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Temporal integration and attentional selection of color and contrast target pairs in rapid serial visual presentation

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ABSTRACT

Performance in a dual target rapid serial visual presentation task was investigated, dependent on whether the color or the contrast of the targets was the same or different. Both identification accuracy on the second target, as a measure of temporal attention, and the frequency of temporal integration were measured. When targets had a different color (red or blue), overall identification accuracy of the second target and identification accuracy of the second target at Lag 1 were both higher than when targets had the same color. At the same time, increased temporal integration of the targets at Lag 1 was observed in the different color condition, even though actual (non-integrated) single targets never consisted of multiple colors. When the color pairs were made more similar, so that they all fell within the range of a single nominal hue (blue), these effects were not observed. Different findings were obtained when contrast was manipulated. Identification accuracy of the second target was higher in the same contrast condition than in the different contrast condition. Higher identification accuracy of both targets was furthermore observed when they were presented with high contrast, while target contrast did not influence temporal integration at all. Temporal attention and integration were thus influenced differently by target contrast pairing than by (categorical) color pairing. Categorically different color pairs, or more generally, categorical feature pairs, may thus afford a reduction in temporal competition between successive targets that eventually enhances attention and integration.

We live in a dynamic environment, in which we are continuously exposed to changes over time. Attention is a powerful cognitive mechanism that helps us to process incoming sensory information, by selecting relevant items and events over irrelevant ones, both in time and space. It has been hypothesized that attention is also required to integrate raw, featural information into coherent representations (Treisman & Gelade, 1980). Thus, the perception of a certain red-green color and roundish shape at a particular location in the visual field may be attentionally forged into that of an apple. Such attentional processing is necessarily limited, and when it comes to shifting attention from one object to another in a very short time interval (200–500 ms), our ability to identify the second object is further constrained. This has been termed the attentional blink (AB), which is a phenomenon that arises due to temporal limitations of attention (Raymond, Shapiro, & Arnell, 1992), and which has been taken to reflect the speed at which feature integration (episodic "tokenization") can occur (Treisman & Kanwisher, 1998).

In the laboratory, rapid serial visual presentation (RSVP) is a commonly used technique to study temporal attention. A classical RSVP task consists of a stream of stimuli comprising two targets (labeled T1 and T2) to be attended, and multiple distractors to be ignored, where the stimuli follow each other at a pace of about 10 items per second in the center of the screen, so that the items mask each other. The ability of the observers to detect and identify the second target (T2) in RSVP then depends on various factors that affect attentional efficiency (for a review, see Dux & Marois, 2010). These include endogenous factors, such as pre-stimulus neural activity and rhythmic brain activity (Ronconi, Pincham, Cristoforetti, Facoetti, & Szűcs, 2016; Ronconi, Pincham, Szűcs, & Facoetti, 2015), as well as exogenous ones, such as the temporal delay or lag between targets (Broadbent & Broadbent, 1987; Raymond et al., 1992), the presence of distractors after T1 (Brisson, Spalek, & Di Lollo, 2011; Nieuwenstein, Potter, & Theeuwes, 2009), and the similarity of targets with other targets and with distractors (Duncan & Humphreys, 1989; Sy & Giesbrecht, 2009).

To account for such factors, several models of the AB have been developed (e.g., Olivers & Meeter, 2008; Taatgen, Juvina, Schipper, Borst, & Martens, 2009; Wyble, Bowman, & Nieuwenstein, 2009). Following accounts of spatial attention (e.g., Wolfe, 1994), the processing

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and integration of stimulus features have been incorporated as a central mechanism in an influential model of the AB, the (e-)STST model of Wyble and colleagues (Bowman & Wyble, 2007; Wyble et al., 2009). The model suggests that items in an RSVP that match with the target template induce attentional excitation. Specifically, when an item's type, that is, its featural representation, matches with the target template, the type is bound to a token, which instantiates an episodic representation of the target stimulus in working memory. Further attentional activation is suppressed during this stage of episodic registration until T1 is linked to a specific token and maintained in working memory. This temporary suppression elicited by T1 induces the AB, as it keeps the subsequent T2 type from binding to a token in turn. The tokenization process in this model might be understood as a form of temporal feature integration, binding (a set of) features to temporal coordinates.

Temporal integration processes have also been proposed to play a crucial role when targets follow each other in direct succession in RSVP (Akyürek et al., 2012; Akyürek, Riddell, Toffanin, & Hommel, 2007; Akyürek & Wolff, 2016; Hommel & Akyürek, 2005). In dual target RSVP, the condition in which T2 directly succeeds T1 without intervening distractors is called Lag 1. Lag 1 often produces unusual performance; instead of resulting in very low performance on T2, which might be expected in view of the very limited amount of time available to process both targets, identification accuracy of T2 can be quite high, which is known as Lag 1 sparing (for a review, see Visser, Bischof, & Di Lollo, 1999). It has also been observed that Lag 1 sparing is often accompanied with a loss of temporal order information of targets, which causes report order errors, where T2 is reported as T1 and vice versa (Hommel & Akyürek, 2005; Potter, Staub, & O'Connor, 2002). This finding has prompted the idea that the targets may have been integrated together into the same perceptual episode (Hommel & Akyürek, 2005). This was later confirmed by using a modified task in which both individual targets (e.g., "\" or "/") as well as integrated targets were valid target identities (e.g., "X") and could thus be reported directly (Akyürek et al., 2012).

If (feature) integration indeed underlies performance in RSVP tasks as described above, then the ease or speed of integration itself should have a modulatory role therein. To our knowledge, this has not been directly investigated to date. However, previous related research has shown that identifying a target in an RSVP stream becomes easier when targets and distractors differ more from each other (Chun & Potter, 1995; Maki, Bussard, Lopez, & Digby, 2003). Differences between T1 and T2 have also been found to modulate performance, implicating temporal integration. Hommel and Akyürek (2005) as well as Chua (2005) observed an increase in target report order errors for targets presented at Lag 1 that had similar contrast. To account for this finding, Hommel & Akyürek proposed that integration and competition may both play a role in the processing of successive targets. When one target is more strongly represented (due to its higher contrast, for instance), it wins out over the other target and is thereby more likely to be reported. However, when both targets are of similar representational strength (e.g., having similar contrasts), they may both persist and together become part of an integrated representation. It must be noted here that order errors in classic RSVP tasks remain an indirect measure of integration and may also be mediated by attentional factors.

The question furthermore remains whether these interactions at Lag 1 are generically related to stimulus strength and/or similarity, such as results from manipulating stimulus contrast. It seems plausible that integration might be driven also by feature-specific differences. One study by Akyürek, Schubö, and Hommel (2013) manipulated featural target similarity (color) in a lateralized RSVP design, hypothesizing that for the identification of two successive targets of the same category (e.g., both letters), feature overlap may cause interference by making it harder to distinguish the targets. For targets of the same color, interference was indeed observed at Lag 1, but this effect must be interpreted in the context of their task, in which T1 and T2 were spatially separated, thus precluding straightforward integration and presumably any benefits that might thereby be obtained. A direct, non-spatial test of the consequences of featural similarity between targets for temporal integration and attention is thus still lacking. The purpose of the present study was to perform this test and to compare the outcomes with a non-featural target difference.

1. The present study

We aimed to investigate how differences in color or contrast of T1 and T2 would influence target identification accuracy and temporal integration in RSVP. In doing so, target templates were held constant for different colors and contrasts, to ensure that targets could not be found on the basis of any unique (specific) color or contrast, and so that these features were truly irrelevant for the identification task. Featural task relevance has been shown to interact with performance in RSVP tasks (Akyürek, Köhne, & Schubö, 2013), which for the present purpose would have made it harder to isolate cause and effect of feature similarity between targets. We adopted the task developed by Akyürek et al. (2012) for this purpose in a way that target color and contrast either matched or did not. As a measure of temporal attention, we first investigated whether targets of different color or contrast resulted in comparable modulations of T2 identification accuracy compared to same-color/contrast pairs. We secondly investigated whether these color/contrast pairs also affected temporal target integration.

2. Experiment 1A

Experiment 1A was conducted to test the effects of manipulating the color match between the targets on temporal integration and attention. We hypothesized that T2|T1 accuracy at short lag when T1 and T2 color did not match would be higher than when T1 and T2 color matched, due to decreased episodic distinctiveness and increased masking in the latter case. In terms of temporal integration at Lag 1, two scenarios may be conceivable. On the one hand, increased featural overlap between same color target pairs may increase mutual competition and consequently induce a stronger segregation response between targets in order to keep them apart episodically (cf. Akyürek, Schubö, & Hommel, 2013). Therefore, integration between targets might occur less frequently in the same color condition. On the other hand, if feature similarity actually diminishes the competition between targets (cf. Hommel & Akyürek, 2005), those same-color target pairs may rather increase temporal integration.

2.1. Method

2.1.1. Participants

For each experiment, 24 was set as the a priori minimum required number of participants; and to meet this number (even after possible exclusions), 30 participants were invited through the departmental subject pool. Consequently, 25 healthy students (17 female) of the University of Groningen participated in the study in exchange for course credits (mean age = 20.3 years, range = 17–31). All participants reported normal/corrected-to-normal visual acuity and none of them reported colorblindness. The study was conducted in accordance with the Declaration of Helsinki (2008) and approved by the ethical committee of the Psychology Department of the University of Groningen (approval number: 15044-NE). Written informed consent was obtained prior to participation.

2.1.2. Apparatus and stimuli

Participants were seated in dimly lit, sound attenuated testing cabins. The distance between participants and the monitor was not fixed, but it was approximately 60 cm. Stimuli were presented on a 22″ CRT monitor (Iiyama MA203DT). The resolution of the monitor was set to 1024 × 768 pixels, at 16-bit color depth, and the refresh rate was set at

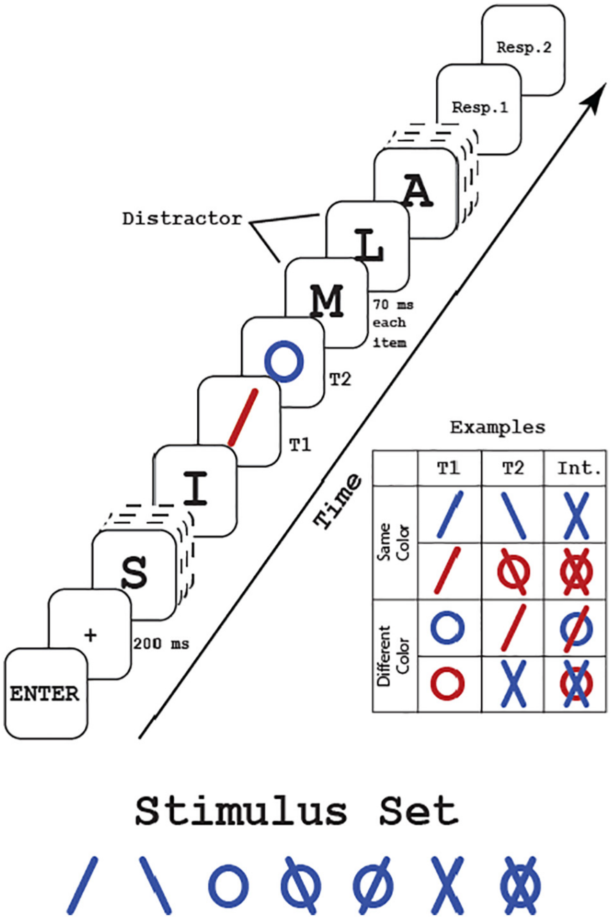

Fig. 1. Illustration of the hybrid rapid serial visual presentation task at Lag 1 where targets follow each other successively. T1 and T2 indicate the first and second target. Letters are distractors, and targets appear among these in the stimulus stream. There was a 10-ms blank interval between stimuli. Resp. refers to the response prompt. Example target stimuli are shown in the right bottom corner of the figure. Int. means temporal integration of targets, which is a unified perception of the targets. Note that stimuli consisting of multiple colors were never shown as targets, but could nonetheless be reported as integrated (configurally). At the bottom of the figure, the full stimulus set of the experiment is shown. The actual RGB values of the stimuli varied depending on experimental conditions.

a frequency of 100 Hz. Stimulus presentations, trial events and data collection were controlled by E-prime 2.0 Professional (Psychology Software Tools) under the Windows 7 operating system. Responses were collected by a standard labeled keyboard.

Stimuli were presented on a light gray background (RGB 192,192,192; 207 cd/m^2). Distractor stimuli were chosen from the full Latin alphabet, excluding O and X, without replacement on each trial. Distractor stimuli were presented in black (7 cd/m^2) 52 pt, Courier New Font. The fixation cross (+) was presented in the same color and font (18 pt) on each trial. All target stimuli were presented within a square area of 60 by 60 pixels (2.22° by 2.22° of visual angle) in the center of the screen. As shown in the Fig. 1, target stimuli were isoluminant, monochromatic figures in either red (RGB 185, 0, 0; 45 cd/m^2) or blue (RGB 0, 0, 255; 46 cd/m^2).

2.1.3. Procedure

There were two blocks in the experiment, and 208 experimental trials in each block. Participants were offered to have a break between two blocks. In one of the blocks, T1 and T2 had the same color (T1 red and T2 red, or T1 blue and T2 blue). In the other block, T1 and T2 had different colors (red-blue, or blue-red). The order of the two blocks (i.e., the same and different color conditions) was counterbalanced between participants. The experiment started with 22 practice trials. These trials were omitted from analyses. The duration of the experiment was approximately 45 min.

Participants started the experiment by pressing Enter. After 100 ms of pressing Enter, a fixation cross showed up on the screen for 200 ms. The ensuing RSVP consisted of 18 stimuli of 70 ms each, separated by 10 ms inter-stimulus interval. The first target appeared in the fifth or seventh position within the RSVP, which was random but equally distributed. The second target similarly followed the first target either as the first item (Lag 1), as the third item (Lag 3), or as the eighth item (Lag 8). There was only one target in 7.7% of the trials. In total, 46.2% of all targets were presented at Lag 1 so as to obtain a reliable estimate of temporal integration frequency, and 23.1% of targets were presented at Lag 3 and at Lag 8. There was a 100 ms blank after the RSVP, followed by two successive response prompts asking the participants to enter T1 and T2 in the correct order. Participants were able to enter two targets by pressing the related labeled key (2, 4, 5, 6, 7, 8, or 9) on the numeric keypad. Moreover, participants could enter just one target by pressing the related button at the first or second response prompt, and skipping the other prompt by pressing Enter.

2.1.4. Design and analysis

T1 and T2 accuracies were measured as the correct identification of targets at the correct response prompts (i.e., order-sensitive). T2 accuracy was measured on the condition that T1 was identified correctly (i.e., T2|T1). The exact combination of T1 and T2, indicated at one of the response prompts, without another response given at the other response prompt, was defined as temporal integration. When T1 was reported as T2 and vice versa, this was defined as an order reversal. Only Lag 1 was included in the analyses for temporal integration and order reversals, since neither temporal integration nor order errors were expected to occur in a substantial number of trials at Lag 3 and 8.

Separate repeated measures analyses of variance were run for T1 accuracy, T2|T1 accuracy and paired sample *t*-tests were used to analyze temporal integration and order reversals. Greenhouse-Geisser corrected *p* values were reported when necessary. A 2 (Color: same/different) by 3 (T2 Lag: 1, 3, 8) design was used in the repeated measures analysis for T1 and T2|T1 accuracies. Tukey HSD scores were computed in order to further characterize interaction effects. Partial eta squared (η_p^2) as a measure of effect size was calculated for T1 and T2|T1 accuracies, and Cohen's *d* was calculated for temporal integration and order reversals in order to characterize the effect size.

A second set of 2 by 2 by 3 analyses was carried out, in which T1 color (blue, red), T2 color (blue, red) and lag were used as independent variables in the model. Although we did not have color-specific hypotheses, these more detailed analyses provide a view on the effects of specific target color pairs, and we, therefore, included them in the Appendix.

Apart from the visualizations of the data as analyzed, additional compound scores for T2 identification were also added to the relevant figures (gray lines). These scores serve to provide a view on target identification performance without taking order into account, as commonly done in RSVP studies. To this end, all trials were selected in which T1 was identified correctly as either the first target, as the second target, or as part of an integrated report. Order-insensitive T2 accuracy, again including order reversals and integrations, was then plotted as a percentage of those trials.

2.1.5. Data availability

In order to provide scientific transparency, we uploaded the data to the Open Science Framework with the identifier rwkx8 (osf.io/rwkx8), where they are publicly available.

2.2. Results

2.2.1. T1 accuracy

Overall accuracy in one-target trials was 89.9%, and overall T1 accuracy in two-target trials was 66.7%. Lag and Color had significant main effects on T1 accuracy, $F(1, 32) = 165.99$, $MSE = 0.03$, $p < .001$, $\eta_p^2 = 0.87$; $F(1, 24) = 4.96$, $MSE = 0.01$, $p < .05$, $\eta_p^2 = 0.17$, respectively. T1 accuracy was 46.3% at Lag 1, 82.7% at Lag 3, and 91.3% at Lag 8. T1 accuracy was 75% in the same color condition, and decreased to 71.8% in the different color condition. A significant interaction effect of Lag and Color was also found, $F(1, 32) = 8.25$, $MSE = 0.01$, $p < .01$, $\eta_p^2 = 0.26$. Tukey HSD comparisons showed that T1 accuracy at Lag 1 in the same color condition (51.2%) was significantly greater than in the different color condition (41.4%) [$t = 6.3$, $p < .05$], while it was not at the other lags.

2.2.2. T2|T1 accuracy

Overall T2 accuracy was 51.2%. Lag and Color affected T2|T1 accuracy significantly, $F(2, 36) = 45.32$, $MSE = 0.05$, $p < .001$, $\eta_p^2 = 0.65$; $F(1, 24) = 9.86$, $MSE = 0.01$, $p < .01$, $\eta_p^2 = 0.29$, respectively. T2|T1 accuracy was 51.5% at Lag 1, increased to 67.7% at Lag 3 and further increased to 86.9% at Lag 8. T2|T1 accuracy was 65.9% in the same color condition and increased to 71.5% in the different color condition. Furthermore, Lag and Color had a significant interaction effect, $F(1, 24) = 22.82$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = 0.49$. Tukey HSD pairwise comparison results showed that T2|T1 accuracy at Lag 1 in the different color condition (61.4%) was significantly greater than in the same color condition (41.6%) [$t = 9.9$, $p < .01$], but not at the other lags.

2.2.3. Temporal integration

A significant main effect of Color was found on temporal integration frequency, $t_{(24)} = 2.4$, $p < .05$, Cohen's $d = 0.44$. Temporal integration averaged 19.4% in the different color condition, compared to just 10.8% in the same color condition.

Order Reversals: Similar to temporal integration, order reversals in the different color condition (11.0%) were significantly more frequent than in the same color condition (6.1%), $t_{(24)} = 3.7$, $p < .001$, Cohen's $d = 0.75$ (Fig. 2).

3. Experiment 1B

Experiment 1A provided evidence that targets of different colors were more often integrated than targets of the same color, and that T2|T1 identification accuracy was similarly enhanced at Lag 1. This outcome suggested that the same-color target pairs triggered a segregation response from the perceptual system, possibly in an attempt to maintain episodic distinctiveness. This account will be detailed further in the General Discussion. However, it seemed important to determine whether this effect was related to the categorical difference in terms of target hues (i.e., red and blue), or whether any spectral difference might suffice. Experiment 1B was thus implemented in order to further investigate whether a within-category change in color would induce a similar effect on T2|T1 identification accuracy and temporal integration. In this experiment, instead of comprising a category-level change in color (red to blue or vice versa), the color of the target stimuli changed within a single color range (shades of blue).

3.1. Method

Experiment 1B was identical to Experiment 1A, except for the following changes.

3.1.1. Participants

A new set of 31 students (13 females) participated in the study (mean age = 20.58, range = 18–25), meeting the same selection criteria as those of Experiment 1A.

3.1.2. Stimuli

The red color stimuli were replaced with a more faded shade of blue (RGB 96, 96, 160; 49 cd/m^2).

3.1.3. Design and analysis

In Experiment 1B, the same color condition thus comprised two targets in pure blue or in faded blue, while the different color condition comprised one pure and one faded blue target.

3.2. Results

3.2.1. T1 accuracy

Overall T1 accuracy was 91% in one-target trials. There was neither a main effect of Color nor an interaction of Color and Lag on T1 accuracy in two-target trials ($F < 0.4$). A main effect of Lag existed on T1 accuracy, $F(1, 43) = 243.68$, $MSE = 0.02$, $p < .001$, $\eta_p^2 = 0.89$. T1 accuracy averaged 51.5% at Lag 1, compared to 85.7% at Lag 3, and 91.1% at Lag 8.

T2|T1 Accuracy: Overall T2 accuracy was 61.0%. Only Lag influenced T2|T1 accuracy significantly, $F(2, 60) = 47.84$, $MSE = 0.02$, $p < .001$, $\eta_p^2 = 0.62$. T2|T1 accuracy was 66% at Lag 1, increased to 77.2% at Lag 3, and further increased to 88.8% at Lag 8. No reliable main effect of Color, nor an interaction of Color with Lag was found to affect T2|T1 accuracy ($F < 1.49$).

3.2.2. Temporal integration and order reversals

There were no significant differences in temporal integration and order reversals between the target color pairs at Lag 1 ($t_{(30)} < 0.9$) (Fig. 3).

4. Experiment 1C

The outcome of Experiment 1B suggested that the effects of target color pairs obtained in Experiment 1A were indeed due to the categorical difference in color in the latter experiment. Apart from this stimulus-based factor, another aspect of the design of Experiment 1A might have facilitated the effects. Specifically, the experiment featured a blocked design in which color pairings were not mixed between trials. It is thus possible that the effects were wholly or in part due to endogenous control strategies. To examine this possibility, Experiment 1C was conducted to replicate the results of Experiment 1A with a modified design. Instead of implementing the color manipulation in blocked fashion, we used a randomized design this time. As indicated, in block designs, learning and task adaptation might contribute to differences between conditions, which can be assessed by comparing the results to a randomized design in which these factors cannot play a (condition-specific) role. We also added a third color (green) to further generalize and test whether the findings, especially with regard to temporal integration, were replicable.

4.1. Method

Experiment 1C was identical to Experiment 1A with the following changes.

4.1.1. Participants

A new group of 29 students (19 female) participated in the study (mean age = 21.14, range = 18–44), meeting the same selection criteria as those of Experiment 1A.

4.1.2. Apparatus and stimuli

A third color, green (RGB 0, 120, 0; 46 cd/m2), was added. Stimuli were presented on a 19” CRT monitor (Iiyama HM903DT). The visual angle of the stimuli was 2.01° by 2.01°.

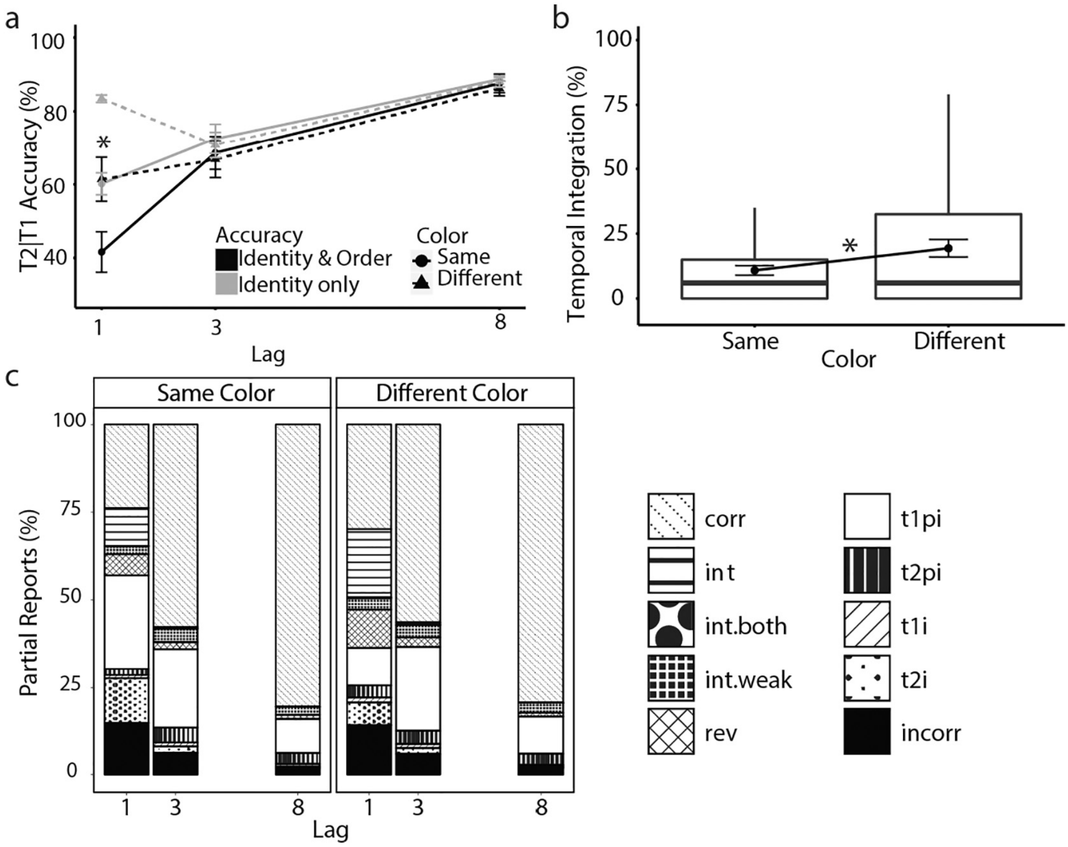

Fig. 2. Task performance in Experiment 1A. Error bars represent ± SEM. a. T2|T1 performance as a function of Lag. Black lines indicate that both identiy and report order of the targets were taken into account (T2 performance given that T1 was identified correctly, in percent correct). Gray lines indicate that order information of targets was ignored. Thus, the trials where T1 identity was correctly reported, regardless of its temporal position (including integrations) were filtered and on that basis T2 identification accuracy including integrations are presented in percent correct. b. Percentage of temporal integration of T1 and T2 at Lag 1. c. Partial reports in Experiment 1A. All variables are shown in %. *corr* indicates correct responses for both targets; *int* indicates temporal integration of targets at one of the response prompts with the additional requirement that no response was given at the other response prompt; *int.both* means that the integrated percept of targets was reported at both response prompts; *int.weak* indicates that the integrated percept was reported at one of the response prompts and an incorrect response (corresponding to neither target) was reported at the other response prompt; *rev* indicates order reversal of targets, when T1 was reported as T2 and vice versa; *t1pi* means only T1 was identified correctly at the correct response prompt; and *t2pi* means that only T2 was identified correctly at the correct response prompt; *t1i* indicates that only T1 identity was reported correctly but at the wrong response prompt; *t2i* indicates that only T2 identity was reported correctly but at the wrong response prompt; and *incorr* indicates both responses were incorrect. Asterisks indicate significance in panels a and b; for panel a (black lines), the asterisk reflects the interaction effect of Color and Lag.

4.1.3. *Procedure*

There were two blocks and each block consisted of 260 experimental trials. 7.7% of the trials included only one target, in 46.2% of the trials the second target was presented at Lag 1, and in 23.1% of the trials each, the second target appeared at Lag 3 and 8. Color pairs now included green and were randomized but equally distributed within a block.

4.2. *Results*

4.2.1. *T1 accuracy*

Overall T1 accuracy was 74% in one-target trials. Lag and Color both significantly influenced T1 accuracy in two-target trials, $F(1, 31) = 205{,}82$, $MSE = 0.03$, $p < .001$, $\eta_p^2 = 0.88$; $F(1, 28) = 86.63$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = 0.76$, respectively. T1 accuracy averaged 37.9% at Lag 1, 77.5% at Lag 3 and 84.0% at Lag 8. T1 accuracy averaged 72.6% in the same color condition and decreased to 60.3% in the different color condition. A significant two-way interaction of Lag and Color was also found, $F(1, 37) = 5.38$, $MSE = 0.01$, $p < .05$, $\eta_p^2 = 0.16$. At Lag 1, T1 accuracy was 49.6% in the same color condition and decreased to 43.5% in the different color condition [$t = 7.7$, $p < .01$]. Moreover, T1 accuracy was also higher in the same color condition at both Lag 3 (82.2% vs. 72.1%) and Lag 8 (92.1% vs. 75.9%) [$t = 8.1$, $p < .01$; $t = 12.3$, $p < .01$].

4.2.2. *T2|T1 accuracy*

Overall T2 accuracy was 48.8%. Lag and Color had significant main effects on T2|T1 accuracy, $F(1, 36) = 65.27$, $MSE = 0.05$, $p < .001$, $\eta_p^2 = 0.70$; $F(1, 28) = 16.49$, $MSE = 0.02$, $p < .001$, $\eta_p^2 = 0.37$, respectively. T2|T1 accuracy was 49.2% at Lag 1, increased to 71.5% at Lag 3 and further increased to 87.8% at Lag 8. T2|T1 accuracy in the same color condition averaged 65.6%, compared with 73.4% in the different color condition. There was a significant two way interaction of Color and Lag as well, $F(1, 41) = 9.63$, $MSE = 0.02$, $p < .01$, $\eta_p^2 = 0.26$. At Lag 1, T2|T1 accuracy averaged 58% in the different color condition, compared to 40.4% in the same color condition [$t = 7.5$, $p < .01$], while the differences at the longer lags were unreliable.

4.2.3. *Temporal integration*

A significant main effect of Color on temporal integration existed, $t_{(28)} = 3.4$, $p < .01$, Cohen's $d = 0.51$. As previously observed in Experiment 1A, at Lag 1, temporal integration in the same color condition was clearly lower than in the different condition (16.7% vs. 26.9%).

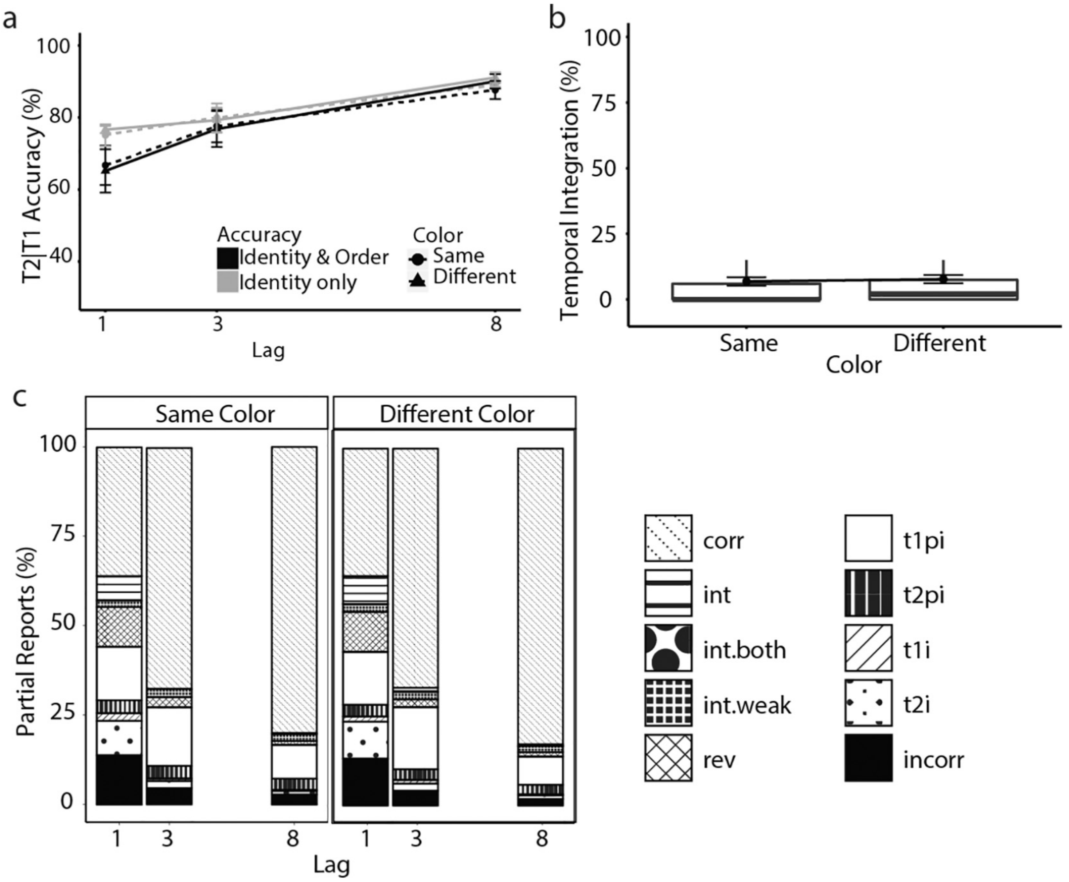

Fig. 3. Task performance in Experiment 1B. Error bars represent ± SEM. a. T2|T1 performance as a function of Lag. b. Frequency of temporal integration (%) of T1 and T2 at Lag 1. c. Partial reports of Experiment 1B. Labels and asterisks follow Fig. 2.

Order Reversals: Color did not influence order reversals at Lag 1 ($t_{(28)} < 0.2$) (Fig. 4).

5. Discussion of Experiment 1

Experiments 1A and 1C were identical to each other in terms of the research question, with only slight differences in design (blocked vs. randomized design, and 2 colors vs. 3 colors). The results of these two experiments were consistent. The results showed that overall T2|T1 accuracy in the different color condition, and the accuracy at Lag 1 in particular was greater than in the same color condition in both experiments, albeit at the expense of reduced T1 accuracy. These findings replicate the previous study of Akyürek, Schubö, and Hommel (2013), in a design without spatial switching.

Importantly, the frequency of temporal integration in the different color condition was significantly greater than in the same color condition in both Experiment 1A and Experiment 1C, with the means showing substantial differences. It bears repeating that actual, individual targets never comprised multiple colors, in either experiment. The perception of integrated, multi-colored targets was thus completely illusory, and not induced by the actual stimuli.

There appeared to be one negative consequence of different color target pairs: T1 accuracy seemed to suffer. However, since these T1 reports concern separate, order-correct responses, they do not reflect shifts in other response categories. In particular, it might be argued that the increased frequency of integrations cannibalized correct single-T1 reports. Indeed, if correct T1 performance would include integrations and order errors (cf. T2 performance), that measure would also show higher T1 performance in the different color condition.

Finally, Experiment 1B differed from Experiments 1A and 1C in terms of the change in color. Instead of a categorical color change, a change within a single color spectrum was tested. This experimental manipulation resulted in notably different outcomes than those of Experiments 1A and 1C. T2|T1 accuracy and temporal integration were not at all influenced by target color pairs. This outcome supports the idea that for a color pair to enhance T2|T1 accuracy and temporal integration, the colors of the targets should likely differ categorically. One caveat with Experiment 1B should nonetheless be mentioned. Although the different color shades were clearly distinguishable on screen, as also confirmed by informal comments made by some of the participants, the results cannot completely exclude the possibility that target dissimilarity was simply too small to notice. This limitation is inherent to the manipulation, which is necessarily more restricted in color space. Experiment 2 further investigates the possible impact of overall visibility by manipulating stimulus contrast.

6. Experiment 2A

The effects observed in Experiments 1A and 1C were so far attributed to a category-level change in color between target pairs. This might be justified by the fact that colors are known to lie on a metathetic continuum, rather than a prothetic one. However, an alternative explanation might be that the difference between the colors was simply large, and that any clearly mismatched target pair would elicit similar responses. In order to check this alternative account, in Experiment 2, a strong difference between targets was introduced in terms of contrast. Contrast (mis)matching between targets is in one way similar to the color manipulation from Experiment 1, in that it visually alters the similarity of the targets. At the same time, contrast is prothetic whereas color is metathetic. Comparison of color and contrast thus allows a

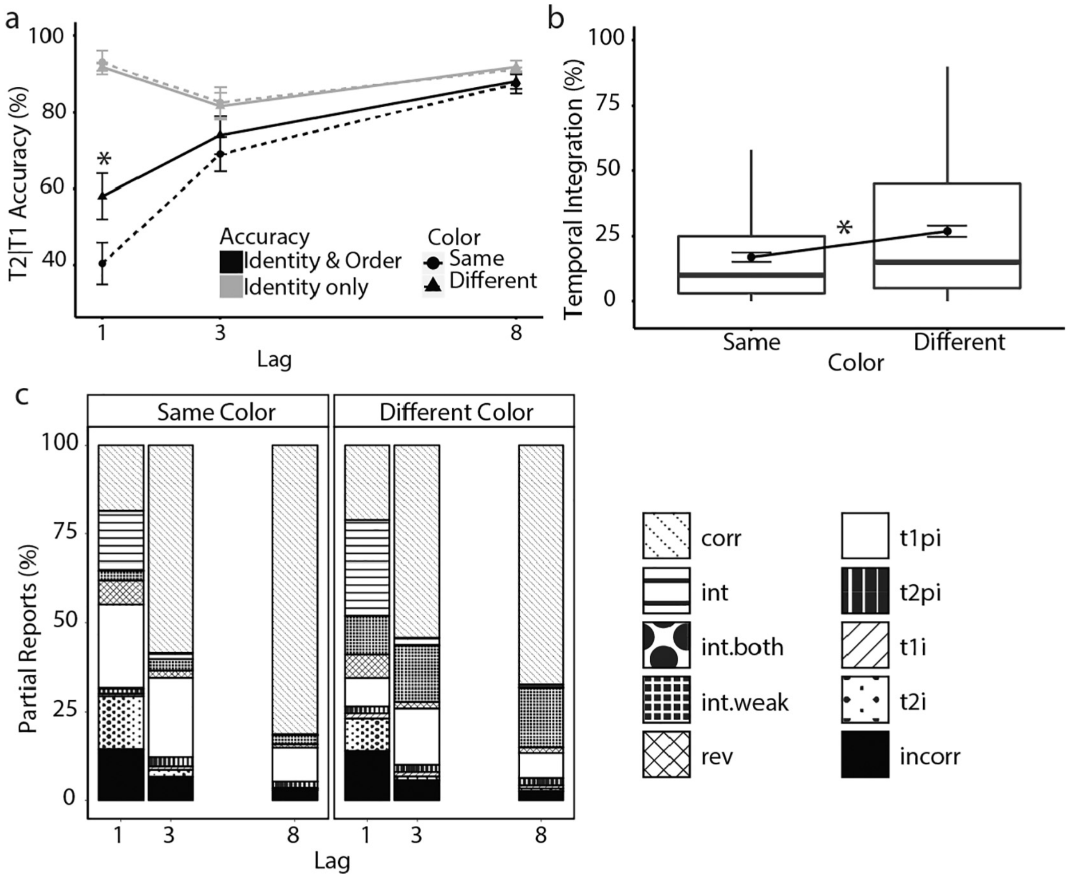

Fig. 4. Task performance in Experiment 1C. Error bars represent ± SEM. a. T2|T1 performance as a function of Lag. b. Frequency of temporal integration (%) of T1 and T2 at Lag 1. c. Partial reports of Experiment 1C Labels and asterisks follow Fig. 2.

characterization of the extent to which the effects are due to overall stimulus similarity, or to color-specific processing.

6.1. Method

Experiment 2 was identical to Experiment 1 with the following changes.

6.1.1. Participants

A new set of 25 students (19 female) participated in the study (mean age = 20.6, range = 18–29). All participants reported normal/corrected-to-normal vision. One female participant was omitted from the analysis because she stated having an attentional deficit disorder.

6.1.2. Stimuli

Distractor stimuli were presented in white (324 cd/m2) in order to prevent confusion between target stimuli and distractors. Target stimuli were the same figures as used before, but now rendered in either dark gray (low contrast; RGB 128,128,128; 73 cd/m2) or black (high contrast; RGB 0,0,0; 7 cd/m2).

6.1.3. Procedure

In one of the blocks, T1 and T2 had the same contrast (i.e., both were low contrast or both high contrast) while in the other block T1 and T2 had different contrast (i.e., low-high or high-low contrast).

6.1.4. Design and analysis

In the analysis of the contrast effect, Contrast had two levels: Same contrast and different contrast. As before, a more stimulus-specific secondary analysis was also carried out, separating both T1 contrast (low/high contrast) and T2 contrast (low/high contrast), which is presented in the Appendix.

6.2. Results

6.2.1. T1 accuracy

Overall target accuracy in one-target trials was 89.7%, and overall T1 accuracy in two-target trials was 69.2%. Main effects of Lag and Contrast were found on T1 accuracy, $F(2, 35) = 180.75$, $MSE = 0.001$, $p < .001$, $\eta_p^2 = 0.89$; $F(1, 23) = 229.53$, $MSE = 0.001$, $p < .001$, $\eta_p^2 = 0.91$, respectively. T1 accuracy averaged 71.3% at Lag 1, increased to 87.4% at Lag 3 and 92.7% at Lag 8. T1 accuracy was 92.0% in the same contrast condition and decreased to 75.6% in the different contrast condition. Furthermore, a significant interaction effect of Lag and Contrast was found, $F(1, 32) = 193.47$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = 0.89$. Pairwise comparisons showed that T1 accuracy in the same contrast condition at Lag 1 (93.9%) was significantly higher than in the different contrast condition (48.7%) [$t = 9.9$, $p < .01$].

6.2.2. T2|T1 accuracy

Overall T2 accuracy was 58.9%. T2|T1 accuracy was affected significantly by Lag and Contrast, $F(2, 46) = 17.56$, $MSE = 0.05$, $p < .001$, $\eta_p^2 = 0.43$; $F(1, 23) = 4.87$, $MSE = 0.01$, $p < .05$, $\eta_p^2 = 0.18$, respectively. T2|T1 accuracy averaged 66.9% at Lag 1, 71.2% at Lag 3 and 90.8% at Lag 8. Furthermore, T2|T1 accuracy was 78.1% in the same contrast condition, compared to 74.5% in the different contrast condition. The interaction term was unreliable ($F < 1.5$).

6.2.3. Temporal integration and order reversals

Contrast influenced neither temporal integration nor order reversals significantly ($t_{(23)} < 0.9$) (Fig. 5).

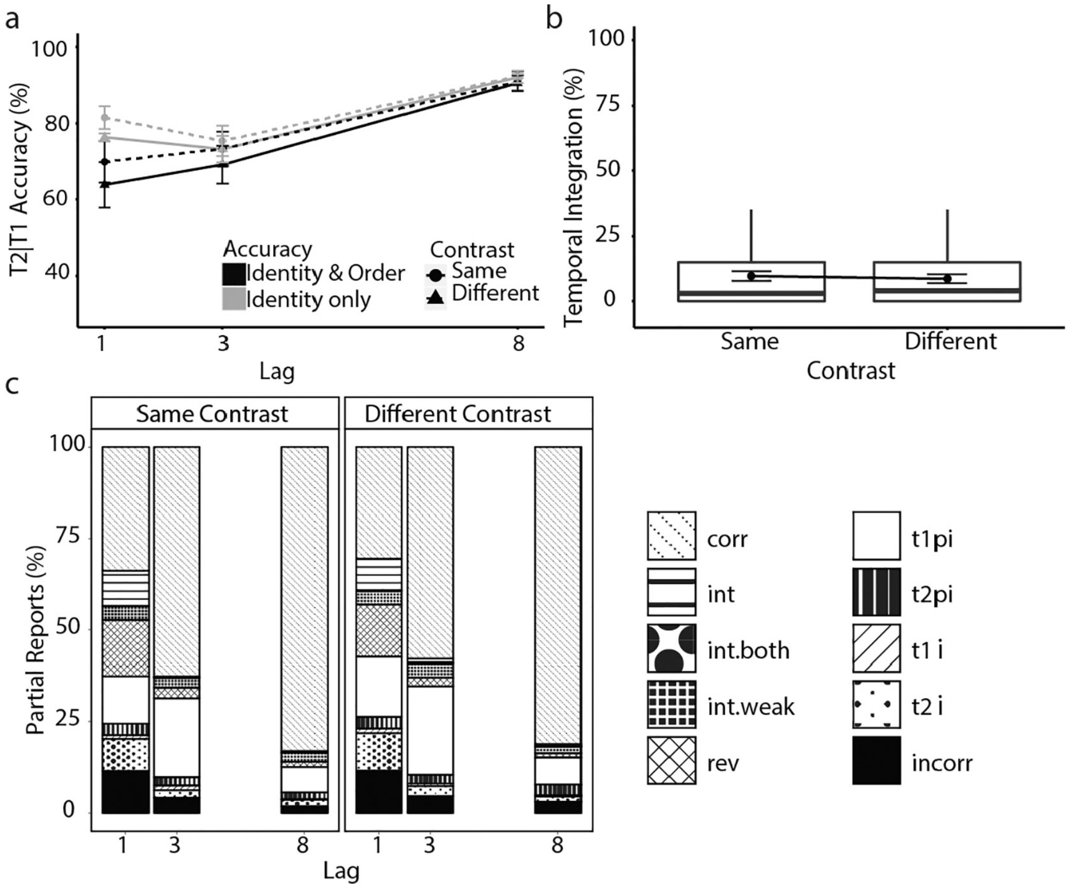

Fig. 5. Task performance in Experiment 2A. Error bars represent ± SEM. a. T2|T1 performance as a function of Lag. b. Percentage of temporal integration of T1 and T2 at Lag 1. c. Partial reports of Experiment 2A. Labels follow Fig. 2.

7. Experiment 2B

Following the motivation for Experiment 1C, Experiment 2B was conducted to replicate the observed effects of Experiment 2A with a randomized design, investigating the possible contribution of endogenous control processes.

7.1. Method

Experiment 2B was identical to Experiment 2A with the following changes.

7.1.1. Participants

24 new students (10 female) participated in the study (mean age = 21.5, range = 19–29), meeting the same criteria as those in Experiment 2A.

Apparatus.

The operating system in the laboratory was updated so that this experiment was run under Windows 10.

7.1.2. Design

A randomized design was used instead of a blocked design.

7.2. Results

7.2.1. T1 accuracy

Mean T1 accuracy was 92.0% in one-target trials, and 71.5% in two-target trials. Only Lag had a main effect on T1 accuracy, $F(1, 27) = 204.19$, $MSE = 0.02$, $p < .001$, $\eta_p^2 = 0.90$. T1 accuracy was 51.4% at Lag 1, increased to 87.2% at Lag 3 and further increased to 92.9% at Lag 8. The main effect of Contrast, as well as the interaction term, were unreliable (F's < 1).

7.2.2. T2|T1 accuracy

Overall T2 accuracy was 57.5%. T2|T1 accuracy was significantly influenced by Lag and Contrast, $F(2, 46) = 27.50$, $MSE = 0.04$, $p < .001$, $\eta_p^2 = 0.54$; $F(1, 23) = 22.05$, $MSE = 0.001$, $p < .001$, $\eta_p^2 = 0.49$, respectively. T2|T1 accuracy averaged 64.3% at Lag 1, increased to 70.9% at Lag 3 and 92.0% at Lag 8. T2|T1 accuracy averaged 77.6% in the same contrast condition compared to 73.8% in the different contrast condition. The interaction of Contrast and Lag did not influence T2|T1 accuracy ($F < 1.9$).

7.2.3. Temporal integration and order reversals

Paired sample t-tests showed no significant effects of Contrast on temporal integration and order reversals ($t_{(23)} < 0.9$) (Fig. 6).

8. Discussion of Experiment 2

The findings of Experiment 2A and 2B clearly differed from those of Experiments 1A and 1C. First, as might have been expected, masking effects seemed to take their toll on T1 performance in Experiment 2A and 2B; lower accuracy was found in the different contrast condition at Lag 1. As supported by the secondary individual target contrast-specific analyses (see the Appendix), the different contrast condition provided more opportunity for masking to have an impact, particularly when a high contrast T2 followed a low contrast T1. This masking effect was not obtained for the color pairs of Experiment 1, which supported the idea that the difference in stimulus strength, caused by the contrast manipulation, was the primary cause of this effect.

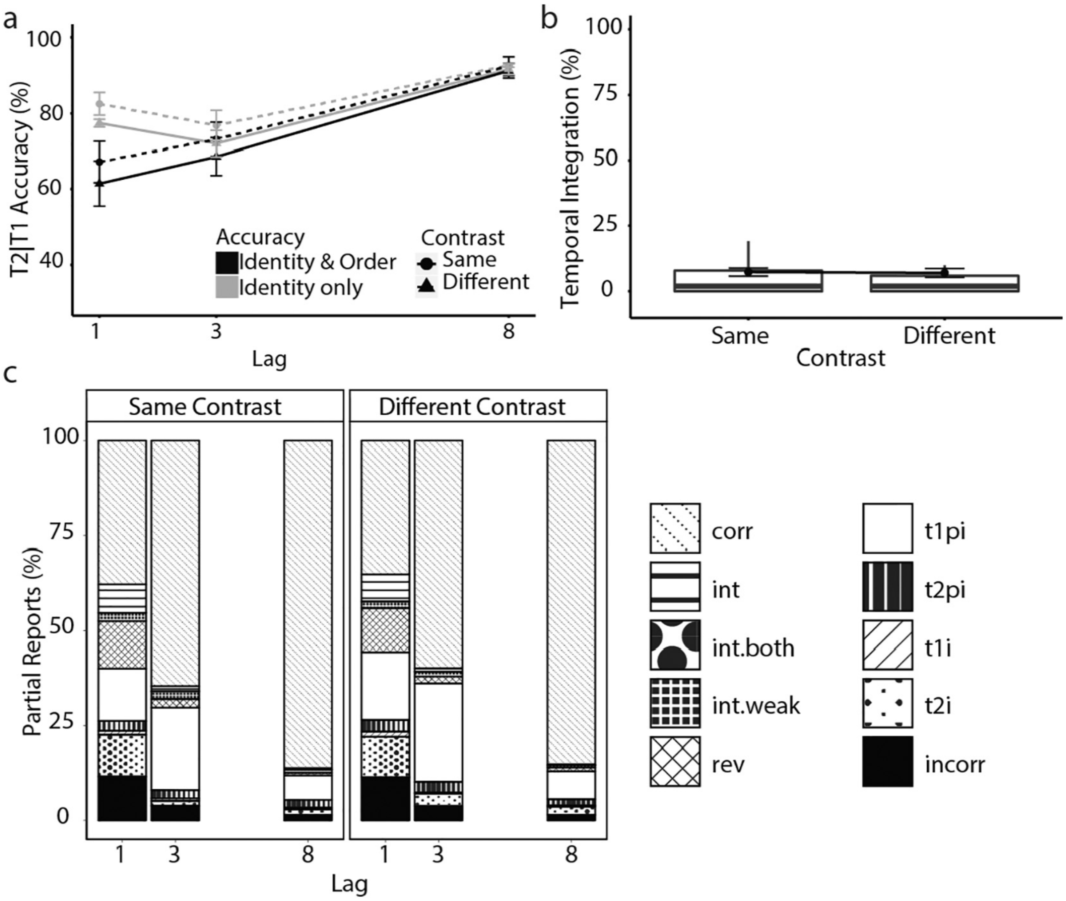

Fig. 6. Task performance in Experiment 2B. Error bars represent ± SEM. a. T2|T1 performance as a function of Lag. b. Percentage of temporal integration of T1 and T2 at Lag 1. c. Partial reports of Experiment 2B. Labels follow Fig. 2.

Second, the results of Experiments 2A and 2B also showed higher T2|T1 accuracy in the same contrast condition than in the different contrast condition, which was diametrically opposed to the results of Experiment 1. This might be explained by assuming that a decrease in target saliency would disrupt the processing of T2. Specifically, there was a decrease in T2|T1 accuracy when a low contrast T2 followed a high contrast T1. That decrease was not only a result of stimulus strength (i.e., a forward masking effect) because there was a slight decrease of T2|T1 accuracy when both targets were low contrast, compared to when both of them were high contrast. Hence, it must have been a decrease in T2 saliency, relative to T1, that specifically disrupted information processing (see the Appendix for means and *F* values).

Third, and constituting the most notable difference between Experiments 1A and 1C on the one side and Experiments 2A and 2B on the other, was that there were no effects whatsoever of target contrast pairs on the frequency of temporal integration and order reversals. Although overall target identification accuracy was clearly moderated by the contrast manipulation, it is important to note that, despite this variation, performance was not at a level that would be expected to preclude integration effects. Integration in same-color and same-contrast conditions was indeed similar overall. The lack of an integration effect for different contrast pairs thus supports the conclusion that the categorical color effect observed in Experiments 1A and 1C cannot be attributed to general stimulus dissimilarity.

9. General discussion

We investigated the effects of matching color and contrast between target pairs on temporal attention and integration in RSVP. To a considerable degree, the color and contrast manipulations caused opposite effects. The principal outcomes of the present experiments can be summarized as follows: First, the results showed that targets with different categorical colors improved T2|T1 identification accuracy (Experiments 1A and 1C), particularly at Lag 1, while a non-categorical change in color (Experiment 1B) did not moderate T2|T1 accuracy. Different contrasts (Experiments 2A and 2B) produced an opposite effect and decreased overall T2|T1 accuracy. Second, targets with different colors were more frequently integrated and more order errors between them were made while targets with different contrasts and targets with a non-categorical color difference (i.e., different shades of blue) were not. Third, all but one of these effects were independent of any (learned) strategic allocation of attention, as the effects replicated regardless of whether the manipulations were implemented in a blocked or randomized fashion. The increase in order reversals at Lag 1 when targets had different colors was the only thing that disappeared when color matching was randomized (Experiment 1C), suggesting it was a result of strategic endogenous control afforded in the blocked design (Experiment 1A).

9.1. *Color-based target matching*

Superficially, the present manipulations of color and contrast may be viewed as ways to vary target similarity. The outcomes clearly indicated that this conception is too simplistic. Target processing did not depend on overall similarity across the present experiments, but on the specific manipulation. The differential effects of color and contrast matching support the more general hypothesis that feature-specific processing should play a role in temporal attention and integration. This fits with theories of the AB that make a similar assumption, such as the (e)STST model by Wyble et al. (2009). On the basis of this model, it could be argued that increased featural similarity should reduce episodic distinctiveness between targets. Because the attentional suppression that is reflected in the AB is an attempt of the perceptual system to keep targets apart, it then makes sense that the increased featural similarity between targets of the same, or a similar, color should result in a need for more (or longer) suppression and an increased AB. In a way, this is reminiscent of the increased difficulty of visual search when targets and distractors share task-relevant features and need to be discriminated (Duncan & Humphreys, 1989).

Temporal integration frequency was also affected by color matching between targets, so that mismatched pairs were more often integrated. This fits with our previous research (Akyürek, Schubö, & Hommel, 2013) in which spatially displaced targets of the same color were observed to interfere with recall at Lag 1. Although the spatial displacement might have mediated that effect, it is compatible with the idea of episodic distinctiveness (Wyble et al., 2009). The outcomes of the current task extend these previous findings and suggest that two same/similar-color targets trigger a rapid segregation response even at a single location, which is possibly attentional in nature, and which specifically works against the tendency to temporally integrate the targets.

If integration behavior is indeed related to an attempt to dissociate two featurally similar targets, this also implies that some part of the integration process in RSVP may be affected by attentional factors. As previously suggested by Akyürek and Wolff (2016), this might be due to the contributions of higher level processes, which has been referred to as informational persistence, as opposed to the lower level factor of visible persistence (Coltheart, 1980; Di Lollo, 1980; Loftus & Irwin, 1998). Evidence from event-related potentials related to temporal integration in RSVP has implicated working memory-related components (i.e., the P3 and the contralateral delay activity [CDA]), suggesting a relatively late locus (Akyürek, Kappelmann, Volkert, & van Rijn, 2017). In this context, it must nonetheless be pointed out that the currently observed frequency of integration was not related to having a blocked or randomized design, suggesting that endogenous, strategic control was not mediating the integration effect, which was the case for order reversals despite the apparently late locus of temporal integration in the processing stream. This discrepancy in control over integration and order reversals may have arisen because, in the current task, the latter report error can be disambiguated from integration and attributed exclusively to attentional priority processing (see also Hilkenmeier, Olivers, & Scharlau, 2012).

The combined facilitatory effects on target identification and integration that were presently found may be related to findings from studies of spatial attention. On the one hand, if observers perform a visual search task by looking for a particular feature (e.g., color) an increase in neural responses is observed for that any occurrence of that feature, even far from the locus of attention (e.g., Saenz, Buracas, & Boynton, 2002), following a coarse-to-fine selectivity profile over time (Bartsch et al., 2017). On the other hand, inhibitory effects are also frequently associated with attention, such as the suppressive surround regions that are commonly observed just outside the locus of attention (e.g., Hopf et al., 2006). Importantly, similar inhibition effects are also observed in feature space. Störmer and Alvarez (2014) showed that colors in the visual field that were similar (though not identical) to an attended color were attentionally suppressed. A similar inhibitory interaction may also have played a role in the current temporal task: A repeated encounter of a feature that is similar to one that was previously targeted may produce an inhibitory response, if it occurs close in time. The idea that a spatial inhibitory surround should help shield the target from potentially confusing neighboring signals (Störmer & Alvarez, 2014) may thus similarly apply in time, which also fits with the idea that temporal attention strives to maintain episodic distinctiveness between targets and other, likely irrelevant items (Wyble et al., 2009). The present results do suggest that there might be a qualitative difference between the temporal and spatial domains, in that the former but not the latter inhibitory effect seems to occur for identical colors.

9.2. *Contrast-based target matching*

As mentioned, in reference to the effects due to color matching, we observed largely opposite effects of target contrast matching. The first effect was that target contrast pairs did not affect integration at Lag 1 (nor order reversals). The lack of a contrast effect might appear to be at odds with previous studies that showed increased order reversal rates when targets had similar contrast (Chua, 2005; Hommel & Akyürek, 2005). Apart from various methodological differences (e.g., ISI, stimulus duration, lag distribution), this might again be related to the fact that integration cannot be measured directly by counting order errors in classic AB tasks (i.e., tasks in which targets cannot be reported in an illusory, combined form). Recall that order error rates in classic tasks reflect both real order errors, possibly mediated by attentional processes (such as prior entry) and integrations, whereas these are kept separate in the current task. Closer inspection of the means (cf. Tables 3 and 4) suggests that integrations and order reversals exhibited opposite patterns. When T1 contrast was high, there were fewer integrations overall when T2 was high contrast also, compared to when T2 contrast was low. Conversely, there were more order reversals in the former case than in the latter. When T1 contrast was low, there were fewer integrations when T2 contrast was high, compared to when T2 contrast was low, but the opposite was true for order reversals. Interestingly, when considering the sum total of both integrations and reversals, the pattern was similar to that reported by Chua (2005) and Hommel and Akyürek (2005); higher frequencies were observed when both targets had the same contrast than when they did not. However, it must be noted that this similarity was not supported statistically. At present, the only safe conclusion to draw from the present data is that the current task seems to have elicited opposite trends in integrations and reversals in response to contrast. It is conceivable that the visual compatibility of the targets played a role therein, but this issue remains to be studied further.

The second effect was that overall T2|T1 accuracy was actually higher when contrast between targets matched. In line with previous findings (Chua, 2005; Hommel & Akyürek, 2005), target contrast specific analyses (see the Appendix) furthermore showed that when T1 contrast was low and T2 contrast was high, increased T2|T1 accuracy was observed. Two factors may have contributed to this effect. First, a salient T2 might capture attention in a bottom-up fashion if its salient feature (i.e., high contrast) is part of the target search template, reducing the AB (e.g., Folk, Leber, & Egeth, 2008). Second, many AB theories assume there exists a trade-off between the 'investment' in T1 and the processing of T2 that might have resulted in the relative success of T2 identification in this condition (e.g., Olivers & Meeter, 2008). That said, however, it should be noted that although the contrast effect seemed more pronounced at shorted lags, the analysis did not provide strong evidence (i.e., from an interaction) that it was indeed AB-specific. Thus, this finding should be interpreted with caution.

From the collective contrast-based results, it seems clear that this manipulation did not trigger the same mechanisms as the color-based manipulation. It thus seems that episodic attentional processing, which comprises both temporal integration at Lag 1 and T2 identification at intermediate lags, is not similarly sensitive to contrast as it is to color, at least in the current task. A parsimonious, comprehensive explanation for this difference is that the color manipulation concerned both a primary visual feature and a change on a metathetic continuum (in Experiment 1A and 1C). Contrast, related to overall brightness, might not only be less of a primary visual feature, but certainly also constitutes a prothethic continuum, in which differences might be processed in a more gradual fashion by definition. Further experiments will nevertheless be needed to elucidate the degree to which these general factors play an overarching role in the perception of episodic distinctiveness in RSVP.

10. Conclusion

In sum, the present results suggested a clear dissociation between (categorical) color-based and contrast-based processing. Color dissimilarity between targets in RSVP improved attentional performance and increased temporal integration, whereas contrast dissimilarity decreased overall performance and did not affect integrational processing at Lag 1. It may finally be concluded that color-related, featural information processing affects not only attentional allocation in space, but also attention and integration in time. Further research may consider the question whether other categorical changes (e.g., orientation or location) influence temporal attention and integration in a similar way to color changes.

Acknowledgments

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Appendix A. T1 and T2 color/contrast -specific performance

Average T1 accuracy for specific T1 and T2 colors and contrasts is presented in Table 1. Table 2 shows average T2|T1 accuracy. Table 3 shows average temporal integration frequency. Table 4 shows order reversal frequency.

Table 1
Average T1 accuracy by T1 color/contrast, T2 color/contrast and lag across experiments.

Exp. 1A	T1-B				T1-R													
	T2-B		T2-R		T2-B		T2-R											
	M	*S*	*M*	*S*	*M*	*S*	*M*	*S*										
L_1	49.3	3.5	41.2	4.5	41.7	4.5	53.1	3.4										
L_3	82.8	2.6	85.2	2.4	80.5	2.4	82.3	2.0										
L_8	90.2	1.7	89.7	1.8	92.8	1.6	92.5	1.3										
Exp. 1B	T1-B				T1- FB													
	T2-B		T2-FB		T2-B		T2-FB											
	M	*S*	*M*	*S*	*M*	*S*	*M*	*S*										
L_1	52.1	3.1	56.9	2.9	46.4	2.8	50.7	2.9										
L_3	86.0	2.2	86.3	2.0	85.9	1.9	84.5	2.7										
L_8	91.3	2.1	92.5	1.3	90.9	1.8	89.9	2.0										
Exp. 1C	T1-B						T1-R						T1-G					
	T2-B		T2-R		T2-G		T2-B		T2-R		T2-G		T2-B		T2-R		T2-G	
	M	*S*	*M*	*S*	*M*	*S*	*M*	*S*	*M*	*S*	*M*	*S*	*M*	*S*	*M*	*S*	*M*	*S*
L_1	43.6	3.3	32.1	3.5	40.9	4.1	35.7	4.5	44.6	2.9	38.1	5.0	29.7	4.1	31.2	4.0	40.5	2.9
L_3	83.4	3.1	87.6	1.8	83.8	2.8	84.8	3.1	86.2	1.6	87.6	2.6	80.7	3.3	85.5	2.5	78.8	2.9
L_8	91.4	1.8	90.3	2.2	90.3	1.8	91.4	2.0	94.0	1.8	92.4	1.9	92.4	1.8	88.6	2.6	90.9	1.7
Exp. 2A	T1-H				T1-L													
	T2-H		T2-L		T2-H		T2-L											
	M	*S*	*M*	*S*	*M*	*S*	*M*	*S*										
L_1	51.0	3.2	55.1	2.8	42.2	2.3	45.5	2.7										
L_3	89.8	2.3	89.1	2.6	83.9	3.3	87.0	2.4										
L_8	94.3	1.8	92.0	2.3	91.2	2.3	93.2	2.0										
Exp. 2B	T1-H				T1-L													
	T2-H		T2-L		T2-H		T2-L											
	M	*S*	*M*	*S*	*M*	*S*	*M*	*S*										
L_1	55.6	3.3	62.4	3.6	45.7	3.2	50.0	3.6										
L_3	89.2	1.9	88.2	2.2	85.4	2.2	85.8	2.4										
L_8	93.2	1.5	95.3	1.9	90.5	1.9	92.5	1.7										

L_1 = Lag 1; L_3 = Lag 3; L_8 = Lag 8; M = Mean (%); S = Standard error of the mean (%); B = Blue; R = Red; FB = Faded blue; G = Green; L = Low contrast; H = High contrast.

Table 2
Average T2|T1 accuracy by T1 color/contrast, T2 color/contrast and lag across experiments.

Exp. 1A	T1-B				T1-R													
	T2-B		T2-R		T2-B		T2-R											
	M	*S*	*M*	*S*	*M*	*S*	*M*	*S*										
L_1	42.2	5	64.4	5.5	58.4	5.8	41.1	4.3										
L_3	67.1	4.2	68.5	4.1	65	4	70.1	3.4										
L_8	85.7	2.9	87	2.6	85.6	3.4	89.4	3										
Exp. 1B	T1-B				T1-FB													
	T2-B		T2-FB		T2-B		T2-FB											
	M	*S*	*M*	*S*	*M*	*S*	*M*	*S*										
L_1	70.1	3.6	59.4	4.5	72.4	3.0	62.9	3.9										
L_3	80.5	3.4	71.1	4.0	82.3	3.0	74.6	3.9										
L_8	89.2	2.3	88.9	2.3	91.4	1.6	86.1	2.3										
Exp. 1C	T1-B						T1-R						T1-G					
	T2-B		T2-R		T2-G		T2-B		T2-R		T2-G		T2-B		T2-R		T2-G	
	M	*S*	*M*	*S*	*M*	*S*	*M*	*S*	*M*	*S*	*M*	*S*	*M*	*S*	*M*	*S*	*M*	*S*
L_1	40.5	4.9	56.4	5.7	66.3	5.7	58.9	6.5	44.7	4.8	63.2	7.2	56.3	6.8	67.5	6.6	36.1	5.2

(*continued on next page*)

Table 2 (*continued*)

L_3	68.6	3.2	76.2	3.6	73.7	4	78.1	3.5	76.7	3.7	67	4.2	74.8	3.5	76.5	4.4	60.4	4.2
L_8	88.2	2.4	90.6	3.1	84.5	3.5	89.9	2.1	89	2.2	89.6	2.2	87.1	2.9	87.8	3.3	85.4	2.8

Exp. 2A	T1-H				T1-L			
	T2-H		T2-L		T2-H		T2-L	
	M	*S*	*M*	*S*	*M*	*S*	*M*	*S*
L_1	71.2	3.8	54.9	4.7	72.0	3.7	65.5	4.7
L_3	76.5	4.4	59.9	4.7	75.6	4.4	67.2	4.9
L_8	91.4	2.6	88.0	3.4	89.5	2.8	87.4	2.6

Exp. 2B	T1-H				T1-L			
	T2-H		T2-L		T2-H		T2-L	
	M	*S*	*M*	*S*	*M*	*S*	*M*	*S*
L_1	69.6	5.0	54.2	4.9	71.9	4.6	63.9	4.5
L_3	75.9	3.6	61.5	5.3	76.3	4.0	70.5	4.3
L_8	94.6	1.5	90.7	1.8	92.0	1.8	90.5	1.8

L_1 = Lag 1; L_3 = Lag 3; L_8 = Lag 8; M = Mean (%); S = Standard error of the mean (%); B = Blue; R = Red; FB = Faded blue; G = Green; L = Low contrast; H = High contrast.

Table 3
Average temporal integration frequency by T1 color/contrast, T2 color/contrast and lag across experiments.

Exp. 1A	T1-B				T1-R			
	T2-B		T2-R		T2-B		T2-R	
	M	*S*	*M*	*S*	*M*	*S*	*M*	*S*
L_1	10.9	2.6	19.2	4.9	19.7	4.9	10.8	2.6
L_3	0.3	0.2	0.7	0.3	0.8	0.3	0.7	0.3
L_8	0	0	0.3	0.2	0.2	0.2	0.2	0.2

Exp. 1B	T1-B				T1- FB			
	T2-B		T2- FB		T2-B		T2- FB	
	M	*S*	*M*	*S*	*M*	*S*	*M*	*S*
L_1	6.4	2.3	8.3	2.3	7.3	2.2	7.4	2.2
L_3	0.0	0.0	1.2	0.5	0.9	0.6	0.3	0.3
L_8	0.1	0.1	0.7	0.7	0.3	0.3	0.4	0.2

Exp. 1C	T1-B						T1-R						T1-G					
	T2-B		T2-R		T2-G		T2-B		T2-R		T2-G		T2-B		T2-R		T2-G	
	M	*S*	*M*	*S*	*M*	*S*	*M*	*S*	*M*	*S*	*M*	*S*	*M*	*S*	*M*	*S*	*M*	*S*
L_1	15.4	2.7	32.9	5.2	27.2	5.2	33.4	5.4	16.9	3.3	31.6	6	31.2	5.5	32.4	5.6	17.8	3.2
L_3	1.7	0.9	1.4	1.1	2.8	1.1	1.4	0.8	1	0.5	1.4	0.8	1.4	0.7	1.4	1.1	2.6	1
L_8	0.3	0.2	0	0	0	0	0	0	0	0	1	0.6	0.3	0.3	0.3	0.3	0.5	0.3

Exp. 2A	T1-H				T1-L			
	T2-H		T2-L		T2-H		T2-L	
	M	*S*	*M*	*S*	*M*	*S*	*M*	*S*
L_1	8.1	2.4	9.0	2.6	7.8	2.5	11.4	3.0
L_3	0.0	0.0	0.5	0.5	0.7	0.3	0.4	0.2
L_8	0.0	0.0	0.4	0.2	0.0	0.0	0.2	0.2

Exp. 2B	T1-H				T1-L			
	T2-H		T2-L		T2-L		T2-H	
	M	*S*	*M*	*S*	*M*	*S*	*M*	*S*
L_1	6.6	1.8	6.7	2.2	7.6	2.7	8.4	2.5
L_3	0.7	0.7	1	0.5	0.7	0.3	1.9	0.7
L_8	0.2	0.2	0.3	0.2	0	0	0.5	0.3

L_1 = Lag 1; L_3 = Lag 3; L_8 = Lag 8; M = Mean (%); S = Standard error of the mean (%); B = Blue; R = Red; FB = Faded blue; G = Green; L = Low contrast; H = High contrast.

Table 4
Average order reversals by T1 color/contrast, T2 color/contrast and lag across experiments.

Exp. 1A	T1-B				T1-R			
	T2-B		T2-R		T2-B		T2-R	
	M	*S*	*M*	*S*	*M*	*S*	*M*	*S*
L_1	6.7	1.1	11.5	1.9	10.4	1.6	5.5	1.0
L_3	1.7	0.6	2.0	0.5	3.5	1.0	2.3	0.6
L_8	1.3	0.5	1.7	0.6	0.5	0.3	1.0	0.4

Exp. 1B	T1-B				T1- FB			
	T2-B		T2- FB		T2-B		T2- FB	
	M	*S*	*M*	*S*	*M*	*S*	*M*	*S*
L_1	10.8	1.2	8.9	1.1	13.4	1.3	11.4	1.2
L_3	2.6	0.5	2.7	0.7	1.6	0.4	3.2	0.8
L_8	0.9	0.4	0.9	0.4	1.5	0.6	1.2	0.4

Exp. 1C	T1-B			T1-R			T1-G		
	T2-B	T2-R	T2-G	T2-B	T2-R	T2-G	T2-B	T2-R	T2-G

(*continued on next page*)

Table 4 (*continued*)

	M	*S*	*M*	*S*	*M*	*S*	*M*	*S*	*M*	*S*	*M*	*S*	*M*	*S*	*M*	*S*	*M*	*S*
L_1	6.7	1.2	9.5	1.8	7.2	1.4	7.8	1.7	7.0	1.4	5.2	1.2	9.8	2.1	10.0	2.0	6.9	1.6
L_3	2.8	0.7	2.1	0.9	2.4	0.9	2.4	0.9	1.6	0.4	0.7	0.5	2.4	1.1	2.8	1.0	1.9	0.6
L_8	1.0	0.4	2.1	0.9	2.4	0.8	1.4	0.7	0.7	0.3	1.0	0.6	1.0	0.6	2.1	0.9	1.2	0.5

Exp. 2A	T1-H				T1-L			
	T2-H		T2-L		T2-H		T2-L	
	M	*S*	*M*	*S*	*M*	*S*	*M*	*S*
L_1	14.8	2.1	12.4	2.2	16.7	1.8	16.3	1.9
L_3	2.4	0.8	1.9	0.8	2.8	0.9	2.8	0.8
L_8	1.0	0.4	0.9	0.5	1.2	0.5	1.2	0.5

Exp. 2B	T1-H				T1-L			
	T2-H		T2-L		T2-H		T2-L	
	M	*S*	*M*	*S*	*M*	*S*	*M*	*S*
L_1	12.1	1.5	9.6	1.6	13.5	1.5	12.9	1.7
L_3	1.6	0.7	1.7	0.6	2.1	0.8	3.1	0.9
L_8	0.4	0.3	0.4	0.2	1.7	0.6	1.2	0.6

L_1 = Lag 1; L_3 = Lag 3; L_8 = Lag 8; M = Mean (%); S = Standard error of the mean (%); B = Blue; R = Red; FB = Faded blue; G = Green; L = Low contrast; H = High contrast.

Appendix B. T1 and T2 color/contrast-specific ANOVA results

In Table 5, target color/contrast-specific repeated measures ANOVA results are shown. *F* values are reported with mean square error within groups (MSW) so that pairwise comparisons can be calculated with Tukey's HSD post hoc test by using MSW, the means from Tables 1–3, and the number of participants.

Table 5
ANOVA table for the main effects of T1 color/contrast, T2 color/contrast, and lag, with all possible interaction effects across experiments. Cross signs (†) next to F values indicate significance.

		Exp.1A		Exp.1B		Exp.1C		Exp.2A		Exp.2B	
		F	*MSW*	*F*	*MSW*	*F*	*MSW*	*F*	*MSW*	*F*	*MSW*
T1 ACC	*T1C*	1.0	0.004	16.3†	0.004	506.2†	0.011	42.4†	0.004	57.8†	0.004
	T2C	4.3†	0.002	8.9†	0.002	358.1†	0.010	4.6†	0.004	8.1†	0.005
	L	165.9†	0.051	243.7†	0.033	174.9†	0.167	186.6†	0.052	204.2†	0.036
	T1C × *T2C*	4.9†	0.016	0.4	0.012	202.6†	0.030	0.6	0.009	0.1	0.003
	T1C × *L*	4.8†	0.005	6.1†	0.004	60.5†	0.007	9.5†	0.005	12.9†	0.004
	T2C × *L*	0.9	0.005	5.1†	0.005	63.3†	0.009	2.4	0.004	5.1†	0.004
	T1C × *T2C* × *L*	8.3†	0.013	0.1	0.005	48.6†	0.015	1.0	0.004	0.4	0.006
T2|T1 ACC	*T1C*	0.65	0.010	6.1†	0.005	264.1†	0.022	9.0†	0.006	8.7†	0.008
	T2C	8.6†	0.007	48.0†	0.010	120.9†	0.042	54.2†	0.011	38.6†	0.012
	L	44.9†	0.093	47.1†	0.040	36.2†	0.258	18.3†	0.103	26.7†	0.072
	T1C × *T2C*	10.3†	0.022	0.1	0.025	108.1†	0.049	4.0†	0.019	13.2†	0.005
	T1C × *L*	1.3	0.011	1.4	0.008	5.6†	0.033	4.3†	0.007	4.4†	0.008
	T2C × *L*	0.6	0.008	6.8†	0.008	3.8†	0.034	13.9†	0.005	8.2†	0.007
	T1C × *T2C* × *L*	22.4	0.021	1.2	0.011	14.1†	0.048	1.0	0.016	0.9	0.007
Int.	*T1C*	4.8†	0.001	0.0	0.000	7.0†	0.005	0.3	0.001	4.8†	0.001
	T2C	2.1	0.001	7.6†	0.000	7.5†	0.009	6.9†	0.001	2.1	0.001
	L	10.0†	0.028	10.2†	0.038	38.9†	0.215	12.5†	0.039	10.0†	0.028
	T1C × *T2C*	2.2	0.002	1.5	0.003	11.4†	0.021	0.0	0.002	2.2	0.000
	T1C × *L*	2.5	0.001	0.0	0.001	14.1†	0.013	2.1	0.001	2.5	0.001
	T2C × *L*	2.5	0.001	1.5	0.000	14.8†	0.014	6.4†	0.001	0.3	0.001
	T1C × *T2C* × *L*	0.05	0.001	0.5	0.002	15.9†	0.037	1.3	0.003	0.1	0.001
Rev.	*T1C*	0.5	0.001	7.2†	0.001	6.2†	0.002	5.6†	0.002	15.9†	0.001
	T2C	0.0	0.001	1.0	0.002	7.6†	0.002	2.2	0.001	1.1	0.001
	L	35.1†	0.004	86.2†	0.006	22.2†	0.010	53.4†	0.010	62.1†	0.006
	T1C × *T2C*	11.7†	0.002	0.3	0.001	9.4†	0.002	1.3	0.002	0.8	0.001
	T1C × *L*	3.9†	0.001	6.2†	0.001	1.1	0.001	4.2†	0.001	0.9	0.002
	T2C × *L*	0.3	0.001	4.7†	0.002	5.1†	0.002	1.0	0.001	1.7	0.002
	T1C × *T2C* × *L*	9.9†	0.002	0.4	0.002	2.3	0.002	0.4	0.001	0.6	0.001

F = F value of the repeated measures ANOVA; MSW = Mean square error within groups; T1 ACC = T1 accuracy; T2|T1 ACC = T2 accuracy in the trials that T1 identified correctly; Int. = Temporal integration; Rev. = Order reversals; T1C = Main effect of T1 color or contrast; T2C = Main effect of T2 color or contrast; L = Main effect of Lag; x = interaction effect.

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