

The path of least persistence: Object status mediates visual updating

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Abstract

On what basis does the visual system use recently sampled information to update existing representations of the world? One possibility is that representations are updated through an image-based point-for-point replacement process. An alternative possibility is that representations are updated on the basis of perceptually organized units that reflect objects in the scene rather than locations within the visual field. We report a new effect involving a modulation of visible persistence that seems to support this alternative possibility. In particular, we show that a moving stimulus leaves a visible trace of itself when it undergoes an abrupt and transient change in size but does not do so when the stimulus does not change. Further we show that this effect is substantially reduced when a scene-based reason for the abrupt change in size is provided (i.e., the object is shown to be passing behind an occluding surface that has a very small window in it through which the stimulus shows briefly). We suggest that the visible persistence in the face of change reflects a disruption of the normal updating process which is object-based and disrupted because of the discontinuity of the object. Providing a scene-based reason for the discontinuity allows the object representation to be maintained, and thus does not result in a disruption of the updating process.

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1. Introduction

The visual system samples information more-or-less continually. As a consequence it is faced with the problem of how to use newly sampled information to update existing representations of the world. One possibility is that representations are updated through a point-for-point image-based process, whereby each “pixel” of the representation is updated independently. Such a mechanism would, by definition, be blind to the organization of the scene, such as what objects are in the scene, where they are relative to each other, and whether or not they are moving. Alternatively, representations may be updated through an object-based process, such that the perceptual organization of the scene is taken into account, and changes to the representation are made only insofar as they are perceived as

occurring to a particular object within the represented scene. The distinction between image-based and object-based updating is analogous to differences between pixel-based “paint” programs and object-based “draw” programs for computer graphics. In an image-based paint program, editing something on one object can inadvertently alter another object. In contrast for draw programs, objects are selected and edited independently. Objects other than the one that is selected are protected from changes that are made to the selected object, even if the two objects overlap each other in the image space.

Boundary conditions can be placed on likely answers to the question of how visual representations are updated, which differ depending on the level of representation in question. At one extreme is the registration of new light information on the array of photoreceptors in the retina; here updating is almost certainly image based. At another extreme is the registration of changes to long-term representations like changes in the appearance of a friend whom you are seeing for the first time in many years; here,

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updating is almost certainly object based. For dynamic online vision like viewing a ball roll across the floor and pass behind a table leg, however, the answer is less obvious.

Image-based solutions are appealing because they can be computationally simple and because they can be implemented easily within models that embody the retinotopic registration of information in different brain areas. The theoretical appeal of image-based updating is evidenced by the fact that it has been incorporated into many models of visual processing, ranging from those concerned with perceptual interference between stimuli (e.g., Breitmeyer & Ganz, 1976; Breitmeyer, Ro, & Ogmen, 2004; Growney, Weisstein, & Cox, 1977; Keyser & Perrett, 2002; Kovacs, Vogels, & Orban, 1995; Scheerer, 1973; Spencer & Shuntich, 1970), perceptual integration over time (e.g., Coltheart, 1980; Di Lollo, 1980), spatial attention (e.g., Eriksen & St-James, 1986; Posner, 1980), object recognition and visual memory (e.g., Logan, 1988; Tarr & Bühlhoff, 1998), and within models of *motion deblurring*, the apparent reduction of visible persistence that accompanies objects in motion (Anderson & van Essen, 1987; Hammett, Georgeson, & Gorea, 1998).

Despite the appeal of image-based updating, this alternative would carry considerable cost for later, higher-order processing. Because such updating would occur without regard to the organization of the scene in terms of surfaces and objects, many important distinctions would be lost with each resampling cycle. Image-based updating would fail, for example, to maintain region assignments to figure vs. ground, edge assignments to luminance change vs. surface orientation, as well as associations between discontinuous regions of a surface caused by occlusion. Given the importance of organized representations for disambiguating the retinal image, image-based updating cannot be the only solution to the problem of representational updating within the visual system.

Here, we report evidence that even at apparently early levels of representation, visual representations are updated on the basis of the perceived organization of the scene, a process we call *object-mediated updating*. The general idea is that, if currently sampled information is perceived as deriving from an object that is already represented in the scene, then it will be used to update that object representation. In contrast, if it is perceived as deriving from a different object, then the original object representation will be 'spared' from updating and will remain unchanged in the face of new sensory information. Finally, if the information is perceived as deriving from a new object, then it may elicit the establishment of a new component object of the represented scene. Notice that in any given sampling cycle, an old object could be in a new location and a new object could be in a location where an old object had been before. In this way, object-mediated updating is dissociable from image-based updating.

Evidence for object-mediated updating derives in part from an effect called *change-related persistence*. The basic phenomenon was reported by Moore and Enns (2004)

and is illustrated in Fig. 1a. When a moving stimulus undergoes an abrupt change in some attribute, such as size, it can cause the perception of two objects, leading to the simultaneous appearance of the original, unchanged object and the changed object (a demonstration is available at <http://viplab.psych.psu.edu/cathleen/demos.htm>). We interpret this effect as indicating that the abrupt change was too great for the perceptual system to tolerate as having occurred within a single object over the given period of time. To accommodate the abrupt change, therefore, a new object representation is established. Because the new object is different from the original, the representation of the new object is spared from updating (i.e., it is not

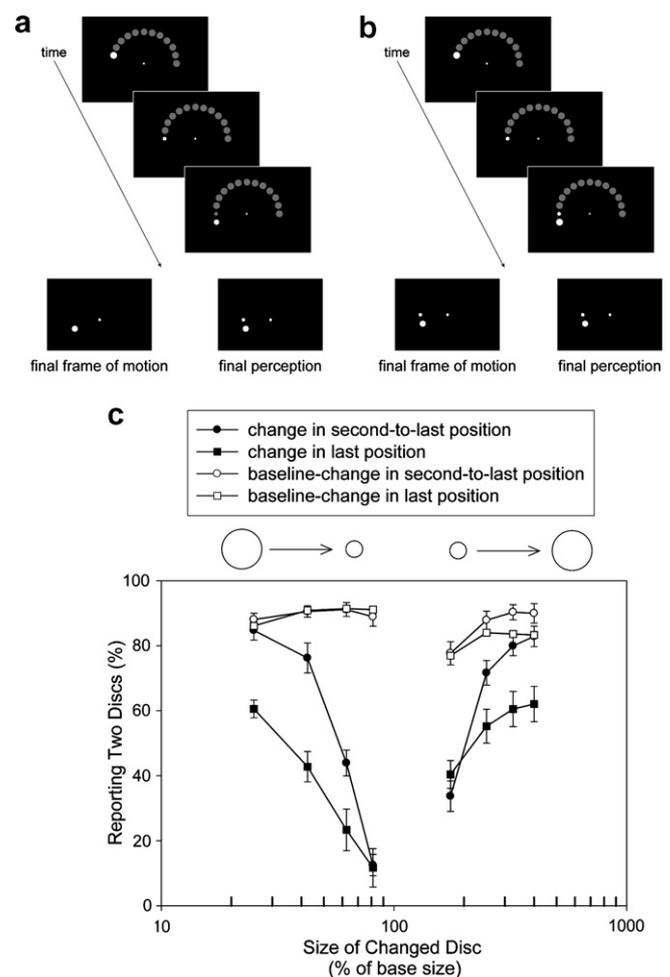


Fig. 1. (a) Illustration of change displays in Experiment 1. Observers fixated the central fixation dot. (b) Illustration of baseline displays in Experiment 1. (c) Data from Experiment 1 for the small-to-large group (left) and large-to-small group (right) separately. Error bars indicate the standard error of the means. Change-related persistence is reflected in the difference between the filled symbols and the corresponding open symbols. The conditions in which they are closer together (i.e., the conditions of greater size change), shows that observers were more likely to report having seen two discs when there was only one present (filled symbol). For those conditions in which the filled and corresponding open symbols are the same, it indicates that observers could not distinguish between the illusory presence of two discs (filled symbol) and the physical presence of two discs (open symbol).

overwritten) by subsequent information that is perceived as a continuation of the original object. Thus, two objects are perceived, the new one with the changed attribute and the original one with the original attribute. Here, we tested this interpretation of change-related persistence.

2. Experiment 1

In this first experiment, we measured change-related persistence for a moving disc that underwent an abrupt change in size while varying the magnitude of the size change and when the change occurred during the path of motion. A moving disc was presented in apparent motion (Figs. 1a and b). On each trial, it started at one of four locations (0, 90, 180, 270) and moved for 90, 180, 270, or 360 degrees along a circular path in either a clockwise or counter-clockwise direction. On change trials (Fig. 1a), the disc was presented at some percentage of the original disc's size in either the second-to-last position or in the final position (not shown) of the motion path. For different groups, the change was from a large to a small disc or from a small to a large disc (not shown). Observers reported whether they perceived one or two discs at the end of the motion display. On baseline trials (Fig. 1b), there were physically two discs presented in the final frame of the motion display corresponding to the sizes and positions of the experimental conditions. Comparing change to baseline conditions provided a comparison of the experience associated with the illusion of two objects caused by abrupt changes with the experience of two objects actually present simultaneously.

2.1. Methods

2.1.1. Equipment

Stimuli were presented on a 17-in. color monitor set at a resolution of 1024×768 with a refresh rate of 72 Hz. The experiment was controlled by an IBM-compatible PC using MATLAB (version 6.5 release 13) software with the Psychophysics Toolbox (Win Version 2.54) extensions (Brainard, 1997; Pelli, 1997).

2.1.2. Stimuli

A white disc (82.6 cd/m^2) was presented on a dark (0.2 cd/m^2) background following a circular path of motion that was centered around a central fixation point which was 0.25 degrees of visual angle (dva) at an eccentricity of 8.2 dva (see Figs. 1a and b). The disc first appeared randomly at one of four locations (0, 90, 180, 270 degree positions) and moved for 90, 180, 270, or 360 degrees along a circular path in steps of 15 degrees randomly in either a clockwise or counter-clockwise. Each frame of motion lasted for 70 ms, and there was no time in between presentations of the disc. The base disc diameter was 1.50 dva for one group of observers (large-to-small) and was 0.38 for the other group of observers (small-to-large group). The final three frames of motion are

illustrated in Figs. 1a and b for the change and baseline conditions, respectively. The gray discs in the figures indicate positions of the disc in the preceding frames. For change trials (Fig. 1a) the disc underwent a change in size by some percentage indicated on the abscissa of Fig. 1c in the second-to-last or last frame of motion. Baseline trials (Fig. 1b) were the same as change-trials except that the final frame of motion included both the changed disc and the unchanged disc in the two final positions of the motion path.

2.1.3. Task and procedure

Observers participated in a single session that lasted approximately 1 h. Following the informed-consent process, they were provided with written and oral instructions regarding the task. The task was to report whether they perceived one or two discs at the end of the trial by making one of two key presses on the keyboard. There was no time pressure to make a decision. They then completed one block of practice trials in which feedback was provided to give them a sense of the decision process. In particular, for this first block, if observers chose "one" on a baseline trial, which physically included two discs at the end of the trial, they received a written message "Oops, there were two discs on that last trial". No feedback was given either way on change trials. After the practice block no feedback was given. Observers were encouraged to ask questions to clarify the task during practice. Following this explicit practice, observers participated in 11 more blocks of trials, the first of which was discarded as additional practice. A total of 20 observations per condition per observer were obtained.

2.1.4. Observers

Thirty-six adults served as observers, 18 in each of the two groups. All observers reported normal or corrected-normal visual acuity and color vision. All were naïve as to the purpose of the experiment.

2.2. Results and discussion

The mean percent of trials on which observers reported seeing two discs at the end of the motion sequence are shown in Fig. 1c for change (filled symbols) and baseline (open symbols) conditions separately. The data on the left are from the big-to-small change group; data on the right are from small-to-big change group. Evidence of change-related persistence is clear in these data. In particular, in none of the conditions indicated by the solid point were their physically two discs in the display, yet for some of the conditions, observers reported seeing two discs on a large percentage of the trials. Moreover, the degree to which change-related persistence occurred was modulated both by the magnitude of the change and by the time of the change within the motion stream.

Observers reported seeing two discs on a high percentage of trials in all of the baseline conditions (open

symbols). However, they also often reported seeing two discs in change conditions (filled symbols), even though there was never more than one disc in the display at the same time. Within-subjects analyses of variance ($\alpha = .05$) were conducted and are reported separately for the two groups of subjects. There was a reliable main effect of change vs. baseline conditions [main effect: $F(1,17) = 197.53$, $p < .001$ for big-to-small group, $F(1,17) = 39.47$, $p < .001$ for small-to-big group]. This difference was greater for larger magnitudes of change than for smaller changes [change vs. baseline \times magnitude-of-size-change: $F(3,51) = 31.95$, $p < .001$ for big-to-small, $F(3,51) = 114.5$, $p < .001$ for small-to-big]. Similarly, this difference was greater when the change occurred in the second-to-last position than in the last position of the motion stream [change vs. baseline \times time-of-change $F(3,51) = 39.63$, $p < .001$, $F(3,51) = 6.53$, $p = .001$]. Finally, the three-way interaction was reliable [$F(3,51) = 15.10$, $p < .001$ for big-to-small, $F(3,51) = 9.22$, $p = .001$ for small-to-big] indicating that the two factors of degree of change and time of change acted together to influence the extent to which two discs were perceived when there was only one present.

In sum, greater magnitude of change and greater frequency of change within a short period of time yielded a

greater tendency to perceive two objects where there was only one. These are exactly the conditions under which the object-mediated updating hypothesis predicts that new object representations will be required to accommodate the changing stimulation and therefore in which two objects will be perceived.

3. Experiment 2

The results of Experiment 1 are consistent with an object-mediated updating account of change-related persistence. In Experiment 2 we tested the hypothesis that change-related persistence depends on the organization of the scene in terms of objects directly. The general strategy was to provide a scene-based explanation for why the change in image-size occurred within a single object. In particular, we provided a perceptual attribution for why the abrupt change occurred in the image while still indicating a single object. Such an attribution should decrease the likelihood of requiring the establishment of a new object representation, and therefore under the object-mediated updating account, decrease change-related persistence. Fig. 2a illustrates the scene-based reason for the change

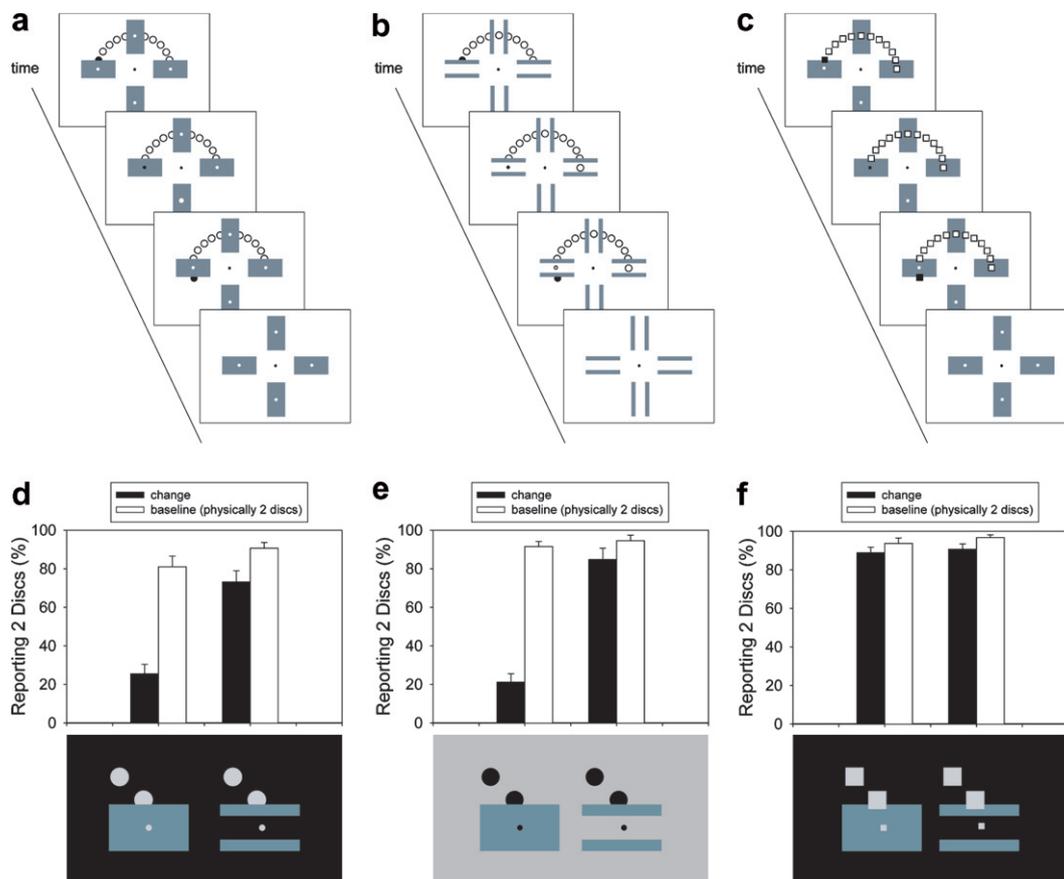


Fig. 2. (a) Illustration of the final four frames of motion in the porthole condition in Experiment 2. (b) Illustration of the slats control condition in Experiment 2. (c) Illustration of just the porthole condition in Experiment 2c. (d) Change (black bars) and baseline (white bars) data from Experiment 2a. Error bars in all cases indicate the standard error of the mean across observers. As indicated by the sample displays, porthole data are on the left and slats data are on the right. (e) Baseline and change data from Experiment 2b. (f) Baseline and change data from Experiment 2a.

in size that was used. The moving disc was shown slipping behind an occluding surface with a “porthole” through which the disc appeared as it passed behind the surface. Because the holes were small and only part of the disc was visible, there was an abrupt change in the size of the image of the disc at the time that it showed through the porthole. However, given the organization of the scene, this change should be attributed to the rest of the disc being occluded. Given that attribution, there would be no need to establish a new object representation in response to the change in size and so little or no change-related persistence should be experienced. Fig. 2b illustrates the control condition in which there were also occluding surfaces within the path of motion, but they were positioned so as to not occlude any of the disc at the time of the change in size. They therefore provided no scene-based reason for why the image of the disc changed.

3.1. Methods

3.1.1. Stimuli and equipment

Experiment 2 was conducted using the same equipment as Experiment 1. The discs and motion parameters were the same as for the big-to-small group of Experiment 1, and changes always occurred in the second-to-last position of the motion stream. In addition, displays included gray (14.0 cd/m^2) rectangles that depicted additional surfaces in the “scene”. For the porthole condition (see Fig. 2a), there were four 2.64×5.29 dva rectangles with central 0.38 dva diameter portholes (i.e., same color as dark background). The rectangles were centered at the 0, 90, 180, 270 degree positions along the circular path. The rectangles at the 0 and 90 degree positions were oriented horizontally, whereas those at the 180 and 270 degree positions were oriented vertically. For the slats condition (Fig. 2b), pairs of parallel thinner (0.8×5.29 dva) occluders were aligned with the same positions as the outer borders of the occluders in the porthole condition. When the disc and occluder regions intersected, the disc was shown “clipped” as though part of it were slipping behind the occluder. When the disc was in the position of the porthole in the porthole condition, the porthole was filled in with the same color as the disc as though the disc were behind the occluder and part of the disc was showing through the opening. Discs were white (82.6 cd/m^2) on a dark (0.2 cd/m^2) background in Experiment 2a and black (0.2 cd/m^2) on a light-gray (30.2 cd/m^2) background in Experiment 2b. Finally, in Experiment 2c, white 1.5×1.5 squares were used instead of discs, and they were not clipped when the rectangles and squares intersected so that they appeared as though they were traveling in front of the occluding surfaces rather than behind s (see Fig. 2c). The squares were white (82.6 cd/m^2) on a dark (0.2 cd/m^2) background.

3.1.2. Task and procedure

The task and procedure was essentially the same as Experiment 1. Observers reported whether they saw one

or two discs (or squares in Experiment 2c) at the end of the motion sequence. They completed one block of practice trials in which feedback was provided on baseline trials only. They then completed 7 more blocks of trials and data were kept from the final 6 blocks. This results in 48 observations per condition.

3.1.3. Observers

Three groups of adults (age range 18–27) served as observers in Experiments 2a ($N = 18$), 2b ($N = 15$) and 2c ($N = 18$), respectively. All observers reported normal or corrected-normal visual acuity and color vision and all were naïve as to the purpose of the experiment. None of the observers had participated in Experiment 1.

3.2. Results and discussion

The results support an object-mediated updating account of change-related persistence. Data from Experiments 2a and 2b are shown in Figs. 2d and e, respectively. These experiments were identical except that discs were white on a dark background in 2a and dark on a light background in 2b. In both experiments, observers were less likely to report seeing two discs when there was only one in the display (i.e., show evidence of less change-related persistence) in the porthole condition than in the slats condition [change vs. baseline \times occluder-type Experiment 2a: $F(1, 17) = 50.24$, $p < .0001$, Experiment 2b: $F(1, 14) = 79.03$, $p < .0001$]. Experiment 2c used the same display elements, but they were organized in such a way that they should not have provided a scene based attribution for the change in image size, and therefore, should not have reduced change-related persistence. In particular, the moving object (a square in this case) was shown to pass in front of the surfaces rather than behind them (Fig. 2c). No modulation of change-related persistence was expected under these conditions under an object-mediated updating account of change-related persistence. Indeed, consistent with this expectation, observers reported seeing two discs when there was only one in the scene as often in the porthole condition as in the slats condition (change vs. baseline \times occluder-type interaction $F(1, 17) = 0.14$, $p = .7129$).

4. General discussion

The fact that such a fundamental aspect of perception—the presence or absence of an additional object—can be modulated on the basis of perceived scene organization indicates that even early (both temporally early and functionally early) representations are updated not in an image-based manner, but in a manner that respects and utilizes the organization of the scene in terms of its component objects. Thus, despite the theoretical appeal of image-based updating, it seems likely that updating becomes object-based very early within the processing stream.

What in particular is causing change-related persistence? We suggest that change-related persistence reflects

an object-based release from motion deblurring. It is well known that when a stimulus is presented briefly, visible persistence can occur; that is the stimulus can remain visible for up to about 150 ms after the offset of the physical stimulus, depending on a variety of specific conditions (see Coltheart, 1980 for a review). If, however, a given stimulus is presented for exactly the same amount of time but as a single frame in the context of an apparent motion sequence (i.e., it is preceded and/or followed a brief time later by another stimulus a short distance away), then the duration of the visible persistence can be reduced considerably. This reduction in visible persistence has been referred to as *motion deblurring* (Burr, 1980), and it is believed to reflect an active suppression of the visible persistence that would normally have occurred outside of the context of the apparent motion sequence (Di Lollo & Hogben, 1987). The existence of motion deblurring seems to be important to our experience of crisp perceptions of the world despite the fact that images of objects are constantly smearing across our retinæ as they and we move (Burr & Morrone, 2004).

In the context of the current work, we suggest that an abrupt change to an object in motion disrupts this active suppression process, and that change-related persistence reflects the “standard” visible persistence that occurs if it is not suppressed in the context of a motion sequence. Within the context of the present study, which has demonstrated that change-related persistence is object-based, it follows that motion-deblurring is itself a result of an object-based process. Such a conclusion presents a challenge to standard explanations of motion-deblurring which are almost all based on image-based mechanisms (e.g., Anderson & van Essen, 1987; Hogben & Di Lollo, 1985; Purushothaman, Ogmen, Chen, & Bedell, 1998; but see Francis & Grossberg, 1996).

Object-mediated updating is suggested as a mechanism that can be accommodated within several existing, broad theories of visual processing (Carpenter & Grossberg, 2003; Di Lollo, Enns, & Rensink, 2000; Kahneman, Treisman, & Gibbs, 1992; see Francis & Grossberg, 1996 for a description of hypothetical neural circuitry that can account for how scene organization can interact with the mechanisms that give rise to visible persistence). We envision object-mediated updating as a specific mechanism that fits within this broader theoretical framework that is concerned with visual object representations. The constructs of *object files* (Kahneman & Treisman, 1984; Kahneman et al., 1992), *fingers of instantiation* (e.g., Pylyshyn, 1989, 2001; Pylyshyn & Storm, 1988), *object tokens* (Kanwisher, 1987) and *proto-objects* (Rensink, 2000) are all proposals aimed at describing object-based aspects of vision (see Kanwisher & Driver, 1992; Scholl, 2001a, 2001b for reviews of some aspects of this work). Of these the object-file framework is both the most frequently invoked in the literature and the one in which our ideas about object-based updating fit most neatly.

Object files are hypothetical constructs at an intermediate level of vision; positioned mid-way between an unorganized mosaic such as the image projected onto the retina and long-term representations that are associated with specific semantic information (e.g., my cat and my chair). Within the object-file framework, three different processes give rise to a changing object being represented as a single continuous object. First, *correspondence* is determined such that an object in the current display is marked as either a new object or as an old object in a new location. Second, if an object is an old object at a new location, a *review* process is applied such that the information that had already been associated with that object is retrieved from longer-term storage. Third, an *impletion* process integrates current and retrieved information to yield a perception of a continuous object that changes or moves.

Within this framework, object-mediated updating corresponds to the process that is a combination of the correspondence and impletion components. These components capture the idea that perceiving a stimulus at one time as the same object as a stimulus that appeared at another time (correspondence) results in an integration of information from those two stimuli (impletion). Previous research that has used the object-file framework, has primarily been focused on the review process. In particular, researchers have looked for object-specific priming effects, which are premised on the idea that if information has already been associated with a given object it is processed more quickly than when presented with a new object. Our work on object-based updating is concerned with the integration of information in the reverse direction; specifically, we are concerned with how newly sampled information is used (or not used) to change existing active representations. We see the ideas of object-based updating fitting into the object-file framework as a process that governs the integration of information over time for online perception. This is an important component of the object-file framework that has not been a focus of research to date. Finally, a number of studies have investigated when object files are maintained (i.e., the persistence of object files) and when they are not (e.g., Flombaum & Scholl, 2006; Mitroff, Scholl, & Wynn, 2004; Noles, Scholl, & Mitroff, 2005). For example, when an object under goes a violation of cohesion (i.e., connectedness and/or boundedness is disrupted), priming effects that are specifically associated with those objects are disrupted (Mitroff et al., 2004). The link between object-specific priming effects, the main measure that has been used in the object file literature, and change-related persistence is a domain ripe for investigation. The fact that object-specific priming effects can be dissociated from conscious perception of objects in the scene (Mitroff, Scholl, & Wynn, 2005) raises the possibility that the two effects reflect at least partially distinct representations.

In summary, the present study adds to the growing list of visual phenomena that have recently become better understood when considered from the perspective of object-mediated updating, including the effects of

backward masking (Di Lollo et al., 2000; Lleras & Moore, 2003; Moore & Lleras, 2005), the flash-lag illusion (Moore & Enns, 2004) and unconscious response priming (Lleras & Enns, 2004, 2005). We believe that this approach is effective because it provides a basis for studying the manner in which the visual brain creates a sense of stability and order out of the spatial and temporal chaos of its sensory inputs.

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