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BRIEF REPORT

Surface feature congruency effects in the object-reviewing paradigm are dependent on task memory demands

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Abstract Perception of object continuity depends on establishing correspondence between objects viewed across disruptions in visual information. The role of spatiotemporal information in guiding object continuity is well documented; the role of surface features, however, is controversial. Some researchers have shown an object-specific preview benefit (OSPB)—a standard index of object continuity—only when correspondence could be based on an object's spatiotemporal information, whereas others have found color-based OSPB, suggesting that surface features can also guide object continuity. This study shows that surface feature-based OSPB is dependent on the task memory demands. When the task involved letters and matching just one target letter to the preview ones, no color congruency effect was found under spatiotemporal discontinuity and spatiotemporal ambiguity (Experiments 1–3), indicating that the absence of feature-based OSPB cannot be accounted for by salient spatiotemporal discontinuity. When the task involved complex shapes and matching two target shapes to the preview ones, color-based OSPB was obtained. Critically, however, when a visual working memory task was performed concurrently with the matching task, the presence of a nonspatial (but not a spatial) working memory load eliminated the color-based OSPB (Experiments 4 and 5). These results suggest that the surface feature congruency effects that are observed in the object-reviewing paradigm (with the matching task) reflect memory-based strategies that participants use to solve a memory-demanding task; therefore, they are not reliable measures of online object continuity and cannot be taken as evidence for the role of surface features in establishing object correspondence.

Keywords Object continuity · Object correspondence · Object files · Object-reviewing paradigm · Spatiotemporal information · Surface features · Visual working memory

The world we perceive is stable and continuous despite changes and disruptions in the visual information resulting from movements of the observer, movements of objects, brief occlusion, saccades, and blinks. To achieve perception of object continuity, the visual system has to establish correspondence between objects viewed across such disruptions. A critical question concerns the nature of the information used by the visual system to solve the problem of object correspondence.

One view claims that object correspondence is based only on the spatiotemporal properties of an object. Theoretically, it follows directly from the object file framework (Kahneman, Treisman, & Gibbs, 1992). Object files are temporary, episodic visual representations that store and update information about objects, and they track objects over time and space. Information about an object (e.g., color) is accessible via object file and, therefore, cannot influence the correspondence process.

Empirical evidence that object correspondence is based only on spatiotemporal information has come from several experiments using the object-reviewing paradigm (Kahneman et al., 1992). In this paradigm, participants view a preview display, which contains two objects (e.g., squares), with a different letter presented in each for a short time. After the letters disappear, the objects move to new locations. A target letter appears in one of the objects, and the participants have to name it. Naming latency is typically shorter when the target letter matches the preview letter that appeared on that same object (congruent condition) than when it appeared on a different object (incongruent condition). This *object-specific preview benefit* (OSPB) is considered a standard index of object continuity. Kahneman et al. found OSPBs

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for congruency by shared location, apparent motion, and explicit motion, but not for color congruency.

Similar results were reported by Mitroff and Alvarez (2007), using a modification of the object-reviewing paradigm, in which the participants had to match the target letter to the preview letters. They found OSPB when the objects moved to their final locations (spatiotemporal condition). When the objects disappeared and reappeared in new locations and surface feature congruency was manipulated (feature condition), no OSPB was observed, regardless of the salience and number of features, suggesting that object correspondence is established only by spatiotemporal continuity; surface features cannot guide object continuity.

Further evidence for the critical role of spatiotemporal information for the perception of object continuity has come from studies of apparent motion, the tunnel effect, and multiple object tracking (see Flombaum, Scholl, & Santos, 2009, for a review).

Other studies, however, have shown that surface features also play a role in guiding object continuity (e.g., Hein & Moore, 2012; Hollingworth & Franconeri, 2009; Moore & Enns, 2004; Moore, Stephens, & Hein, 2010; Richard, Luck, & Hollingworth, 2008). For example, Moore and Enns found that an abrupt change in the size or color of a moving object disrupts its perception as a single object, resulting in a perception of two objects, the original unchanged object and the changed object. Richard et al. found that spatiotemporal and surface features can be used to establish object correspondence across saccade, depending on the saccade target selection (whether it was selected on the basis of its position or its surface feature).

Of particular relevance to the present article are the color congruency effects in the object-reviewing paradigm reported by Hollingworth and Franconeri (2009). They suggested that surface features effects were not found in the object-reviewing paradigm because the salient spatiotemporal discontinuity in the feature condition, which is directly in conflict with an interpretation of object continuity, may have masked an effect of surface feature congruency. To eliminate salient spatiotemporal discontinuity, they introduced spatiotemporal ambiguity by object manipulations during a brief period of occlusion. In a critical experiment, participants were presented with two colored disks. A novel shape appeared in each disk for a short time. Then the disks moved toward the center and disappeared behind an occluder at the same vertical position. When the occluder was removed, the two disks appeared separated vertically, with a target shape in each disk. Participants had to decide whether the two target shapes were the same as the preview shapes or not. The results showed a color-based OSPB, suggesting that object correspondence was established on the basis of a surface feature.

However, Hollingworth and Franconeri (2009) not only eliminated salient spatiotemporal discontinuity, but also used a task that involved unfamiliar shapes and matching two targets to the preview ones. Color-based OSPB was obtained with such a task even under salient spatiotemporal discontinuity (Hollingworth & Franconeri, 2009; Moore et al., 2010), in a clear contrast with the finding of Mitroff and Alvarez (2007), who used a simpler task. Therefore, it is unclear whether the color congruency effects observed by Hollingworth and Franconeri indicate that surface features can guide object correspondence under spatiotemporal ambiguity or, alternatively, that they emerged from a strategy participants adopted to solve a memory-demanding task (see also Moore et al., 2010).

To address this issue, we first examined whether object correspondence can be established on the basis of surface features when spatiotemporal information is ambiguous, using the object-reviewing paradigm with Mitroff and Alvarez's (2007) task, which minimizes memory load (Experiments 1–3). To foreshadow the results, no color-based OSPB was observed. We then examined whether the color-based OSPBs observed in the object-reviewing paradigm can be accounted for by memory-based strategies (Experiments 4 and 5).

Experiments 1–3

Experiment 1 introduced spatiotemporal congruency: The two objects followed a consistent trajectory from their initial locations to their final locations, briefly occluded on their way (Fig. 1a). Experiment 2 introduced spatiotemporal ambiguity due to unpredictable change in the object trajectory when the objects were briefly occluded. Color congruency was manipulated such that the color of the square in which the target letter appeared was either congruent or incongruent with the color–letter pairing in the preview display (Fig. 1b). Color congruency was also manipulated in Experiment 3, in which two colored squares disappeared and then reappeared at the final position, introducing spatiotemporal discontinuity (Fig. 1c).

If object correspondence can be established on the basis of the available information, be it spatiotemporal or surface features, as long as there is no strong evidence against object continuity, then OPSB is expected in Experiment 1 based on spatiotemporal congruency and in Experiment 2 based on color congruency, but not in Experiment 3, because of salient spatiotemporal discontinuity. If, however, object correspondence is determined solely by spatiotemporal properties, OSPB should be found only in Experiment 1.

Method

The three experiments used the same methods, except where noted below.

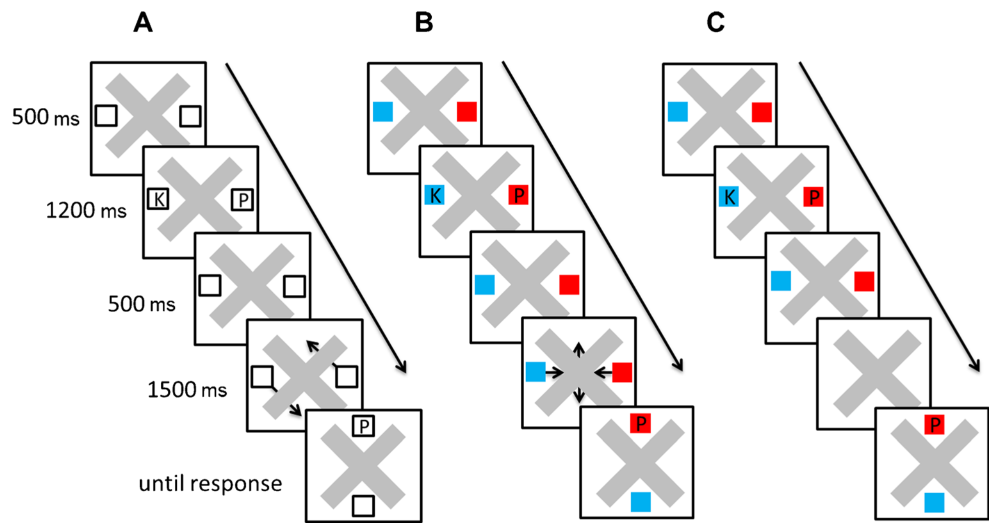

Fig. 1 Examples of a trial in **a** Experiment 1: Spatiotemporal continuity, **b** Experiment 2: Spatiotemporal ambiguity, and **c** Experiment 3: Spatiotemporal discontinuity. All examples depict congruent trials: spatiotemporal congruency in panel a and color congruency in panels b and c

Participants

Participants were students at the University of Haifa and were paid or received course credit. All had normal or corrected-to-normal vision. Twenty-two individuals (19–33 years old, 5 males) participated in Experiment 1, 21 (17–35 years old, 10 males) participated in Experiment 2, and 20 (19–41 years old, 7 males) participated in Experiment 3. None participated in more than one experiment.

Stimuli and apparatus

The stimuli included black outline squares in Experiment 1 and red and blue solid squares in Experiments 2 and 3, each of which subtended 1.9° × 1.9°, presented on a white background. Black Arial Narrow font letters (K, M, P, S, T, V, X, H, F, R) were used as preview and target letters. Stimuli appeared 6.14° to the left and right of center in the preview display and 6.14° above and below the center in the target display. All distances are calculated from center of the stimuli. A gray X-shape occluder (3° width) was centered on the screen, subtending 14.24° × 14.24°.

The experiments were conducted on a PC with a 17-in. CRT color monitor set at a resolution of 1,024 × 768 pixels and a refresh rate of 85 Hz, using E-Prime. Viewing distance was fixed at 57 cm with a chinrest.

Procedure, task, and design

All experiments were conducted in a dimly lit room and lasted about 1 h. Instructions described the matching task.

All trials began with the appearance of two squares to the left and right of center along with a central gray X. After 500 ms, two preview letters, one letter centered within each square, were presented for 1,200 ms, and the squares stayed in place for an additional 500 ms. All trials ended with two squares above and below the center. A target letter appeared in one of the squares, until response. The task was to indicate, as quickly and as accurately as possible, whether the target letter was the same as either of the preview letters by pressing one of two response keys. The linking phase between the preview and target displays varied across experiments.

Experiment 1 The two black outlined squares moved from their initial locations to their final locations on a diagonal path for 1,500 ms, briefly occluded for 55 ms by the X on their way (Fig. 1a).

Experiment 2 The two colored squares moved horizontally for 615 ms, disappeared behind the occluder at the same vertical position for 270 ms of full occlusion, and reappeared again, moving up or down to their final location for an additional 615 ms (Fig. 1b). Color congruency was manipulated: When the target letter matched one of the preview letters, it could appear in the same color square as in the preview display or in a different color square.

Experiment 3 The two colored squares disappeared for 1,500 ms and then reappeared at the final position (Fig. 1c). Color congruency was manipulated as in Experiment 2.

A 2 (match, no match) × 2 (congruent, incongruent) within-subjects design was employed in all three experiments. The target letter was one of the letters in the preview display on half of the trials (match trials), and it was neither of the preview letters on the other half (no-match trials). On half of the match trials, the target letter was the same as the preview letter that appeared on that square (congruent trials), and on the other half, the target letter was the same as the preview letter that appeared on the other square (incongruent trial). Congruency was defined by spatiotemporal history (the square's trajectory) in Experiment 1 and by the square's color in Experiments 2 and 3. All variables—target location (top/bottom), motion direction (clockwise/counterclockwise, Experiment 1), and square location (right/left and top/down, Experiments 2 and 3)—were counterbalanced.

Each experiment included 384 experimental trials, preceded by 12 practice trials.

Results

We consider only the data of the match trials, because the congruency effect is meaningful only for these trials. Responses shorter than 150 ms or longer than 1,500 ms were omitted from the analyses (3.10 %, 3.94 %, and 2.62 % of all trials in Experiments 1, 2, and 3, respectively). Mean correct response times (RTs) and error rates (ERs) for the incongruent and congruent trials for each experiment are presented in Table 1. The final column shows OSPB, calculated as the difference (in RT and in ER) between incongruent and congruent trials.

Table 1 Mean correct response times (RTs, in milliseconds) and error rates (ERs, in percentages) for each of the congruent match and incongruent match trials in Experiments 1–5, with the final column showing the object-specific preview benefit (OSPB)

	Congruent Match	Incongruent Match	OSPB
Experiment 1			
RT	718	737	19*
ER	2.48	2.83	0.35
Experiment 2			
RT	721	725	4
ER	3.72	3.84	0.12
Experiment 3			
RT	735	733	-2
ER	3.28	3.69	0.14
Experiment 4			
Single task			
RT	1,028	1,067	39*
ER	4.77	6.59	1.82
Dual task			
RT	1,013	1,016	3
ER	8.50	8.75	0.25
Experiment 5			
Single task			
RT	1,061	1,071	10
ER	4.92	6.81	1.89*
Dual task			
RT	1,031	1,056	25
ER	6.98	9.18	2.20*

*Statistically significant effect ($\alpha = .05$)

A significant OSPB was observed only in Experiment 1 ($M = 19$ ms), $t(20) = 3.23$, $p = .0042$, indicating a spatiotemporal congruency effect. This finding is consistent with the tunnel effect: Object continuity is not disrupted by occlusion as long as the object follows a consistent trajectory.

No OSPB was observed in Experiment 2 ($M = 4$ ms), $t(20) = 0.82$, $p = .42$, and Experiment 3 ($M = -1$ ms), $t(19) = 0.21$, $p = .83$, indicating no effect of color congruency. These results suggest that color was not used to establish object correspondence under spatiotemporal ambiguity or under spatiotemporal discontinuity.

A comparison between the OSPBs in the three experiments, using a one-way ANOVA, confirmed that the OSPBs differed between the experiments, $F(2, 59) = 3.25$, $p = .046$, $\eta_p^2 = .10$. Tukey HSD comparisons ($\alpha = .05$) revealed a significant difference between Experiments 1 and 2 and between Experiments 1 and 3 and no difference between Experiments 2 and 3.

One could argue that the absence of OSPB in Experiments 2 and 3 is due to a longer occlusion time (270 ms) in Experiment 2 than in Experiment 1 (55 ms) and to a longer disappearance time (1,500 ms) in Experiment 3 than, for example, in Hollingworth and Franconeri (500 ms; 2009, Experiment 5). This account, however, is not supported by previous findings demonstrating that position-based and color-based OSPBs occurred with longer occlusion time than in Experiment 2 (500 and 400 ms; Hollingworth & Franconeri, 2009, Experiments 1 and 2) and that no feature-based OSPB was observed with a shorter disappearance interval than in Experiment 3—1,000 ms (Mitroff & Alvarez, 2007; Moore et al., 2010, Experiment 3B) and even 0 ms (Mitroff & Alvarez, 2007, Experiment 6). Thus, the absence or presence of surface feature OSPBs does not seem to depend on a specific time-course, and therefore, the different occlusion and disappearance times cannot account for the difference in results between Experiment 1 and Experiments 2 and 3.

The present results show that surface features were not used to guide object continuity under spatiotemporal ambiguity when the task had minimal memory demands. This result indicates that salient spatiotemporal discontinuity cannot account for the absence of feature-based OSPB in the object-reviewing paradigm. In Experiment 2, salient spatiotemporal discontinuity was eliminated, and although the final location of the objects was not predicted by their initial motion, this ambiguity is not in conflict with an interpretation of object continuity, because a change in an object trajectory is a reasonable possibility. Nevertheless, no color-based OSPB was observed.

Thus, the color congruency effects observed by Hollingworth and Franconeri (2009) are likely to have emerged from strategies that participants adopted to meet task demands (see also Moore et al., 2010). Possibly, the complex shapes and the request to match two targets to the preview ones induced memory load, leading the participants to organize and memorize the preview stimuli. This hypothesis was examined in Experiments 4 and 5.

Experiments 4 and 5

These experiments introduced spatiotemporal discontinuity and manipulated color congruency as in Experiment 3 but used a task similar to the one used by Hollingworth and Franconeri (2009) and Moore et al. (2010), which involved meaningless shapes and matching two targets to the previewed ones. Previous results predict color-based OSPB with this task. The present experiments included two conditions. In the single-task condition, the participants performed only the matching task. In the dual-task condition, the participants performed a visual working memory (VWM) task (nonspatial in Experiment 4 and spatial in Experiment 5) concurrently with the matching task. We reasoned that if the color-based OSPB is due to memory-based strategies, such as memorizing the preview color–shape pairing, then the presence of a working memory load would interfere with memorizing and reduce or even eliminate the OSPB. Furthermore, it has been suggested that spatial and nonspatial visual representations are stored in separate working memory subsystems (Luck, 2008); therefore, spatial and nonspatial memory loads may differ in their effect on the color-based OSPB.

Method

Experiments 4 and 5 used the same method as Experiment 3, except as noted below.

Participants

Twenty individuals (18–27 years old, 5 males) participated in Experiment 4, with data from 2 removed for performing at chance level in the memory task, and 20 (20–30 years old, 5 males) participated in Experiment 5.

Stimuli and tasks

The matching task Black Bodoni Ornament font elements () were used as preview and target shapes. Two shapes appeared in the target display, one in each square (Fig. 2), and the participants had to indicate whether the two targets were the same two shapes that were presented in the preview display or whether one of them was different.

The nonspatial memory task The memory and test stimuli for each trial were arrays of four bars, each of which was randomly selected from a set of four orientations (vertical, horizontal, −45º, and +45º) and subtended 0.06° × 1.14°. The bars were located at the corner of a centered imaginary square, and any two bars were separated by 2.77° (center to center) (Fig. 2a). The participants were asked to remember the four oriented bars until the end of the trial. The test array was identical to the memory array on half of the trials and differed in the orientation of one of the bars on the other half. The participants had to indicate whether the memory test array was identical to the original memory array (see Luck & Vogel, 1997).

The spatial memory task The memory array included four black solid circles, each of which subtended 0.6° × 0.6° and was located at one of eight possible locations on an imaginary circle, 2.22° from fixation. The participants were asked to remember the locations of the four circles until the end of the trial. The test array included one black outlined circle, which could appear at one of the eight possible locations, with the restriction that its location was the same as one of the four memory stimuli on half of the trials (Fig. 2b). The participants had to report whether the test circle was present at the same location as one of the four circles in the memory array (see Oh & Kim, 2004).

Procedure and design

Besides using the nonspatial memory task in Experiment 4 and the spatial memory task in Experiment 5, all other aspects of the two experiments were the same. In the single-task condition, participants performed only the matching task; in the dual-task condition, participants performed the matching task while maintaining four objects (Experiment 4) or four locations (Experiment 5) in VWM. The sequence of events on each trial was identical to that in Experiment 3, except that in the dual-task condition, each trial began with 500-ms presentation of the memory array, followed by a 500-ms blank period; then the sequence for the matching task followed, and 500 ms following the matching response, a memory test array was presented until response (Fig. 2).

A 2 (condition: single-task, dual-task) × 3 (congruency: no match, congruent match, incongruent match)[1] x 2 (memory test: change, no change) within-subjects design was used in each experiment. Memory test was meaningful only for the dual-task condition. The two conditions were administered in separate blocks of 192 trials each, preceded by 12 practice trials. The order of blocks was counterbalanced across participants.

[1] Since the critical comparison involved the congruent and the incongruent trials, we increased the relative number of trials of each.

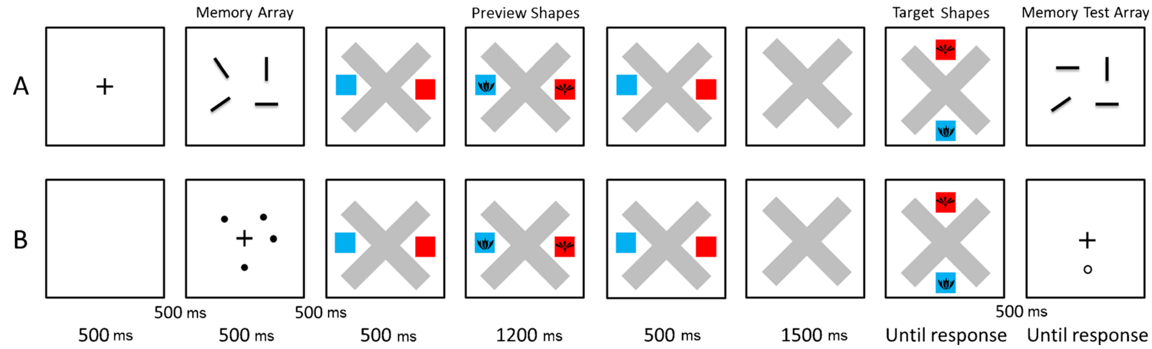

Fig. 2 Examples of a dual-task trial in **a** Experiment 4 and **b** Experiment 5. The example in panel a depicts a change in the memory test array: One of the bars from the memory array changed its orientation. The example in panel b depicts no change: The circle's location in the memory test array was one of the locations in the memory array

Results

Overall accuracy in the memory task was 72 % in Experiment 4 and 68 % in Experiment 5. Mean correct RTs and ERs for the incongruent and congruent trials and OSPBs are presented in Table 1. Responses shorter than 150 ms and longer than 2,000 ms were omitted from the analyses (3.17 %, and 3.10 % of all trials in Experiments 4 and 5, respectively).

Experiment 4

A 2 (condition: single-task, dual-task) × 2 (congruency: congruent, incongruent) repeated measures ANOVA showed a significant effect of congruency, $F(1, 17) = 7.67$, $p = .0131$, $\eta_p^2 = .31$, which interacted with condition, $F(1, 17) = 6.15$, $p = .0239$, $\eta_p^2 = .27$. Planned specific comparisons confirmed a significant color-based OSPB in the single-task condition ($M = 39$ ms), $t(17) = 3.76$, $p = .0016$, replicating previous results. On the other hand, no color-based OSBP was observed in the dual-task condition ($M = 3$ ms), $t(17) = 0.29$, $p = .7717$. Thus, maintaining four objects in VWM eliminated the color-based OSPB.

Experiment 5

The results of this experiment showed significant effects in accuracy rather than in RT. The 2 (condition) × 2 (congruency) repeated measures ANOVA conducted on the ERs showed a significant effect of congruency, $F(1, 19) = 10.27$, $p = .0047$, $\eta_p^2 = .35$, which did not interact with condition, $F < 1$. Planned specific comparisons confirmed a significant color-based OSPB both in the single-task condition ($M = 1.89$ %), $t(19) = 2.21$, $p = .0393$, and in the dual-task condition ($M = 2.20$ %), $t(19) = 2.45$, $p = .0243$. Similar analyses conducted on the RTs revealed no significant effects, but the pattern was the same as that in the ERs. Thus, maintaining four spatial locations in VWM did not eliminate, nor did it reduce, the color-based OSPB, presumably because it involves a separate storage subsystem than maintaining the color–shape information.

Discussion

The results from our study provide clear evidence that surface feature congruency effects that are observed in the object-reviewing paradigm are dependent on task memory demands. Consistent with previous results, when the task required matching one target letter to two preview letters, no color congruency effect was observed, both under spatiotemporal discontinuity (Experiment 3; Mitroff & Alvarez, 2007: Moore et al., 2010) and under spatiotemporal ambiguity (Experiment 2), indicating that salient spatiotemporal discontinuity cannot account for this finding. When the task involved complex shapes and matching two target shapes to the preview ones, color congruency effects were obtained (Experiments 4 and 5; Hollingworth & Franconeri, 2009; Moore et al., 2010). Critically, however, when participants performed a VWM task concurrently with this matching task, the presence of a nonspatial memory load eliminated the color-based OSPB (Experiment 4). This finding suggests that the color-based OSPB was related to memory demands of the matching task. Occupying the VWM with four objects substantially impaired the maintenance of the color–shape information in VWM. This suggestion is supported by the finding that spatial memory load had no influence on the color-based OSPB (Experiment 5), as predicted by the notion that spatial and nonspatial visual representations are stored in separate working memory subsystems.

These results indicate that the color congruency effects that are observed in the object-reviewing paradigm reflect memory-based strategies that participants use to solve the memory-demanding task, and therefore, they cannot be taken as evidence that surface features guide object continuity.

The issue of task memory demands seems irrelevant to the original object-reviewing paradigm (Kahneman et al., 1992), because the naming task, unlike the matching task, does not *require* remembering the preview stimuli. Considering the matching task as an advantage of the modified object-reviewing paradigm (Mitroff & Alvarez, 2007) is presumably driven by the assumption that there is a necessary reliance on brief visual memory in establishing object continuity. But the matching task opens up the possibility for the involvement of memory-based strategies that are used to meet task demands and have nothing to do with the object correspondence process. Indeed, the dependence of congruency effects on the task memory demands casts doubt on the reliability of OSPB as a measure of online object continuity (see also Moore et al., 2010).

Finally, the fact that the color congruency effects in the modified object-reviewing paradigm cannot be taken as evidence that surface features play a role in establishing object correspondence does not necessarily imply that they have no such role. Several studies have demonstrated that surface features can guide object continuity, using other paradigms such as apparent motion (e.g., Hein & Moore, 2012) and gaze correction (e.g., Richard et al., 2008). Further research is needed to elucidate the similarities and differences between paradigms and to provide converging evidence.

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