affected by Lag, as expected, *F*(1.1, 24.3) = 22.68, *MSE* = .033, *p* < .001. Integration was more frequent at Lag 1 (24.1%) than at Lag 3 (2.8%) and Lag 8 (.7%). Overall, Experiment 3B and Experiment 4 were comparable. In an analysis of integration frequency between experiments, there was no difference even in the overall level of performance, *F*(1, 37) = 1.42, *MSE* = .033, *p* < .24. Importantly, there was also no reliable change related to lag (*F* < 2.3). Order reversals again followed suit across the lags,

$F(1.2, 26.8) = 43.15$, $MSE = .004$, $p < .001$. Average reversal frequency was 13.1% at Lag 1, compared to 3.2% at Lag 3, and 1.2% at Lag 8. Figure 12 shows integrations and order reversals as a function of Lag, as well as partial reports.

insert Figure 12 about here

The results of this experiment clearly showed that integration occurred frequently at Lag 1, regardless of the degree of overlap between targets, and despite the more meaningful nature of the targets (i.e., they were individually recognizable as letters). The assumption that integration plays an important role at Lag 1 also in classic dual-target RSVP tasks seems thereby justified.

EXPERIMENT 5

Experiment 5 was designed to examine the hypothesized link between integration and order reversals in classic paradigms (i.e., those in which integrations cannot be reported as such). Although the evidence so far did show that it is plausible that such order reversals are a consequence of integration taking place, the present data did not yet present evidence for a more direct link. To this end, a straightforward prediction was made: If integrations do underlie order reversals in classic paradigms, then removing the possibility to report an integrated percept should cause a commensurate rise in reversals. This prediction was tested in Experiment 5.

Method

Participants

Twenty-eight new participants (17 female, 11 male) were recruited using the same procedures and criteria as in Experiment 1. Mean age was 20.6 years (range 18-25 years).

Apparatus and stimuli

The experiment was a replication of Experiment 4, but the possibility to report an integrated percept was removed. This was accomplished by making small changes to the stimuli. The “l” and “o” stimuli (see Figure 6) were now centered, so that their combination no longer formed a “p”, “q”, “d”, or “b”. The “8” was furthermore rotated 90 degrees (“∞”), so that the appearance of an “8” resulting from a combination of “p” and “d” (etc.) was no longer a feasible target identity.

Procedure and design

The procedure and design were otherwise fully identical to those of Experiment 4. To test whether order reversals differed reliably from those observed in Experiment 4, their frequencies were compared between Experiment 4 and 5.

Results and discussion

Lag had an effect on T1 identification accuracy, $F(1.6, 44.5) = 277.98$, $MSE = .004$, $p < .001$. As before, performance at Lag 1 (52.2%) was lower than at Lag 3 (80.4%) and Lag 8 (85%). Ignoring report order again principally improved Lag 1 performance (to 72.7%), and had a much smaller effect at Lag 3 (86.6%) and Lag 8 (88.2%). The left panel of Figure 13 shows T1 performance as a function of Lag.

insert Figure 13 about here

T2|T1 performance was also affected by Lag, $F(2, 54) = 27.38$, $MSE = .009$, $p < .001$. At Lag 1 accuracy averaged 59.7%, and dropped further to 54.4% at Lag 3, before recovering to 72.9% at Lag 8. Ignoring report order further increased the strength of sparing, with performance averaging 67.7% at Lag 1, compared to 55.5% at Lag 3, and 72.3% at Lag 8. The right panel of Figure 13 shows T2|T1 performance as a function of Lag.

As expected, order reversals were frequent at Lag 1 (32.5%), but not at the other lags (6.3% at Lag 3, and 2.4% at Lag 8), $F(1.6, 42.8) = 202.37$, $MSE = .005$, $p < .001$. In comparison with Experiment 4, it was clear that order reversals were specifically more frequent at Lag 1, as evidenced by an interaction between Lag and Experiment, $F(2, 100) = 42.82$, $MSE = .003$, $p < .001$. At Lag 1, order reversals rose strongly from 13.1% in Experiment 4 to 32.5% in Experiment 5, compared to increases of 3.1% at Lag 3, and 1.2% at Lag 8. Reports of T1 identity-only did not increase meaningfully at Lag 1 (1%, $F < 1.9$). Reports of T2 identity-only did show a modest change from Experiment 4 to 5 at Lag 1, $F(2, 100) = 3.93$, $MSE = .009$, $p < .05$, but this constituted a decrease instead (-5.2%). Finally, although the overall level of fully correct reports was higher in Experiment 5 (33.6% vs. 46.6%), this difference did not vary at all across Lag, $F < 1$. Figure 14 shows order reversals as a function of Lag, as well as partial reports in Experiment 5.

insert Figure 14 about here

Using the paradigm of Experiment 4, which demonstrably elicited frequent integration reports at Lag 1, and by simply disabling this report possibility, an almost threefold increase in order reversals at Lag 1 was caused. Other types of responses were not similarly affected. These results clearly supported the idea that integrations as observed in the present Experiments 1-4 are indeed associated with order reversals in paradigms in which integrations cannot be reported as such.

GENERAL DISCUSSION

The present study investigated the hypothesis that the order reversals that are typically obtained when two targets appear after each other in the AB task can arise due to integration of the targets into the same episodic trace, rather than to precedence exclusively. Using a task that for the first time enabled participants to report such illusory integrations, the results of four experiments supported this hypothesis in showing that participants indeed frequently reported an integrated percept of T1 and T2 at Lag 1. [3] Additionally, as soon as the option to report an integrated percept was removed, the low frequency of order reversals previously observed was greatly increased. Also when compared to the frequency of order reversals in previous studies, which presumably also consist of 'hidden' integrations (see below) and actual order reversals, the numbers seemed quite comparable. For instance, Chun and Potter (1995) reported about 30% reversals at Lag 1 (from their Figure 8), calculated relative to the number of trials in which both target identities were reported. In the present Experiment 1, assuming that half of the integrations would produce fully correct reports (see further below), that number would come to about 30% as well. In Experiment 5, where no integration report could be made, reversals also averaged just above that level at Lag 1.

While integration reports occurred frequently for Lag 1 trials in the present study, they were much rarer for Lag 3 and Lag 8 trials, and the frequency of integration by far exceeded the frequency of 'real' order reversals at Lag 1 in Experiment 1-4. The present results also underscore the fact that an increased probability of identifying T2 is not the only difference between performance at Lag 1 and performance at later lags in which T2 appears during the AB. Rather, our results show that reports of targets appearing at Lag 1 differ from reports of targets appearing at Lag 3 and Lag 8 in that more integrations, order reversals, and cases in which only T2 identity was preserved (and reported as T1) occur.

In demonstrating that participants more often perceive the T1 and T2 as an integrated, single stimulus, than they perceive T1 and T2 as separate, but in the incorrect order, the present results suggest that integration may well be the primary cause of the majority of order reversals observed in previous studies of the attentional blink in which observers did not have the opportunity to report an integrated percept of T1 and T2. In this regard, the results present a compelling argument against recent claims that precedence and prior entry constitute the sole mechanisms responsible for order reversals (Olivers et al., 2011; Reeves & Sperling, 1986; Wyble et al., 2009). Indeed, precedence accounts ultimately fail to predict the occurrence of integration altogether.

Our results are consistent instead with previous claims made by Hommel and Akyürek (2005; Akyürek & Hommel, 2005; Akyürek et al., 2007; 2008), and the STST model proposed by Bowman and Wyble (2007) in providing support for the idea that integration may constitute the primary mechanism involved in order reversals, as there were only few trials on which reversals occurred in the absence of integration. By implication, it follows that previous studies in which reversals were examined would have shown a reduced rate of reversals if observers would have been allowed to report an integration of T1 and T2. Comparison of Experiment 4 and 5 provided direct evidence for the existence of such a relationship between these types of report.

Given that integration reports are generally not feasible in RSVP tasks, one might wonder how integrated percepts fare in such circumstances. Consider, for example, the integrated percept of two letters, “R” and “T”; their combination does not result in a meaningful stimulus, as would indeed be the case for the combination of the majority of letter-based target stimuli. Yet, it does not seem that observers consequently fail to disentangle these stimuli (i.e., they do not seem to become entirely illegible). If they were unable to do so, performance at Lag 1 would suffer severely. Instead, observers seem to be able to dissociate the individual letters, and report them—even if frequently in the wrong order. This ability does not run counter to the idea that integration is taking place, however. As alluded to previously in the introduction, at the intervals used in RSVP, performance is not limited by the temporal resolution of the visual system, that is, full fusion of the two targets into a percept that cannot in any way be distinguished from a truly singular stimulus, does not take place. Rather, a more ‘unstable’, but nonetheless still singular percept emerges, which is also indicated by the detection of some ‘flicker’ in the stimulus stream. This percept may allow the perceptual system to perform a post-hoc disentanglement of the stimuli (presumably at a later stage of processing), particularly when they consist of overlearned letters or digits, whose combination is meaningless and undesirable. The consequences of their integration can nonetheless still be observed in the irreparable loss of order information that resulted.

The question of how integrations relate to sparing presents itself at this point. Before discussing this issue, it is important to highlight the fact that sparing is not realized by a single type of response. Sparing is defined by the frequency of correct identification of T1 and T2, without taking into account possible order errors. As a result, several types of report are heaped together. Sparing can consist of fully correct reports (i.e., in a task with digit targets, T1 is “4” and T2 is “6”, and the participant reports them as such), true order reversals (the participants reports the targets as “6” and “4”, respectively), or by disentangled integrations—which could result in either a fully correct report or in an order reversal (in the case of classic RSVP paradigms). The evidence presented in the current study implies a link between integration and order reversals, and as a consequence also between integration and sparing, but the latter is indirect. Consider, for example, a hypothetical task or condition in which integration is relatively frequently elicited, but also relatively few fully correct reports (as may happen if targets mask each other more strongly). The former may increase sparing, but the latter may decrease it again, which may result in finding no difference overall. Indeed such a mechanism seems to have occurred in several of the experiments reported here: Frequent integration at Lag 1 was accompanied by infrequent fully correct reports, compared to longer lags. Thus, although the data suggest that integration underlies many order errors at Lag 1, which implicates a contribution to sparing, the indirect nature of this link means that other factors may counteract its effects.

How then might integration be related to the attentional blink? Classic two-stage models of the attentional blink (e.g., Chun & Potter, 1995; Shapiro, Raymond, & Arnell, 1994) can provide a general framework for the present results by assuming that successful report requires access to specific attentional resources, which is controlled through some sort of attentional gate. This attentional gate may close after variable intervals that depend on time and the properties of post-T1 stimuli. If the gate is opened upon the arrival of T1, T2 can thus “slip in” and benefit from attentional resources the sooner it appears and the faster it is processed. In addressing the role of integration, the ‘neo-classical’ STST model proposed by Bowman and Wyble (2007) is also particularly well-suited to provide an explanatory framework, as it is able to specify (computationally) how sparing, the AB, and integrations may arise. According to the model, T2 performance at Lag 1 depends on the extent to which T2 is able to benefit from the attentional response elicited by T1, which in turn may depend on the spatial and temporal proximity of T1 and T2, and the extent to which the two targets both match the same attentional template. While these factors determine the level of T2 accuracy at Lag 1, the definition of “sparing” is such that performance at Lag 1 should be better than performance at later lags at which the AB is said to be in effect (e.g., Lag 3; Visser et al., 1999). According to STST, performance at blink lags is mostly determined by the difficulty of the T1 task, the idea being that at these lags, the attentional response elicited by T1 has receded and T2 performance is now primarily determined by the difficulty of encoding T1 in working memory as this constitutes the cause of the AB in STST. Accordingly, the occurrence of a sparing effect depends on both the extent to which T2 can benefit from the attentional response elicited by T1 and on the magnitude of the AB elicited by encoding T1. Within this framework, integration is thought to arise whenever the two targets activate their types to a sufficient degree and within sufficiently close temporal proximity. In this case, the two target representations would be bound to a single token, resulting in a memory trace of an integrated representation of T1 and T2, and an inability to distinguish the order in which T1 and T2 appeared. Since integration requires temporal proximity between activation of the T1 and T2 types, it follows that the probability of integration and order reversals is greatest at Lag 1.

Aside from offering a mechanism that can explain the occurrence of integration at Lag 1, the STST model also offers an explanation for the present finding of order reversals on trials in which integration did not occur. In particular, the model assumes that the occurrence of integration requires a sufficient degree of temporal overlap between the activation of the T1 and T2 types. In case this overlap is sufficient, the T1 and T2 types are bound to the same token, and integration is achieved. In case the overlap is insufficient, however, the T1 and T2 types are bound to separate tokens, and observers will report T1 and T2 separately. On these trials, an order reversal can occur when the T2 type is bound to a token before the T1 type is successfully bound to a token. In this case, the T2 type will be bound to the first token and the T1 type will be bound to the second token, effectively yielding an order reversal that is not due to integration but to prior entry.

While the tokenization mechanism envisioned by STST (Bowman & Wyble, 2007) thus appears to provide a comprehensive account of the present data by specifying a memory encoding mechanism that allows for integration, prior entry, and correctly ordered reports to occur at Lag 1, a potential caveat lies in the possibility that integration might also arise at an earlier level than the association between types and tokens at the time of working memory encoding. In particular, it is also possible that integration starts and *finishes* at an early stage of perceptual encoding, effectively producing a perceptual representation in which T1 and T2 are integrated. This representation would then activate the corresponding compound type node instead of activating the individual type nodes, resulting in integration by means of consolidation of the compound type. An interesting issue for future research will be to distinguish between this potential early mechanism of perceptual integration and integration that arises as a consequence of binding two types to a single token.

Another interesting question raised by the present findings regards whether integrations are qualitatively different from other types of responses with regard to the *degree* to which target identity is preserved, and the degree to which subsequent attentional processing at longer lags is modulated. Results from other paradigms, such as the missing element task, suggest that there are indeed measurable consequences of perceiving an integrated event as opposed to two separate events; modulations of the event-related potential start at the N1 but also carry forward to the N2 and P3, over half a second after stimulus onset (Akyürek, Schubö, & Hommel, 2010). Thus, it may be predicted that a single integrated percept will differentially modulate further processing in RSVP, compared to two percepts whose order has been missed (i.e., a reversal). For instance, it is possible that integrated percepts occupy only one slot in working memory, while separate target representations occupy two. This suggests that integration reduces the effective memory load, which could be tested in tasks that are taxing working memory more severely than the standard AB task.

Conclusion

The present findings show that when two targets appear at Lag 1 in an RSVP sequence, the outcome can be a report of only one of the two targets, a report of the two targets separately in the correct or incorrect order, or a report of an integrated percept comprising both target stimuli. Our results suggest that the latter type of outcome dominates the results obtained at Lag 1, indicating that integration plays a central role in performance at Lag 1 in the attentional blink task. In relating the present findings to the various models that have recently been proposed to explain the AB, sparing, and order reversals, the STST model proposed by Bowman and Wyble (2007) fares well, while precedence- or competition-based accounts do not.

However, an alternative view is that integration and competition may mark two poles of the same dimension: Both require that some sort of selection has taken place (given that the relative salience of actual targets seems to matter more than the relative salience of distractors; cf. Experiment 3A and 3B) and that, in some sense, both targets are part of the same temporal, if not attentional, episode (Shapiro & Raymond, 1994; Sperling & Weichselgartner, 1995). The latter idea fits reasonably well with the latest iteration of the eSTST model (Wyble, Potter, Bowman, & Nieuwenstein, 2011), which assumes an important role for attentional episodes that already accommodate order reversals, and which could potentially allow for integration within, as well. In general, becoming part of the same episode need not require complete fusion of the stimuli, but may lead to the loss of order information. Indeed, in their MEG study Kessler et al. (2005) reported that Lag 1 sparing is associated with distinct M300 (the magnetoencephalographic equivalent of the P300) components for the two targets in cortical areas related to identification but only a single component in left temporo-parieto-frontal areas that might be related to the representation of temporal order. At the same time, being part of the same episode may be a necessary requirement to engage in competition, which would suggest that precedence effects may even presuppose a level of global, temporal integration (Hommel & Akyürek, 2005). Fusion, in turn, may be regarded as the extreme of that state of affairs, in which not any information about order or even the existence of two events is left, so that competition is replaced by complete integration. Hence, rather than putting integration and precedence into theoretical opposition, it may make more sense to consider them both as being an integral part of the processing dynamics. As suggested, it may turn out that precedence does not represent an alternative to but, rather, rely on integration to take place.

ACKNOWLEDGMENTS

We are most grateful to David Jungclaussen for efficiently collecting the data of Experiment 5, and to Brad Wyble and two anonymous reviewers for their helpful comments on a previous draft. Part of this research was supported by a Rosalind Franklin Fellowship from the University Medical Center Groningen and a VIDI grant from the Netherlands Organisation for Scientific Research (NWO) to DB.

FOOTNOTES

1. The common term for this phenomenon is “Lag 1 sparing”, where the term “Lag 1” is used to indicate that in studies using RSVP sparing mainly occurs when T2 appears in the serial position immediately following T1 in the RSVP sequence. However, recent work has shown that sparing is tied to the moment in time at which T2 appears, and not to its serial position (Bowman & Wyble, 2007; Nieuwenstein, Potter, & Theeuwes, 2009; Nieuwenstein, Van der Burg, Theeuwes, Wyble, & Potter, 2009), indicating that sparing is not necessarily confined the Lag 1 position. To avoid confusion with constraints regarding T2’s serial position, the term “sparing” will be used here.

2. For completeness, the same analyses of integration frequency over lag were also conducted on absolute percentages. The pattern of results did not change meaningfully as a result and integration continued to be most frequent at Lag 1. Experiment 1: $F(1, 17.1) = 19.95$, $MSE = .01$, $p < .001$. Experiment 2: $F(1, 25.4) = 37.06$, $MSE = .015$, $p < .001$. Experiment 3A: $F(1.2, 17.3) = 22.43$, $MSE = .002$, $p < .001$. Experiment 3B: $F(1, 14.1) = 16.58$, $MSE = .012$, $p < .001$. Experiment 4: $F(1, 23) = 14.71$, $MSE = .005$, $p < .001$.

3. In other tasks that measure temporal integration, such as the missing element task, it is often found that integration is quite constrained in time. For instance, in the study by Akyürek, Schubö, and Hommel (2010), the frequency of integration of a simple 5x5 pattern grid of squares between just two stimuli, at a total stimulus time of 120 ms (100 S1 + 10 ISI + 10 S2), was only around 40%, and integration was a prerequisite for correctly performing the experimental task in their experiments. In the present paradigm, the total stimulus time at Lag 1 was 150 ms (70 T1 + 10 ISI + 70 T2), and whenever integration took place that actually constituted an error (if only in the sense of perceiving one target when there were two), and it was thus not particularly desirable to integrate. In that light, the frequency of integration

presently observed at Lag 1 was remarkably high, demonstrating a certain ubiquity of the temporal integration process.

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FIGURE CAPTIONS

Figure 1. Illustration of the procedure and design of Experiment 1. Targets consisting of one or more corners of a square appeared amongst letter distractors in a rapid serial visual presentation of 80 ms per frame (70 ms stimulus and 10 ms blank). Dotted frames represent a varying number of distractors. A Lag 1 trial is shown, for which the actual identities of the targets are shown as well as the jointly integrated percept (“Int.”) that might be reported instead (see the first column of the table). The table includes two more examples of possible T1-T2 configurations to illustrate the design. Stimuli are not drawn to scale.

Figure 2. Experiment 1: The left panel shows task performance on T1 in percent correct, plotted over T1-T2 Lag (1^{st}, 3^{rd} or 8^{th} stimulus after T1). Error bars represent ± 1 standard error of the mean. The right panel shows T2 performance, given that T1 was identified correctly (T2|T1) in percent correct as a function of Lag. Dashed lines represent identification accuracy if report order is ignored (using a relaxed accuracy criterion).

Figure 3. Experiment 1: The left panel shows the frequency of report of integrated percepts and that of order reversals as a function of Lag, as a percentage of the total number of responses in which both target identities were reported correctly. The right panel shows the distribution of responses for each lag, as a percentage of the total number of responses.

Figure 4. Experiment 2: The left panel shows task performance on T1 in percent correct, plotted over T1-T2 Lag. The right panel shows T2 performance, given that T1 was identified correctly (T2|T1) in percent correct as a function of Lag.

Figure 5. Experiment 2: The left panel shows the frequency of integrations and order reversals as a function of Lag, as a percentage of the total number of identity-correct responses. The right panel shows the absolute distribution of responses for each lag.

Figure 6. (A) Target stimuli used in Experiment 3. In the experiment these were presented without repetition as T1 and T2. In Experiment 3A these appeared in black, and in Experiment 3B in blue. (B) Target stimuli used in Experiment 4.

Figure 7. Experiment 3A: The left panel shows task performance on T1 in percent correct, plotted over Lag. The right panel shows the same for T2|T1 performance.

Figure 8. Experiment 3A: The left panel shows relative integration and reversal frequency in percent as a function of Lag. The right panel shows the distribution of responses by Lag.

Figure 9. Experiment 3B: The left panel shows task performance on T1 in percent correct, plotted over Lag. The right panel shows the same for T2|T1 performance.

Figure 10. Experiment 3B: The left panel shows relative integration and order reversal frequency in percent as a function of Lag. The right panel shows the distribution of responses by Lag.

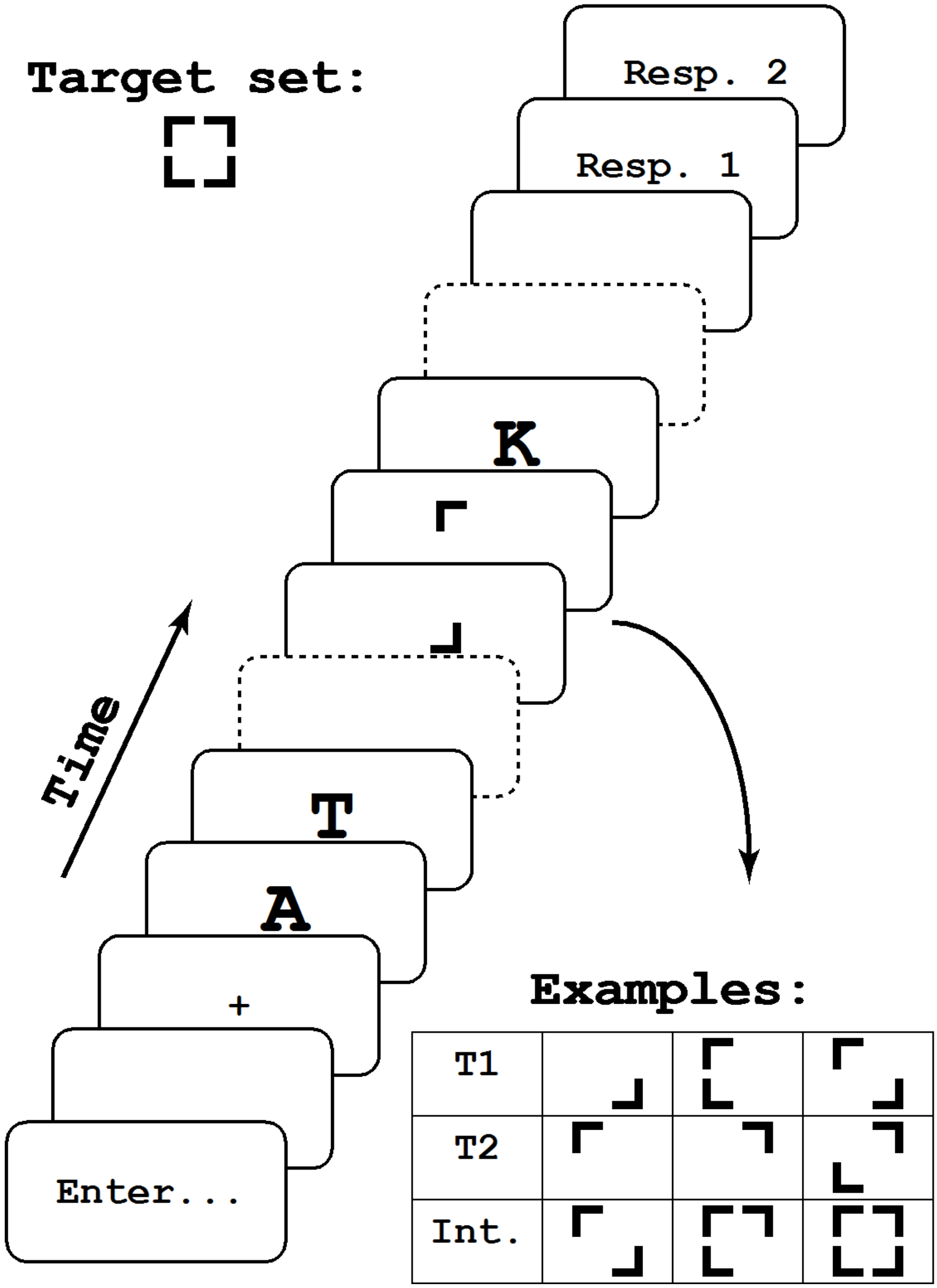
Figure 11. Experiment 4: The left panel shows task performance on T1 in percent correct, plotted over Lag. The right panel shows the same for T2|T1 performance.

Figure 12. Experiment 4: The left panel shows relative integration and order reversal frequency in percent as a function of Lag. The right panel shows the distribution of responses by Lag.

Figure 13. Experiment 5: The left panel shows task performance on T1 in percent correct, plotted over Lag. The right panel shows the same for T2|T1 performance.

Figure 14. Experiment 5: The left panel shows relative integration and order reversal frequency in percent as a function of Lag. The right panel shows the distribution of responses by Lag.

Figure 1



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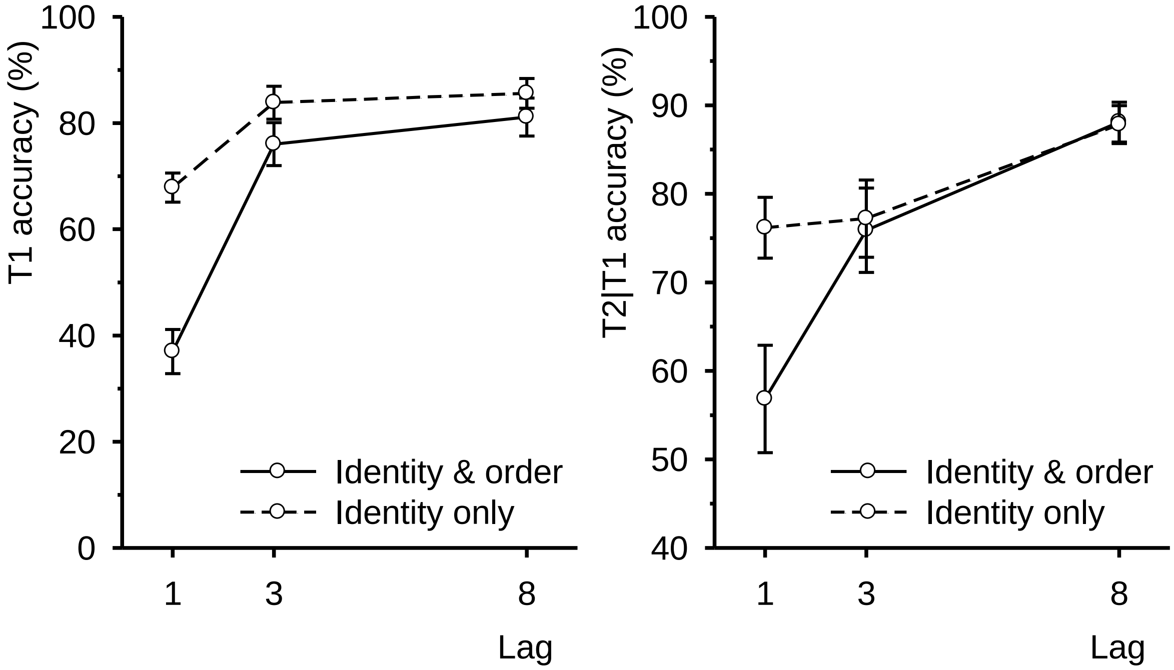
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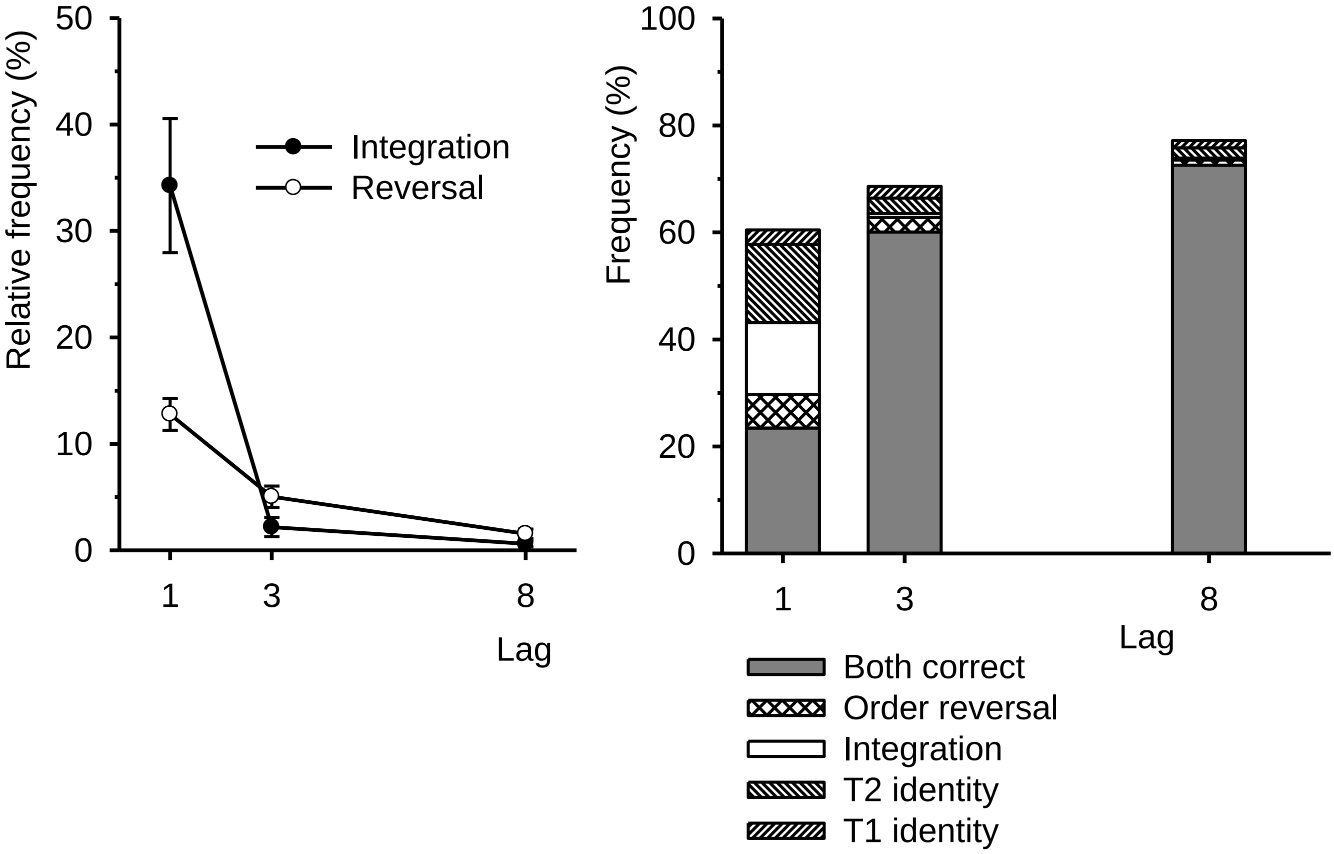
Figure 3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Integration
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Figure 4

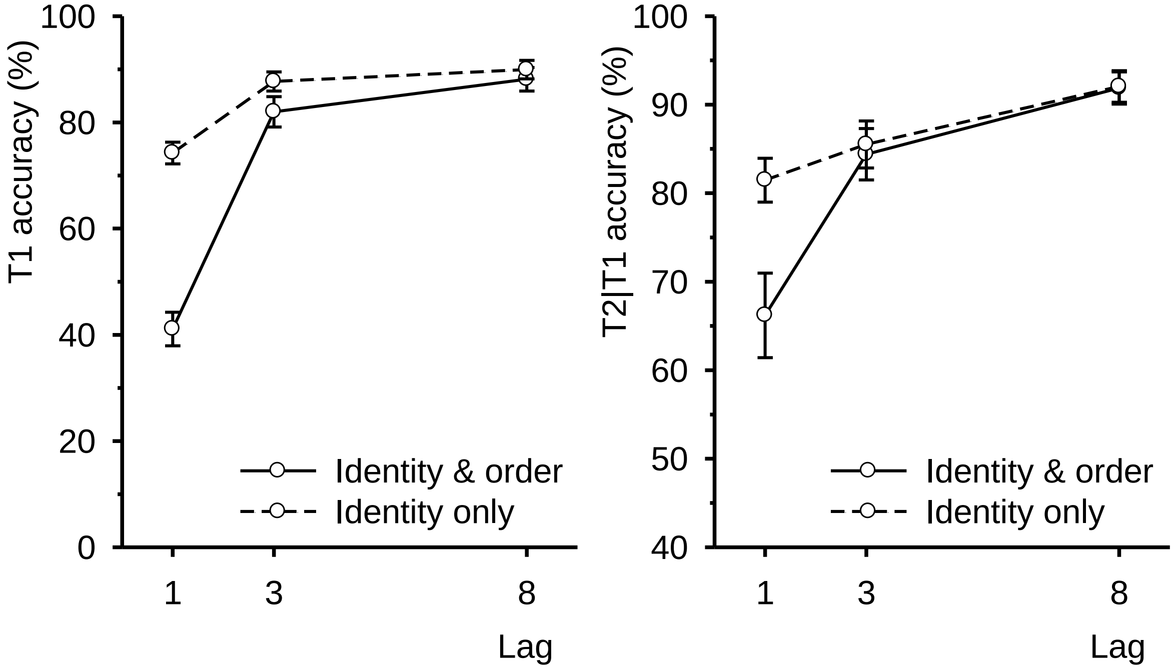
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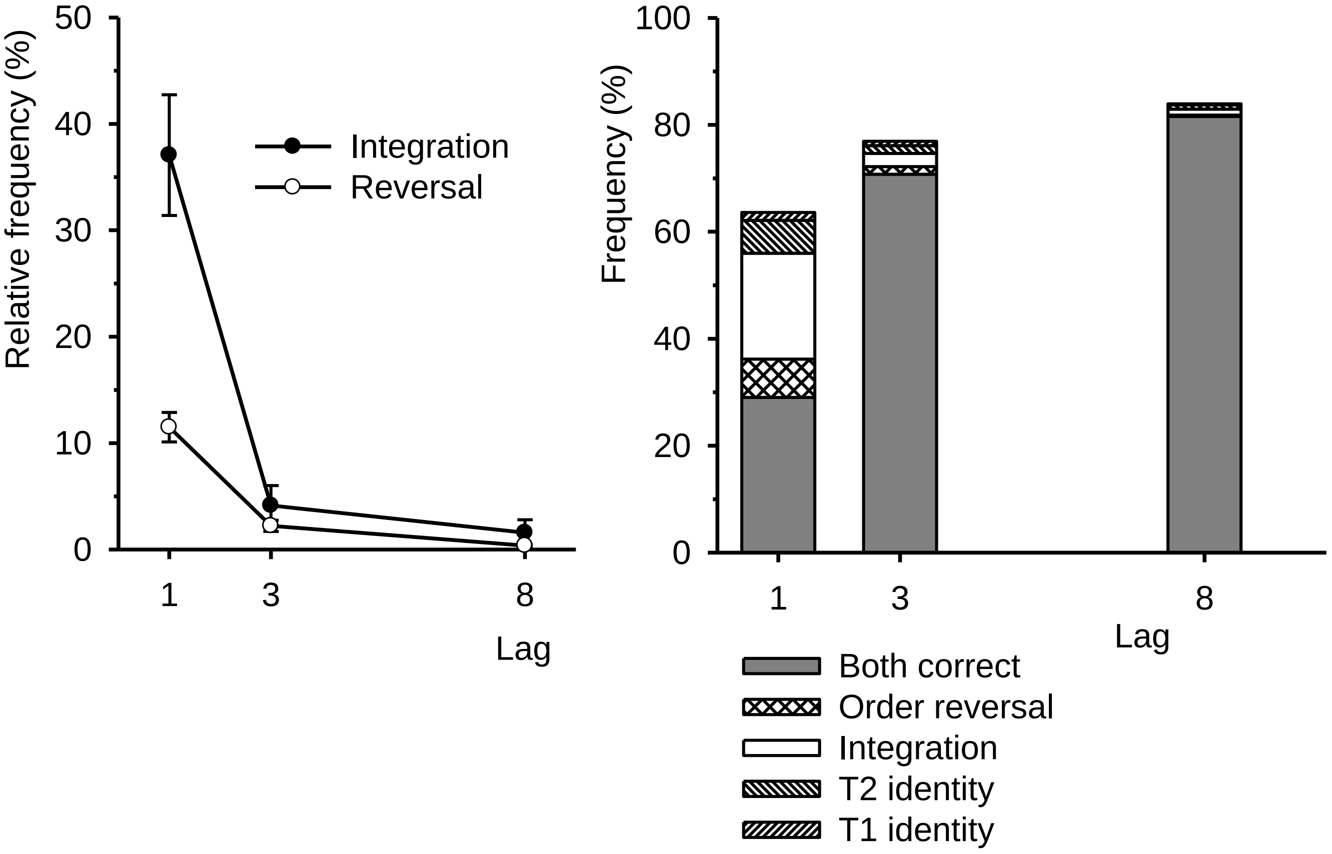
Figure 5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Order reversal
Integration
T2 identity
T1 identity

Figure 6

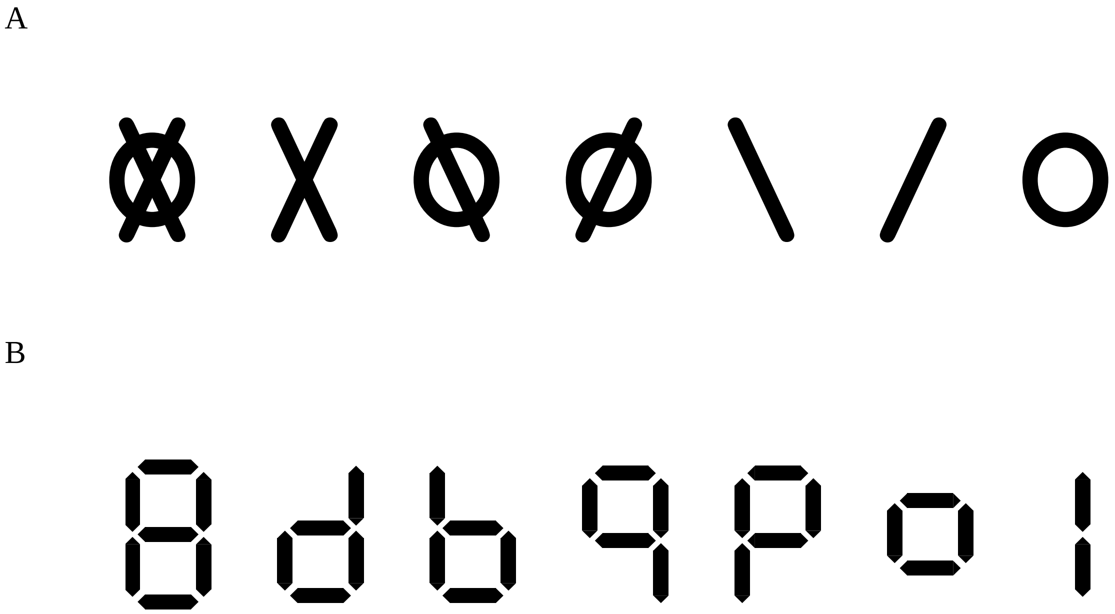

Figure 7

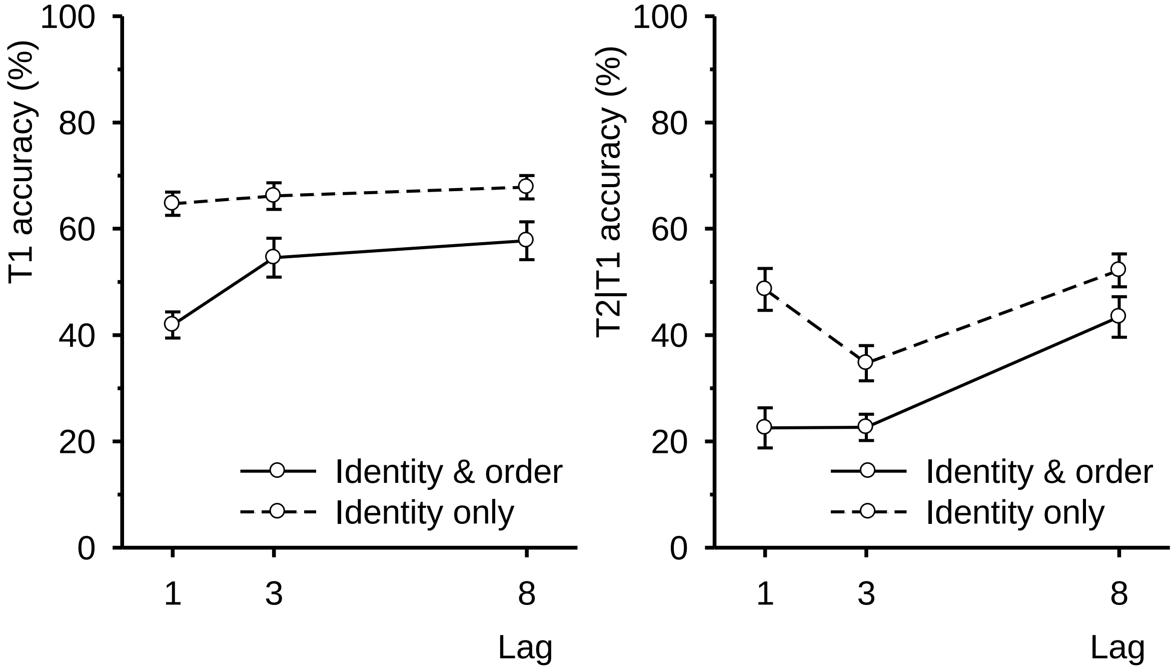
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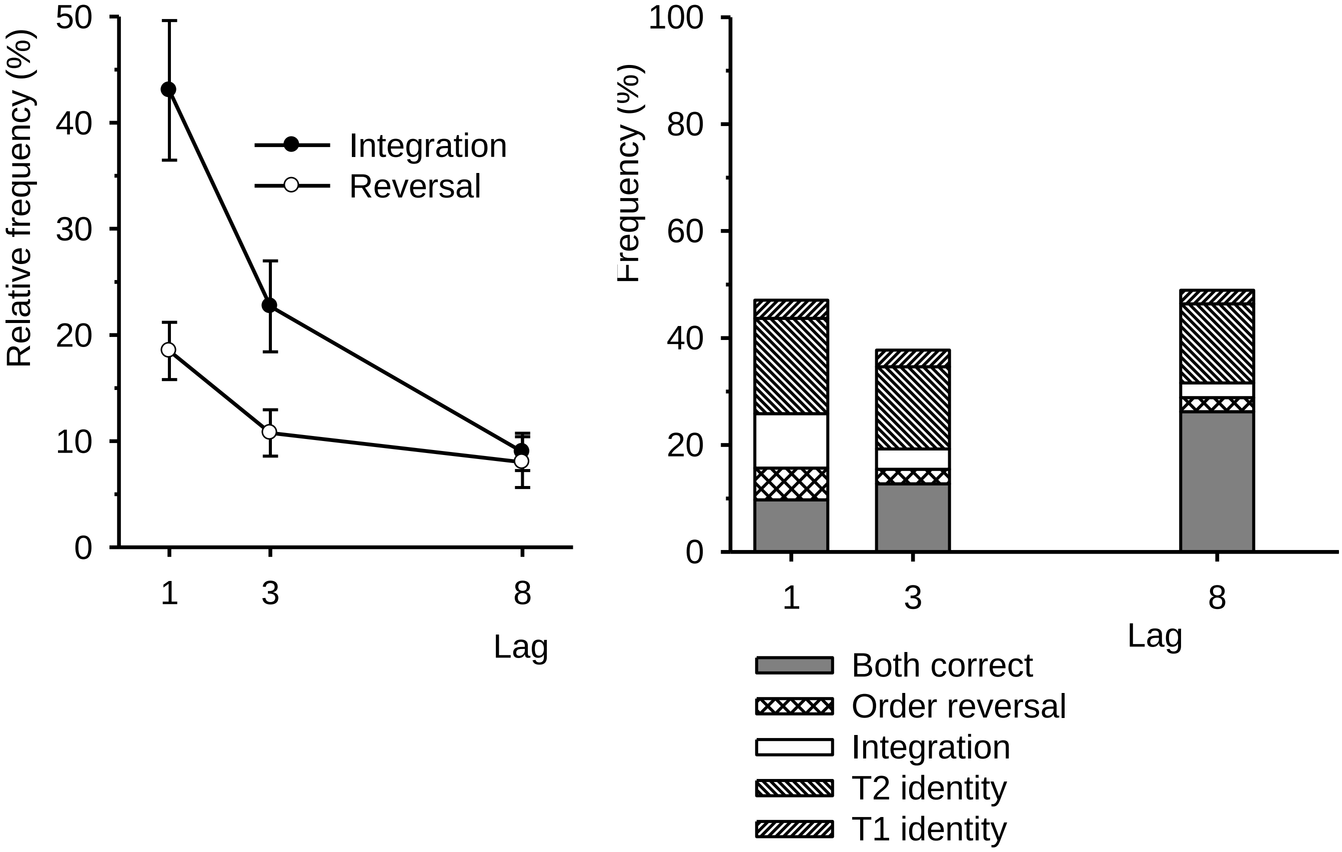
Figure 8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Both correct
Order reversal
Integration
T2 identity
T1 identity

Figure 9

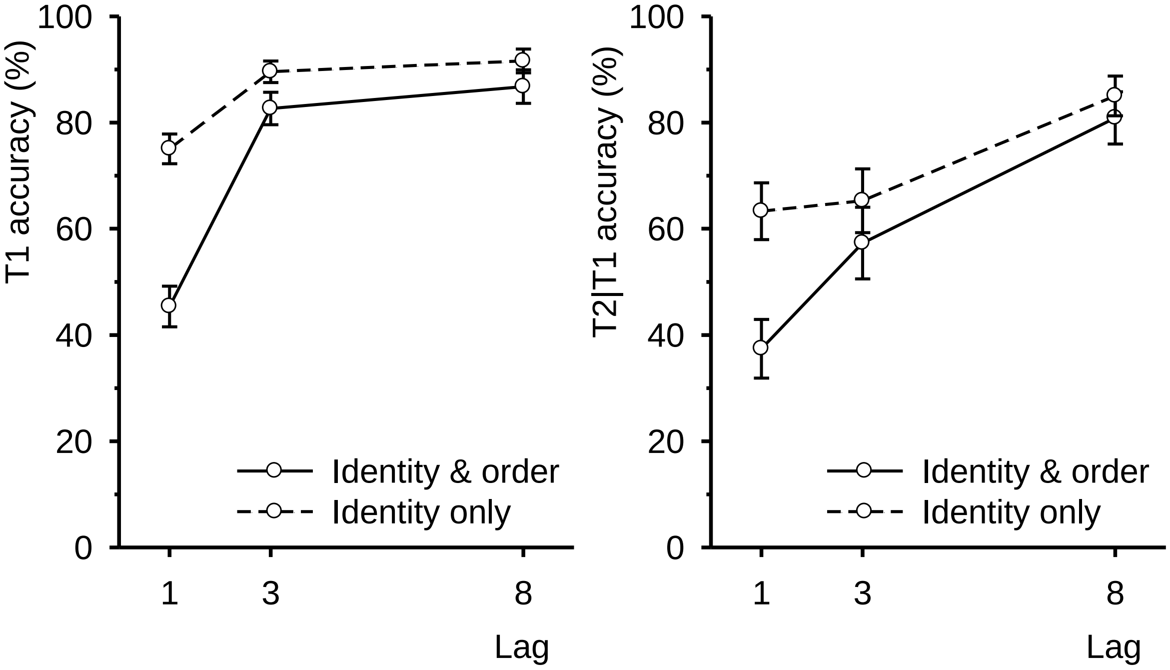
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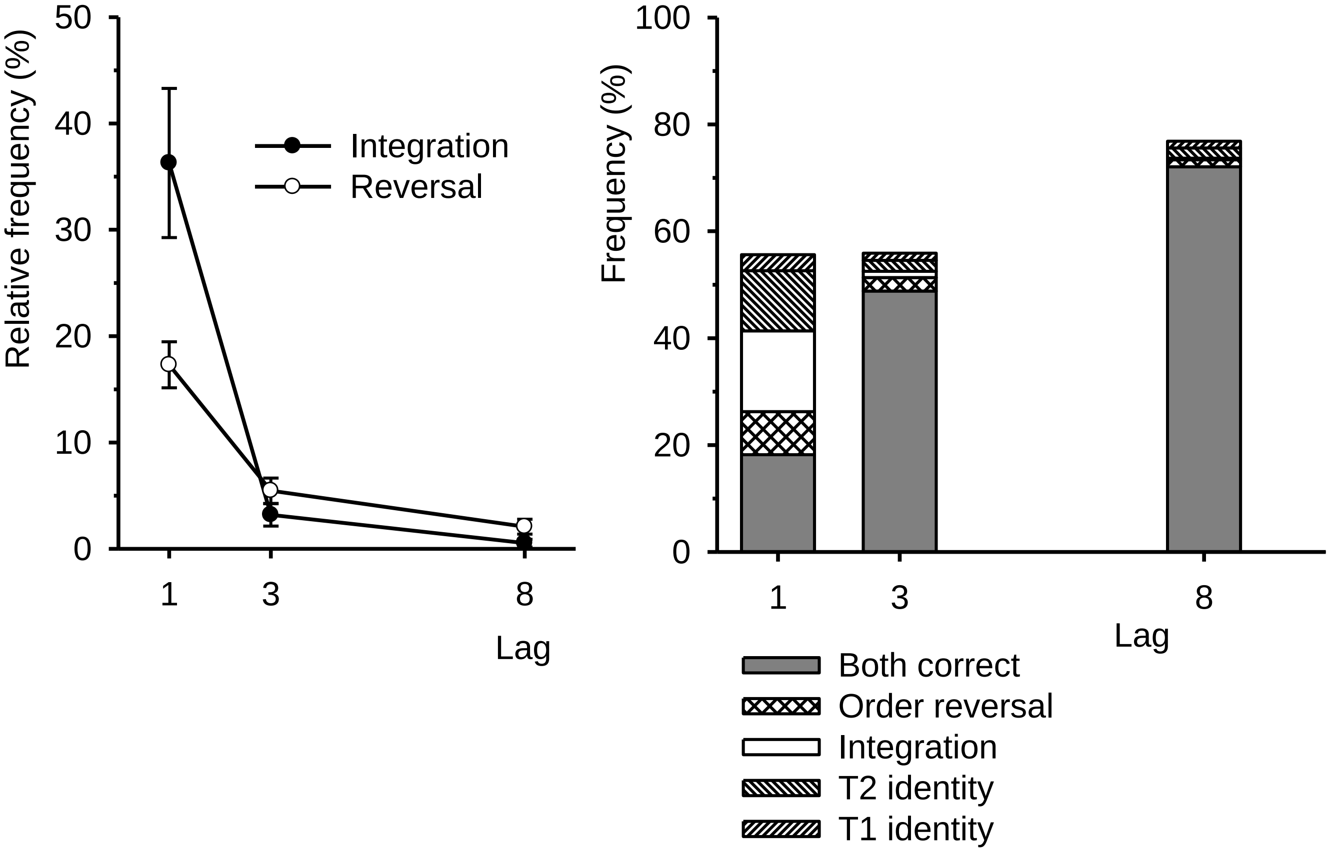
Figure 10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Order reversal
Integration
T2 identity
T1 identity

Figure 11

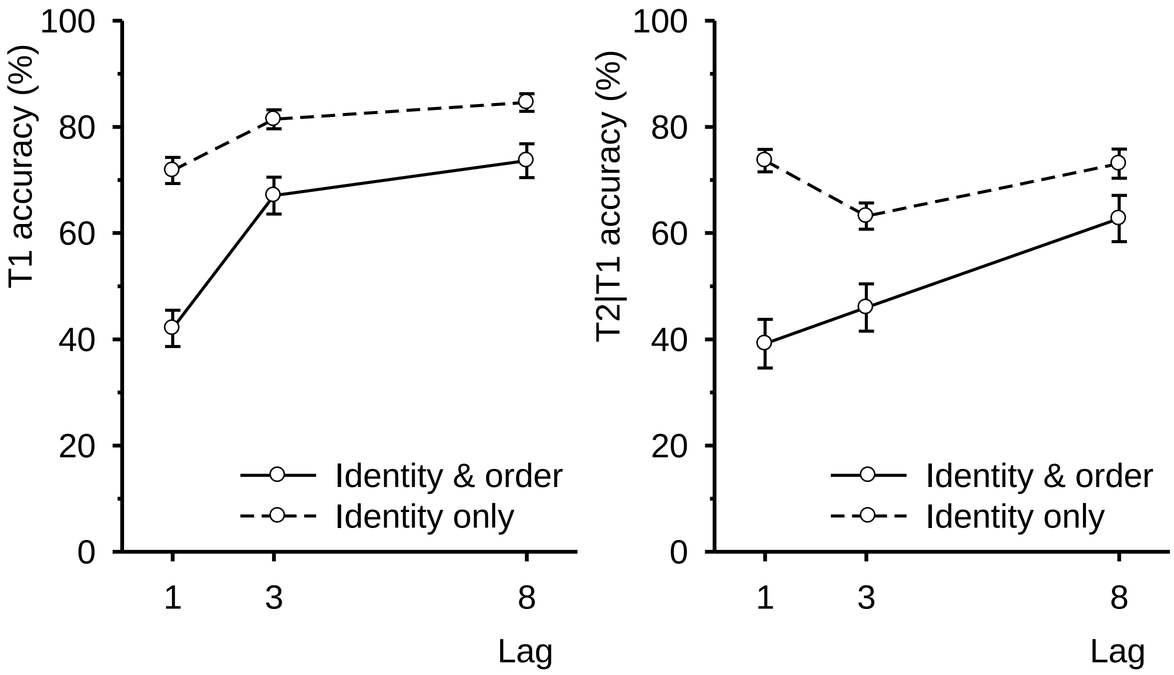
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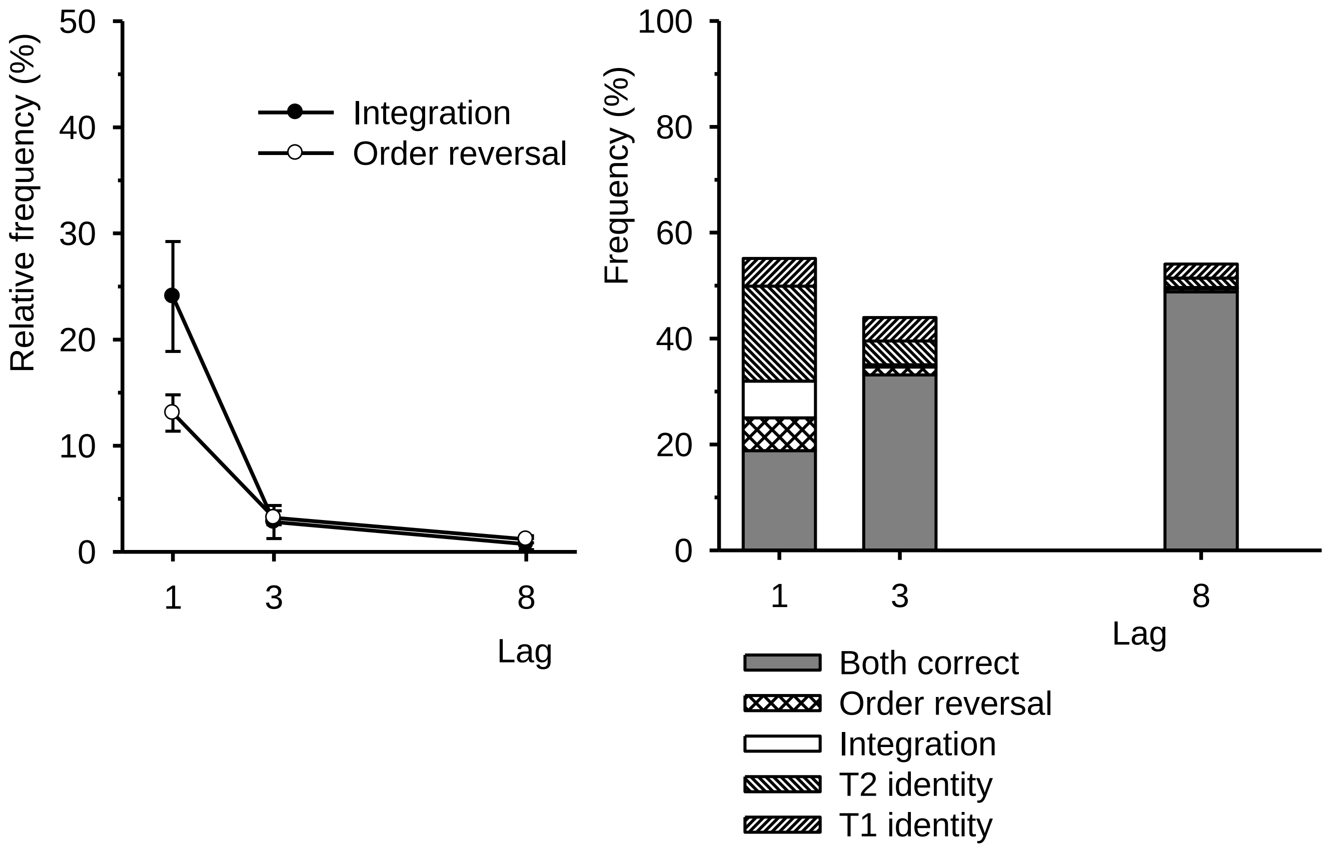
Figure 12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Order reversal
Integration
T2 identity
T1 identity

Figure 13

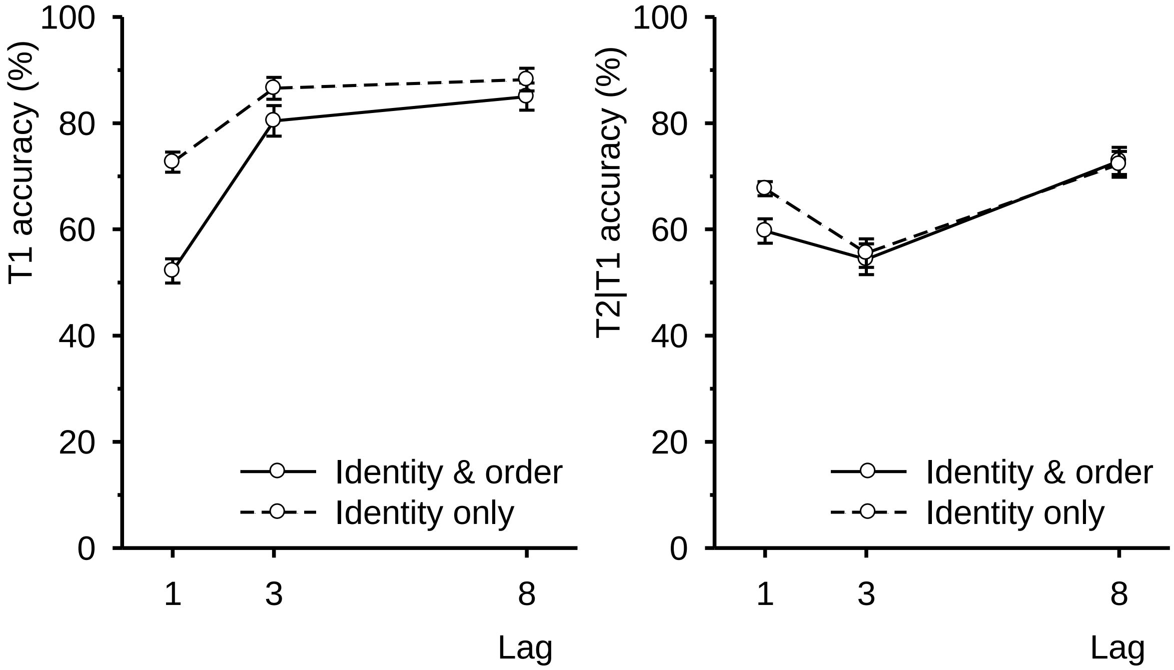
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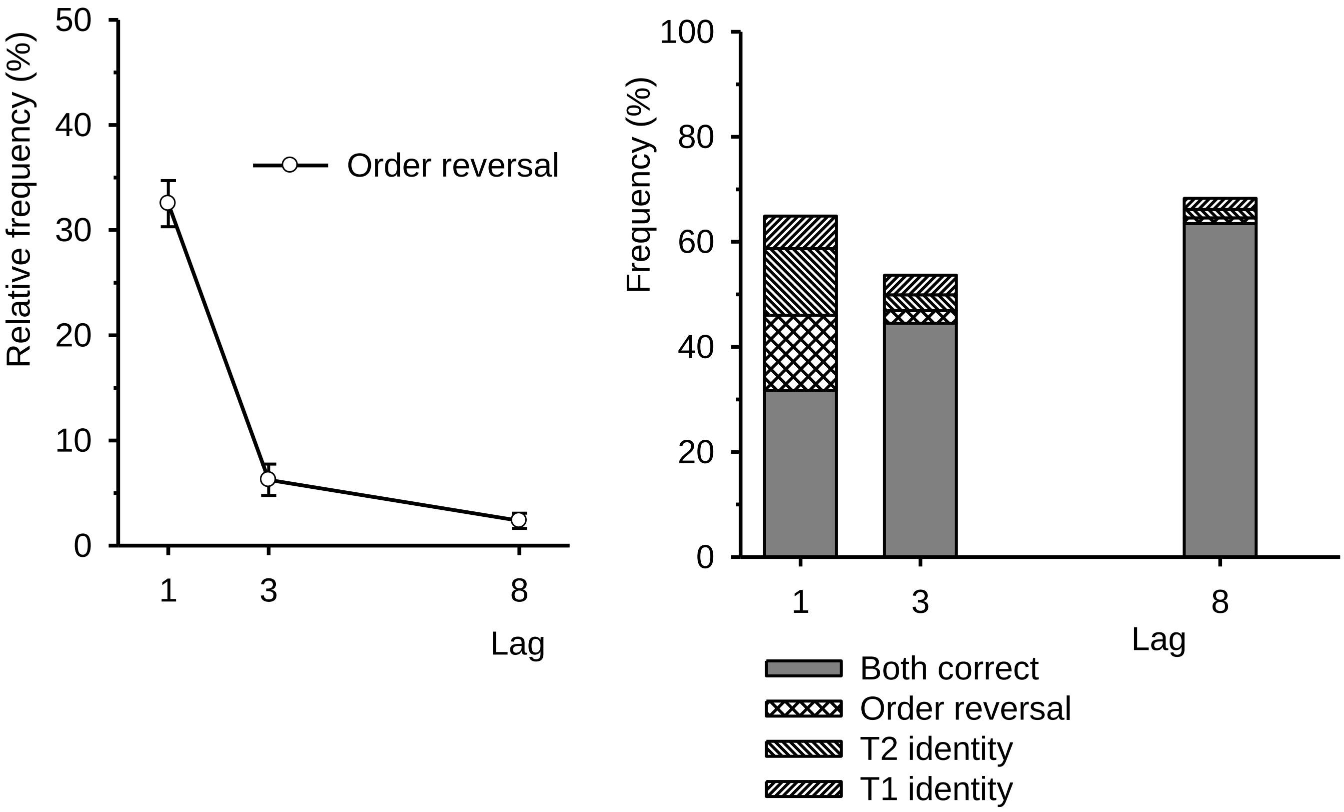
Figure 14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Both correct
Order reversal
T2 identity
T1 identity