Research Article

Object Updating and the Flash-Lag Effect

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ABSTRACT—Flash lag *is a misperception of spatial relations between a moving object and a briefly flashed stationary one. This study began with the observation that the illusion occurs when the moving object continues following the flash, but is eliminated if the object's motion path ends with the flash. The data show that disrupting the continuity of the moving object, via a transient change in size or color, also eliminates the illusion. We propose that this is because a large feature change leads to the formation of a second object representation. Direct evidence for this proposal is provided by the results for a corollary perceptual feature of the disruption in object continuity: the perception of two objects, rather than only one, on the motion path.*

The perception of even the most basic events, such as the position of an object in space, is prone to illusion. This study examined one such illusion, *flash lag* (FL), which involves the misperception of the spatial relations between a moving object and a briefly flashed one. Our interest in this illusion lies in its illustration of *object updating*, which we consider to be a fundamental aspect of vision.

The middle panel of Figure 1a illustrates this illusion. In this case, a disc is traveling in a circular path. At some point in its journey, a square is flashed briefly, in a position that is aligned with the disc relative to the fixation point (i.e., at the same radial position). If the disc continues on its path, past the frame in which it was aligned with the square, then the disc tends to be seen as spatially "ahead" of the briefly flashed stationary square, even though when the square appeared, the two objects were aligned; this is the illusion known as FL (MacKay, 1958; Nijhawan, 1994). If instead of continuing on its motion path, the moving disc is erased immediately after it is aligned with the square, then the two stimuli are seen correctly as being aligned (Eagleman & Sejnowski, 2000; Whitney & Murakami, 1998; Whitney, Murakami, & Cavanagh, 2000). The present study indicates that the different perceptions associated with these two conditions, referred to as *continued motion* versus *stopped motion*, can be understood in terms of a fundamental process of vision that we refer to as object updating.

Object updating is a process whereby recently sampled information is integrated with an existing representation of a scene. If the scene has not changed from one point in time to the next, then the original representation is simply reinforced by the process. However, if the scene has changed, then the updating process can lead to the replacement of existing information with more recent information. Object updating has been studied extensively in the context of backward masking, where it has also been called *object substitution*, because in masking the perception of an earlier stimulus (the target) is disrupted by the presence of a later one (the mask; Di Lollo, Enns, & Rensink, 2000; Enns, 2002; Enns & Di Lollo, 1997; Jiang & Chun, 2001a, 2001b; Lleras & Moore, 2003; Neill, Hutchinson, & Graves, 2002). An important characteristic of the substitution process in masking is that it is mediated at an object level of representation. Specifically, an object can be spared from substitution by later information if the later information is perceived as belonging to a different object (Enns, 2002; Lleras & Moore, 2003; Moore & Lleras, in press).

The present study shows that similar rules apply to FL. We propose that the difference between continued motion, which gives rise to FL, and stopped motion, in which perception is accurate, hinges directly on the object-updating process. When the moving disc moves to a new position following the flash, the new position information replaces that acquired at the time of the flash. In contrast, when there is no new position following the flash, there is no new position information to overwrite the previous information, and so the alignment of the two objects is perceived accurately.

The present study lends support to and goes beyond this basic observation. Our results show that disrupting the continuity of the moving disc eliminates the FL, as it should if the substitution is object mediated. Moreover, the disruption in continuity causes the perception of an additional object, as is expected if

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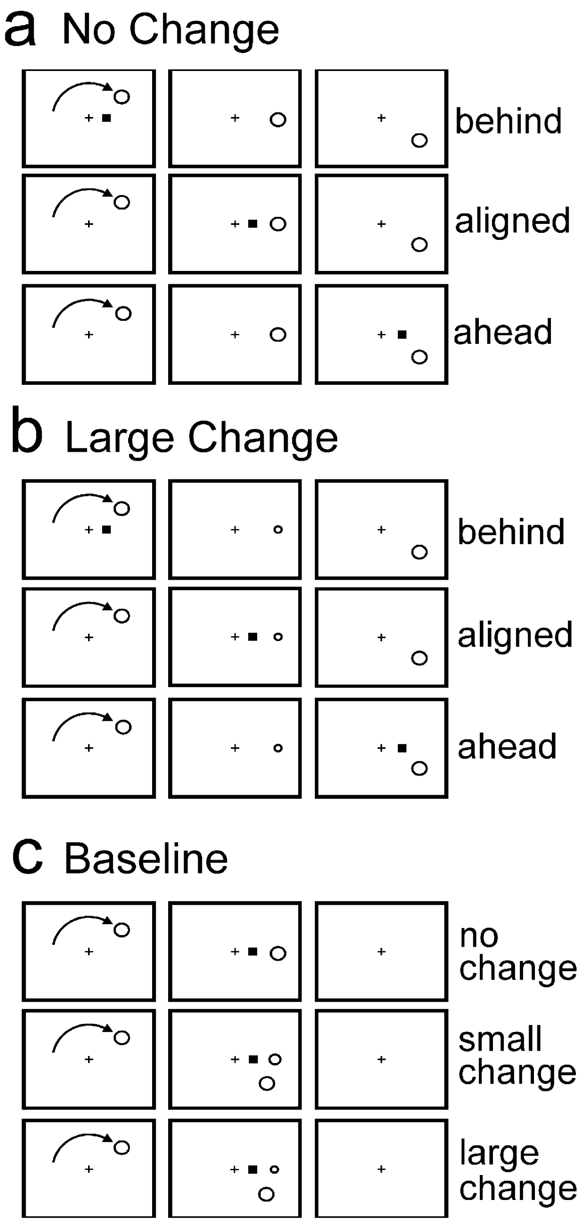

Fig. 1. Illustration of the displays used in the experiment. In the continued-motion, no-change displays (a), the moving disc was physically behind, aligned with, or ahead of the stationary flashed square. In other continued-motion displays, the moving disc became smaller at the radial position of the flash (b shows a large change in size); for the critical aligned displays (center row), the change occurred at the time of the flash. In the stopped-motion baseline displays (c), the motion stopped with the presentation of the flash, and in the change conditions, two discs were physically present with the flash; one of these discs was aligned with the flash.

such disruption breaks the history of an old object and initiates the representation of a new object.

The study was conducted in three parts. Part 1 demonstrated the standard FL for continued motion and the elimination of FL for stopped motion. Part 2 showed that disrupting object continuity, by having the moving object undergo a large and abrupt change at the time of the flash, allowed the alignment of the moving disc and the flashed square to be perceived accurately. Finally, Part 3 showed that the disruption was accompanied by the perception of two objects: a new object aligned with the flash and the original object in the last position of the motion trajectory.

METHOD

Observers

Thirty students from the University of British Columbia, Canada, participated in this experiment, 10 in each part.

Stimuli

Displays were presented on 17-in. color monitors controlled by Presentation software by Neurobehavioral Systems (Albany, California). Observers viewed displays from a distance of 50 cm in a dimly lit room. A white fixation cross was in the center of all displays. On each trial, a white disc moved in a circular trajectory, beginning from one of four locations (0°, 90°, 180°, or 270°) on an imaginary circle with a radius of 5.2° of visual angle. The direction of motion was randomly chosen to be clockwise or counterclockwise.

In the *stopped-motion*, or *baseline*, condition, the disc traveled one of three distances (90°, 180°, or 270°) in 15° steps. The disc was presented for 70 ms at each step, with no time between steps. The *continued-motion* condition was the same, except that the disc traveled one step farther, resulting in total distances of 105°, 195°, and 285°. On all trials, at some point during the movement of the disc, a red square (0.6°) was flashed 3.6° from fixation at the radial position corresponding to what was the final position in the stopped-motion condition. In stopped motion, the flash always appeared in the same frame as the aligned moving disc, and this was the final frame of the sequence. In continued motion, the flash could appear one frame prior to, in the same frame as, or one frame following the frame in which the moving disc appeared in that radial position; these conditions were labeled *behind*, *aligned*, and *ahead*, respectively (see Fig. 1a), reflecting the relation between the position of the moving disc and the flash at the time of the flash.

The critical factor was a change in the size of the moving disc: no change, a small change (from 1.0° to 0.6° in radius), or a larger change (from 1.0° to 0.3° in radius). The size change occurred for only a single frame of the motion—in either the second-to-last or the last frame. (See Fig. 1b for an illustration of the large-change displays.) For purposes of analysis, we were concerned only with trials in which the change occurred in the second-to-last frame. Changes in the last frame were presented to increase the observer's uncertainty about which display was being presented.

As noted, the stopped-motion trials constituted a baseline condition in that the motion of the disc stopped at the time of the flash (see Fig. 1c). In the no-change baseline condition, the final frame included just the original disc and the flashed square. In

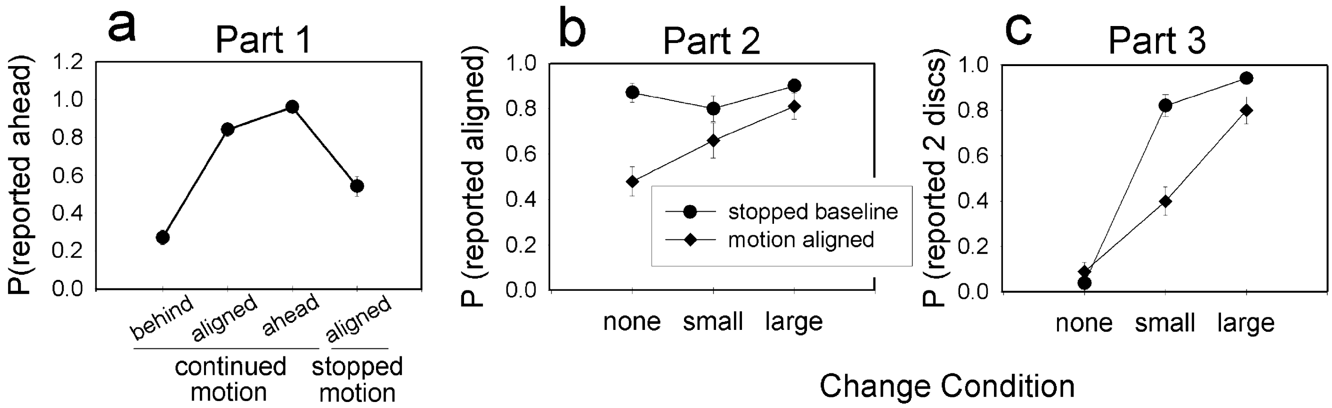

Fig. 2. Results. The graph in (a) shows the mean proportion of Part 1 trials on which observers reported the moving disc as ahead of the flash. On continued-motion trials, the moving disc was physically behind, aligned with, or ahead of the flash; on stopped-motion trials, the disc was physically aligned with the flash, but the motion stopped with the presentation of the flash. The graph in (b) shows the mean proportion of Part 2 trials on which observers reported the moving disc as aligned with the flash, as a function of the degree to which the disc changed size at the time of the flash. Results are shown separately for continued-motion and stopped-motion baseline trials. All data are from trials on which the moving disc was physically aligned with the stationary flash. The graph in (c) shows the proportion of Part 3 trials on which observers reported seeing two discs at the time of the flash, as a function of the change condition. The trial types are the same as for (b).

the change baseline conditions, the final frame included a smaller disc at the radial position of the flash and a larger disc (i.e., the same size as the original disc) one position beyond that of the flash. If observers responded reliably on the basis of what they saw in the displays, then they should have reported that a disc was aligned with the flash on baseline trials. In addition, for the change baseline trials, they should have reported two discs as being present at the time of the flash.

Procedure

Each observer completed at least 40 trials of practice prior to testing. Following each display, the observer entered a response on the keyboard. Each session was divided into blocks of 54 trials.

Part 1 measured the basic FL effect in no-change displays. Observers reported whether the moving disc appeared ahead of or behind the flashed square and were asked to guess if uncertain. Conditions were mixed randomly within blocks of trials, and each block consisted of equal numbers of four kinds of no-change displays: behind, aligned, and ahead continued-motion displays and stopped-motion (baseline) displays.

Part 2 measured perceived alignment of the disc and the flashed square in both no-change and change displays. Observers reported whether any disc (regardless of size) appeared aligned with the flash at the time of the flash (yes or no). Conditions were mixed randomly within blocks of trials, and each block consisted of equal numbers of no-change, small-change, and large-change displays. In addition, to minimize response biases, we divided the displays equally among continued-motion behind, aligned, and ahead (Figs. 1a and 1b) and stopped-motion, or baseline (Fig. 1c), displays. However, only the data from the continued-motion aligned and baseline displays are reported because these trials are the most directly comparable insofar as the disc was aligned with the flash at the time the flash was presented.

Part 3 measured the number of discs that were visible in each condition. Observers reported whether one or two discs were present simultaneously with the flash. The displays had the same composition as in Part 2.

RESULTS

Part 1

Figure 2a shows the mean proportion of trials on which the moving disc was reported as ahead of the flash. These data show the standard FL for continued motion and its elimination for stopped motion. When the moving disc was physically behind the flash, reports that it was ahead of the disc were below .50, indicating that perception was generally consistent with the actual display. However, when the moving disc was physically aligned with the flash, reports that it was ahead were the majority, and the proportion of "ahead" reports was about the same as when the moving disc was physically ahead of the flash. In stopped motion, when the flash and disc terminated together, observers were equally likely to report that the disc was ahead of or behind the flash, indicating that the two events were seen as aligned.[1] Statistical tests confirmed that "ahead" responses occurred reliably more often in the aligned condition than in both the behind condition, $t(9) = 15.79$, $p < .01$, $\eta^2 = .965$, and the stopped-motion condition, $t(9) = 6.59$, $p < .01$, $\eta^2 = .828$, but not the ahead condition, $t(9) = 0.16$, $p > .05$, $\eta^2 = .003$. Also, response rates in all conditions other than stopped

[1]A three-alternative forced-choice version of this experiment in which subjects reported "ahead," "behind," or "aligned" following each trial yielded analogous results.

motion were reliably different from chance (.50), behind: $t(9) = 4.30$, $p < .01$, $\eta^2 = .673$; aligned: $t(9) = 14.55$, $p < .01$, $\eta^2 = .96$; ahead: $t(9) = 3.88$, $p < .01$, $\eta^2 = .626$; stopped motion: $t(9) = 0.35$, $.05 < p < .06$, $\eta^2 = .014$.

Part 2

Figure 2b shows the mean proportion of trials, for stopped-motion (baseline) and continued-motion aligned conditions, on which the moving disc was reported as aligned with the flash. The baseline data show that observers correctly saw one of the two discs as being aligned with the flash in all three change conditions, confirming that regardless of size, discs were reported as aligned when they were indeed physically aligned and there was no additional motion frame. In contrast, the data for the continued-motion aligned displays show that when the motion continued for a single frame following the flash, reports that the disc was aligned were strongly influenced by the disc's size change. When there was no size change, the proportions of "aligned" and "not aligned" were about equal. With a small change in size, the proportion of "aligned" reports increased to .65, and with a large change in size, this proportion increased to .80, approaching the .90 rate in the corresponding baseline trials. An analysis of variance (ANOVA) examining motion (baseline, continued-motion aligned) and change (none, small, large) confirmed a significant interaction, $F(2, 18) = 8.14$, $p < .01$, $\eta^2 = .475$, in addition to main effects of both motion, $F(1, 9) = 33.23$, $p < .01$, $\eta^2 = .787$, and change, $F(2, 18) = 4.80$, $p < .01$, $\eta^2 = .348$. Specific comparisons revealed that although a significantly smaller proportion of displays were reported as aligned on continued-motion trials than stopped-motion trials in the no-change condition, $t(9) = 5.05$, $p < .01$, $\eta^2 = .739$, this trend was weaker in the small-change condition, $t(9) = 2.631$, $p < .05$, $\eta^2 = .435$, and only approached significance in the large-change condition, $t(9) = 2.13$, $p > .05$, $\eta^2 = .335$.

A control experiment was conducted to rule out the possibility that the FL was reduced simply by the transient stimulation of the change, rather than by the change to the moving object per se. The fixation point was a disc the size of the standard moving disc (i.e., 1.0° radius). The design was identical to that of the main experiment, with three exceptions: (a) Only no-change and large-change conditions were tested; (b) when the change occurred, it always occurred at the time of the flash; and (c) the fixation point underwent a large change (i.e., from 1.0° to 0.3° radius) on half the trials at the time of the flash. The irrelevant transient at fixation failed to eliminate the FL in the no-change condition. Without the irrelevant transient, the proportions of "aligned" responses on continued-motion aligned and stopped-motion trials were .45 and .99, respectively. With the transient, the corresponding proportions were .35 and .97. Thus, rather than being disrupted, the FL was even slightly larger when there was a transient than when there was none. An ANOVA examining irrelevant transient (present, absent) and motion (stopped-motion baseline, continued-motion aligned) revealed a marginally significant interaction, $F(1, 9) = 4.66$, $.05 < p < .06$, $\eta^2 = .341$, and significant main effects of both motion, $F(1, 9) = 73.3$, $p < .01$, $\eta^2 = .891$, and transient, $F(1, 9) = 8.75$, $p < .01$, $\eta^2 = .493$. Thus, the near elimination of the FL in Part 2 of the main experiment cannot be attributed simply to the transient introduced by the change to the moving object.

Part 3

Figure 2c shows the mean proportion of trials, for stopped-motion (baseline) and continued-motion aligned conditions, on which two discs were reported as visible at the time of the flash. The baseline data show that observers only rarely reported two discs when there was only one disc in every motion frame (.04), but reported two discs frequently when there was either a small disc (.81) or a large disc (.93) presented simultaneously with the original disc in the final frame of motion. The continued-motion aligned data showed a different pattern of "two discs" reports over changes in disc size. When there was no change in size, reports of two discs were again quite rare (.09). However, when there was a small change in size, these reports began to increase (.40), and when there was a large change in size, reports of two discs were in the majority (.81), even though only one disc was ever present in a single frame of motion in these conditions. An ANOVA examining motion (stopped-motion baseline, continued-motion aligned) and change (none, small, large) confirmed a significant interaction, $F(2, 18) = 24.38$, $p < .01$, $\eta^2 = .730$, in addition to main effects of both motion, $F(1, 9) = 22.26$, $p < .01$, $\eta^2 = .712$, and change, $F(2, 18) = 162.77$, $p < .01$, $\eta^2 = .948$. Specific comparisons revealed that the trend for "two discs" responses to occur more often on stopped-motion, baseline trials (when there were actually two discs present) than on continued-motion aligned trials (when there was only one) was weaker in the large-change condition, $t(9) = 2.48$, $p < .01$, $\eta^2 = .406$, than in the small-change condition, $t(9) = 6.276$, $p < .01$, $\eta^2 = .814$. Not surprisingly, the proportion of "two discs" responses was not reliably different for the stopped-motion and continued-motion trials in the no-change condition, $t(9) = 1.69$, $p > .05$, $\eta^2 = .241$.

DISCUSSION

This study points to the critical role of object representations in the FL in that disrupting the continuity of the moving object, by transiently altering its size, nearly eliminated the FL and caused the perception of multiple objects. We have obtained similar results when, instead of changing the size of the disc, we have changed the disc's color and luminance from white to blue. We propose that these large and transient changes of the moving disc are interpreted by the visual system as evidence for two separate objects (see also Rauschenberger, 2003). When the original disc then reappears in a new location, its current position or color information is updated, and, critically, this information is not assigned to the new disc. Thus, the new disc is spared from the normal process of object updating, and its spatial position can be perceived accurately.

In our opinion, these findings point to the FL as a powerful tool for studying the object-updating process that is normally used to support a stable perceptual experience. The appearances of objects are constantly changing over time: Objects change their position relative to one another as the observer moves; luminance values vary as lighting and shadow conditions change; and even categorization of objects changes as more information becomes available. Sometimes an object really is first "a bird," and then "a plane," even if it rarely becomes "Superman." The twin goals of perceptual stability and flexibility in the face of change are both met when updating is mediated through object representations, rather than through individual locations or larger patterns in the scene. New information overwrites old information if and only if it is perceived as emerging from the object from which the old information was registered.

The general idea that vision is organized in terms of objects is not new. *Object files* (Kahneman & Treisman, 1984; Kahneman, Treisman, & Gibbs, 1992), *fingers of instantiation* (FINSTs; e.g., Pylyshyn, 1989, 2001; Pylyshyn & Storm, 1988), *intermediate representations* (Ullman, 1984), and *proto-objects* (Rensink, 2000) are all proposals aimed at describing this aspect of vision. Of these, the object-file proposal bears the closest resemblance to the view we espouse, because it predicts the perceived continuity of objects as they move and change over time. Yet it also differs notably in several ways. First, whereas the object-file proposal can accommodate semantic categorization, the representations we studied in the present experiment need only reflect the current contents of awareness, which can be fleeting and changing, and in many cases may never reach a semantic interpretation. Second, a major emphasis of object files is the review process, whereby information that is associated with the current state of the object is compared with memory for an earlier state of the object. In contrast, updating in the FL illusion provides little opportunity for consultation with memory, because the old information is constantly being overwritten. Finally, object files are initiated and maintained through the allocation of attention, whereas the representations discussed here are established passively, on the basis of scene-parsing processes that are likely governed by the spatiotemporal structure of the stimulus.

The critical role played by spatiotemporal cues in organizing dynamic scenes is well documented (see Scholl, 2001, for a review). One of the rules for this process seems to be that object continuity is maintained across a wide range of property changes, provided there is smooth motion of the object (e.g., Kolers & Pomerantz, 1971). It is therefore notable that an abrupt change in the size or color of a smoothly moving object in our paradigm is sufficient to disrupt the history of one object representation and force the establishment of a new one. One way to reconcile this new finding with previous ones is to propose that only property changes that are substantial, abrupt, and transient will serve to disrupt object continuity (see Rauschenberger, 2003, for discussion of similar issues). Regardless, this issue deserves further study.

Finally, we note that the view presented here is consistent with nearly all current accounts of the FL, which have focused on (a) visual integration over a temporal window (Eagleman & Sejnowski, 2000; Krekelberg & Lappe, 2000), (b) visual extrapolation (Nijhawan, 1994, 2002; Schlag & Schlag-Rey, 2002), or (c) the relative speed of neural signals from moving and static stimuli (Whitney, 2002; Whitney & Murakami, 1998; Whitney et al., 2000). Our findings are not presented as yet another competing theory, but rather as an insight into the FL at a level of analysis that has not yet been considered, namely, the role of perceptual objects in FL sequences. Specifically, the findings suggest that perceptual organization of the display in terms of objects is critically important, because the illusion occurs only when the continuity of the moving object is preserved. Conversely, the illusion is eliminated when object continuity is disrupted. Along with the results from backward masking (Enns, 2002; Lleras & Moore, 2003; Moore & Lleras, in press), these findings suggest that visual updating operates at the level of object representations.

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