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Forming and updating object representations without awareness: evidence from motion-induced blindness

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Abstract

The input to visual processing consists of an undifferentiated array of features which must be parsed into discrete units. Here we explore the degree to which conscious awareness is important for forming such object representations, and for updating them in the face of changing visual scenes. We do so by exploiting the phenomenon of motion-induced blindness (MIB), wherein salient (and even attended) objects fluctuate into and out of conscious awareness when superimposed onto certain global motion patterns. By introducing changes to unseen visual stimuli *during* MIB, we demonstrate that object representations can be formed and updated even without conscious access to those objects. Such changes can then influence not only how stimuli reenter awareness, but also *what* reenters awareness. We demonstrate that this processing encompasses simple object representations and also several independent Gestalt grouping cues. We conclude that flexible visual parsing over time and visual change can occur even without conscious perception. Methodologically, we conclude that MIB may be an especially useful tool for studying the role of awareness in visual processing and vice versa.

Keywords: Visual perception; Motion-induced blindness; Gestalt grouping; Segmentation; Consciousness

1. Introduction

We perceive the world in terms of discrete objects and events, and their interactions. The raw input to visual processing, in contrast, consists of an undifferentiated array of features. Accordingly, a considerable amount of visual processing—and of research in vision science—focuses on the formation of object representations. This work has proceeded on many fronts, involving several types of segmentation and grouping cues (for recent reviews, see Kimchi, Behrmann, & Olson, 2003; Palmeri & Gauthier, 2004; Scholl, 2001). Despite this extensive literature, the underlying nature of segmentation and visual-object formation still remains unclear in several respects. One especially important issue is the role of conscious visual awareness in the formation of object representations (and vice versa). While some earlier work argued that unit formation via perceptual grouping cues required attention and awareness (e.g. Mack, Tang, Tuma, Kahn, & Rock, 1992; Rock, Linnet, Grant, & Mack, 1992), more recent work has demonstrated that in some cases grouping can occur even outside awareness (e.g. Chan & Chua, 2003; Driver, Davis, Russell, Turatto, & Freeman, 2001; Mack & Rock, 1998; Moore & Egeth, 1997).

In a recent study of inattentional blindness (Moore & Egeth, 1997), for example, observers had to compare the length of two lines which on each trial were

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superimposed onto a background of black and white discs (which were irrelevant to the task). On a 'critical trial' the discs of one luminance were arranged coherently around the lines to form the classic Ponzo or Müller-Lyer illusions. Observers reported no conscious awareness of the unexpectedly-coherent grouping, but the illusions nevertheless affected the line-length judgments, illustrating a type of grouping without awareness which still affected other aspects of conscious perception.

Inspired by the fact that real-world perception consists of a constantly shifting array of visual input, the experiments reported here explore a related question: can object representations not only be formed but also *updated* in the face of changing dynamic scenes without awareness? To our knowledge, no previous studies have addressed this question. Here we present not only unseen objects, but also unseen *changes* to these unseen objects, which fundamentally alter how the scenes are parsed—for example, connecting two objects into one, or splitting one into two outside of awareness. We thus ask not only whether object representations can be formed outside of awareness, but also whether representations can be *re-formed* and updated in response to unseen visual changes.

We ask these questions by exploiting motion-induced blindness (MIB), wherein salient (and even attended) objects fluctuate into and out of conscious awareness when superimposed onto certain global motion patterns (Bonneh, Cooperman, & Sagi, 2001). This phenomenon does not require any particular expectations, sudden disruptions, or attentional manipulations: instead, MIB gives rise to the striking phenomenology wherein you actually see objects fade away from awareness even while you are looking at them. Whereas previous studies have explored the underlying nature and causes of MIB (e.g. Bonneh et al., 2001; Carter & Pettigrew, 2003; Funk & Pettigrew, 2003; Graf, Adams, & Lages, 2002), here we simply exploit it as a tool for studying object representations. [1]

Two recent studies suggest that other types of visual processing occur during episodes of MIB. In one study, one of two gabor patches was physically removed after observers reported that both had faded from awareness. The remaining gabor, even though unseen, still produced orientation-specific adaptation effects (Montaser-Kouhsari, Moradi, Zandvakili, & Esteky, 2004). In another study, more salient objects were physically removed after perceptually disappearing during MIB. Surprisingly, such disappearances were still detected: in some cases, an image of the object momentarily flashed back into awareness, and this sudden burst of conscious access reflected small changes such as rotation that occurred outside of awareness (Mitroff & Scholl, in press).

In the current experiments, we ask whether a particularly important type of visual processing (the formation and updating of object representations) still occurs with a particularly critical type of visual change (to the underlying segmentation of the stimuli).

2. Experiment 1: Updating object representations

To study object updating during MIB, we utilize the fact that multiple objects tend to fluctuate into and out of awareness independently, whereas parts of a single object leave and reenter awareness together (Bonneh et al., 2001). We explore such differences using a particularly direct manipulation, involving *dumbbells*: based on previous work we expect (and actually find, as described below) that two discs will undergo MIB independently, but that two discs connected into a dumbbell—by a single-pixel line—will tend to undergo MIB together. The primary questions we then ask in this experiment are: (1) When a dumbbell disappears due to MIB, and the connecting line between the discs then physically fades away outside of awareness, will the two discs still reenter awareness together (see Fig. 1a)? (2) Similarly, when two discs eventually disappear perceptually due to MIB, and a connecting line between them physically fades in outside of awareness, will the two discs still reenter awareness independently (see Fig. 1b)?

2.1. Method

Five observers from neighboring laboratories participated. Stimuli were presented on a Macintosh iMac computer using custom software written with the VisionShell graphics libraries (Comtois, 2004). Viewing distance was approximately 40 cm but was unrestricted. The displays contained a central fixation point of two concentric white circles (0.89° and 0.45° in diameter), a grid of blue crosses (13.76° across) which continuously rotated counterclockwise at 470 deg/s, and a bright yellow target object (see Fig. 1). In the *shrinking block*, the target object began as a 'dumbbell'—two yellow discs (0.89° in diameter, 2.98° above fixation, with their centers 1.49° from the vertical midline) connected by a single pixel line. In the *growing block*, the target object was the same except the outermost 0.74° of each side of the line was not drawn, leaving an 'unconnected'

[1] MIB allows us to ask questions that other popular paradigms do not, and may thus prove to be an especially useful tool for studying dynamic aspects of visual awareness. Unlike repetition blindness (e.g. Kanwisher, 1987) and the attentional blink (e.g. Shapiro, Arnell, & Raymond, 1997), for example, MIB does not impose strict timing constraints: targets can remain present for extended periods of time, and undergo dynamic changes. Unlike change blindness (e.g. Rensink, 2002; Simons, 2000), MIB allows observers to indicate their awareness of particular attended objects which can disappear from awareness multiple times. And unlike inattentional blindness (e.g. Mack & Rock, 1998; Most, Scholl, Clifford, & Simons, in press), observers can be tested on more than a single critical trial.

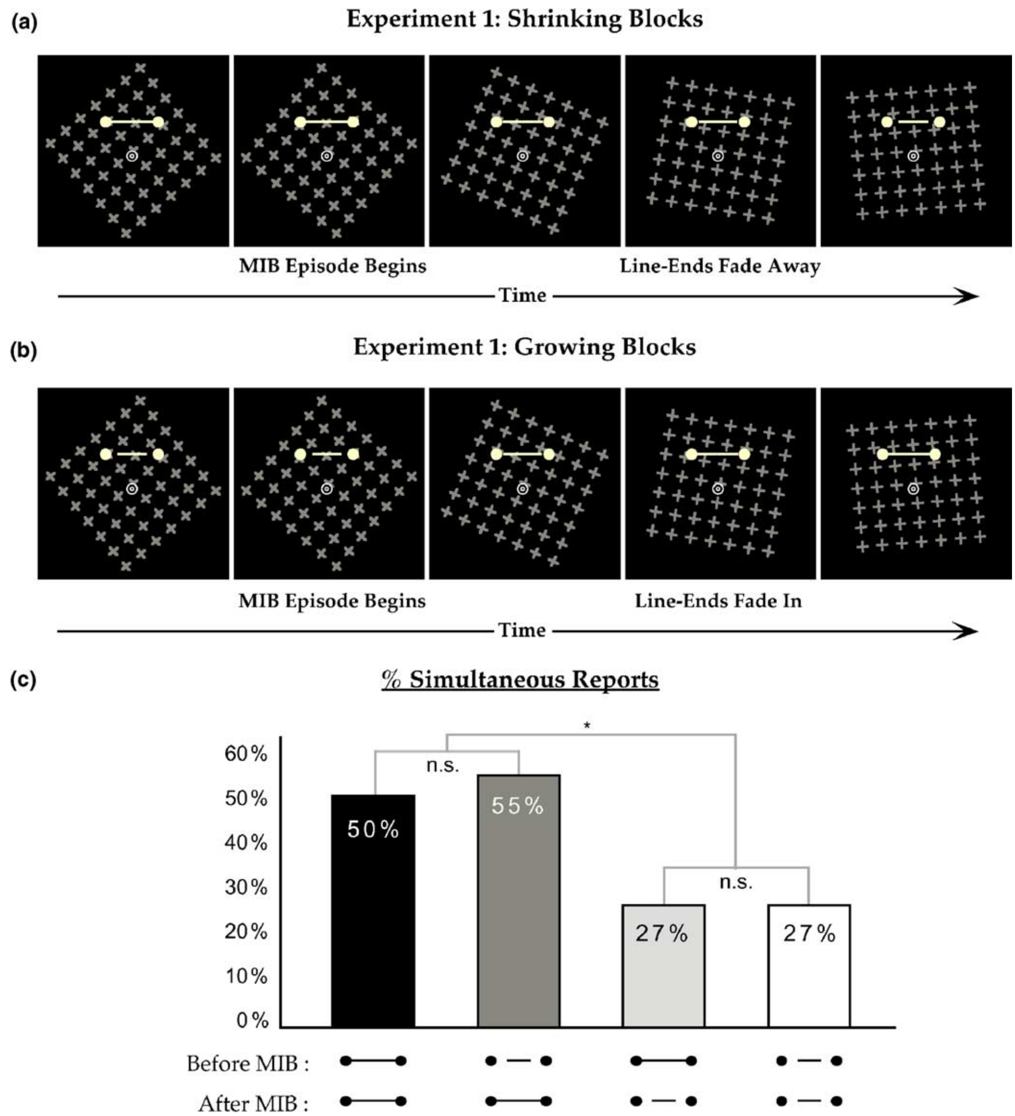

Fig. 1. Methods, stimuli, and results from Experiment 1. (a) In the shrinking blocks, observers fixated while a uniform grid of crosses rotated counterclockwise. After a variable duration, the 'dumbbell' target object would gradually fade from awareness due to motion-induced blindness (MIB). Observers reported their loss of awareness for both discs of the dumbbell (as well as the connecting line) by pressing and holding two keys. Once both keys were pressed, there was a 50% chance that the ends of the dumbbell's connecting line would shrink and fade away gradually over 1000ms. The two discs eventually returned to awareness, and observers indicated this by letting go of the keys. (b) The growing blocks were identical to the shrinking blocks except that observers initially viewed an 'unconnected dumbbell' target object. Once observers lost awareness of the discs and the unconnected line due to MIB, there was a 50% chance that the ends of the line would gradually grow and fade in over 1000ms resulting in a connected dumbbell. (c) After the discs returned to awareness, observers indicated whether the two discs had perceptually reappeared simultaneously or asynchronously. In the no-change baseline conditions, the discs reappeared simultaneously nearly twice as often when connected into a dumbbell. Critically, unseen changes affected object parsing, such that newly-connected discs also reappeared simultaneously more often than newly-unconnected discs—in direct opposition to what observers last perceived.

dumbbell. [2] All images were displayed against a black background in a dark room.

Observers participated in four practice blocks and six 8-min test blocks, alternating between shrinking and growing. During the shrinking blocks, when observers experienced MIB for the entire dumbbell they pressed and held two keys (one for each disc). Once both keys were pressed, there was a 50% chance that the ends of the dumbbell's connecting line would shrink and fade away gradually over 1000ms. The outermost 0.74° on each side of the line gradually decreased in luminance to black and simultaneously shrank inwards. (In the

[2] Previous research using dumbbell stimuli in other paradigms has confirmed that such gaps attenuate or eliminate the grouping effect which is present in fully connected dumbbells (e.g. Scholl, Pylyshyn, & Feldman, 2001). As such, we used small gaps here—instead of fading the entire line in and out—because such changes were less likely to interrupt MIB, and because the subtlety of this manipulation emphasizes the strength of the resulting effects.

other half of such trials, the display did not change.) When observers reported MIB for both discs and the line in the growing blocks, there was a 50% chance that the ends of the line would similarly fade and grow in over 1000 ms. (For demonstrations, see http://www.yale.edu/perception/mib/).

If observers let go of either key before 1000 ms elapsed, the trial was aborted. Otherwise, the two discs eventually returned to awareness, and observers indicated this by letting go of the keys. After the discs returned to awareness, observers pressed one of three additional keys to indicate whether the two discs had perceptually reappeared (a) 'simultaneously'—reentering awareness together, (b) 'definitely asynchronously'—one unequivocally reappearing before the other, or (c) 'slightly asynchronously'—not clearly simultaneous or asynchronous. (Observers could also press a fourth key to abort the trial—and were encouraged to do so liberally—if they had any awareness of the change.) This perceptual report served as our primary dependent measure.

2.2. Results

The percentage of 'simultaneous' responses per condition is presented in Fig. 1c. The no-change trials confirmed that our dumbbell manipulation was effective: the discs simultaneously reentered awareness almost twice as often when connected into a dumbbell than when unconnected (50.21% vs. 26.61%; $t(4) = 3.08$, $p = .037$). The critical comparisons involved the displays changing outside of awareness, and the results clearly show that such changes affected the target objects' reappearances. When initially-independent discs were connected into dumbbells during MIB, they reentered awareness together just as often as when the dumbbell was present throughout the trial (54.79% vs. 50.21%; $t(4) = 0.53$, $p = .625$). Similarly, when initial dumbbells dissolved during MIB, the two discs reentered awareness together no more often than when the discs remained unconnected throughout the trial (26.52% vs. 26.61%; $t(4) = 0.02$, $p = .988$). [3]

2.3. Discussion

These results illustrate that object representations can be formed and updated without awareness: changes made to the displays during MIB effectively caused the visual system to re-parse the targets as single objects (i.e. dumbbells) or multiple objects (two independent discs) without any conscious perception. As a result of this re-parsing, the updated object representations in turn affected how and when the salient target stimuli reappeared. This updating process could have involved processing the change per se, triggering a representational transformation (splitting one object representation into two, or merging two into one). Alternatively, this could reflect ongoing sampling without awareness, such that the object representations are being continually regenerated, without any direct transformation as a result of the change itself (e.g. Hollingworth & Henderson, 2004). In either case, our results show that the object representations formed as a part of conscious perception do not simply persist unchanged during failures of visual awareness. Rather, object representations can be updated or reformed completely outside of awareness of either the objects themselves or the changes made to them.

To our knowledge, the only context in which related manipulations have been tested is with binocular rivalry, wherein different patterns are simultaneously presented to the left and right eyes, and the patterns compete for perceptual dominance such that one rises to awareness while the other is temporarily suppressed (for a review see Blake & Logothetis, 2002). Two studies of binocular rivalry have introduced changes to patterns which were suppressed. In one study (Blake & Fox, 1974) observers failed to reliably detect most changes made to suppressed gratings (e.g. in orientation, spatial frequency, or contrast decrements), and succeeded only for large contrast increments which dramatically increased the energy of the stimulus (see also O'Shea & Crassini, 1981). In another study (Walker & Powell, 1979), changes to the phase, orientation, or spatial frequency of a suppressed grating affected the perceptual alternation rate such that it immediately reentered awareness, but observers often failed to detect the changes themselves.

3. Experiment 2: Updating based on specific grouping cues

The difference between one object (a dumbbell) vs. two objects (separate discs) in Experiment 1 was driven by a particular grouping cue: connectedness. In general, this is how visual 'objects' are formed, but object representations can be independently strengthened or weakened by multiple grouping cues (e.g. Driver et al., 2001; Marino & Scholl, under review). In this experiment we ask whether our results are specific to cues such as connectedness, which intuitively affect object representations directly—or whether similar results can be obtained for other grouping cues which may not change the number of 'objects' present.

[3] We could also measure these effects indirectly via the timing of the release of the two initial keys: one key was assigned to each disc, and so simultaneous reappearances involved releasing the two keys roughly synchronously, whereas asynchronous reappearances involved releasing one key before the other. In all cases these results matched the perceptual reports as described above. In particular, the delay from the release of the first key to the second was shorter when the discs were connected than when unconnected.

Earlier work has demonstrated that perceptually grouped items (e.g. two collinear gabor patches exhibiting good continuation) will tend to undergo MIB together more often than ungrouped items (e.g. two orthogonally oriented gabor patches; Bonneh et al., 2001). Here we ask whether *changes* in such grouping relations made during MIB will affect how such stimuli reenter awareness. As illustrated in Fig. 2, we ask such questions with two classic Gestalt grouping cues (good continuation and proximity) and one more recently proposed cue (common region; e.g. Palmer, 1992). These conditions allow us to explore cues based on the arrangement of internal features (good continuation), the relationships among distinct feature clusters (proximity), and the influence of contextual elements (common region).

3.1. Method

This experiment was identical to Experiment 1, except as noted here. Different groups of five observers participated in the three conditions.

3.1.1. Good continuation

In this condition the background was gray, the rotating grid of crosses was black, and the target objects were two 4 cycle gabor patches (1.49° in diameter). The gabors' centers were 1.86° apart and the rightmost one was 2.97° above and 1.86° to the left of fixation. The gabors began with 45° orientations such that they were angled toward each other (as in Fig. 2a). Once observers reported that both had perceptually disappeared (by pressing and holding two keys), each gabor rotated

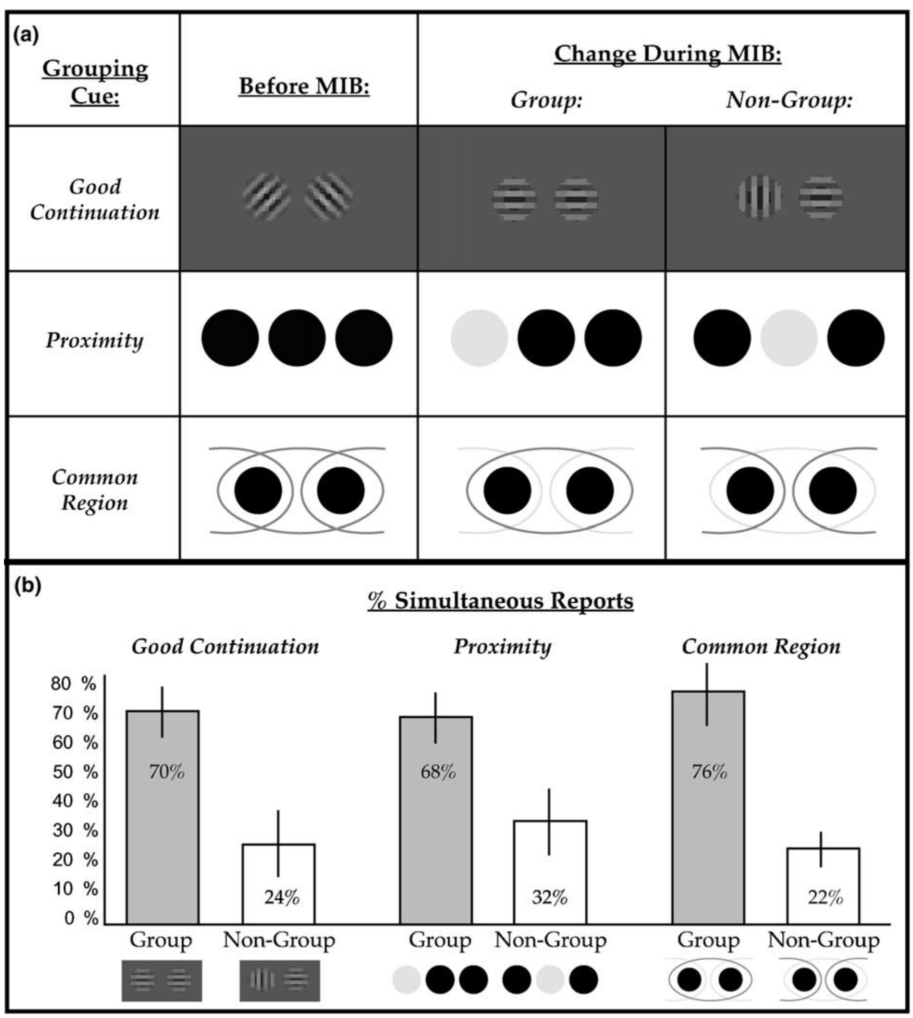

Fig. 2. Stimuli and results for the grouping cues tested in Experiment 2. (a) In the *good continuation* condition, the target objects started as two misoriented gabor patches. Once both gabors faded from awareness due to MIB, they rotated (entirely outside of awareness) into either orthogonal alignment or into perfect alignment (forming a group via good continuation). In the *proximity* condition, the target objects started as three evenly spaced discs. Once all three faded from awareness due to MIB, one disc faded leaving the two remaining discs either separated or grouped by proximity. In the *Common Region* condition, the target objects were two discs surrounded by an oval and two arcs. Once the discs, oval, and arcs faded from awareness due to MIB, either the arcs faded (leaving the two discs grouped within a common region), the oval faded (leaving the discs segmented into separate regions), or nothing faded. (b) For all three conditions, the target objects came back into awareness together more often when they were transformed into a group during MIB.

45° over 800 ms such that they either ended up aligned in either a (horizontally) collinear or orthogonal arrangement. After practice, observers completed three 8-min test blocks.

3.1.2. Proximity

The target objects in this condition were three horizontally aligned bright yellow discs (1.19° in diameter, their centers 1.49° apart). The middle disc was 3.35° above and 5.58° to the left of fixation. When observers reported that all three had perceptually disappeared, one disc faded (decreasing in luminance by 75% over 800 ms). [4] The center disc was twice as likely to fade as the others. Observers were instructed to let go of either key when the first disc reentered awareness, and to assign the second key to the other reappearing disc. After practice, observers completed a single 6-min test block.

3.1.3. Common region

The target objects in this condition were two yellow discs (0.89° in diameter, their centers 1.12° apart), a red outlined oval which surrounded both discs, and two red arcs which separated the discs (see Fig. 2a). The center of the discs, oval and arcs was 3.35° above and 4.83° to the left of fixation. When observers reported MIB for the discs, oval, and arcs, there was a 1/3 chance that the oval would fade (as described in the previous condition), a 1/3 chance that the two arcs would fade, and a 1/3 chance that nothing would fade. After practice, observers completed a single 6-min test block.

3.2. Results and discussion

As is clear from Fig. 2b, the target objects were more likely to reenter awareness together when they became grouped during MIB than when they did not (*good continuation*: 69.68% vs. 23.73%, $t(4) = 3.97$, $p = .016$; *proximity*: 67.54% vs. 31.58%, $t(4) = 3.03$, $p = .029$; *common region*: 76.51% vs. 21.93%, $t(4) = 5.20$, $p = .006$). [5] These results indicate that perceptual groups can be updated outside of awareness, as was indicated for object representations in Experiment 1. That such effects held across such different types of grouping cues suggests that these results reflect a general property of visual parsing, operating at both the level of full-fledged object representations and the level of individual cues to objecthood.

[4] We did not have the fading disc disappear entirely, since our previous work has demonstrated that such disappearances may bring about sudden flashes of awareness which could interfere with ongoing MIB (Mitroff & Scholl, in press).

[5] In the common region condition, the two discs reappeared together 61.43% of the time on the 1/3 of trials where nothing faded. (These results are not depicted in Fig. 2b.) This was significantly different from the separate-region trials ($t(4) = 2.93$, $p = .043$), but not from the common-region trials ($t(4) = 1.30$, $p = .263$). This suggests that the display as a whole was already perceptually grouped from the start of the trial—i.e. that the common-region cue trumped the additional arcs. This in turn suggests that the observed difference between the two fading manipulations (as depicted in Fig. 2b) reflects an effect of the two discs being parsed into separate regions by the arcs (when the oval faded), rather than by the formation of a new group by the oval (when the arcs faded).

4. General discussion

The results of these experiments demonstrate that object representations (and perceptual groups more generally) can be formed and updated without conscious awareness in response to unseen changes to visual scenes. This discovery extends previous research which has demonstrated processing of static visual cues without awareness, and exemplifies the automatic and flexible nature of online object representation. Given that much of the visual world at any moment is unattended and not represented in conscious perception (e.g. Mack & Rock, 1998; Most et al., in press), this ability may be critical for making sense of dynamic visual scenes in real-world perception. In addition, these results indicate for the first time that such implicit processing occurs not only for unattended and unexpected background stimuli, but also for salient and attended objects. In this respect, we suggest that MIB—beyond being a striking phenomenon in itself—may also prove to be a useful tool for studying the role of awareness in visual processing and vice versa.

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