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Features, as well as space and time, guide object persistence

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Abstract

What role do surface features (e.g., color) play in the establishment and maintenance of episodic representations of objects (object files)? Mitroff and Alvarez (2007) showed that stimuli that were linked by a continuous spatiotemporal history yielded object-specific preview benefits—a standard index of object files—whereas stimuli linked only by shared surface features did not. Here, it is shown that abruptly changing the features of an object that has been established on the basis of spatiotemporal history can disrupt object-specific preview benefits (Experiments 1 and 2). Moreover, under some conditions, feature match alone can give rise to the preview benefits (Experiment 3). These results indicate that surface features, as well as spatiotemporal factors, play an important role in establishing and maintaining episodic object representations.

Much of what is understood about vision concerns the perception and representation of static displays, scenes in which objects do not move or change. Even in the case of motion perception, the literature tends to be focused on the properties of motion, rather than on how the system maintains a representation of objects as persistent entities in the scene as they move, and perhaps change, over time. An exception to this generalization is the literature surrounding the object file framework first presented by Kahneman, Treisman, and Gibbs (1992). Object files, as hypothetical constructs, are episodic visual representations with which information (e.g., color, shape, identity) can be flexibly associated. Object files allow an object to exist as a persistent entity, even as it (or the interpretation of it) changes. To illustrate the construct of an object file, Kahneman et al. used the exclamation made by crowds in *Superman* comics as a streak in the sky became increasingly clear: “It’s a bird. It’s a plane. It’s Superman!” Object files are the representations that remain constant across that reinterpretation process (see Flombaum, Scholl, & Santos, 2009, and Scholl, 2007, for recent reviews of some of the more recent object file literature).

An assertion concerning object files is that they are indexed only on the basis of spatiotemporal information (Kahneman et al., 1992). At a theoretical level, this assertion derives from the idea that other information such as color, shape, and identity can be associated with, and later dissociated from, a particular object file because objects can change over time. They cannot, therefore, serve to define the carrier representation. At an empirical level, there are many examples of visual phenomena that are consistent with a spatiotemporal priority hypothesis (Flombaum et al., 2009; Scholl, 2007). Apparent motion, for example, can be perceived across changes in color, shape, and other features (e.g., Burt

& Sperling, 1981; Kolers & Pomerantz, 1971; Ullman, 1979). Another example is the tunnel effect, in which an object is perceived as disappearing behind an occluding surface, and as long as it reappears in a manner consistent with the spatiotemporal parameters of its having traveled behind that surface, it is perceived as the same object (Michotte, 1946/1963). The tunnel effect occurs despite changes in color, shape, and other features (e.g., Flombaum & Scholl, 2006). As long as the spatiotemporal parameters are appropriate, infants (10–12 months old) seem to tolerate enormous changes in appearance, such as a truck becoming a duck (e.g., Xu & Carey, 1996). Older children and adults are not as tolerant as that but do tolerate changes in basic features like color and shape. Finally, using the paradigm that Kahneman et al. (1992) developed for measuring object file status—the object-reviewing paradigm—Mitroff and Alvarez (2007) found no evidence that any features other than spatiotemporal continuity could be used to define object files. We return to this study in more detail below.

Although a number of perceptual phenomena are consistent with spatiotemporal priority, other evidence suggests that features other than spatiotemporal continuity do play a role in defining and maintaining persistent, episodic object representations. In apparent motion, for example, features can influence the perception of motion, albeit relatively weakly (e.g., Dawson, 1991). Similarly, corrections of misdirected eye movements to objects that moved during a period of saccadic suppression were determined by the features of objects (Hollingworth, Richard, & Luck, 2008; Richard, Luck, & Hollingworth, 2008). This suggests that the object representations in visual working memory were defined on the basis of features. Finally, a phenomenon referred to as *change-related persistence* seems to reflect a substantial influence of features on episodic object representations (Moore & Enns, 2004). When a moving stimulus undergoes an abrupt change in some feature (e.g., size, color, or luminance), two objects are perceived: the original unchanged object and the changed object. Importantly, if no features change, only one object is perceived. This phenomenon suggests that disrupting the features of an object can disrupt the representation of it as a single object. Consistent with this, when a reason that the change occurred was introduced into the scene (i.e., an occluding surface with a small hole in it that the large object passed behind, revealing only a small part for a short time), the disruption was nearly eliminated (Moore, Mordkoff, & Enns, 2007).

Thus, there is evidence that features do play a role in defining object representations, despite other evidence that objects are defined only on the basis of spatiotemporal information and are feature blind. In the present study, we tested the hypothesis that regardless of whether features are sufficient to establish an object representation, once an object representation is established, features play a substantial role in maintaining that object representation as a persistent object. We did this in the context of addressing the specific apparent contrast between evidence that object files cannot be defined on the basis of features alone (Mitroff & Alvarez, 2007) and evidence that abrupt changes in features can disrupt object representations (Moore et al., 2007).

Mitroff and Alvarez (2007) used the object-reviewing paradigm in their study. Observers were shown displays of two different-colored shapes to the left and right, for example, of fixation. A letter was presented inside each of the shapes briefly. In the spatiotemporal

condition, the shapes then moved smoothly 90° along a circular path and stopped. A single letter then appeared in one of the two shapes. The task was to report whether that letter was one of the two original letters (regardless of which shape it had appeared in). When the letter was a match, it could appear either in the same object as it had before (congruent trials) or in the other object (incongruent trials), where *object* was defined by the spatiotemporal history (i.e., motion) of the stimuli. Consistent with previous findings, response times (RTs) were shorter on congruent than on incongruent trials. This congruency effect is taken as evidence of an object-specific representation with which the letter identity was associated (i.e., an object file; Kahneman et al., 1992). The critical new condition was the feature condition, which began and ended in exactly the same manner as the spatiotemporal condition, but instead of moving smoothly from the start location to the end location, the two shapes simply disappeared. The feature conditions did not support apparent motion, because either the time between stimuli was too long or, as in one control experiment, the time was too short, given the distance that the object would have traveled (e.g., Neuhaus, 1930, as described in Kolers, 1972). There was therefore no spatiotemporal basis on which to link the two objects in the final display with the two objects in the initial display. They could only be linked on the basis of color. Despite increasing the number of feature differences between the objects across a set of three experiments, no reliable feature-based congruency effects occurred, suggesting that features alone were insufficient to establish object representations.

We used the same object-reviewing paradigm to test the hypothesis that once an object representation is established, features play a significant role in maintaining that object representation. In the critical condition of Experiment 1, two objects, which were defined by smooth motion, abruptly changed colors. If features are irrelevant to the maintenance of object files, the congruency effect should be unchanged by this manipulation. The congruency effect, however, was eliminated in this condition. Experiment 2 ruled out the possibility that the disruption of the congruency effect was caused by general interference from physical transients that were introduced by the color change. Finally, Experiment 3 demonstrated that congruency effects can occur even when stimuli are associated only on the basis of color (i.e., no spatiotemporal support). We conclude, therefore, that features—space and time—all play a significant role in defining and maintaining object representations and their persistence.

METHOD

Observers

Seventeen individuals (18–23 years old) reporting normal or corrected-to-normal visual acuity and color vision participated in each of four experiments. None participated in more than one experiment.

Apparatus

A Mac Pro drove a 17-in. CRT color monitor set at a spatial resolution of $1,024 \times 768$ pixels and a refresh rate of 100 Hz, using MATLAB software with the Psychophysics Toolbox (PTB3) extensions (Brainard, 1997; Pelli, 1997). Viewing distance was fixed at 65 cm with a chinrest.

Stimuli

The stimuli included blue (21 cd/m²), green (110 cd/m²), red (36 cd/m²), and yellow (99 cd/m²) solid 2° squares presented on a gray (60 cd/m²) background. The following set of Bodoni Ornament font elements (black) were used as targets: , , , . These elements corresponded to the following set of letters: a, b, c, d, e, f, g, h, j, l, m, n, o, p, q, r, s, t, u, x, and w. In Experiment 3B, Geneva letters (K, M, P, S, T, V, X, F, H, and R) were used.

A 0.5° × 0.5° fixation cross was presented at the center of the screen throughout the trial. The stimuli appeared along an imaginary circle centered on fixation with a radius of 4.5°. The squares started either directly above and below or directly to the left and right of fixation. When they moved, they did so clockwise or counterclockwise 90° along the circular path at a velocity of 7°/sec.

Task

The task was to report whether the two elements presented in the final display were the same two elements that were presented at the beginning of the trial or whether one of them was different.

Procedure

The experiments were conducted in 1-h sessions in small dimly lit (39 cd/m²) rooms. Instructions described the matching task; no mention of object identity was included. Practice consisted of a block of 32 trials while the experimenter was still in the room to answer questions. The data were collected from nine blocks of 32 trials each.

Trials began with two squares above and below or to the left and right of fixation for 500 msec. Two elements from the stimulus set were chosen randomly and presented for 1,500 msec, centered in the two squares. The elements then disappeared for 1,000 msec. Trials in all three experiments ended the same way, with two squares in the pair of positions opposite from where they were at the beginning of the trials. Two elements were presented in the two squares (until a response), and the observers reported as quickly as possible whether they were the same as the original two or whether one was different. If the response was incorrect, “incorrect” was displayed for 1,000 msec. What happened during the 1,000-msec period between the preview and response displays varied across experiment (see Figure 1).

Experiment 1.—In the spatiotemporal condition, the two colored squares moved smoothly from their initial locations to their final locations with no changes in color. In the feature-switch condition, the two squares moved smoothly from their initial locations to their final locations, but for the final three frames of motion (30 msec) and the response displays, they swapped colors.

Experiment 2.—The spatiotemporal condition was the same as that for Experiment 1. In the flash condition, the two squares moved smoothly from their initial locations to their final locations, but for the final three frames of motion, they changed to the color of the

background (i.e., disappeared), and in the response displays, they were the same color as they had been at the beginning of the trial and throughout the trajectory.

Experiment 3A and 3B.—The spatiotemporal condition was the same as that for Experiments 1 and 2, except that the squares were both gray instead of colored differently. In the feature condition, the squares disappeared for the entire 1,000-msec period. Experiment 3B was identical to Experiment 3A, except that letters were used instead of shapes, and a single letter appeared in the final display, to which the observers reported whether it was the same as either of the two letters in the preview display. The letters, task, and timing in Experiment 3B all matched those used by Mitroff and Alvarez (2007).

Design

A 2 (display condition: spatiotemporal vs. another) $\times$ 2 (match vs. no match) $\times$ 2 (congruent vs. incongruent) repeated measures design was used in each experiment. All factors were mixed (with no replacement of error trials) within experiments. The display conditions are described above. *Match versus no match* refers to whether the elements in the response display matched those at preview. *Congruent versus incongruent* was meaningful only for the match trials. It refers to whether the two elements in the response displays were in the same squares as those in the preview display (as defined by spatiotemporal history or, in the case of the feature condition of Experiments 3A and 3B, color). Half of the trials were match and half were no match. Because the critical comparison (congruency) was meaningful only for the match trials, those are the data that we consider. Finally, start positions (above and below vs. left and right) and direction of motion (clockwise vs. counterclockwise) were counter-balanced and randomized.

RESULTS

Figure 1 shows the mean RTs and error rates (ERs) for the incongruent and congruent match conditions for each experiment. The final column provides the congruency effect for each condition. All four experiments yielded robust spatiotemporal congruency effects. When the colors of the two spatiotemporally defined objects abruptly switched, however, the congruency effect was eliminated and actually reversed (Experiment 1). A 2 (display type) $\times$ 2 (congruency) repeated measures ANOVA conducted on the RTs from Experiment 1 revealed a reliable interaction [$F(1,16) = 48.29, p < .001$], but neither main effect was significant [display type, $F(1,16) = 0.034, p = .856$; congruency, $F(1,16) = 0.44, p = .517$]. Planned comparisons confirmed that the congruency effect was reliable but in opposite directions for both the spatiotemporal condition ($M = 64$ msec) [$t(16) = 4.13, p < .001$] and the feature-switch condition ($M = -46$ msec) [$t(16) = 3.28, p = .005$]. There were no effects in the ERs that were not in the RTs or were in the opposite direction from those in the RTs. These results indicate that features played a role in determining congruency effects in the object-reviewing paradigm. The reverse effect in the feature-switch condition suggests that the stimuli were associated with their original colors. When the features switched objects, stimuli in the *different* condition were presented with their original colors. In this case, color match had a greater impact on performance than spatiotemporal continuity did.

In Experiment 2, we tested whether the change in the congruency effect observed in the feature-switch condition of Experiment 1 could be attributed to general interference caused by physical discontinuities that were introduced by the feature switch. The flash condition in Experiment 2 was designed to introduce similar interference by having the squares disappear and reappear, thus introducing two abrupt physical transients. The brief disappearance (flash) of the stimuli should present little or no challenge to representing the items as persisting object representations because the displays were consistent with an object's appearing in apparent motion across a brief spatiotemporal gap. Therefore, if the elimination of the congruency effect in the feature-switch condition of Experiment 1 was due to general interference caused by the physical transients introduced by the feature switch, it should have occurred in Experiment 2 as well, whereas if the elimination was due to the feature switch in particular, it should not.

The results of Experiment 2 differed from those of Experiment 1 in that many of the effects occurred in accuracy rather than in RT. The congruency effect was robust in both the spatiotemporal and the flash conditions. A 2 (display type) $\times$ 2 (congruency) repeated measures ANOVA conducted on the ERs revealed a main effect of congruency [$F(1,16) = 8.3, p = .011$] but none for display type [$F(1,16) = 1.69, p = .212$] and no reliable interaction [$F(1,16) = 3.47, p = .081$]. Planned specific comparisons confirmed that the congruency effect was reliable in the ERs in both the spatiotemporal condition ($M = 7.0\%$) [$t(16) = 2.45, p = .026$] and the flash condition ($M = 5.4\%$) [$t(16) = 2.41, p = .028$]. An analogous set of analyses conducted on the RTs revealed no reliable effects, but the pattern was the same as that in the ERs. The results of Experiment 2 indicate that the elimination of the congruency effect that was observed in Experiment 1 cannot be attributed simply to general interference caused by physical transients that were introduced into the stimulus by the color change in Experiment 1. The flash did seem to affect performance and, in particular, may have caused the observers to respond less accurately overall, pushing the effects into the ERs instead of the RTs. There was, however, no sign of the reversal of the congruency effect that was observed in Experiment 1 when the objects switched colors.

Finally, we conducted two versions of the experiment, in which spatiotemporal continuity was compared with feature congruence to ascertain whether features can be used to define object files, as indexed by object-specific preview benefits (Mitroff & Alvarez, 2007). In Experiment 3A, we used the same stimuli and task as those in the present Experiments 1 and 2. In this case, reliable congruency effects were observed in both the spatiotemporal and the feature conditions (see also Hollingworth & Franconeri, 2009). In Experiment 3B, we used the same stimuli and task as those used by Mitroff and Alvarez. In particular, the stimuli were letters instead of figural font elements, and one stimulus instead of two was presented in the final frame, to which the observers reported a match or no match to the previewed letters. Experiment 3B replicated Mitroff and Alvarez's finding of no reliable color-congruency effect.

A 2 (display type) $\times$ 2 (congruency) repeated measures ANOVA conducted on the RTs of Experiment 3A revealed main effects of congruency [$F(1,16) = 25.55, p < .001$] and display type [$F(1,16) = 12.36, p = .003$] but no reliable interaction [$F(1,16) = 0.38, p = .563$]. Planned specific comparisons confirmed a reliable congruency effect in both the

spatiotemporal condition ($M = 66$ msec) [$t(16) = 3.28, p = .005$] and the feature condition ($M = 49$ msec) [$t(16) = 3.41, p = .004$]. The same analyses conducted on the RTs of Experiment 3B revealed a main effect of display type [$F(1,16) = 19.04, p = .001$] and a marginal effect of congruency [$F(1,16) = 3.69, p = .073$] but no reliable interaction [$F(1,16) = 2.44, p = .138$]. Planned specific comparisons confirmed a reliable congruency effect in the spatiotemporal condition ($M = 30$ msec) [$t(16) = 2.29, p = .036$] but not in the feature condition ($M = 4$ msec) [$t(16) = 0.35, p = .731$]. Thus, using familiar namable stimuli (letters) and a task that required only a single stimulus to be matched to the two preview letters, there was no evidence that features played a role in defining object representations. The contrasting results of Experiments 3A and 3B suggest the possibility that the role of features in maintaining object representations is more evident when memory demands are greater and more information is used to consolidate the scene representation.¹

DISCUSSION

The results from this study indicate that abrupt changes in features of established object representations can disrupt those object representations, as measured in the object-reviewing paradigm (Experiments 1 and 2) and, moreover, that features can be used to establish object representations (Experiments 3A and 3B). These findings provide a resolution to the apparent conflict between previous results from the object-reviewing paradigm in which no evidence of feature-defined object files was found (Mitroff & Alvarez, 2007) and in which the conclusion drawn on the basis of change-related persistence that abrupt changes of an object's features can disrupt the episodic representation of that object (Moore et al., 2007).

The present results contribute to a growing body of work that indicates a role for feature information in establishing and maintaining object correspondence. Hollingworth and Franconeri (2009), for example, found color congruency effects in an object-reviewing paradigm similar to that in Experiments 3A and 3B of the present study. Stephens and Moore (2010) found that feature correspondence (color, contrast polarity, or size) contributes to the solution of object correspondence in the perception of causality. Hein and Moore (2009) showed that feature correspondence (color, size, and orientation) contributes to the solution of object correspondence in a form of ambiguous motion, known as Ternus (1926/1950) motion. Finally, using gaze correction as an index of object correspondence, Richard et al. (2008) found that correspondence can be solved flexibly on the basis of features when features define the task or on the basis of space when space defines the task (see also Hollingworth et al., 2008).

The fact that a color congruency effect occurred when the task involved remembering meaningless squiggles and required that the observers match two of these stimuli to two previewed stimuli (Experiments 1–3A) but did not occur when the stimuli were letters and

¹A mixed ANOVA comparing Experiments 3A and 3B indicated that the main effect of display type was reliable [$F(1,32) = 28.23, p < .001$], and it did not differ across experiments [$F(1,32) = 0.10, p < .753$]. The main effect of congruency was also reliable [$F(1,32) = 26.75$], but it did differ across experiments [$F(1,32) = 7.93, p < .001$]. Finally, the interaction between display type and congruency was not reliable in this omnibus ANOVA [$F(1,32) = 1.84, p = .19$], nor was that interaction modulated reliably by experiment [$F(1,32) = 0.10, p = .75$]. This pattern presumably reflects the fact that there was no interaction between display type and congruency in Experiment 3A, and whatever reduction or elimination of that interaction effect that occurred in Experiment 3B was not detectable with the power of this between-subjects analysis.

required only one letter stimulus to be matched to previewed letters suggests the possibility that the congruency effects that are observed in this paradigm are dependent on memory and other nonperceptual task demands. Specifically, they may reflect more than the organization of the scene in terms of online perception and, instead, include strategic organizations of information that are useful for completing the specific task (see also Richard et al., 2008). As such, the color congruency effect, or indeed any congruency effect, may reflect, in part or in whole, associations of information that are used in the service of a demanding memory task. When the task is not as demanding, they may not be used. This last observation raises the question of whether object-specific preview benefits, outside of the context of converging validation, can be taken generally as reliable measures of online object organization and persistence.

The present focus on the role of feature information in defining and maintaining object representations should not be taken as an assertion of feature dominance. Spatiotemporal information is clearly a critical factor in establishing object representations. Rather, the assertion is that the importance of feature information in these processes has been underestimated, because many tasks and paradigms that have been used to assess their influence have favored spatiotemporal influence.

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				Incongruent Match	Congruent Match	Difference	
Experiment 1
Spatiotemporal			RT (msec)	816	752	64*
				ER (%)	20.8	10.8	10.0*
Feature Switch			RT (msec)	765	811	-46*
				ER (%)	11.8	11.4	0.4
Experiment 2
Spatiotemporal			RT (msec)	742	697	45
				ER (%)	26.1	19.1	7.0*
Flash			RT (msec)	747	721	26
				ER (%)	23.2	17.8	5.4*
Experiment 3A/3B
Spatiotemporal			RT (msec)	910/520	844/490	66*/30*
				ER (%)	14.3/9.2	10.5/7.9	3.8/1.3
Feature			RT (msec)	962/555	913/551	49*/4
				ER (%)	16.7/5.9	13.4/4.7	3.3/1.2

Figure 1. Illustrations of the conditions of the three experiments and the mean response time (RT) and error rates (ER) for each of the two match conditions. The final column shows the congruency effect (i.e., the difference between the incongruent match and the congruent match trials). *Statistically reliable effect ($\alpha = .05$).