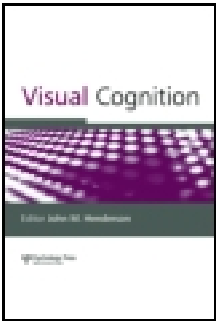

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The relationship between apparent motion and object files

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The relationship between apparent motion and object files

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Object files (OFs) play an important role in theories of mid-level vision. On some influential views, OFs operate and persist only via spatiotemporal continuity. One open question concerns what occurs when direct spatiotemporal continuity is absent: Do OFs move in accordance with any motion correspondence ultimately resolved? Specifically, do OFs accord with apparent motion (AM) correspondences, which arise despite a lack of continuous spatiotemporal stimulation? In Experiment 1, subjects were presented with an AM display consisting of two circles that, across two frames, were seen as moving between two noncontiguous locations. The two objects were primed with two symbols and were then moved in a single step; a third symbol appeared, and could either match the symbol from the closer or the further object. We found a robust object specific preview benefit (OSPB) for the shorter path, in other words, the path along which AM was perceived. In order to control for the possibility that priming occurs at any nearby object, in Experiment 2, the original two objects never disappeared, but two new objects appeared in the would-be AM locations. No AM was perceived, and no OSPB obtained. In the third experiment the OSPB effect persisted even when motion along the shorter path included an unlikely featural transformation (circles turning into squares). In Experiment 4, which was nearly identical to Experiment 2, no OSPB obtained despite unique featural matches between the initial and new objects, seemingly because no AM was perceived. In Experiment 5, we failed to find an effect of featural priming, even when distance between the objects was equated. Finally, we extended the OSPB effect to two additional kinds of AM—line motion (Experiment 6) and phi motion (Experiment 7), supplying strong evidence that AM correspondences and OF correspondences are controlled by the same basic rules.

Keywords: Apparent motion; Correspondence problem; Object files; Phi motion.

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Visual cognition is often differentiated from visual perception in terms of the units over which it operates. While visual perception is thought to traffic in simple visual features, visual cognition—our ability to think about, judge, and remember the visual world—seems to require "higher level", invariant representations of feature bundles, i.e., objects (Cavanagh, 2011; Pinker, 1984; Scholl, 2001). Moreover, many theories and related experimental findings suggest that visual cognition requires representations that go beyond bound features: Visual cognition may require token-like representations (Marr, 1982; Trick & Pylyshyn, 1994; Ullman, 1984). Tokens are representations that lack a necessary connection to any particular feature, feature set, or position in the world and, instead, serve a similar role to demonstratives in language (e.g., "this" or "that"), allowing us to reference a specific thing that persists in time and space without any commitments to what it looks like or where exactly it is (Pylyshyn, 2001, 2011).

Different proposals regarding token representations in visual processing have emerged over the years (e.g., Kanwisher & Driver, 1992), but perhaps the most explicit and influential theory is the object file theory of Kahneman, Tresiman, and Gibbs (1992). On this account, object files (OFs) are mid-level representations that solve a particular problem: Given that objects in the world move, become occluded, and appear to change in appearance, how do we come to represent any specific object as a persisting individual rather than a continuous succession of novel ones? For example, in the now-classic Superman analogy, how are we able to see an object in the sky as the same object that we saw a moment before, despite radically changing assessments of what it is and what it looks like as its position changes (e.g., "it's a bird, it's a plane, it's Superman!")? According to Kahneman and colleagues, OF representations satisfy this need, supplying persisting object representations whose features and positions can be updated while maintaining token identity.

OBJECT FILES

Kahneman and colleagues (1992) argue that the maintenance of an OF representation requires at least three steps: Correspondence, reviewing, and impletion. During the correspondence procedure, the currently indexed object is compared to the objects indexed a moment ago, and given appropriate spatiotemporal conditions, two encounters will be linked and identified as instances of the same object. The correspondence procedure, thus, is the critical step that decides whether a given object is new, or one that was previously indexed. Kahneman and colleagues hypothesized that the primary mechanism for matching two encounters as arising from the same object involves spatiotemporal correspondences. A currently viewed object is considered to be the same as one seen before if they appear close to one another in time and space. It is often argued that this calculus takes place at the expense of, and perhaps even ignoring surface features (i.e., what an object looks like; Mitroff & Alvarez, 2007; Scholl, Pylyshyn, & Feldman, 2001; but see Hollingworth & Franconeri, 2009; Moore, Stephens, & Hein, 2010). Such a procedure conveniently allows OFs to explain the classic Superman example, as token identity is maintained through temporal and spatial changes and the features bound to a token are updated continuously and independently.

The second procedure inherent to OF maintenance is reviewing, whereby the characteristics of the old object are retrieved. This, critically, includes its previous spatiotemporal locations and visual features such as colour and shape, as well as any other associations made with that token representation. The final process, impletion, employs current observations and prior associations to produce the perception of persistence across moments (i.e., create the impression of a persisting object).

The OFs theory has played a pivotal role in many disparate research areas. It has, for example, been implicated in the mechanisms underlying classical phenomena, including the tunnel effect and causality (Flombaum & Scholl, 2006). It has been related frequently to literature on object-based attention (Scholl, 2001), and it has played a role in theories of working memory capacity (Luck & Vogel, 1997), and multiple object tracking (Scholl et al., 2001), where limited human capacity has been related to a possibly limited set of OF representations. And, in addition, OFs have been influential in theories of infant object cognition, including the surprising finding that young infants fail to individuate objects based on surface features, relying instead on spatiotemporal correspondence (Carey & Xu, 2001; Xu, Carey, & Quint, 2004; but see Wilcox, 1999).

APPARENT MOTION

Despite their influential role in theories of visual cognition, it may not be the case that OFs are needed for everything. As we noted earlier, visual perception is often distinguished from cognition insofar as perception traffics in more atomic mechanisms and representations. It is not obvious that object files are necessary so that one can see—only so that one can think certain thoughts about what they see. Even relatively complex percepts may be tractable without mid-level representations. Motion itself, and especially apparent motion (AM), is perhaps the best such example. AM refers to the phenomenon wherein an observer perceives an object as moving through a continuous set of points, though the stimulus contains only discontinuous stimulation at two or just a few of the relevant points successively (e.g., Burt & Sperling, 1981; Dawson, 1991; Kolers, 1972).

The AM literature demonstrates a wide range of phenomena that clearly can be discussed in terms of objects, but need not appeal to object tokens at a mechanistic level (although see Hein & Moore, 2010; Moore & Enns, 2004). Indeed, theories of AM perception do not typically appeal to object representations, focusing instead on the nature of early motion detectors that may operate over features as basic as sudden changes in first-order luminance (Dawson, 1991; Gilroy & Hock, 2004; Lu & Sperling, 2001). In contrast, however, the literature on OFs frequently appeals to work on AM, especially with respect to the prioritization of spatiotemporal information at the expense of surface properties (Carey & Xu, 2001; Kahneman et al., 1992; Mitroff & Alvarez, 2007). Accordingly, the present study sought to explore the relationship between OFs and AM; in particular, whether they share similar mechanisms for resolving object correspondences over time.

THE OBJECT REVIEWING PARADIGM

Kahneman and colleagues (1992) supplied evidence for OF representations and their maintenance in the now classic "reviewing paradigm". Since then, several groups have updated and adjusted their methods, but the core remains the same. Here we describe the more current practice, since the experiments reported later employ these methods. In the reviewing paradigm, two objects are presented on a screen, and a symbol or letter is presented inside each. According to the theory, this causes two distinct OFs to index each of these objects, and the symbol identities to be added into the pool of associations attached to each object. The objects subsequently smoothly move through space, and after some time, they stop in novel locations. A symbol then reappears inside one of the objects, and it either matches the symbol earlier presented in that object (congruent trials), matches the symbol earlier presented in the other object (incongruent trials), or is entirely novel (novel trials). Participants must judge whether the symbol they see is the same as either of the two that they saw before, regardless of what object it initially appeared in.

Typically, congruent trials show a response time advantage compared with incongruent trials, and this difference is known as the Object-Specific-Preview-Benefit (OSPB). OSPBs are the primary source of evidence for OF maintenance. The reasoning is straightforward: Over the course of the motion period, the OF reviewing process maintains formed associations between each object token and its preview letter. As the object moves, the correspondence procedure continues to update the position of the OF, thus maintaining associations between the now expired preview letter and the new locations traversed by the object. When the target letter is shown in that same object, it is shown in a location which, albeit new, is one that already bears an association with the letter through the correspondence and reviewing procedures. As a result, a priming-like effect is obtained: The letter is responded to more quickly when shown in a location (and object) that is already associated with it compared to a location (and object) where it was both never observed and to which it bears no associations (incongruent trials).

Given that AM perception may not require token assignment, it seems appropriate to ask whether AM percepts and OF assignments typically accord with one another. Surprisingly, since the original report by Kahneman and colleagues (1992), no work to our knowledge has explicitly taken up the similarities between OF assignments and AM. Additionally, the only relevant experiment in the original report leaves many issues unresolved. In the relevant experiment of Kahneman and colleagues, two letters appeared on the screen, they disappeared for a nominal interstimulus interval (ISI), and then they reappeared, diagonally displaced from where they were before. This created a strong AM percept in which each of the two letters moved diagonally during the ISI (as is typical in AM displays, each letter was perceived to move to its "nearest neighbour"; Dawson, 1991). Subjects had to identify whether the letters were the same or different as before, and they were faster when the letters moved such that the match was at the closer spatial location to the original letter, suggesting that the correspondence for OFs was the same as for AM perception.

These results do not reveal a relationship between OFs and AM for two reasons. First, congruent trials always involved a letter cue that appeared closer to its original position than it did in incongruent trials. Accordingly, the priming advantage may simply have been the result of proximity, and it may have reflected purely spatial cueing (as opposed to object-based cueing; Downing & Pinker, 1985; Egly, Driver, & Rafal, 1994; Posner, 1980). Second, in the experiment by Kahneman and colleagues (1992), the letters served as both the "objects" and the "targets". Given that the purpose of an object file is to maintain an association between features and an object token, this experiment only shows an association between one set of features and itself. Under such conditions, a token representation is not necessary to mediate between encounters and explain priming effects. By analogy, OFs allow us to understand why we might associate a plane with Superman, but not why we associate Superman's appearance with Superman's appearance. This point is worth making, in part, because it serves as a reminder that not all object priming effects should be taken as evidence of OFs (see also Gao & Scholl, 2010).

At first glance, it may seem reasonable that the link between AM and OFs has remained relatively unexplored since the connection between the two may appear entirely intuitive. The correspondence problem solved at the level of early motion detectors may be precisely what feeds into mid-level vision and determines OF correspondences. However, several recent findings raise the possibility that OF assignments and AM percepts could dissociate.

First, recent work has suggested that AM may be perceivable in the absence of object perception, perhaps even in the absence of perception altogether. Azzopardi and Hock (2011) reported the case of a blindsight patient who continues to perceive "objectless" AM in his cortically blind field through a general perception of motion energy, but with no perception of a segmented object. This is entirely consistent with many theories and models of AM perception that operate not over segmented objects, but simply over motion energy (Lu & Sperling, 2001). It would be strange, however, to use the mere presence of motion signals to construct an OF. In other words, it seems unlikely that blindsight patients use OF representations, despite perceiving AM.

Second, theories of AM correspondence strongly suggest that spatiotemporal factors are the only ones that matter for solving the correspondence problem (Burt & Sperling, 1981; Kolers, 1972; Kolers & Pomerantz, 1971; Navon, 1976; but see Green, 1989; Hein & Moore, 2009; Petersik & Rice, 2008). In contrast, recent findings with the OF reviewing paradigm have suggested that objects' surface features may be employed by OF mechanisms to infer correspondences (Hein & Moore, 2009; Hollingworth & Franconeri, 2009; Richard, Luck, & Hollingworth, 2008). Hollingworth and Franconeri (2009) created a display where two differently coloured objects smoothly moved behind an occluder and continued to move while out of sight. Once the occluder was removed, the target was revealed in one of the objects, and participants were significantly faster when the target appeared in the same-coloured object as it had appeared in before. Spatiotemporal evidence, in this case, was ambiguous with respect to appropriate OF assignment, and so, according to the authors, a feature-based analysis provided an alternative mechanism. No similar findings have appeared in the AM literature.

Third, in a surprising study by Mitroff, Scholl, and Wynn (2005), participants saw a display in which two smoothly moving objects appeared to pass through one another (traversing the opposite side of the display). The OSPB effect, however, was strongly aligned with an interpretation of the display in which the two objects bounced off of one another and ended up on the same side of the display. This finding demonstrates that what we see explicitly may sometimes contradict the way we assign OFs, thus evidencing at least one instance of dissociation between motion perception and OFs.

Finally, Gao and Scholl (2010) found OSPB effects for loci on the surface of a single rotating object. In their paradigm, a single disc showed two symbols on opposite sides and then the disc smoothly spun through 90°. A clear OSPB effect was found when the symbols were tested in the locations that they should now occupy, given the disc's motion. In this instance, OF positions where clearly updated, though no AM of those individual objects on the rotating disc was observed. In other words, OFs were updated because the motion of a third object implied the motion of the two relevant objects, though the motion of these two object was not explicitly or independently perceived. These results suggest that one need not explicitly observe the motion of an object—whether smoothly or under apparent motion—in order to update the location of an OF and its associations.

Given these findings, and more generally, the influential role of AM and OFs in the study of human cognition, we sought to determine whether OF assignments and AM percepts typically converge. To foreshadow, in seven experiments, we found that OSPB effects emerged in accordance with perceived AM. Moreover, in both phenomena, determining correspondences favoured spatiotemporal cues over featural ones when they conflicted with one another. And both phenomena obeyed certain pragmatic principles, evaluating a scene broadly to determine whether a representation's position should be updated in the first place, rather than operating ballistically whenever certain transients were present. The final two experiments showed that OFs accord with AM even under conditions of line motion and phi motion, suggesting an especially strong link between the two.

GENERAL METHODS

Participants

Unless otherwise noted, each experiment consisted of a group of 15 participants. All were Johns Hopkins University undergraduates who participated in exchange for course credit. No participant was in more than one experiment. All participants were over 18 and had normal or corrected-to-normal visual acuity. The protocol was approved by the Johns Hopkins University IRB.

Materials

All stimuli were presented on a 19-inch LCD iMac computer. All programs were custom-made in MATLAB with Psychophysics Tooxbox (Brainard, 1997; Pelli, 1997). We did not constrain viewing distance, but it was approximately 30 cm for each subject. The diameter of objects we presented on the screen subtended 1.5° of visual angle from a distance of 30 cm. Objects presented were either dark grey circles or squares. Following recent studies that use symbols rather than letter stimuli, the cues were black symbols: $, &, !, #, =, and % (cf. Gao & Scholl, 2010); the cues appeared inside of objects and subtended about 0.75° of visual angle from a viewing distance of 30 cm.

Procedure

AM was induced via motion quartets (Ramachandran & Anstis, 1985), in which correspondence is resolved across the shortest distance (Hock, Kelso, & Schöner, 1993). Figure 1 illustrates the typical procedure, and Figure 2 illustrates the differences in the *Motion Frame* of the seven experiments.

Participants initiated each trial by keypress. A fixation cross first appeared in the centre of the screen and remained present for 1500 ms. Next, the first stimulus frame appeared (object frame). With the exception of the seventh experiment, the object frame consisted of two objects (in the seventh experiment it consisted of four; see Figure 2). The objects were presented in two corners of an invisible rectangle with a longer side measuring 8.26° and a shorter side of 2.75°; this 3:1 ratio usually yields unambiguous motion

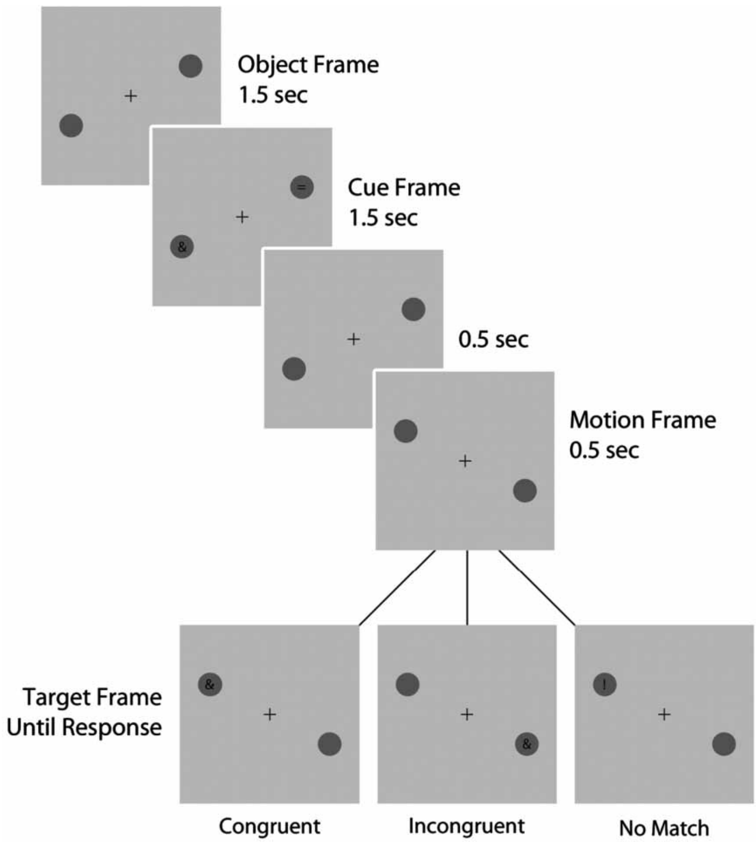
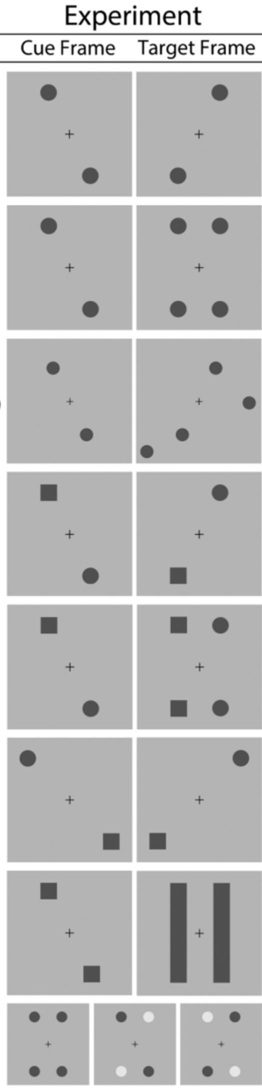


Figure 1. General methods for all seven experiments. Perceived motion is usually along the shorter dimension (i.e., objects here should appear to move up and down).



Experiment	Trial Type: Congruent	Trial Type: Incongruent	AM-OSPB milliseconds
1	747.00	775.97	28.96*
2a	689.78	685.49	-4.29
2b	809.14	831.89	22.74*
3	818.78	836.10	17.31*
4	883.89	880.33	-3.56
5	833.43	837.05	3.62
6	774.61	786.01	11.41*
7	831.97	854.58	22.60*

Figure 2. Cue and target frames and the RTs (in milliseconds) from congruent and incongruent trials. Note that the seventh experiment had an extra object frame. We also present OSPB effects to the right; asterisks indicate an OSPB that was significantly different from 0. Also note that the distractors in Experiment 2b appeared further away from the targets, and the exact locations of the distractors in the figure are only illustrative.

percepts favouring the shorter distance (Hock et al., 1993). Indeed, the AM effect of the objects moving along the shorter path is compelling (readers can see for themselves at https://jshare.johnshopkins.edu/PBS/odic/demo_object files.htm where we supply demonstrations of each experiment, or by rapidly moving their eyes between two fixation points in Figure 2). In half the trials the rectangle was oriented so that the longer side was parallel to the top and bottom border of the screen, and in the other half the rectangle's longer side was parallel to the left and right borders (contrast Figures 1 and 2). Objects were presented in geometrically opposite (i.e., diagonal) corners; in half the trials, the top-left and bottom-right corners were occupied, and in the other half the bottom-left and top-right corners were occupied.

The second frame (cue frame) consisted of two randomly selected symbol cues that appeared inside of the two objects from the object frame (i.e., the objects from the first frame remained present during the second frame). The cue frame also lasted for 1500 ms.

At the start of the third frame, the symbol cues disappeared from the display; the third remained present for 500 ms. In the fourth frame (motion frame) two novel objects appeared in the previously empty corners of the virtual rectangle. In Experiments 1 and 3, the original two objects—the ones that initially appeared in the object frame—disappeared at this time, creating an AM illusion of two objects moving along the shorter side of the virtual rectangle (Ramachandran & Anstis, 1985, 1986). The motion frame remained present for 500 ms.

In the fifth frame (test frame), a single cue symbol appeared inside of one of the circles and remained present until the participant entered a response. Participants were instructed to press the "Y" key if the symbol was the same as either one of the two that had been present in the cue frame, regardless of which object it appeared in or which location it appeared in.

They were instructed to press the "N" key if they thought the symbol was not previously present in the second frame.

Since all motion in these experiments was apparent it can be confusing to talk about the symbol cues appearing in the same or a different object in the object frame and target frame. Therefore we refer to the congruency, here, in terms of the typical AM percepts obtained. When a cue from the object frame appeared in the target frame it could appear in either the closer virtual rectangle position to its original position (consistent with AM nearest-neighbour assignment), or the farther virtual rectangle position (inconsistent with AM nearest-neighbour assignment). Thus, "congruent trials" were those in which the cue appeared in the closer location, since AM percepts tend to traverse the shortest available distance; 25% of all trials were congruent. In contrast, 25% of all trials were Incongruent, wherein the cue symbol appeared at the farther of the available locations. If object-specific-preview-benefits (OSPBs) accorded with AM, they would appear in these data as faster response latencies to congruent compared with incongruent trials. Finally, 50% of all trials included a novel cue symbol that had not appeared in the cue frame at all (novel trials); we report novel trial RTs for completion only, and have no prediction about how they should behave. Since every test frame included two objects, the cue appeared in each one half of the time.

In each experiment, participants saw a total of 320 trials, and they needed about 45 minutes to complete an entire experiment. Participants could take a break at any point by waiting to start the next trial. Once done, they were debriefed and received course credit.

Analysis

To calculate any OSPBs we first trimmed any trial in which participants made an unusually fast (< 100 ms) or slow response (> 2000 ms). We report the percentage of trials lost in each experiment individually, but in each experiment no more than 6% of trials were trimmed by this method. As is typical in this literature, novel trials and trials with incorrect responses were removed from the analysis (Hollingworth & Franconeri, 2009; Mitroff & Alvarez, 2007; Mitroff, Arita, & Fleck, 2009).

An OSPB is normally calculated by subtracting response latencies in congruent trials from incongruent trials. We therefore defined an Apparent Motion OSPB (AM-OSPB) as the difference between incongruent response latencies and congruent response latencies. We expected that if OFs and AM are related, that we would observe positive AM-OSPBs whenever AM was present in the display. But if AM and OFs are not related, we expected not to find AM-OSPBs (i.e., the difference between incongruent and congruent trials would be zero). In the literature, typical OSPBs range from 10 to 30 ms (Hollingworth & Franconeri, 2009; Mitroff & Alvarez, 2007; Mitroff et al., 2005, 2009)

EXPERIMENT 1: CONVERGENCE BETWEEN OBJECT FILE AND APPARENT MOTION CORRESPONDENCES

Method

This experiment was designed to supply a basic demonstration of convergence between OFs and AM. In each trial, participants saw a simple AM quartet: Two objects appeared in one frame, followed by two objects in new locations a few frames later. In this experiment, the initial and subsequent objects were featurally identical. Under the conditions of our experiment, AM perception was such that objects travelled along the shorter side of the invisible rectangle. If AM and OFs share the same correspondence procedures, then we should find significantly positive OSPBs, that is, shorter response latencies in congruent compared to incongruent trials.

Participants. Fifteen participants completed the task.

Results

Accuracy did not differ between congruent and incongruent trials (94.4% vs. 93.8%), $t(14) < 1$, $p = .58$, but was higher for novel trials compared to the average of congruent and incongruent trials (97.8%), $t(14) = -4.32$, $p < .01$. 2.04% of trials were removed due to slow and fast responses. The difference between average RT in congruent trials (747 ms, $SE = 42.92$ ms) and incongruent trials (775.97 ms, $SE = 42.93$ ms) yielded a significantly positive AM-OSPB of 28.96 ms ($SE = 8.45$), $t(14) = -3.428$, $p < .01$ (see Figure 2). At an individual level, 11/15 participants showed a positive AM-OSPB (binomial test, $p = .06$). Average RT during novel trials was 766 ms ($SE = 43.81$ ms).

Discussion

Experiment 1 identified an AM related OSPB. Participants showed priming effects for the symbol cues when they appeared in brand new locations, which were only related to their original locations via AM. These results are consistent with the possibility that AM is sufficient to drive OF correspondence and reviewing procedures, and thus, with the possibility that AM and OFs share mechanisms for determining correspondences over time.

There is one obvious alternative: The priming effect may simply be due to a "spreading" of attention to locations near the cue (Posner, 1980). On such an account, one would expect more spreading to nearby locations than farther ones and, given that AM correspondences were solved along the shortest path, it is possible that the convergence of priming and AM was merely a coincidence. Indeed, such "bleeding" of AM priming to nearby spatial locations was demonstrated by Mitroff and colleagues (2009), a study in which the target could appear *outside* the primed object, and still produce an OSPB. We take up this issue in the next experiment (see also Experiment 6).

EXPERIMENT 2a: NO OBJECT FILE UPDATING IN THE ABSENCE OF APPARENT MOTION

The purpose of this experiment was to demonstrate that the OSPB found in Experiment 1 was not caused by the automatic spread of associations from the locations where the cues originally appeared to nearby spatial locations. Towards this end, we extinguished the perception of AM by causing two new objects to appear in previously unoccupied locations, but without ever deleting the original objects. This manipulation very saliently prevents AM.

Cues then appeared in the new objects, and, for simplicity, we continue to refer to their positions as congruent and incongruent, though in this experiment, there was no AM. The logic of the experiment was that a failure to find OSPBs would constitute evidence that priming in Experiment 1 was not simply caused by spreading associations to nearby locations, since all locations and distances were identical in this experiment. Additionally, such a result would demonstrate that (in the absence of smooth motion) AM is necessary for correspondence and reviewing procedures to transfer OF associations to new locations.

Method

Objects consisted of two circles. The only difference between this and the previous experiment was that in the motion frame the original two objects did not disappear, resulting in a total of four objects present during the test frame (see Figure 2). Pilot testing revealed that this manipulation removed any perception of AM (a demonstration can be viewed online).

Results

Accuracy did not differ between congruent and incongruent conditions (93.2% vs. 92%), $t(14) < 1$, $p = .42$, but their average was, as in Experiment 1, lower than the novel condition (96.75%), $t(14) = -3.4$, $p < .01$. 1.17% of trials were removed because of excessively fast or slow responses. The average RT in congruent trials (689.78 ms, $SE = 27.92$ ms) was not reliably different from incongruent trials (685.49 ms, $SE = 24.89$ ms), $t(14) < 1$. This experiment did not produce an AM-related OSPB. To compare this effect to Experiment 1, we performed a 2 (experiment: 1, 2a) × 2 (trial type: congruent, incongruent) ANOVA, and found a significant Experiment × Trial type interaction, $F(1, 28) = 9.01$, $p < .01$.[1] At an individual level, 6/15 subjects showed a positive AM-OSPB (binomial test, $p = .85$). Average RT during novel trials was 705 ms ($SE = 32.92$ ms).

Discussion

This experiment supplied clear evidence that cue and location associations do not automatically spread to nearby locations. Instead, transferring OF associations requires AM (or smooth motion). Because the same

[1] In all of the cross-experiment ANOVAs reported, we failed to find a significant main effect of experiment (all ps > .08). Additionally, unless otherwise reported, we always found a significant main effect of trial type (all ps < .05). The critical test of an Experiment × Trial type interaction is always fully reported.

manipulation extinguished both AM and object specific priming, this lends further support to the hypothesis that AM and OFs share mechanisms for correspondence matching.

EXPERIMENT 2b: OBJECT FILE UPDATING IS NOT DISRUPTED BY NOVEL ONSETS

In Experiment 2a we eliminated AM perception by having two novel objects appear, while the original two objects stayed in place. That experiment was designed as a distance priming control for Experiment 1. But Experiment 2a ultimately included four total objects in the test display, whereas Experiment 1 included only two objects. Perhaps it is possible that the sudden onset of two new objects, resulting in a total of four objects in the display, captures attention and makes it difficult to measure the presence of spreading associations? To address this concern, we replicated Experiment 1, but now with two novel and irrelevant objects appearing at the same time as the AM correspondence objects. In this way, we set out to replicate Experiment 1, but in a display that included two new onsets and four total objects at test.[2]

Methods

The only difference between this experiment and Experiment 1 was that in the motion frame two novel objects appeared at the same time as the motion of the two cued objects (see Figure 2 and online demonstration). The two novel objects were identical to the ones participating in AM (i.e., grey circles). In order to make sure that the two novel objects were not seen as part of the AM, they were shown randomly along an invisible circle approximately 16° visual angle from the centre of the screen. Participants were instructed that no symbols would ever appear inside these peripheral two circles.

Participants. Eleven participants took part in this control experiment.

Results

Accuracy did not differ between congruent, incongruent, and novel conditions (97.2% vs. 97.8% vs. 98.2; all *p*s $>.40$). 4.3% of trials were removed because of excessively fast or slow responses. The average RT in congruent trials (809.14 ms, $SE = 70.34$ ms) was lower than the incongruent trials

[2] We thank one of the reviewers for bringing up this concern and suggesting Experiment 2b as a control.

(831.89 ms, $SE = 68.02$), $t(10) = 2.79$, $p < .02$, thus producing a significant OSPB of 22.74 ms. Compared to Experiment 1, there was no main effect of experiment, $F(1, 24) < 1$, $p = .44$, nor an Experiment × Trial type interaction, $F(1, 24) < 1$, $p = .61$. At an individual level, 9/11 subjects showed a positive AM-OSPB (binomial test, $p = .03$). Average RT during novel trials was 820 ms ($SE = 61.90$ ms).

Discussion

Experiment 2b confirmed that an AM-OSPB effect can be observed even when two novel objects appear and that the failure to observe an effect in Experiment 2a is not due to the presence of four objects at the end of the display.

EXPERIMENT 3: SPATIOTEMPORAL AND FEATURAL CORRESPONDENCES IN APPARENT MOTION AND OBJECT FILES

Experiment 2a demonstrated that a manipulation that extinguishes AM percepts also blocks the transfer of object specific priming to a new location. The current experiment was designed to explore, in some sense, the converse—that factors that do not impact AM also do not impact OF correspondences. Specifically, it is a well-known feature of AM that surface features such as shape and colour play a limited role in solving the correspondence problem (Burt & Sperling, 1981; Dawson, 1991; Kolers, 1972; Kolers & Pomerantz, 1971; Navon, 1976). At a minimum, when pitted against one another, surface properties almost always lose to spatiotemporal ones in AM correspondences. For example, in AM quartets like those used in the current study, motion is always perceived along the shortest path, even if this results in the perception of unlikely featural transformations.

As reviewed in the introduction, an open debate surrounds the role of features in OF correspondences (Hollingworth & Franconeri, 2009; Mitroff & Alvarez, 2007; Moore et al., 2010; Richard et al., 2008). Moreover, in AM, recent work has emphasized a potential role for surface features. Recent experiments by Moore and colleagues (2010; see also Hein & Moore, 2009) found an effect of surface features in AM displays when spatiotemporal factors alone could not reliably drive correspondences because all potential correspondences were equidistant. In the current experiment we first sought to directly pit spatiotemporal cues and featural ones against each other in an OF experiment.

To accomplish this we employed two different shapes, a square and a circle, in the object frame. The motion frame put features in conflict by having opposing shapes appear at closer distances to one another (see Figure 2). This produced AM percepts in which a circle turned into a square along one pathway while a square turned into a circle along the other pathway. The question of interest concerned whether and where OSBPs would emerge. If OF correspondences favour surface properties, then we expected to find significantly *negative* AM-OSPBs (an object-specific-preview-*cost*) at the consistent correspondences. However, if OF correspondences favour spatial factors at the expense of featural ones, then we expected to continue to find a positive AM-OSPB. In summary, by employing unambiguous AM that conflicts with featural cues we were able to ask whether OF correspondences favour spatiotemporal factors when they conflict directly with featural ones.

Methods

This experiment was identical to Experiment 1, except that each object frame comprised one circle and one square. In the motion frame, each feature (circle or square) reappeared in the location along the longer path causing apparent motion (along the shorter paths) to produce the perception of an unlikely featural swap (see Figure 2)

Participants. Sixteen subjects completed this experiment, though one subject was removed from the analysis due to low accuracy (less than 85% correct).

Results

Accuracy did not differ between the congruent, incongruent, and novel conditions (96% vs. 94.1% vs. 97.5%; all $ps > .10$). 2.59% of trials were removed due to excessively slow and fast responses. The average RT in congruent trials was 818.78 ms ($SE = 44.12$ ms), and in incongruent trials was 836.1 ms ($SE = 45.73$ ms). We found a significant AM-OSPB of 17.31 ms ($SE = 6.57$), $t(14) = -2.631$, $p < .05$. When compared to Experiment 1, there was no main effect of Experiment, $F(1, 28) = 1.13$, $p = .30$, nor an Experiment × Trial type interaction, $F(1, 28) = 1.18$; $p = .29$, suggesting that Experiments 1 and 3 produced an equally robust effect. At the individual level, 11/15 participants showed a positive OSPB (binomial test, $p = .06$). Average RT during novel trials was 830 ms ($SE = 40.84$ ms).

Discussion

Despite requiring an assignment that conflicted with the one implied by surface features, we continued to find an OSPB consistent with AM. This provides further evidence for a shared correspondence mechanism for both OFs and AM. With respect to the role that features may play in OF correspondences more broadly, these results suggest that if spatiotemporal factors are unambiguous, correspondences favour them. Previously, Mitroff and Alvarez (2007) demonstrated that under ambiguous spatiotemporal situations OFs ignore surface features. But that conclusion has since been challenged by Hollingworth and Franconeri (2009) and by Moore and colleagues (2010), who concluded that when spatiotemporal information is ambiguous, surface features can play a role. Our experiment was different from both these prior studies because motion here was apparent and spatiotemporally *unambiguous* (cf. Moore et al., 2010), in a way that caused spatiotemporal cues to conflict directly with featural ones. When placed into conflict, we found that spatiotemporal cues dominated featural ones, consistent with OFs and AM sharing correspondence mechanisms.

EXPERIMENT 4: CAN FEATURES DRIVE OBJECT FILES IN THE ABSENCE OF MOTION?

The purpose of the current experiment was to determine whether a shape-based priming effect could obtain in the absence of motion. That is, we sought to investigate another potential fissure between OF and AM correspondences. In Experiment 3, OF correspondences clearly favoured spatiotemporally driven motion correspondences when pitted against featural ones. However, Experiment 2a demonstrated that AM could be extinguished via a simple manipulation that kept old objects present in the display. Perhaps this manipulation would extinguish motion-driven OF correspondences, making way for featurally driven ones? Such a result would suggest that when clear motion is present (whether smooth or apparent), OFs accord with spatiotemporal factors because motion accords with them. But when motion is absent, perhaps entirely featural correspondences can take hold? In other words, the presence of AM may overwrite the featural match but, in cases of ambiguous or nonexistent motion, perhaps surface features can support a correspondence solution (cf. Hollingworth & Franconeri, 2009).

To explore this possibility, the current experiment combined Experiments 2a and 3. As in Experiment 2a, we extinguished AM by leaving the initial objects present in the display throughout a trial. As in Experiment 3, the two initial objects were differently shaped. Since in Experiment 2a we did not find object specific priming at nearby locations, we did not expect to find such priming here either. Therefore, we expected to either find no priming at all, or *negative* feature-based priming at the farther new object locations—a result which would evidence featurally driven associations.

Methods

The procedure was identical to Experiment 3, save for the fact that in the motion frame the original two objects did not disappear (see Figure 2).

Results

Accuracy did not differ between the congruent, incongruent, and novel conditions (94% vs. 94.6% vs. 95.4%; all ps > .40). 4.4% of trials were removed due to excessively slow or fast responses. There was no evidence of a significant positive or negative AM-OSPB, $t(14) < 1$, with an average RT in congruent trials of 883.89 ms ($SE = 51.04$ ms), and 880.33 ms ($SE = 49.56$ ms) in incongruent trials. Although there was no Experiment × Trial type interaction when compared to Experiment 3, $F(1, 28) = 2.17$, $p = .15$, there was a significant Experiment × Trial type interaction when compared to Experiment 1, $F(1, 28) = 4.63$, $p < .05$. At an individual level, 9/15 subjects evidenced a positive AM-OSPB (binomial test, $p = .30$). Average RT during novel trials was 868.68 ms ($SE = 43.83$ ms).

Discussion

This experiment supplied further evidence of shared correspondence mechanisms for AM and OFs. When perception failed to produce AM, it also failed to produce any object specific priming. This is actually somewhat surprising. After all, in each trial each type of potential cue (e.g., the "%" sign) appeared in only one of the possible shapes during the preview—either a square or a circle. This should have produced strong associations between the cues and the shapes, and, at test, when a particular cue appeared in the same shape again, those associations should have been expressed through priming. But we found no such priming. This is likely because the object that a cue originally appeared in was still present and, therefore, not the same as the new object that a cue appeared in at test. Indeed, the absence of a shape-based effect evidences the extent to which object-specific priming really is object specific. It depends on a token-based representation of an object through time and, at least in these experiments, spatiotemporal, motion-based updating mechanisms.

EXPERIMENT 5: CAN FEATURES DRIVE OBJECT FILES WHEN APPARENT MOTION IS AMBIGUOUS?

The purpose of the fifth experiment was to investigate whether featural priming can occur when spatiotemporal evidence is present (as in Experiment 3), but is unreliable for determining the correspondence between the objects.[3]

[3] We thank a reviewer for suggesting this experiment.

As discussed earlier, such an approach was previously taken by Mitroff and Alvarez (2007) and by Moore and colleagues (2010), who both rendered spatiotemporal cues ambiguous with respect to correspondences, producing an opportunity for featural cues to have an effect. But the results of these two studies did not produce a consensus. Moore and colleagues (2010) found an effect of features on the OSBP, but Mitroff and Alvarez (2007) did not. Here we sought to similarly test the effects of features under one set of conditions that render spatiotemporal cues ambiguous with respect to correspondences.

Specifically, we continued to employ an AM quartet, making the distance between all the objects equivalent (essentially changing the invisible rectangle into a square). Now, each object moved an equivalent distance, and spatiotemporal evidence (and AM perception) was equivalently biased towards seeing motion along either side of the invisible square (i.e., sometimes up–down motion was perceived, and sometimes left–right motion was perceived). If featural evidence can, in this instance, modulate OF correspondences, then we expected to find a significant OSPB in the direction of features: Participants would more quickly respond to a target when it appeared in the same shape at test as it had at preview.

Methods

This experiment was identical to Experiment 3, except that objects appeared on an invisible square instead of a rectangle (see Figure 2). Given such a display, it is impossible to predict, for each trial, which AM direction a participant would perceive. Because we were not interested in whether features drove AM, but whether they drove OF assignments, we report the effect of feature-congruent (i.e., cue and target appeared inside same shape) and feature-incongruent trials (i.e., cue and target appeared inside different shapes).

Participants. Sixteen subjects completed this experiment, though one subject was removed from the analysis due to low accuracy (less than 75% correct).

Results

Accuracy did not differ between feature-congruent and feature-incongruent trials (97.1% vs. 95.6%), $t(14) = -1.94$, $p = .12$, but was higher for novel trials compared to the average of feature-congruent and feature-incongruent (98.1%), $t(14) = -2.58$, $p < .05$. 4.5% of trials were removed due to excessively slow and fast responses. The average RT in feature-congruent trials was 833.43 ($SE = 43.52$ ms), and on feature-incongruent trials it was 837.05 ms ($SE = 43.33$ ms). There was no significant feature-based OSPB, $t(14) < 1$, $p = .55$. We also found a significant Experiment $\times$ Trial type interaction when compared to Experiment 3, $F(1, 28) = 5.63$, $p < .05$; there was no main effect of trial type, $F(1, 28) = 2.43$, $p = .13$. At an individual level, 8/15 participants had a positive, feature-based OSPB (binomial test, $p = .50$). Average RT during novel trials was 833 ms ($SE = 38$ ms).

Discussion

Even when holding the distance between the objects constant, we failed to find evidence for feature-based priming. In effect, we conceptually replicated the finding of Mitroff and Alvarez (2007) and failed to find results that would have converged with Moore and colleagues (2009). Although our results may suggest that features have no role to play in determining correspondences, we believe this to be too strong a conclusion. Instead, it is possible that although spatiotemporal cues were ambiguous here—i.e., they did not support a specific set of correspondences over another—they were still possible—i.e., a mutually exclusive set of correspondences could be spatiotemporally selected. Perhaps in order for features to have an impact, spatiotemporal cues need be more than just ambiguous. For instance, perhaps it must be implied that they are unreliable or computationally difficult to identify (see Hollingworth & Franconeri, 2009). Additionally, it is possible that our choice of features (i.e., shape) was not strong enough to produce an impact (Moore & colleagues used colour/luminance, whereas Mitroff & Alvarez used shape and topology).

EXPERIMENT 6: OBJECT FILE CORRESPONDENCES IN LINE MOTION

In all of the earlier experiments we found a convergence between OF correspondences and AM correspondence. However, in each of these cases objects travelled to their nearest neighbours. Although Experiments 2a and 4 demonstrated that this type of spatial priming is not sufficient for the consistent OSPB effect to obtain, it is possible that it is still necessary. Ideally, we should extend these findings to a case where AM is consistent with motion along the longer path.

One case wherein apparent does tend to move along a longer path is “line motion” (Azzopardi & Hock, 2011; Hikosaka, Miyauchi, & Shimojo, 1993). In this type of AM, a single object appears to move by extending itself into a line (see Figure 2 and demo online). Because all the points along the line become visible at once, the spatiotemporal contiguity of these points can drive motion along a longer distance than the one that would be favoured in a quartet situation. Observers can see two growing lines along the edges of a rectangle because of spatiotemporal contiguity among the points in each line.

In the current experiment, we adapted line motion into the frames of our motion quartets, so that each of the initial objects in the display turned into a line and appeared to move along *the longer distance*. We would expect that if AM and OFs share a correspondence procedure, priming should now occur along the longer distance (i.e., opposite to the OSPB in Experiments 1 and 3). Furthermore, this would solidify our hypothesis that object, and not spatial-based priming, is responsible for these effects, since spatially-based priming would favour the shorter distance (cf. Egly, Driver, & Rafal, 1994).

Methods

The procedure was identical to Experiment 1, except that in the motion frame the original two objects transformed into two extended lines that stretched across the longer distance of the invisible rectangle (see Figure 2 and demo online).

Participants. Fifteen subjects completed this experiment, although an additional six were tested and excluded. Four of these were excluded for low accuracy (less than 85%), and two for having OSPBs beyond 2.5 standard deviations from the mean.[4]

Results

Accuracy did not differ between the congruent, incongruent, and novel conditions (95.5% vs. 96.7% vs. 97.5%; all $ps > .17$). 5.4% of trials were removed due to excessively slow or fast responses. Average RT in congruent trials (i.e., longer distance) was 774.61 ms ($SE = 30.95$ ms), and 786.01 ms ($SE = 32.64$ ms) in incongruent trials (i.e., the shorter distance). Thus, we found a significant AM-OSPB of 11.41 ms ($SE = 5.28$), $t(14) = -1.77$, $p < .05$. Additionally, we failed to find a significant Experiment $\times$ Trial type interaction when compared to Experiment 1, $F(1, 28) = 3.11$, $p = .08$. At an individual level, 11/15 participants showed a positive AM-OSPB (binomial test, $p = .06$). Average RT during novel trials was 791.82 ms ($SE = 33.16$ ms).

[4] Although the same exclusion criteria were used on all seven experiments, we recognize that the exclusion rate in Experiment 6 was higher than in the other experiments. One possible reason for this higher rate may be an increased difficulty in the task with line motion. The second, and more probable reason, was that Experiment 6 was run during the second to last week and last week of subject testing in the semester, a time during which many of our experiments see erratic performance and high exclusion rates.

Discussion

This experiment extended the evidence for shared correspondence mechanisms in OFs and AM via yet another canonical case of AM—line motion. The experiment also provided evidence that priming does not always occur along the shortest distance, since here we found OF priming along the longer path. Finally, while we have described OFs as moving to new locations in this experiment, in fact, the objects did not leave their original locations to occupy new ones; they grew into the new ones. In Experiments 2a and 4, OFs did not seem to move to new locations when their original anchors remained in the display. But here, they did occupy new locations despite the fact that the anchors remained in the display. Thus, this experiment further demonstrates that predicting where OFs will go cannot be achieved based on individual display properties, but can be based on knowledge of AM correspondences.

EXPERIMENT 7: OBJECT FILE CORRESPONDENCES IN PHI MOTION

Our final experiment sought to further investigate the relationship between OFs and AM by exploring a more idiosyncratic case of AM. Specifically, we wanted to explore a case where a fissure between the two may emerge. One phenomenon that evidences the way that AM may rely on low-level mechanisms is phi motion. In phi motion, sometimes also termed "pure" or "object-less" motion, a light is observed to travel across two static objects briefly occupying or "possessing" each one of them (Wertheimer, 1912). The illusion is generated by a rapid change in brightness on one object's surface followed by a change on the surface of a nearby object (e.g., as in Christmas lights and storefront signs).

In phi motion, AM is perceived despite the fact that the "host" objects never disappear; instead, AM supports the perception of a ghostly entity moving between several placeholder objects. Recall that in Experiments 2a and 4 we failed to find OF priming when the original objects did not disappear from the screen before new objects appeared. But what should happen when phi motion is present? Since the original hosts remain present in a phi display, it may be the case that OFs remain associated with their original positions, producing no priming to the novel locations. On the other hand, as strange as it may seem, phi motion makes a strong impression of a moving object, and perhaps OF correspondence and reviewing procedures would be seduced by the phi illusion, moving to new locations despite the ongoing presence of the objects to which they were originally associated. Given the seeming a priori plausibility of either of these scenarios, we expected that phi motion is perhaps among the stronger tests of the relationship between AM and OFs.

Methods

After the fixation screen, the objects frame consisted of four identical dark grey circles, one in each corner of the invisible rectangle. After 500 ms, two of the circles in opposite corners turned a light shade of grey and remained this way for 1500 ms (see Figure 2 and demo online). The cue frame consisted of two cues appearing in the two light-grey areas. The motion frame consisted of the original two objects turning back to dark grey, while the opposite two objects turned light grey. In the test frame, a novel or repeated cue appeared in one of the two light grey objects. Pilot testing revealed that this display created a strong sense of phi motion traversing the shorter side of the invisible rectangle.

Participants. Seventeen participants completed this experiment. Data from two subjects were removed from the analysis due to low accuracy (less than 80%).

Results

Accuracy did not differ between congruent and incongruent trials (95.6% vs. 96.8%), $t(14) < 1$, $p = .25$, but was higher for novel trials (98.3%) compared to the average of congruent and incongruent trials, $t(14) = -3.33$, $p < .01$. 1.7% of trials were removed due to excessively slow or fast responses. Average RT in congruent trials was 831.97 ms ($SE = 51.5$ ms) compared to 854.58 ms ($SE = 50.69$ ms) in incongruent trials produced a significant AM-OSPB of 22.6 ms ($SE = 7.49$), $t(14) = -3.015$, $p < .01$. There was no Experiment × Trial type interaction when compared to Experiment 1, $F(1, 28) < 1$, At an individual level, 10/15 participants showed a positive AM-OSPB (binomial test, $p = .15$). Average RT during novel trials was 853.21 ms ($SE = 50$ ms).

Discussion

OF priming patterned with observed phi motion despite the fact that the objects in which cues originally appeared never disappeared. The strong impression of AM caused by the phi illusion appears to be sufficient to cause reviewing procedures to associate an OF with a new location, in this case, even a new object. These results evidence a strong parallel between OSPBs and AM suggesting that they share mechanisms for object updating and correspondence over time.

GENERAL DISCUSSION

Although apparent motion has played a prominent role in theories of object files, there has not been a direct test of whether object file correspondences and apparent motion tend to align with one another. By its very nature, the correspondence problem faced by apparent motion and object file mechanisms is a problem because multiple possible solutions may appear reasonable. Do these two phenomena usually arrive at the same solutions? In seven experiments, we demonstrated a convergence between AM and OFs. In the first experiment, we found an OSPB effect in AM displays, thus conceptually replicating the results of Kahneman and colleagues (1994). Experiments 2a and 2b excluded a potential confound in both the original study and Experiment 1, the possibility that priming effects spread to nearby spatial locations. In Experiment 3 we put spatiotemporal correspondence cues in direct conflict with featural ones, and we found OSPB effects consistent with spatiotemporal correspondence solutions, as with apparent motion. Experiment 4 demonstrated that surface properties do not independently generate priming effects in the absence of perceived motion. Experiment 5 demonstrated that, even when spatiotemporal cues are unreliable for solving the correspondence problem, surface features do not generate priming effects. Experiment 6 extended the relationship between AM and OFs to a novel motion illusion—line motion—and it confirmed that priming can occur along the longer available distance, but only given that this is the location consistent with the AM correspondence. Finally, Experiment 7 demonstrated that object file correspondences align with a particular case of apparent motion, phi motion, despite the fact that in those displays, the object frames that served as anchors for object file associations remained present throughout. Thus, Experiment 7 demonstrated that apparent motion could drive object file motion assignments even when put in conflict with alternative cues, namely the permanence of the original anchor objects.

The role of surface features in object file correspondences

Our findings have implications for the recent debate surrounding the role of surface properties in OF correspondences. In Experiment 3, we put surface properties—in this case, shape—in direct conflict with spatiotemporal properties—perceived motion on the basis of distance—and found that object preview benefits patterned with spatiotemporal considerations. In Experiment 4, we extinguished the perception of any motion, exploring the possibility that an independent feature-driven effect might now arise (i.e., that on each trial squares would be associated with one symbol, and circles with another). Had a priming effect emerged, we may not have wanted to interpret it is an object-driven effect, perhaps only as evidence that features can be associated with symbols. But we found no priming whatsoever, making the point moot. Finally, in Experiment 5, we kept the distance between the objects constant, thus making spatiotemporal evidence unreliable for determining the final locations of objects; even under these conditions, we failed to find evidence for feature-based priming. These latter two results should not be over interpreted, though, since both were null results with respect to feature associations. The methods employed are clearly powerful enough to evidence motion-driven and object-specific benefits when warranted, but they may not be powerful enough to identify feature-based effects even if they are present.

Some prior evidence has suggested that, in the absence of clear spatiotemporal cues, OF correspondences may be solved on the basis of surface properties (Hollingworth & Franconeri, 2009; Moore et al., 2010). For example, in an experiment by Hollingworth and Franconeri (2009), two differently coloured objects were associated with symbols. The objects then moved behind an occluder, and they continued to move while out of sight. When the occluder was removed, and a congruent or incongruent symbol appeared inside one of the objects, participants were faster to identify the symbol when it appeared in the same-coloured object as before, evidencing priming driven by a surface property.

The seeming contrast between our findings and those of Hollingworth and Franconeri (2009) can be explained in one of two ways. First, it is possible that the colour-driven effect in Hollingworth and Franconeri's study was just an association between symbols and features, but not an object-driven effect per se. In other words, not all associations and resulting priming must be based on object representations (see also Gao & Scholl, 2010). Feature representations may be sufficient to supply a substrate for an association and to produce priming effects. In our experiment, we did not find such purely feature-driven priming, but perhaps this was because there were always clear object-driven cues—the permanence of the original objects (in Experiment 4) and some observed AM (in Experiment 5)—that interfered with feature-driven priming. As a result, if more than one set of associations is present in a display it will be hard to interpret null results as the absence of a particular kind of effect as opposed to an averaging out of effects caused by multiple, independent associations. The crucial distinction between our Experiment 4 and Hollingworth and Franconeri, then, is that in our experiment, the two objects that originally hosted the symbols remained present in the display and anchored to their original positions at test. Thus, they may have generated a strong association with the symbols, and an expectation that the symbols should reappear in those old locations. Those expectations may have negated any effects of additional feature-driven associations. In Hollingworth and Franconeri's study, in contrast, the two original objects were not present in the test display in the same places as they originally appeared, and indeed, in those experiments, it was a fair pragmatic assumption that each of the two objects behind the occluder were an instance of one of the original two objects, the question was just which one.

This leads to the second way to resolve the apparent conflict between our studies, namely, that in our experiment object assignments were actually unambiguous on the basis of spatiotemporal factors, but in their experiment spatiotemporal factors were ambiguous. The use of occlusion in Hollingworth and Franconeri, and the fact that objects appeared at new vertical coordinates from the ones where they occluded, made it so that there was no spatiotemporal basis for preferring one correspondence to another. Perhaps surface properties play a role in OF assignments and in driving priming only when spatiotemporal factors supply no basis for a correspondence. If this is the case, we suggest that when they do provide a basis for a preference—for instance, when they support motion perception via closest distance—that spatiotemporal factors trump featural ones. One might wonder, however, why we found no feature-based priming in our Experiment 5, given that spatiotemporal evidence was also somewhat ambiguous. As discussed previously, one possibility is that spatiotemporal information *did* provide strong evidence for both up–down or left–right motion, and that each type of motion was stochastically perceived across the entire experiment. As such, it was impossible for us to determine which trials were congruent and incongruent, and the mix of the two may have led to a null effect. Perhaps, in the long run, the presence of featural effects can be used to identify instances when spatiotemporal factors really do not supply any basis for correspondences, or those where the nature of the surface feature (e.g., shape vs. topology) may be an especially strong cue for correspondence.

How are object correspondences determined by the visual system?

In many ways, much of the research on object files and apparent motion is driven by the same question: How are object correspondences determined by the visual system? AM experiments often employ some form of ambiguity, in motion quartets, for instance, to ask how the visual system makes decisions about correspondences so that motion can be perceived. And object reviewing experiments exploit OSPB to determine the conditions under which the visual system successfully maintains object correspondences across successive encounters, for instance, when objects move over long distances and durations (Noles, Scholl, & Mitroff, 2005), when they move through spatially ambiguous paths (Mitroff et al., 2005), or when global patterns imply the motion of hidden objects (Gao & Scholl, 2010). In the current set of experiments we used motion quartets, line motion, and phi motion to demonstrate that under at least some ambiguous situations OF correspondences and AM correspondences are determined in the same way.

An obvious question arises: Do they share the same mechanisms for determining correspondences? We can think of three possible answers. First, it is possible that a single set of mechanisms analyses visual inputs, determining object correspondences, which are then used to drive AM percepts as well as OF assignments. But this seems unlikely because, as we noted earlier, there is at least one documented case of OF assignments diverging from perceived motion (Mitroff et al., 2005), and because AM relies on low-level, more implicit kinds of mechanisms (i.e. motion detectors) that produce correspondences without necessarily engaging in any inference-like processes. It is unclear whether all OF results could be accounted for in this way, but generally, OF theories seem to endorse a more explicit, inference-like calculus (Kahneman et al., 1992).

In contrast, OF and AM may often find the same solutions, but via entirely redundant mechanisms. The systems may be separate, but designed to work together. This seems unlikely as well, however, first because it would be inefficient, and second because the alignments observed in the current experiments went beyond just the emergence of AM and OSPBs in basic quartet situations. Specifically, we observed that both AM and OSBPs ignored surface features under the same circumstances, respected pragmatic cues despite the presence of distracting objects, and could emerge under line and phi motion conditions. This convergence appears to be more than just a coincidence. Phi motion, especially, suggests that low-level AM can drive OF assignments. In other words, the presence of a clear AM percept can cause OF associations to occupy new locations.

Therefore, we suggest that a third possible reason for convergence seems the most likely. Specifically, correspondence mechanisms may be hierarchical. The visual system may contend with the problem of object correspondences at every stage in processing, and higher level mechanisms may rely on the outputs of lower level ones when appropriate, but also possibly overriding them when incorporating additional evidence leads to a different solution (Cavanagh, 1992; Odic & Pratt, 2008). In this way, phenomena such as phi motion may be able to drive object specific preview benefits, while at the same time, motion percepts and OF assignments may diverge under unusual and ambiguous circumstances. Further experiments exploring the relationship between OFs and AM may therefore be warranted and theoretically influential, especially if they employ known phenomena in AM, such as Ternus displays (Petersik & Rice, 2006). The potential divergences between AM and OF systems may ultimately prove as informative as the convergences. Fortunately, in the case of apparent motion, correspondence mechanisms at the algorithmic level have been proposed and studied elsewhere, including simple computational proposals such as the application of the "nearest neighbour principle"

(Dawson, 1991; Hildreth & Koch, 1987). Thus, it may be especially productive to evaluate object file correspondences in light of those mechanisms.

Overall, we have demonstrated that under a well-studied class of ambiguous displays, AM mechanisms and OF assignments converge upon specific correspondences solutions. Broadly, we think that these converges likely reflect the fact that certain algorithms supply sensible ways of solving correspondence problems. Indeed, it is likely that the mechanisms involved in solving correspondences to perceive AM and to maintain OFs reflect some of the same algorithms used throughout the visual system to deal with correspondence problems, which arise perennially and inescapably. Visual detection of motion, generally, requires placing temporally displaced features in correspondence with one another (e.g., Hildreth & Koch, 1987). Global stereopsis involves establishing a correspondence relation among features in the two retinal images (e.g., Marr & Poggio, 1976; Pollard, Mayhew, & Frisby, 1985). Early stages of object identification depend on matching or aligning properties of a mental representation with properties in the visual scene (e.g., Ullman, 1996). Tracking moving objects requires correspondence mechanisms (Bae & Flombaum, 2012; Vul, Frank, & Tenebaum, 2009). And even basic visual working memory tasks require operations that place objects in memory in correspondence with new observations, providing a basis for comparison (Levillain & Flombaum, 2012). Thus, the current results emphasize that a computational challenge faced at every level in the visual system involves the merging of distinct encounters to produce a coherent visual experience of objects.

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