Perceived timing of new objects and feature changes

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Recent psychophysical studies have shown that perceived timings of events can be dissociated from their physical temporal relationship. In the flash-lag effect (FLE), a flash presented at the same spatiotemporal position as a continuously moving stimulus is perceived to lag behind the moving stimulus. In the present study, we report a peculiar condition in which FLE does not occur even when the position of a moving object is estimated at the moment of a transient event. In a series of experiments, we compared perceived timings and processing delays for appearance of a new object against feature changes of an existing object. We found that perceived timing of the appearance of a new object is delayed compared to the perception of feature changes updating the properties of an object. Our results suggest the construction of a new object representation requires additional time to establish a stable neuronal representation.

Keywords: temporal vision, flash lag, time

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Introduction

How temporal relationships of visual events are registered in our perception is an important non-trivial question for understanding conscious vision. The visual illusion called the flash-lag effect (FLE) (MacKay, 1958; Nijhawan, 1994) has been widely studied to gain insight into the issue of perceived timing of visual events. In the flash-lag effect, a flash presented at the same spatiotemporal position as a continuously moving stimulus is perceived to lag behind the moving stimulus. To account for the flash-lag illusion, various hypotheses have been proposed such as motion extrapolation (Khurana & Nijhawan, 1995; Maus & Nijhawwan, 2006; Nijhawan, 1994), attentional shift between moving and flashed stimuli (Baldo & Klein, 1995), differential latency for motion and flashed stimuli (Purushothaman, Patel, Bedell, & Ogmen, 1998; Whitney & Murakami, 1998), postdiction (Eagleman & Sejnowski, 2000; Rao, Eagleman, & Sejnowski, 2001), temporal integration (Krekelberg & Lappe, 1999, 2000) and asymmetric spreading of activity (Kanai, Sheth, & Shimojo, 2004; Sheth, Nijhawan, & Shimojo, 2000). These hypotheses of the flash-lag illusion have been reviewed by several authors (see, Krekelberg & Lappe, 2001; Nijhawan, 2002, 2008).

In the present study, we first describe a stimulus condition in which FLE does not occur even though the position of a moving object is estimated at the time of a flashed event (cf. the baseline condition of Carlson, Hogendoorn, & Verstraten, 2006). The stimulus consists of a computer-animated clock in which a single hand revolves on the clock surface at 1 revolution per second (see, Figure 1A). Although FLE is expected to occur, no flash lag is observed when their subjects judged the position of the moving hand at the moment when the black rim of the clock briefly flashed. The lack of FLE in this simple stimulus configuration demands an explanation and could possibly shed a new light on the mechanisms underlying FLE.

The goal of the present study is to determine why FLE is not observed in this clock display. In Experiment 1, we show that the reason for the absence of FLE is the fact that in the clock display, the transient event is defined by a feature (i.e., color) change rather than an appearance of a new object. In the second set of experiments (Experiments 2A and 2B), we examine whether this principle generalizes to another simplified situation using temporal order judgment tasks and compare the results with reaction times.

Experiment 1A: Spatial localization task

Methods

Participants

Six participants took part in the experiment. All had normal or corrected-to-normal vision. All participants

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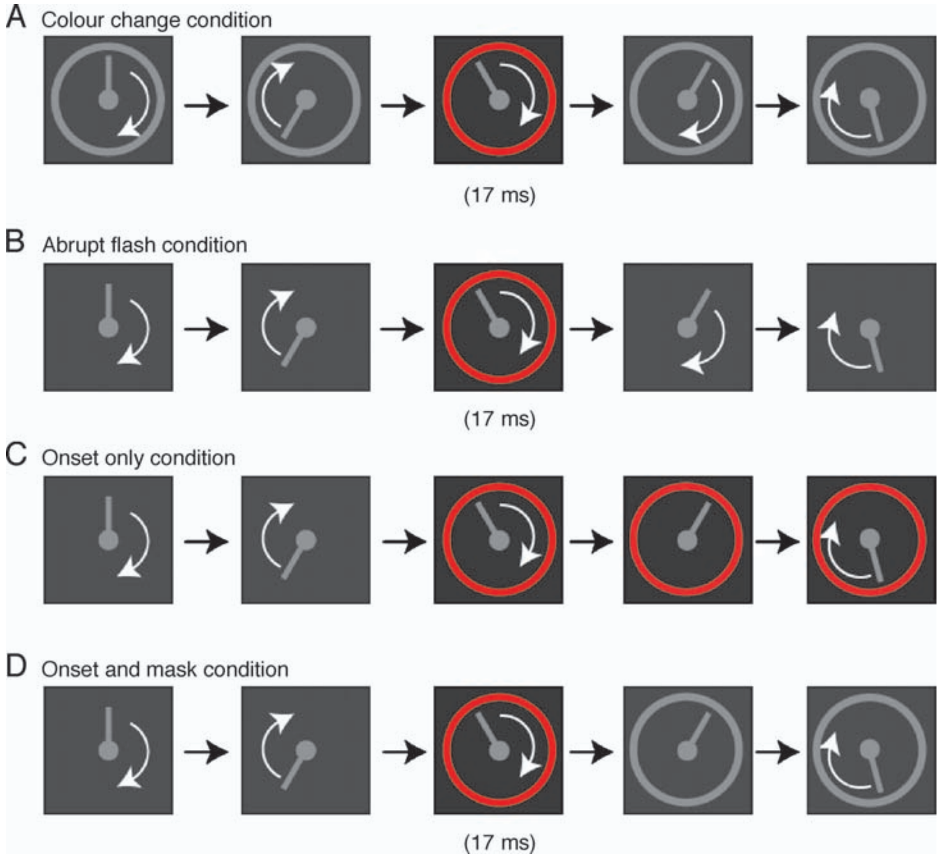

Figure 1. Conditions of Experiment 1. A. Color change condition. The gray rim was displayed continuously throughout a trial. The red rim was flashed for one frame (17 ms). B. Abrupt flash condition. No rim was displayed except that a red rim was flashed for one frame (17 ms). C. Onset only condition. No rim was presented until a red rim was displayed. The red rim stayed on until the end of a trial. D. Onset and mask condition. Similar to the onset only condition, no rim was presented until a red rim was presented. The rim was red only for one frame (17 ms) and then was gray until the end of a trial.

gave informed consent prior to participating in the experiment. They sat 57 cm away from a 17-inch CRT monitor running at 60 Hz refresh rate.

Stimuli and procedure

We displayed a single clock stimulus at fixation at a refresh rate of 60 Hz on a 17-inch CRT monitor. The clock stimulus was simplified from those used in Carlson et al. (2006). The clock consisted of a gray (CIE x = 0.292, y = 0.342, Y = 31.6) hand and a fixation marker at the center of the stimulus drawn on a black background (CIE x = 0.395, y = 0.421, Y = 2.82) (see Figure 1). Ticks were not drawn because we wanted to confirm that FLE is absent even without the ticks, as the tick marks could potentially be a reason of the absence of FLE.

The radius of the rim was 2.0 deg from the fixation marker, and the width of the rim was 0.48 deg. The hand (1.46 deg in length) revolved about the fixation at one revolution per second. In a trial, the hand initially appeared at a random position, and moved for 3 seconds (i.e., 3 revolutions). The rim turned red (CIE x = 0.603, y = 0.349, Y = 30.9) during the second revolution at a random timing. After the end of the stimulus presentation, the same clock stimulus with an adjustable hand was displayed. By adjusting the position of the hand using the keyboard, participants reported the time when the red rim turned on.

We tested three conditions.

1. Color change condition (Figure 1A): A gray rim was presented throughout a trial, and it turned red for one frame (16.7 ms). This corresponds to the baseline condition in Carlson et al.'s study (2006) where no flash-lag was observed.
2. Abrupt flash condition (Figure 1B): No rim was presented except when the red rim was flashed for one frame (16.7 ms). Therefore, the red rim was a new object. If the construction of a new object file would be a factor for producing FLE, a lag would be observed in this condition.
3. Onset only condition (Figure 1C): As in the abrupt flash condition, we did not show a gray rim. Instead of presenting the red rim only for one frame, we kept the red rim until the end of a trial once it was presented. Therefore, participants were asked to

report the position of the moving hand at the onset of the red rim. This condition was included because the possible presence of FLE might be explained by the visible persistence of the flash. In the color change condition, the flash was followed by the gray rim, which may mask and shorten the persisting representation of the red rim.

4. Onset and mask condition (Figure 1D): This condition is identical to the onset only condition above with the exception that the rim turns red only for one frame (16.7 ms) and became gray for the remaining frames after the rim onset. This condition was included to examine potential contributions of backward masking in the abrupt flash condition.

Each condition was tested in a separate block of 50 trials. The order of the blocks was randomized for each participant.

Results and discussion

The results are shown in Figure 2. The color change condition did not produce any flash lag effect ($t(3) = 0.57$, $p = 0.30$, without bonferroni correction, one-tailed t-test), but the other three conditions in which the flash was an appearance of a new object produced a significant flash lag effect (abrupt flash condition, $t(3) = 4.88$, $p < 0.05$, corrected; onset only condition, $t(3) = 8.02$, $p < 0.01$, corrected; onset and mask condition, $t(3) = 7.23$, $p < 0.01$, corrected). The amount of FLE was 47.1 ± 9.6 (*SEM*) ms, 77.6 ± 9.7 ms and 63.3 ± 8.8 ms for the abrupt flash condition, onset only condition and onset and mask condition, respectively. These results are consistent with the hypothesis that perception of a new object is delayed compared to the perception of feature changes within a pre-existing object.

The difference between the color change condition and the other two onset conditions cannot be attributed to different levels of changes in luminance or to a change in contrast. The luminance contrast change from the black background to the red rim in the onset conditions was designed to be larger than that in the color change condition. Typically, stimuli with higher luminance contrast are perceived earlier than those with low-contrast (Purushothaman et al., 1998). However, in our case, even a lower contrast change led to a shorter delay in perception.

Because there is no stimulus following the isolated flash in the abrupt flash condition, the flash would persist longer than in the color change condition in which the flash was followed by the original ring stimulus (Hogben & Di Lollo, 1974). One theory of the flash lag effect argues that the flash lag effect is due to the long visible persistence of flashed stimuli (Krekelberg, 2001; Krekelberg & Lappe, 2000). The onset only condition and the onset and mask condition were included to examine this possibility. In those two conditions, we kept the rim after its onset in order to limit the visible persistence by masking of succeeding stimuli. In particular, the stimuli in the onset and mask conditions were identical to the color change condition after the critical red rim frame. Nevertheless, a lag was found only when the red rim appeared without a preceding stimulus. These results further support the distinction between new objects and feature changes of existing objects.

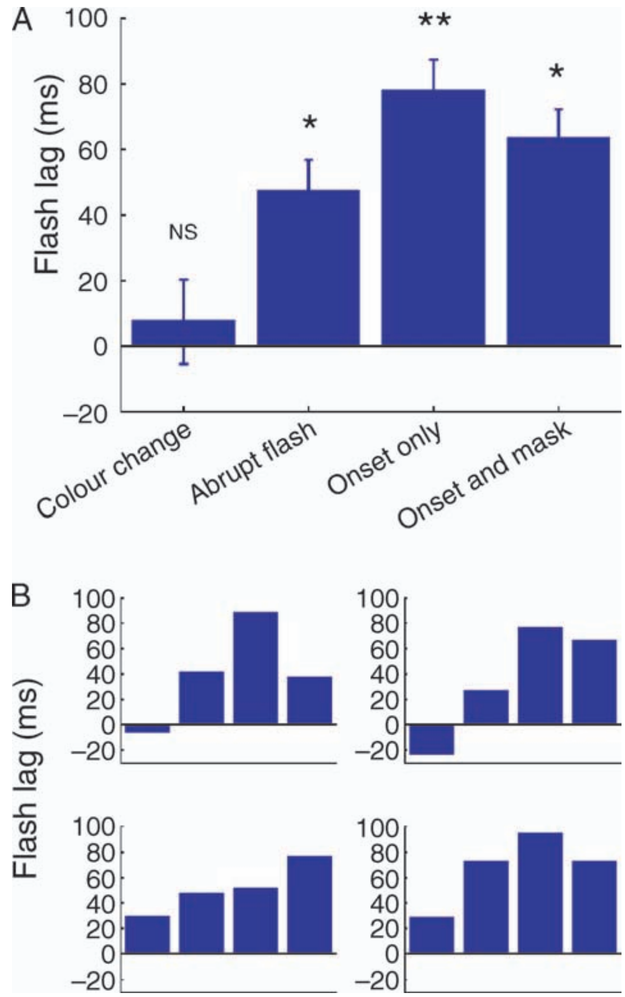

Figure 2. The results of Experiment 1A. A. The perceived timing of the red rim onset is shown for each condition. The positive values indicate a perceptual lag of the red rim event. Statistical significance is indicated by a single asterisk ($p < 0.05$, bonferroni corrected) or by a double asterisk ($p < 0.01$ bonferroni corrected). Error bars correspond to one standard error of the mean (n = 4). B. The results of individual observers are plotted separately in the same format as Figure 2A.

Experiment 1B: Temporal order judgement task

Methods

Participants

Seven participants took part in the experiment. All had normal or corrected-to-normal vision and were naïve as to the purpose of the experiment. All participants gave informed consent prior to participating in the experiment. They sat 57 cm away from a 17-inch CRT monitor running at 60 Hz refresh rate.

Stimuli and procedure

The stimuli and conditions were identical to the localization task in Experiment 1A. In this experiment, the revolving hand changed its color to red for one frame (17 ms) with a lag of −167 ms, −100 ms, −67 ms, −33 ms, 0 ms, 33 ms, 67 ms, 100 ms or 167 ms relative to the presentation of the red ring. The task was to report whether the hand color change occurred before or after the presentation of the red ring in a two-alternative forced choice fashion. The observers were instructed to fixate on the central marker during trials. Each of the temporal condition was tested for 20 trials in a randomized order and different conditions were tested on separate blocks. The order of the blocks was randomized for each subject.

A cumulative normal function was fitted to individual's data to obtain a point of subjective simultaneity (PSS) where the psychometric curve passes the 50% response point.

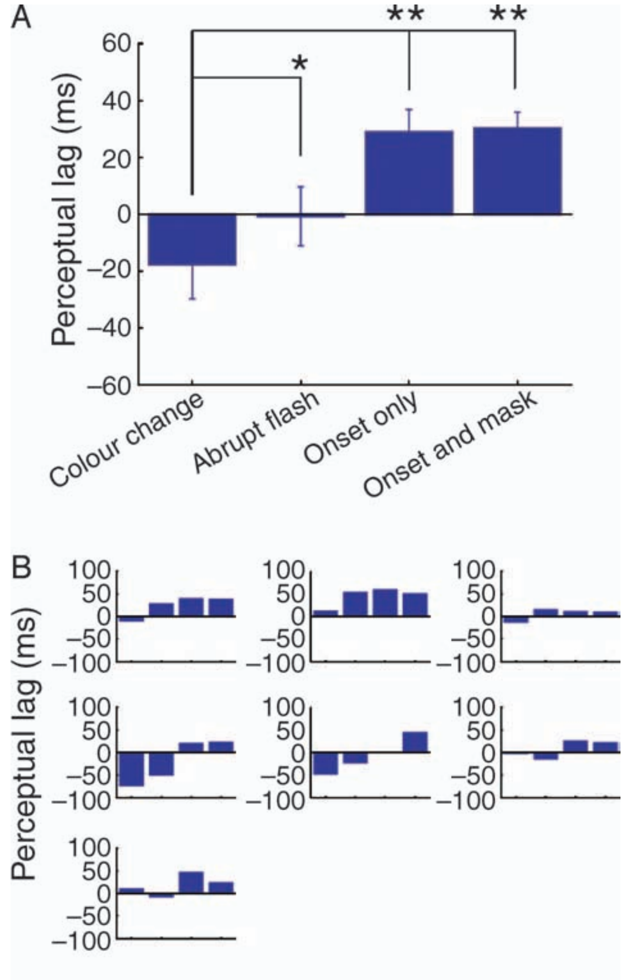

Figure 3. The results of Experiment 1B. A. The perceived timing of the red rim onset relative to the color change of the moving hand is shown for each condition. The positive values indicate a perceptual lag of the red rim event. Statistical significance is indicated by a single asterisk ($p < 0.05$) or by a double asterisk ($p < 0.01$). Error bars correspond to one standard error of the mean (n = 7). B. The results of individual observers are plotted separately in the same format as Figure 3A.

Results and discussion

The perceived timing of the ring onset relative the common event (i.e., the color change of the revolving hand) is shown for each condition (Figure 3). Consistent with the localization task in Experiment 1A, the results of the TOJ task showed that the color change was perceived significantly earlier than all other three conditions in which the critical event was an appearance of a new object (abrupt flash condition, $t(6) = 2.81$, $p < 0.05$; onset condition, $t(6) = 5.29$, $p < 0.01$;onset and mask, $t(6) = 3.75$, $p < 0.01$). However, the delay of the PSS for the abrupt flash was less consistent in the TOJ task than the localization task (Experiment 1A). Thus, the mean PSS for the abrupt flash condition was earlier than those in the onset-only and onset-and-mask conditions. Five out of seven observers showed an earlier PSS for the color change condition than for the abrupt flash condition, but the two remaining observers showed an opposite trend.

One important difference between this TOJ task and the previous localization task is the addition of a transient color change to the moving hand. At the outset of this TOJ experiment, it was assumed based on a previous report of Cai and Schlag (2001) that the colored hand would be perceived at the position of the continuously moving gray hand. However, it should be noted that the red hand was usually perceived at the trailing end of the moving hand, indicating lack of Cai's effect in our display. This means that the position of the red flash was perceived to lag behind the moving hand as in the flash-lag effect. This makes difficult a direct comparison of the results of the TOJ experiment with those of the localization task. However, the results of the TOJ experiment provides relative perceived timing of the red rim across the four conditions, because the frame of the red hand served as a common timing reference against the manipulations of the onset conditions for the rim. In this regard, our TOJ results can be taken as a support for the hypothesis that perception of a new object is delayed compared with updating a feature within a pre-existing object.

Experiment 2A: Temporal order judgments

The previous experiments support the hypothesis that perception of a new object is delayed compared to the perception of a feature change. Here, we examine whether the hypothesis generalizes to other situations. For this purpose, we used a set of simple stimuli where the objecthood of a target stimulus was varied by using different preceding contextual stimuli.

Methods

Participants

A total of eight observers including one of the authors (R.K.) participated in this experiment. The other observers were naïve as to the purpose of the experiment. All observers had normal or corrected-to-normal visual acuity. They sat 57 cm away from a 17-inch CRT monitor running at 100 Hz refresh rate.

Stimuli and procedure

There were five stimulus conditions in all of which the observers were asked to compare the relative timing between a brief flash at fixation and the onset of a red (CIE x = 0.603, y = 0.349, Y = 30.9) disk presented below the fixation. The background was gray (CIE x = 0.292, y = 0.342, Y = 31.6). The five conditions listed below are designed to manipulate whether the physically identical target onset is a feature change of a visual object or an appearance of a new object (see Figure 4).

1. Abrupt onset: The red disk appeared without any context preceding the onset (Figure 4A). Since there was no stimulus before the onset, this condition serves as a condition for the appearance of a new object.
2. Color change: Before the onset of the red disk, a green (CIE x = 0.297, y = 0.572, Y = 35.2) disk of the same size was presented at the same location (Figure 4B). In this condition, the target onset is perceived as a color change of an existing object.
3. Position change: Before the onset of the red disk, another red disk of the same size was displayed at another location until the onset of the target disk (Figure 4C). There was no gap in time between the offset of the first disk and the onset of the target disk, and this stimulus produced a clear sensation of apparent motion between the two disks. Because of the percept of apparent motion, the stimulus is perceived as a relocation of a single object.
4. Color and position change: This condition involved changes in both color and position. It was similar to the position change condition above except that the first disk was green instead of red (Figure 4D). The interpretation of this condition was ambiguous as to whether the target should be considered as simultaneous changes of two features or as a new object

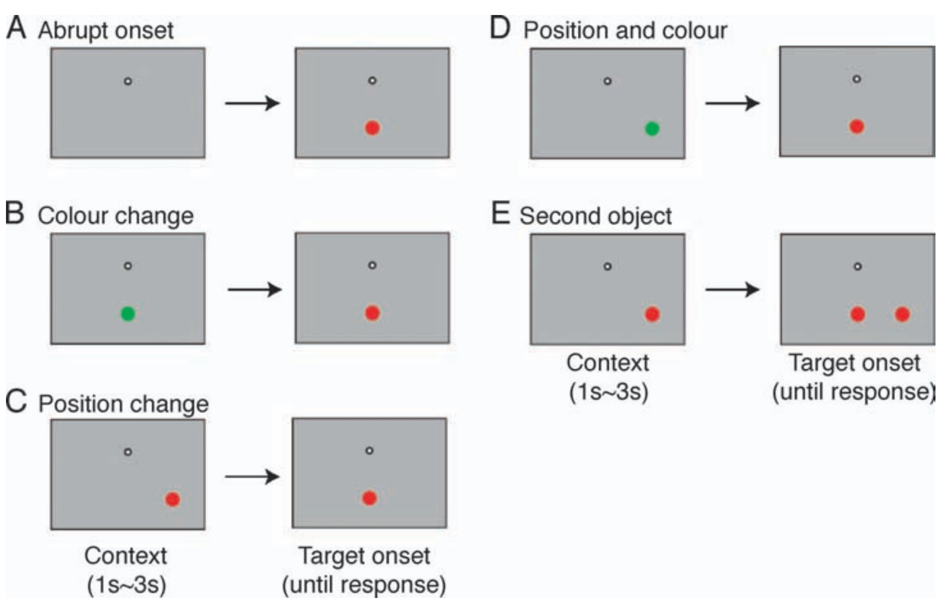

Figure 4. Conditions of Experiments 2A and 2B. A. Abrupt onset condition. B. Color change condition. C. Position change condition. D. Position and color change condition. E. Second object condition. In all conditions, there was a variable duration preceding the onset of the target red disk. The target disk remained on the screen until the response.

because the change in two features make the target stimulus distinct from the prior contextual stimulus. However, we included this condition to observe how the effects of color change and position change studied individually in the above two conditions (color change and position change) interact when they occur simultaneously.

5. Second object: This condition was similar to the position change condition except that the first red disk stayed on after the onset of the target disk (Figure 4E). Therefore, while the context before the target onset is similar to the position change condition, the target appears to a new object.

In order to measure relative delays of the perceived timings for those conditions above, we conducted a temporal order judgment (TOJ) experiment between the onset of the target disk and a brief contrast reversal of a fixation marker, which served as a common reference event for all the conditions. The observers were instructed to fixate on the central marker during trials. We varied the temporal gap of the two events between −150 ms to +150 ms with a step size of 30 ms. The observers' task was to report whether the target onset occurred before or after the reference event. Twenty samples were made for each of the 11 temporal gaps per condition. Each of the five conditions was tested in a separate block of trials. Thus, each block consisted of 220 trials, and each observer completed five blocks in a randomly assigned order. A cumulative normal function was fitted to individual's data to obtain a point of subjective simultaneity (PSS) where the psychometric curve passes the 50% response point. Repeated measures ANOVA was used for testing a main effect of the conditions and Tukey test was used for post hoc comparisons.

The fixation marker was a black disk (diameter 0.27 deg) enclosed by a white ring (outer diameter 0.67 deg). The diameter of the target and contextual disks was 0.83 deg. The vertical eccentricity of the target disk and contextual disks was 3.33 deg below the fixation, and in Conditions 3, 4 and 5, the contextual disks were placed 5 deg away from the fixation horizontally. The stimuli were presented against a gray background, and the luminance of the red and green disks were adjusted to equiluminance for individual observers using a heterochromatic flicker method. The flash of the fixation marker was a contrast reversal between the black and white parts of the marker for a single frame (10 ms). In order to minimize predictability of the timing of the target onset, the time between the beginning of a trial and the target onset was random for each trial (uniform sampling between 1 s and 3 s).

Results and discussion

The perceived timing relative to the common reference event (flicker of the fixation marker) is shown for each condition in Figure 5. A repeated measures ANOVA revealed significant differences between the test conditions ($F(4,28) = 4.785$, $p < 0.01$). Post hoc pairwise comparison showed that the perceived timings of color change and position change were earlier than the other three conditions (all $p < 0.05$) with the exception of the comparison between position change versus color-position change, which showed a slightly smaller effect (the mean difference is 18.3 ± 8.2 ms (*SD*), $p = 0.062$).

The two types of events that were perceived early involved a change in only one of the object's features, namely, the position or color. The other three conditions

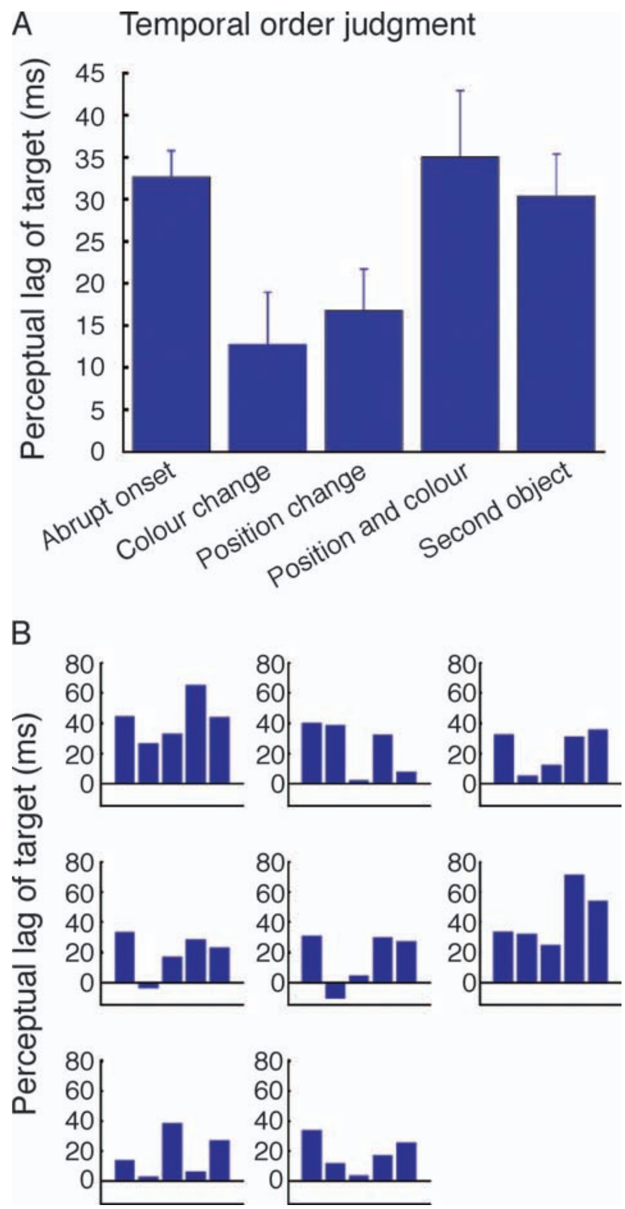

Figure 5. Results of Experiment 2A (temporal order judgment task). A. The perceived timing relative to the common reference event is shown for each condition. Error bars correspond to one standard error of the mean (n = 8). B. The results of individual observers are plotted separately in the same format as Figure 5A.

can be interpreted as an appearance of a new object. Clearly, the abrupt onset condition is an appearance of a new object. Also, the appearance of a second disk would be interpreted as an appearance of a new object. However, the condition of color-position change is more difficult to interpret. While they can be considered as feature changes of a previously existing object, the changes may have made the stimulus appear more distinct from the preceding one and prompted the interpretation that it was a new object. Notwithstanding the ambiguous status of the objecthood, the results of the color-position change condition is informative, because it indicates that a change in feature, which individually speeded the perceived timing of the events, did not jointly support the speeding of perception.

In comparison to the difference in the perceived timings between new objects and feature changes measured in Experiment 1 (40–70 ms), the results of TOJ showed a much smaller difference (20 ms). This could be due to various factors such as the difference in the reference stimulus (color change in Experiment 1 and brief blinking of fixation in Experiment 2) or the difference in the nature of the task (spatial localization in Experiment 1 and TOJ in Experiment 1). Moreover, in the clock experiments in Experiment 1, there was a spatial uncertainty as to the position of the hand, the target location was fixed in Experiment 2. Despite the qualitative and quantitative differences between the two experiments, the general pattern that perception of appearances of new objects is delayed in comparison to that of corresponding feature changes is consistent across the two experiments.

Although we have discussed the results in terms of whether the target onset was an appearance of a new object or a feature change of an existing object, differences in low-level sensory signals presented in the differences in the stimulus configurations need to be considered. First, the speeding of perception in the color change condition could be due to retinotopic adaptation to the green disk prior to the onset of the target red disk. Since they are roughly opponent colors to each other, it is likely that adaptation to the green disk speeded the processing of the red disk. Second, speeding of perceived timing in the position change condition could be due to the presence of an offset signal together with the onset signal for the target. However, the results of color-position change suggest that the offset signal, which is present in this condition, does not necessarily speed the perception of an event.

In order to further investigate possible contributions of low-level signal strength, we conducted simple reaction time tasks described in the next section.

Experiment 2B: Reaction times

Reaction times (RTs) to a visual event are another measure for processing latency. It has been argued that a simple RT task and a TOJ task may rely on different aspects (e.g. thresholds) of internal responses to a stimulus (Sternberg & Knoll, 1973). In line with this idea, it has been shown that RTs can be dissociated from the timing of conscious perception (Neumann, Esselmann, & Klotz, 1993; Rutschmann & Link, 1964; Tappe, Niepel, & Neumann, 1994). RTs are thought to reflect the time required for visual events to reach the motor output in a feedforward fashion (Neumann et al., 1993; Thorpe, Fize, & Marlot, 1996; VanRullen & Thorpe, 2001). Thus, they are more directly connected to the strength of low-level sensory signals such as luminance (Roufs, 1963) or disparity (Arnold & Wilcock, 2007) than the timing of conscious perception (Bacon-Macé, Macé, Fabre-Thorpe, & Thorpe, 2005). Thus, measurements of RTs for the stimulus conditions explored in Experiment 2A are informative as to how fast the target onset is processed due to possible differences in the bottom-up signal strength. For this purpose, we measure RTs for those five conditions in a simple task that does not require complex decisions.

Methods

Observers

The same eight observers as the previous experiment (Experiment 2A) participated. Half of the observers completed this experiment before the previous experiment on the same day to counterbalance possible order effects between the two experiments.

Stimuli and procedure

The same five conditions were tested in separate blocks. Each block consisted of 120 trials, and the order of the blocks was randomized for each observer. The stimulus parameters were identical to Experiment 1. The time between the beginning of a trial and the target onset was random for each trial (uniform sampling between 1 s and 3 s). The task was to press a key as soon as the target appeared. The median of RT data was used as the estimates of RTs for given conditions.

Results and discussion

The results of the RTs are shown in Figure 6. A repeated measures ANOVA on the RT data did not show any significant differences between the conditions ($F(4,28) < 1$). Thus, the statistical analysis did not support the notion that the PSS differences across conditions are due to differences in processing speed caused by low-level signal strength of the stimuli. However, it remains inconclusive whether RTs are influenced by the same perceptual delay, because it is possible that the measure-

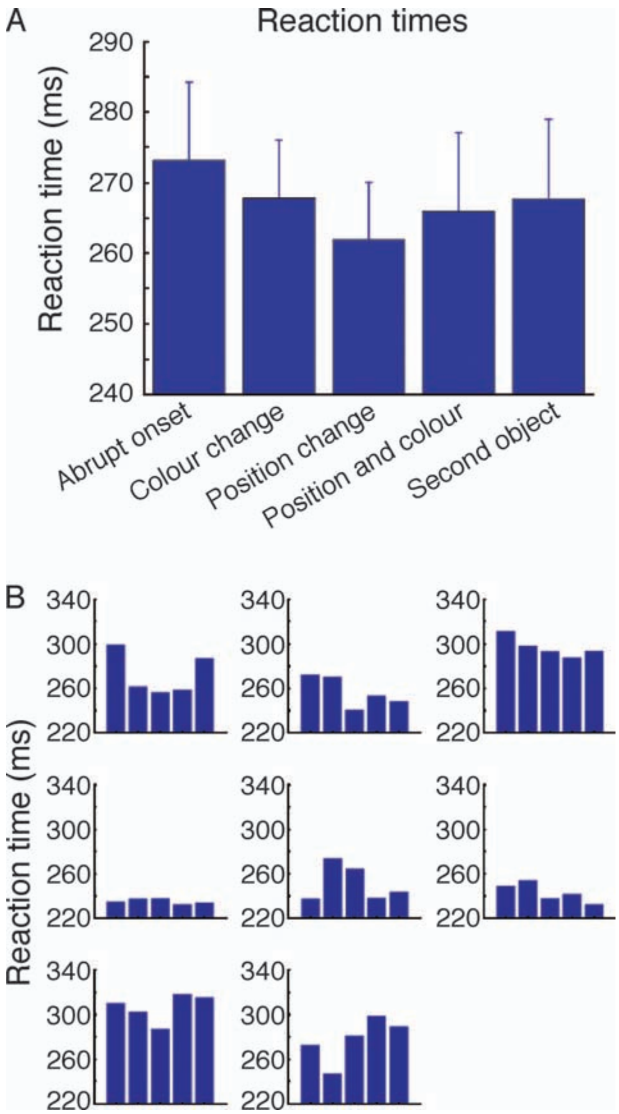

Figure 6. Results of Experiment 2B (reaction time task). Simple reaction times to the onset of a red disk are shown for each condition. Error bars correspond to one standard error of the mean (n = 8). B. The results of individual observers are plotted separately in the same format as Figure 6A.

ments of RT were simply noisier than the estimates of perceived timing in the TOJ task. In order to further examine possible relationship between perceived timing and RT in our experiment, we conducted a correlation analysis using individual's data points for the five test conditions. This analysis did not show any systematic relationship between perceived timing and RTs either. The correlation was −0.14 and not significantly different from zero ($t(38) = -8.69$, $p = 0.39$). The lack of positive correlation suggests that RTs has little predictive power on perceived timing of events in the TOJ task. Therefore, it seems unlikely that simple processing latency dictated by low-level signal strength accounts for the differences in the perceived timings between the different conditions in Experiment 2A. Moreover, in Experiment 1 we found that despite the higher contrast change, the perceived timing of abrupt onset was delayed compared to the color change condition. This finding further supports the idea that perceived timing is delayed when a new object representation needs to be constructed.

Experiment 2C: Simultaneity judgments

While TOJ is frequently used as a method to estimate subjective simultaneity between two perceptual events, a difference found by a TOJ task could be due to response bias at a decision stage without a difference in perception (Frey, 1990; Spence, Shore, & Klein, 2001). Indeed, it has been shown that estimates of subjective simultaneity can be biased even by different instructions to the subjects (Navarra et al., 2005). In this regard, it has been argued that a simultaneity judgment (SJ) task provides a more reliable estimation of subjective simultaneity (Schneider & Bavelier, 2003; Zampini, Shore, & Spence, 2005). Moreover, it has been argued that TOJ and SJ are based on different types of incoming information (Stelmach & Herdman, 1991). Therefore, it is informative to examine whether the pattern of results found in the TOJ experiment (Experiment 2A) can be observed also with a SJ task.

Methods

Participants

A total of eight observers including one of the authors (R.K.) participated in this experiment. The observers except for R.K. were naive as to the purpose of the experiment and were different from those who participated in Experiments 2A and 2B. All observers had normal or corrected-to-normal visual acuity. They sat 57 cm away from a 17-inch CRT monitor running at 100 Hz refresh rate.

Stimuli and procedure

The same five conditions were tested in separate blocks. Each block consisted of 220 trials, and the order of the blocks was randomized for each observer. The stimulus parameters were identical to Experiment 2A except that the temporal gap of the two events between −80 ms to +80 ms with a step size of 10 ms (instead of −150 ms to +150 ms with a step size of 30 ms). This finer variation around the physical synchrony was used because we found in our pilot experiment that the temporal judgments in the SJ task was much more accurate and less variable than the TOJ experiment. The task for the observers was to report whether the blinking of the fixation was synchronous with the onset of the red disk or not. A Gaussian function with a constant offset from zero was fitted to individual's data and the peak of the Gaussian curve was taken as the point of subjective simultaneity.

Results and discussion

The mean PSS are shown in Figure 7A. A repeated measures ANOVA revealed significant differences between the test conditions ($F(4,28) = 3.507$, $p < 0.05$).

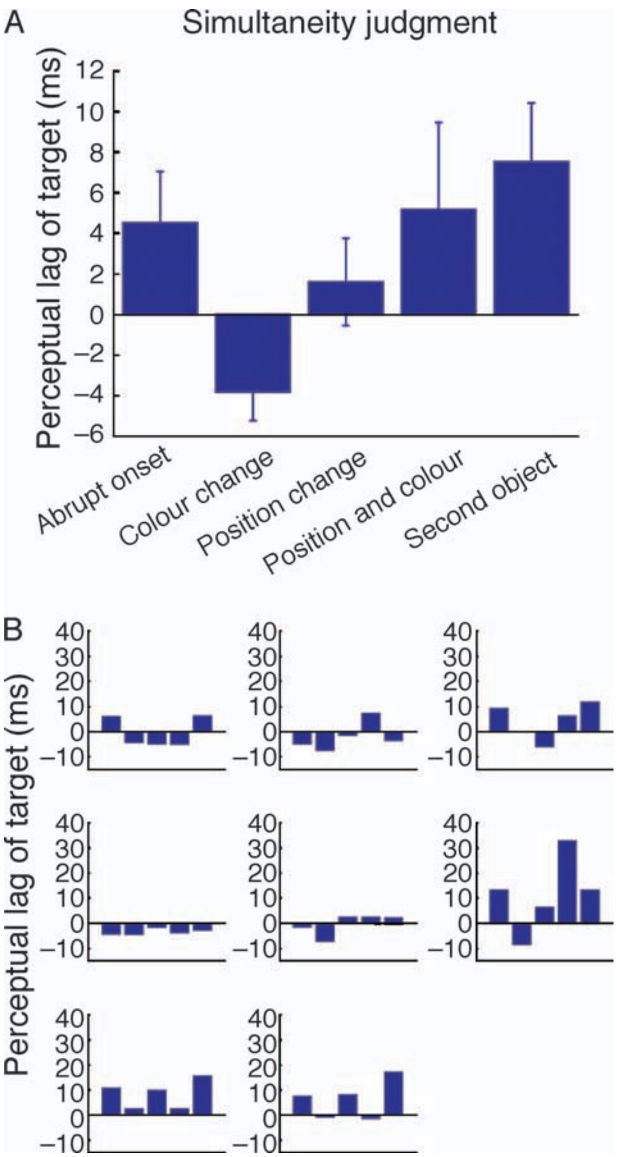

Figure 7. Results of Experiment 2C (simultaneity judgment task). The perceived timing relative to the common reference event is shown for each condition. Error bars correspond to one standard error of the mean (n = 8). B. The results of individual observers are plotted separately in the same format as Figure 7A.

Post hoc pairwise comparisons showed that the perceived timing of color change was earlier than the abrupt condition ($p < 0.05$) and the second object condition ($p < 0.05$). We also found a significant difference between the position change condition was perceived earlier than the second object condition ($p < 0.05$).

Although the general tread of the bias induced by preceding contexts (e.g. green disk etc.) was consistent with the results of the TOJ experiment, it should be noted that the effect size was much weaker with the SJ task. In the TOJ experiment, the difference in PSS between the old object conditions (i.e., the color change and position change conditions) versus new object conditions (i.e., the abrupt onset condition and second object condition) was about 20 ms, whereas the difference estimated with the SJ task was at most 10 ms. The reduction in the effects of preceding context may be attributable to different attentional deployments between the TOJ and SJ tasks. Nevertheless, the consistent pattern of results between the TOJ and SJ tasks rules out the possibility that the effects we found with the TOJ are simply due to unexpected biases involved in the TOJ task.

General discussion

In the present study, we explored whether perceived timing of an event is delayed when the context suggests that it was an appearance of a new object compared to when the event was interpreted as a change of an existing object. Based on these findings, we conclude that perceived timing for a new object is slower than perceived timing of a feature change. Given the delay in perceiving new objects, the delay for perceiving a flash must be one of the critical factors in FLE. This idea is essentially identical to the differential latency hypothesis (Purushothaman et al., 1998; Whitney & Murakami, 1998), but provides specific reasons why the delay arises, that is, the delay in constructing a new object representation for a flashed stimulus. Although the delay in perceiving a new object may not be the only factor contributing to FLE, our findings indicate that the delay in constructing a new object representation contributes to FLE to a great extent.

Various concepts for an entity to which features are bound have been proposed, among which are the notions of object files (Kahneman & Treisman, 1984), tokens (Kanwisher, 1987) and the FINST (Pylyshyn, 1989, 2001). While these concepts have different nuances and emphasis, they share the idea that features are bound to an object-like entity that can be maintained over time and feature changes are updated within the entity. Our results suggest that the process of constructing a neural representation of an object-like entity takes time, but feature changes are updated online with a minimal delay.

The role of updating object representation in FLE has been studied previously by Moore and Enns (2004); see also Moore, Mordkoff, and Enns (2007). When the continuity of a moving object in a flash lag display is disrupted by a sudden change of the size of the object, FLE was abolished. The size change as such can be interpreted as a feature change and our hypothesis would predict that FLE should still occur if the size change was updated on the moving object. Importantly, their effect size depended on the magnitude of the size change; while a large change abolished FLE, a small change seemed to be integrated into the moving object. Therefore, it was argued that only a large change in size was interpreted by the visual system as a second object dissociated from the continuous moving one (Moore & Enns, 2004).

Our result of the position-color change condition provides a further insight about the question of what kind of changes require a construction of a new object. When features are changed in more than one dimension, the result was similar to the abrupt onset condition and the second object condition. In other words, they behaved similarly to a presentation of a new object. Moreover, the abrupt onset of a new stimulus can be interpreted as simultaneous changes in multiple dimensions such as color, position and shape. Moore and Enns (2004) also found that a change in a single dimension (i.e., size) required a construction of a new object. Moreover, it has been shown that the object-mediated update of features depends on contextual information about the continuity of a moving object (Moore et al., 2007). Therefore, it can be inferred that whether the visual system interprets a change as appearance of a new object or a feature change of a preexisting object is determined by the magnitude of discrepancy between the status of an object and the change introduced in a given context.

Previously, the relationship between perceived spatial offsets in FLE and the relative perceived timings of moving and flashed stimuli has been studied. For example Kreegipuu and Allik (2004) compared the perceived timing of a color change of a moving object against the timing of a flashed reference. Their results are consistent with our findings. In their study, when the flash was presented either at the physically aligned location or perceptually aligned position, the color change was perceived earlier (Figure 3 of Kreegipuu & Allik, 2004). On the other hand, when the flash was presented in front of the moving object the flash was perceived earlier. While this aspect of their results is inconsistent with our interpretation, it should be considered as an additional bias produced by the task irrelevant dimension, which need to be further examined as a separate phenomenon from FLE.

Another relevant study that compared perceived timing against spatial offset in FLE is the visual illusion reported by Cai and Schlag (2001). In the Cai illusion, the color of a moving stimulus is briefly changed for a single frame, and the position of the colored frame is perceived to be shifted in the direction of the movement. Originally, it was suggested that the illusion is due to a temporal misbinding in which the binding of the color of a singleton frame is delayed compared to registration of its position signal. This interpretation poses an apparent challenge to the idea that feature changes are updated on an object with a minimum delay. If the color were to be updated immediately, the singleton color would be perceived at the veridical position. However, an alternative interpretation of the illusion proposed by Eagleman and Sejnowski (2007) is compatible with our present hypothesis. They showed that the Cai illusion is due to a dragging of the colored frame by the motion signal in the stimulus rather than temporal delay of the color to the moving object. With this interpretation, the color frame is treated in a similar manner as the abrupt size change in the study by Moore and Enns (2004), creating a separate object representation. The difference of the Cai illusion from the size change experiment in Moore and Enns' study is that instead of remaining at the physically veridical position, the singleton object seems to be shifted in the motion direction. We predict based on Eagleman and Sejnowski's interpretation that there would be no temporal lag between the perceived timing of the singleton frame and a reference frame defined by a similar feature change (e.g., a stationary stimulus that changes its color for a single frame).

Given the accumulating rich data in the literature of the flash-lag effect, it is unlikely that the delay in perceiving new objects is the only reason of the flash lag effect. As we argued in the beginning of the discussion, our hypothesis of object-based feature updating makes similar predictions as the differential latency hypothesis (Purushothaman et al., 1998; Whitney & Murakami, 1998). However, one important difference is that our framework predicts that FLE should not be observed in the flash-initiated cycle (Khurana & Nijhawan, 1995). In the flash-initiated cycle, both a flash and a moving stimulus appear at the same time and thus both require construction of a new object. It has been shown, however, the size of the FLE is comparable to that of the condition in which a moving stimulus is present both before and after a flash (Eagleman & Sejnowski, 2000; Khurana, Watanabe, & Nijhawan, 2000; Nijhawan, Watanabe, Khurana, & Shimojo, 2004). On the other hand, a TOJ task between the onsets of a moving object and a static object showed no systematic asynchrony (Nijhawan et al., 2004). While this strongly argues against the differential latency account, it is consistent with our proposal because in that task, both moving and static stimuli are new objects and the percepts for both should be equally delayed. That is, while our hypothesis can account for the perceived timing in FIC, the presence of a spatial shift in FIC asks for an additional explanation.

These considerations based on previous findings suggest that the delay for appearances of new objects is not the only cause of FLE. Instead, it is likely that multiple mechanisms additively contribute to the FLE. In particular, there are several lines of evidence to assume that the displacement of perceived position of a moving object has a significant contribution to FLE (Eagleman & Sejnowski, 2007). For example, a spatially confined moving stimulus (e.g. a drifting Gabor) is perceived as displaced in the direction of the movement (De Valois & De Valois, 1991; Ramachandran & Anstis, 1990). Also, the vanishing point of a moving stimulus can be perceived beyond its final position when the strong stimulus offset cues signaling the final position are reduced (Kanai et al., 2004; Maus & Nijhawwan, 2006). Therefore, our proposal that perception of new object's appearance is delayed should be regarded as one contributing factor in FLE. Moreover, in one study, a robust FLE was observed even when a color change analogous was used as a time marker for making a judgment about the position of a moving stimulus (Linares & Holcombe, 2008). This experiment consists of a conceptually identical stimulus as our color change condition: the position of a moving stimulus was compared against stationary reference stimuli at the time when the color of the fixation point changed. While the discrepancy between the two studies could be due to various bottom-up factors such as the stimulus eccentricity and the luminance change of the maker, one prediction derived from our study is that the FLE size would have been larger if they used an isolated flash instead of a color change.

Furthermore, there are two recent studies that impose strong constraints to theories of the FLE. One is the study by Linares and Holcombe (2008) mentioned above. In that study, they compared shifts in the perceived position between a drifting Gabor without changing its position and a static Gobor undergoing translational motion, a condition similar to typical FLE conditions. They found that their effect sizes are influenced by motion direction with respect to the fixation point, suggesting that the FLE can be dissociated from purely motion-based spatial mislocalization. The other recent study relevant to our present study is done by Arnold, Ong, and Roseboom (2009). They showed that although manipulations of signal strengths (i.e., chromatic contrast) informing changes in the stimuli modulate the perceived timing and the flash-lag effect, differential latencies as such cannot account for the typical flash-lag effect. Taken these studies together, these recent studies suggest that both motion-induced spatial shifts and signal-dependent latencies are modulating factors for the FLE but are not the primary cause of the FLE. Based on these recent findings, we suggest that the delay for constructing a new object representation may be the primary cause of the FLE.

A similar distinction between the perception of new objects and feature change has been reported in the literature of the attentional blink (AB) (Raymond, Shapiro, & Arnell, 1992), a phenomenon in which report of a second target (T2) is degraded when its presented in a temporal proximity to a first target stimulus (T1). In a study by Raymond (2003), it was found that when T1 was a change in a feature relative to the preceding distractors, there was no attentional blink for T2. In contrast, when the T1 was a new object, AB was observed. In their study, the feature change was a change in the orientation of the same trident shaped stimulus. Based on the absence of AB for feature changes, it was argued that creation of new object-level representations is an attention-demanding process, while updating pre-existing objects is not.

Our conclusion is also compatible with the perceptual "retouch" hypothesis proposed by Bachmann and colleagues in the context of visual masking (Bachmann, 1988) and FLE (Bachmann, Luiga, Põder, & Kalev, 2003; Bachmann & Põder, 2001). According to this hypothesis, perception involves two distinct processes. One is fast and specific information about features; the other is a slower non-specific activation, which is facilitated by preceding stimuli. Thus, when a stimulus is preceded by other stimuli, its perception is facilitated because the non-specific activation is established before its presentation (Bachmann & Põder, 2001). Our findings specify that the slow process reflects the creation of a new object rather than non-specific activation of the visual system. For example, in the second object condition and color and position change condition, the target was preceded by another stimulus, but their perception was delayed compared to similar conditions (color change and position change conditions) in which the target was defined as a feature change rather than a new object. Thus, the facilitation of perception is not merely due to a prior exposure to other stimuli, but is dependent on the continuity of the target and the prior stimulus as a common object.

In summary, our present findings suggest the construction of a new object representation requires additional time to establish a stable neuronal representation. The distinction between the construction of a new object representation and feature updates within a pre-existing object offers a new perspective on perceived timings of visual events.

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