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The Influence of Object Location on Identity: A "Spatial Congruency Bias"

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Objects can be characterized by a number of properties (e.g., shape, color, size, and location). How do our visual systems combine this information, and what allows us to recognize when 2 objects are the same? Previous work has pointed to a special role for location in the binding process, suggesting that location may be automatically encoded even when irrelevant to the task. Here we show that location is not only automatically attended but fundamentally bound to identity representations, influencing object perception in a far more profound way than simply speeding reaction times. Subjects viewed 2 sequentially presented novel objects and performed a same/different identity comparison. Object location was irrelevant to the identity task, but when the 2 objects shared the same location, subjects were more likely to judge them as the same identity. This "congruency bias" reflected an increase in both hits and false alarms when the objects shared the same location, indicating that subjects were unable to suppress the influence of object location—even when maladaptive to the task. Importantly, this bias was driven exclusively by location: Object location robustly and reliably biased identity judgments across 6 experimental scenarios, but the reverse was not true: Object identity did not exert any bias on location judgments. Furthermore, while location biased both shape and color judgments, neither shape nor color biased each other when irrelevant. The results suggest that location provides a unique, automatic, and insuppressible cue for object sameness.

Keywords: object recognition, feature binding, location invariant, spatial perception, congruency

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One of the most fundamental human behaviors is our ability to recognize and locate objects in the environment. For example, to reach for your mug of coffee on your desk, you need to be able to both recognize the shape of the mug and know where to reach your hand. In the realm of vision, these are often thought of as separate processes (e.g., "what" and "where" pathways; Mishkin, Ungerleider, & Macko, 1983; Ungerleider & Haxby, 1994). But in order to be useful, this "what" and "where" information needs to be combined.

The Binding Problem

This challenge is often known as the "binding problem," and has spurred a number of neural and psychological theories (Holcombe, 2009; Reynolds & Desimone, 1999; Treisman, 1996, 1999; Treisman & Gelade, 1980; von der Malsburg, 1999; Wolfe & Cave, 1999). The binding problem most generally refers to the idea that different features or properties (e.g., color, shape, location) are coded separately in the brain, yet need to be integrated together to identify objects. We are generally able to combine this information effortlessly, say, to recognize that your desk contains two objects: a blue mug and a red pen. However, under suboptimal conditions, we may be susceptible to errors in feature binding, often called "illusory conjunctions" (Treisman & Schmidt, 1982). The binding problem can refer to the binding of different object features (e.g., blue plus round), or to the binding of object features to their location, which may involve different neural mechanisms (Piekema, Rijpkema, Fernández, & Kessels, 2010). The primary focus of the current article is on object–location binding.

Different theories of binding propose various solutions, including hierarchical combination of information at later stages of processing (Riesenhuber & Poggio, 1999), temporal synchrony (Singer, 1999; von der Malsburg, 1999), and attentional mechanisms (Reynolds & Desimone, 1999; Treisman & Gelade, 1980). A common theme, especially among the latter class of theories, is that spatial location plays an important role in the binding process, with spatial attention acting as the glue that binds an object's features together (Treisman & Gelade, 1980).

Is Location Special?

One oft-asked question is whether location is special: Although some have posed that location is just one of many object properties (Bundesen, 1991), the predominant view seems to be that of a special role for location in the binding problem. Treisman's feature

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integration theory (Treisman & Gelade, 1980) posited that spatial attention is required to bind different features of an object into a coherent whole. Kahneman, Treisman, and Gibbs (1992) proposed "object files" that are created and defined by location; the analogy is that of a file drawer sorted by location, where each file contains information about the object features currently present at that location. Location-based selection is also a critical feature of the object index model (Leslie, Xu, Tremoulet, & Scholl, 1998), guided search theory (Wolfe, 1994), FeatureGate model (Cave, 1999), salience map model (Koch & Ullman, 1985), and Boolean map theory (Huang & Pashler, 2007), among many others. Moreover, recent evidence suggests that splitting or shifting spatial attention can alter the binding process (Golomb, L'Heureux, & Kanwisher, 2014).

If spatial location is so critical for object binding, this leads to the question, Is spatial location automatically bound to an object representation? Is it possible to ignore location information, or does even irrelevant location information still affect behavior? It is well known that attending to or remembering a spatial location leads to enhanced processing of objects appearing at that location (Awh, Jonides, & Reuter-Lorenz, 1998; Posner, 1980). There is also evidence that location is encoded or attended even when irrelevant to the task. Although early versions of feature integration theory posited that features could be represented independent of their locations (Treisman & Gelade, 1980), many subsequent studies have argued that location is automatically encoded. For example, Johnston and Pashler (1990) found no evidence for object identification without localization after correction for guessing, and Nissen (1985) similarly showed that identification of object shape is dependent on correct localization.

Tsal and Lavie (1988, 1993) presented even stronger evidence for the automatic encoding of location. In one set of experiments, when subjects were instructed to report a target letter specified by color or shape, they were more likely to report additional letters that were located in close spatial proximity to the target, as opposed to letters similar in the cued dimension (Tsal & Lavie, 1988). In subsequent experiments they made location information not only irrelevant but detrimental to the task (i.e., attending to location could hurt performance): Subjects were instructed to report one of two targets based on the color of a cue, not its location. However, subjects were unable to ignore the cue's location, suggesting that attending to any object feature requires attending to its location (Tsal & Lavie, 1993).

More recently, other groups have also presented evidence for an automatic and special role of location, where location is automatically encoded whenever subjects attend to other object features (e.g., shape, color), but those other features are not automatically encoded when attending to location (Cave & Pashler, 1995; Chen 2005, 2009).

Separate "What" and "Where" Pathways in the Brain?

The interplay of object identification and localization is an issue that has been investigated in parallel by cognitive psychologists looking for behavioral evidence elucidating the binding process and by neuroscientists investigating where and how object location and features are represented in the brain. The classic neuroscience dissociation holds that "what" and "where" information are processed separately in the ventral and dorsal visual streams, respectively (Mishkin et al., 1983). This dissociation is sometimes reframed in terms of vision for perception versus vision for action (Goodale & Milner, 1992), or more recently, multiple dorsal visuospatial pathways (Kravitz, Saleem, Baker, & Mishkin, 2011). Human patients (Goodale, Milner, Jakobson, & Carey, 1991; James, Culham, Humphrey, Milner, & Goodale, 2003; Newcombe, Ratcliff, & Damasio, 1987) and lesioned monkeys (Ungerleider & Mishkin, 1982) with damage in the ventral temporal lobe exhibit difficulty recognizing—but not locating—objects, while those with parietal lesions exhibit impaired localization and spatial attention abilities. Single-unit recording studies have demonstrated that neurons become selective to stimuli that are increasingly complex and invariant (to changes in size, location, etc.) along the ventral hierarchy (Desimone, Albright, Gross, & Bruce, 1984; Rust & DiCarlo, 2010), while maintaining specialization for location and spatial attention in the dorsal stream (Colby & Goldberg, 1999). Early neuroimaging studies supported this dissociation (Haxby et al., 1991, 1994; Ungerleider & Haxby, 1994; Valyear, Culham, Sharif, Westwood, & Goodale, 2006), with ventral areas, such as the lateral occipital complex, specialized for object processing (Grill-Spector et al., 1999; Malach et al., 1995) and parietal areas specialized for visually guided grasping (Culham et al., 2003) and spatial attention (Corbetta, Kincade, Ollinger, McAvoy, & Shulman, 2000; Yantis et al., 2002).

However, more recent studies have challenged this strict dichotomy. In particular, there is now ample evidence that even higher order ventral visual areas preserve information about spatial location, albeit with decreased precision. Neurons in monkey inferior temporal cortex are more sensitive to spatial location than initially thought (DiCarlo & Maunsell, 2003; Op De Beeck & Vogels, 2000), and analogous human areas (e.g., lateral occipital complex) have been reported for some time to exhibit at least contralateral spatial biases (Hemond, Kanwisher, & Op de Beeck, 2007). More recently, more sophisticated retinotopic mapping techniques have revealed considerable topographic information in object-sensitive ventral stream areas (Arcaro, McMains, Singer, & Kastner, 2009; Brewer, Liu, Wade, & Wandell, 2005; Larsson & Heeger, 2006; Saygin & Sereno, 2008; Sayres & Grill-Spector, 2008), and multivariate pattern analysis has demonstrated that robust category/identity-tolerant location information exists in the fine-grained patterns of functional magnetic resonance imaging (Carlson, Hogendoorn, Fonteijn, & Verstraten, 2011; Cichy, Chen, & Haynes, 2011; Golomb & Kanwisher, 2012; Kravitz, Kriegeskorte, & Baker, 2010; Schwarzlose, Swisher, Dang, & Kanwisher, 2008) and magnetoencephalography (Carlson, Hogendoorn, Kanai, Mesik, & Turret, 2011) responses. Additional studies report evidence for location–identity binding in the medial temporal lobe and prefrontal cortex (e.g., Hannula & Ranganath, 2008; Mitchell, Johnson, Raye, & D'Esposito, 2000; Rao, Rainer, & Miller, 1997).

Indeed, the increasing evidence that neurons are jointly tuned for multiple types of information within the same brain regions has led to the controversial suggestion that the binding problem itself is ill-posed because features to be bound are not represented independently in the first place (Di Lollo, 2012). However, this notion has been disputed by others arguing that the prolific behavioral errors are evidence that a binding problem does exist (Holcombe & Clifford, 2012; Wolfe, 2012). Even if location and feature information are jointly represented in the same brain re-

gions, we still know relatively little about how these representations interact.

Current Study

If location information is represented in object recognition areas and automatically encoded, what other influences might location have on object recognition? Most of the behavioral investigations described above focused on attention effects, that is, a speeding of processing or enhanced sensitivity at or near the object location. But if spatial location is such an automatic, integral part of object recognition, might there be an impact of spatial location beyond attentional orienting? In the current investigation, we explored whether object location can influence the perception of other object properties. In other words, can object location influence not just *how* objects are perceived, but *what* is perceived?

In Experiment 1, we presented subjects with two objects sequentially and asked them to judge whether or not they were the same identity/shape. In line with prior studies, subjects were faster to respond when the two objects were presented in the same spatial location. However, we also discovered a novel effect: When the two objects were presented in the same location, the identity responses themselves were biased. Subjects were more likely to report that the identity of the objects was the same when they were presented in the same location, even though location was irrelevant to the task.

In the subsequent experiments, we explored this "spatial congruency bias" more thoroughly. Experiment 2 tested a variety of object locations to examine whether the bias scales with distance, Experiment 3 tested whether the bias was driven by perceptual or response-level effects, and Experiments 4–6 focused on whether the congruency bias is robust and specific to location by testing multiple tasks and feature dimensions. The result was a consistent and substantial biasing of identity judgments by irrelevant location information.

General Method

Subjects

All subjects reported normal or corrected-to-normal vision. Informed consent was obtained for all subjects, and study protocols were approved by the Ohio State University Behavioral and Social Sciences Institutional Review Board (or the Massachusetts Institute of Technology Committee on the Use of Humans as Experimental Subjects; Experiment 4). All subjects were compensated with a small monetary sum or course credit.

Experimental Setup

Stimuli were generated with the Psychtoolbox extension (Brainard, 1997) for MATLAB (MathWorks) and presented on a 21-in. (53.34-cm) flat screen CRT monitor. Subjects were seated at a chinrest 60 cm from the monitor. The monitor was color calibrated with a Minolta CS-100 colorimeter.

Eye Tracking

Eye position was monitored with an EyeLink 1000 eye-tracking system (ISCAN system for Experiment 4) recording pupil and corneal reflection position. Fixation was monitored for all experiments. If at any point the subject's fixation deviated greater than 2°, the trial was aborted and repeated later in the block.

Analyses

For each trial, we recorded the subject's response and reaction time (RT). We also calculated d' and response bias measures using signal detection theory:

$$d' = z(\text{hit rate}) - z(\text{false-alarm rate})$$

$$\text{Response bias} = -(z(\text{hit rate}) + z(\text{false-alarm rate}))/2$$

Values for all measures were averaged separately for each subject and condition and submitted to random-effects analyses (repeated-measures analyses of variance [ANOVAs] and planned two-tailed t tests). Effect sizes were calculated with partial eta squared and Cohen's d. Trials on which subjects failed to respond, or responded with RTs greater than or less than 2.5 standard deviations of the subject's mean RT, were excluded (less than 3.9% of trials for each experiment). Subjects who had an overall task accuracy of less than 50% (criterion set in advance) were excluded from analyses.

Statistical Power

We set a target sample size of 16 subjects for the experiments involving a single two-alternative forced-choice task (Experiments 1, 2, and 5), and 20 subjects for the experiments involving multiple tasks and increased levels of comparison (Experiments 3, 4, and 6). Sample size for Experiment 1 was chosen based off power analyses from the most methodologically similar prior study from our group (Golomb, Chun, & Mazer, 2008), involving an RT effect for cued versus uncued locations in a two-alternative forced-choice task. The prior study had an effect size of $d = 1.38$; with a sample size of $N = 16$, the power $(1 - \beta)$ to detect such an effect is estimated at .999. To ensure we collected enough data by the end of the semester (anticipating a certain number of no-shows and exclusions), we scheduled approximately 25% more subjects for each experiment than our target sample size.

Experiment 1

Does Object Location Influence Identity Judgments?

In the first experiment, we investigated what effect—if any—location information has on the representation of an object's identity. Subjects were presented with two sequential objects in the periphery and performed a two-alternative forced-choice same/different identity judgment. The objects were presented in four conditions: same or different identity by same or different location. Object location was completely irrelevant to the identity task. Nonetheless, we asked whether location would influence the identity judgments. We considered three possible types of location influence: priming (faster RTs for same vs. different location), increased sensitivity (higher accuracy or d' for same vs. different location), and bias (a shift in the distribution/criteria of identity responses for same vs. different location).

To ensure that subjects were in a sensitive range of performance to test these measures, we used a set of morphed object stimuli that varied in similarity (see Figure 1 inset). The morph level was adjusted for each subject with an adaptive staircase procedure to achieve performance near 70%–75% correct on the identity task.

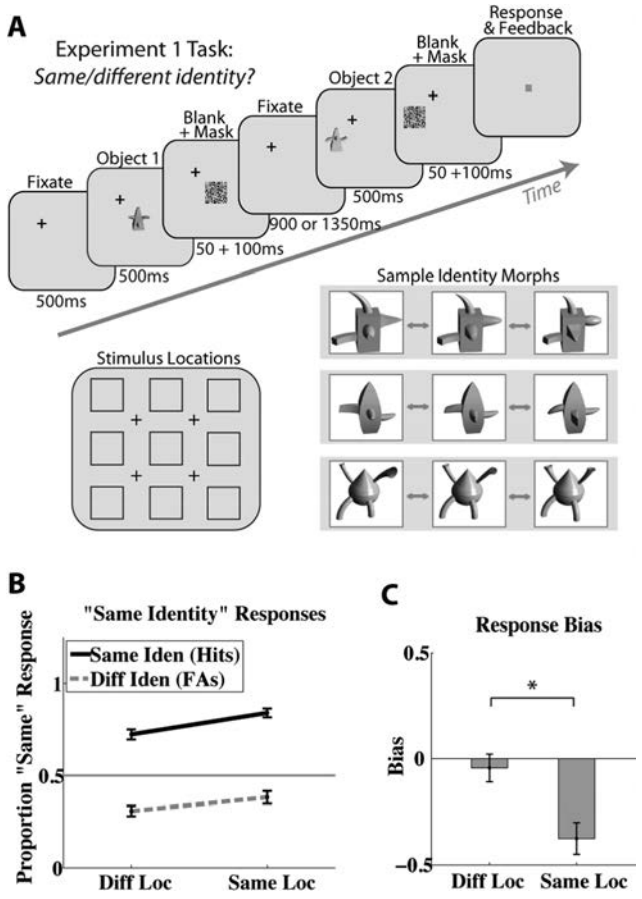

Figure 1. Experiment 1 methods and results. (A) A sample trial is illustrated. While fixating, subjects saw two sequential object presentations in the periphery, followed by masks. The task was to judge whether they were the same or different identity. Subjects received feedback on each trial (green = correct, red = incorrect). Objects could be same/different identity (relevant dimension) and presented in same/different locations (irrelevant dimension). Left inset illustrates possible stimulus locations (only the four adjacent locations were used for a given fixation location; fixation location was varied across trials but always stable within a trial). Right inset shows sample identity morphs (three exemplars representing 0%, 50%, and 100% morph levels are shown from each of three example morph families). When the objects differed in identity, the difference was subtle (i.e., the objects were always drawn from the same family, with morph distance staircased for each subject). (B) Proportion of "same identity" responses, broken down by identity and location conditions. Black line shows hits (actual same identity); gray dashed line shows false alarms (FAs; actual different identity). Chance is 50%. (C) Response bias (criterion) on the identity task plotted for same and different location. Error bars are standard error of the mean; asterisk indicates $p < .05$ (paired t tests). $N = 16$. Iden = identity; Diff = different; Loc = location.

Method

Subjects. Sixteen subjects (six female, 10 male; mean age = 19.75 years; range: 18–25) participated in this experiment; one additional subject completed the study but was excluded for poor task performance (accuracy < 50%).

Stimuli. Stimuli were a set of novel objects modified from the Tarr stimulus set (stimulus images courtesy of Michael J. Tarr, Center for the Neural Basis of Cognition and Department of Psychology, Carnegie Mellon University, http://www.tarrlab.org). We selected 10 pairs of objects and created a morph series between each pair using FantaMorph software (Abrosoft; http://www.abrosoft.com). Each of these 10 families contained 20 individual exemplar objects (5% morph difference between each image). Within a family, the "body" of the object always remained constant, while the "appendages" could vary in shape, length, or relative location. Differences between morph levels in each family were roughly equated for difficulty in a series of pilot tasks. Stimuli were sized 6.25° × 6.25° and centered at 7.07° eccentricity. Stimulus orientation was never varied.

Task and design. Subjects began each trial by fixating on a black fixation cross in one of four fixation locations (see Figure 1A). Once subjects were fixating for 500 ms, an object appeared in the periphery (upper left, upper right, lower left, or lower right of fixation; centered at 7.07° eccentricity). The object remained visible for 500 ms, followed by a blank screen (50 ms) and a mask (100 ms). After a delay of 900 or 1,350 ms, during which subjects maintained fixation, a second object appeared. (Delay time did not interact with our results of interest, so data are presented collapsed across delay.) The second object was presented for the same duration and masked as the first.

The second object could be in either the same or different location as the first, and it could be the same or different identity. These four conditions were counterbalanced and equally likely. Initial variables (fixation location, Object 1 location, Object 1 identity) were randomly assigned for each trial. When location was different, one of the other three stimulus locations was randomly chosen for Object 2. When identity was different, the second object was chosen as a different exemplar from the same morph family (the difference was meant to be subtle, and morph distance was chosen individually for each subject based on a staircase conducted during practice and adjusted after each block if necessary to maintain performance near 70%–75% accuracy).

Subjects were instructed to make a two-alternative forced-choice same/different judgment comparing the two objects' identities; location was irrelevant to the task. Subjects responded by button press and were presented with visual feedback (a green or red square) informing them whether their response was correct. They were also provided with feedback if they broke fixation at any point during the trial: a large red X would appear in the middle of the screen and the trial was aborted and repeated later in the run.

After a 1,500-ms intertrial interval, the next trial began. Subjects completed 24 trials per block (six trials for each of the four Location × Identity conditions, in randomized order). Each subject completed one practice block and between six and eight main blocks. (A few subjects were unable to complete the full eight blocks in the time allotted.).

Results

Figure 1B illustrates the proportion of "same identity" responses broken down by hits and false alarms for each location. Visual inspection of the data suggests that both hits and false alarms were increased when the two objects were in the same location, as if subjects were more biased to report "same identity" when location was the same. To quantify these data, we used signal detection theory to calculate bias (criterion) and sensitivity (d') measures. Below we report analyses for the effects of location on bias, sensitivity, and RT priming; complete tables listing all measures (including proportion "same" responses and accuracy) can be found in the supplemental materials.

Bias. Figure 1C illustrates the response bias (criterion); a negative bias indicates a greater tendency to respond "same." Response bias was significantly larger (more negative) for same versus different location, $t(15) = 4.02$, $p = .001$, $d = 1.01$. Post hoc one-sample t tests comparing each to chance (zero bias) revealed a significant bias for same location, $t(15) = -5.04$, $p < .001$, $d = 1.26$, but not for different location, $t(15) = -0.67$, $p = .515$, $d = 0.17$.

Sensitivity. Concerning sensitivity, d' (see Table S1) was not significantly influenced by object location, $t(15) = -1.77$, $p = .097$, $d = 0.44$.

Priming. RT priming (see Table S1) was significant; presenting objects in the same location resulted in faster responses than different locations, $F(1, 15) = 13.57$, $p = .002$, $\eta_p^2 = .48$.

Discussion

The results from Experiment 1 reveal two significant effects of object location on identity judgments. In addition to RT priming, which has been previously reported (e.g., Tsal & Lavie, 1993), we found a significant shift in response bias: Subjects were more likely to judge two objects as having the same identity when they appeared in the same location, even when location was irrelevant to the task and its influence could be detrimental to performance. We term this phenomenon the *spatial congruency bias*. This influence of object location goes beyond attentional orienting benefits (such as RT priming) and suggests a more profound effect of location on the responses themselves.

This novel finding raises a number of follow-up questions that we systematically investigate in the subsequent experiments. (a) What kind of location information causes a bias? Is there a gradient of spatial congruency? (b) Does the bias occur at the perceptual level, or is it a response-level bias? (c) Is it something special about location, or do other features cause similar congruency biases?

Experiment 2

Does the Spatial Congruency Bias Scale With Distance?

In Experiment 2 we presented objects at different distances from each other to test whether the congruency bias exhibits a location gradient. Subjects performed the same task as in Experiment 1, judging whether two objects had the same or different identity. Instead of only two location conditions (same/different), in Experiment 2 we used six location conditions: same (0° difference) and different by 1°, 2°, 4°, 10°, and 14° visual angle. All objects were presented at equal visual eccentricity from fixation.

Method

Subjects. Sixteen subjects (seven female, nine male; mean age = 19.56 years; range: 18–27) participated in this experiment.

Stimuli, task, and design. Stimuli, task, and design were identical to those in Experiment 1, with the following exceptions: The fixation point was always presented in the center of the screen. The first stimulus could appear anywhere along an invisible circle (of radius 7.07°) centered on the fixation point (see Figure 2A). The second stimulus appeared along the same circle, with the angle between the two stimuli being selected from the following possibilities: ±0°, 7.5°, 15°, 30°, 90°, 180°, corresponding to an actual distance between the stimuli of 0°, 1°, 2°, 4°, 10°, and 14° visual angle. Subjects completed eight

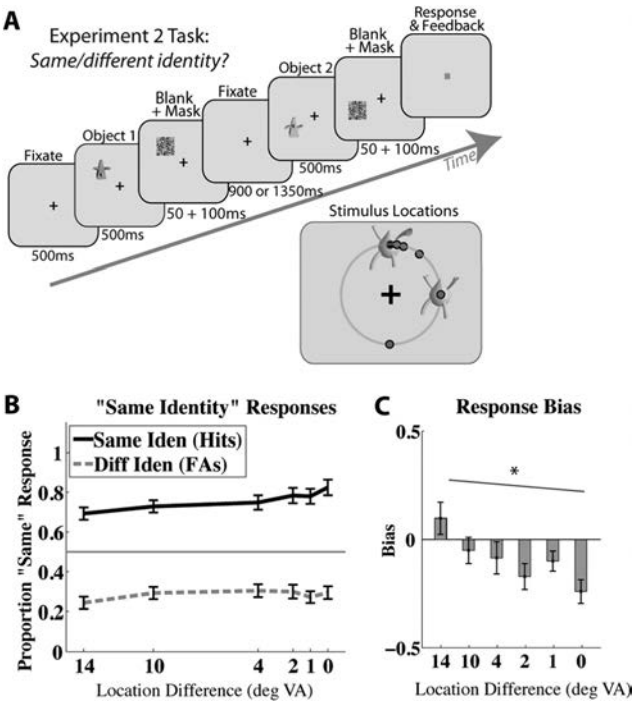

Figure 2. Experiment 2 methods and results. (A) A sample trial is illustrated. The task was the same as in Experiment 1 (see Figure 1), but there were six location conditions. Inset illustrates the stimulus configuration and location differences. For example, if the first stimulus appeared directly above the fixation cross, the second object could be in the same location (0° difference, dark gray dot), or it could differ by 1°, 2°, 4°, 10°, or 14° (light gray dots, corresponding to 7.5°, 15°, 30°, 90°, 180°, along an isoeccentricity circle). (B) Proportion of "same identity" responses, broken down by location and identity. Black line shows hits, and gray dashed line shows false alarms (FAs). Chance is 50%. (C) Response bias (criterion) on the identity task plotted by location difference. Error bars are standard error of the mean; asterisk indicates $p < .05$ (main effect of location). $N = 16$. Iden = identity; Diff = different; deg VA = degrees of visual angle.

to 10 blocks of 56 trials each (16 same location [0°] trials per block; eight each of the other distances).

Results

Figure 2B illustrates the proportion of "same identity" responses (hits and false alarms) as a function of location difference.

Bias. Response bias is plotted in Figure 2C for each location condition. The greatest (most negative) bias was found when the two objects were in the same location, with the bias decreasing as the distance between the objects grew (significant effect of location: $F(1, 15) = 37.35$, $p < .001$, $\eta_p^2 = .71$, linear contrast). One-sample t tests revealed that the bias was significant for 0°, 1°, and 2° location differences ($t = -4.36$, $p = .001$, $d = 1.09$; $t = -2.14$, $p = .049$, $d = 0.54$; and $t = -2.86$, $p = .012$, $d = 0.72$, respectively), but not for greater distances ($|t|s < 1.14$, $ps > 0.205$, $ds < 0.33$). Additional tests revealed that the bias was significantly greater at the same location than at the smallest different location (0° vs. 1°), $t(15) = -3.160$, $p = .006$, $d = 0.79$, but importantly, that the main effect of location was not driven by the 0° condition: An ANOVA on the five "different" locations still confirmed a main effect of location on response bias: $F(1, 15) = 14.16$, $p = .002$, $\eta_p^2 = .49$, linear contrast.

Sensitivity. Interestingly, in this experiment we found that object location influenced sensitivity in addition to bias. The d' values increased with similarity in location (see Table S2): $F(1,15) = 11.94$, $p = .004$, $\eta_p^2 = .44$, linear contrast.

Priming. RT analysis (see Table S2) also revealed a significant main effect of location: $F(1, 15) = 43.72$, $p < .001$, $\eta_p^2 = .75$, linear contrast.

Discussion

In Experiment 2 we replicated the spatial congruency bias and revealed a gradient of spatial similarity: The more similar in location two objects are, the more likely they are to be judged as the same identity. Interestingly, whereas in Experiment 1 we found what appeared to be a pure bias effect (no influence of location on sensitivity), in Experiment 2 we found both increased bias and increased sensitivity with more similar locations.

Experiment 3

Response Interference or Perceptual Bias?

The first two experiments demonstrated a spatial congruency bias where subjects were more likely to judge two objects as having the same identity when their location was the same (or more similar). An important theoretical question is whether this bias occurs on a perceptual level or is more of a response-level interference. In other words, is the "sameness" of the location interfering with the "sameness" of the response, or is it actually influencing how subjects perceive the object identities?

In Experiment 3 we used a different paradigm that eliminates the response-level conflict arising from the two-alternative forced-choice same/different task. Subjects saw a pair of objects, as before, but instead of making a binary same/different judgment, they made a graded similarity judgment using a sliding scale. Subjects moved the indicator along the scale to estimate "how similar" the two objects were in identity. In this experiment we included three identity conditions (see Figure 3): The pair of objects could be identical, slightly different (using the same subtle morph differences as before), or very different (drawn from different object "families"). We used the original two location conditions (same/different) from Experiment 1.

If the congruency bias were simply driven by response interference, we would not expect to see an influence of location on the similarity ratings. A perceptual-level account, however, would make two key predictions. First, subjects should rate objects appearing in the same location as more similar (not just more likely to respond "same"). Second, we would expect to see this effect primarily when the task is perceptually difficult; for example, we would not expect someone to confuse a coffee mug with a pencil just because they are in the same location. Likewise, in the current task, when two objects have very obvious physical differences (our "very different" condition), we should expect less of an influence of location than when the objects are only subtly different.

Method

Subjects. Twenty-two subjects (13 female, nine male; mean age = 19.22 years; range: 18–24) participated in this experiment. Two additional subjects completed the study but were excluded for not performing the task properly: One of them always positioned the slider at the far right or far left (turning it into the binary same/different task we had been trying to avoid), and the other only used three slider positions (far left, unmoved middle position, far right), also making it a categorical instead of continuous similarity judgment. Note that the pattern of results described below would have still been the same had we not excluded these subjects.

Stimuli, task, and design. Stimuli, task, and design (see Figure 3A) were similar to those in Experiment 1, with the following exceptions: Three identity conditions were used. "Identical" and "slightly different" conditions used the same stimuli as "same" and "different" identity conditions in Experiment 1. "Slightly different" objects were chosen from the same morph family, although in this experiment the morph distance was fixed at a set amount for all subjects (based on the average morph distance from Experiment 1), since staircasing based on accuracy was not feasible. A third "very different" condition was also added, where stimuli were drawn from two separate morph families (instead of different morph levels in the same object family; see Fig 3A inset). Because stimuli could be drawn from nine families, this created a range of differences for both "slightly different" and "very different" pairs. We did not have the power to look for individual or systematic family-wise differences in these ratings, but the same set of stimulus pairs was presented for both location conditions. Thus, we should expect to see a distribution of similarity ratings for each subject and identity condition; the question is whether these similarity distributions differ based on object location.

Critically, instead of a binary two-alternative forced-choice same/different response, subjects were presented with a sliding scale during the response period. The scale was a rectangle sized 11.5° × 2.9°, labeled with "identical" at the left end and "very different" at the right end. The slider was initially positioned at the

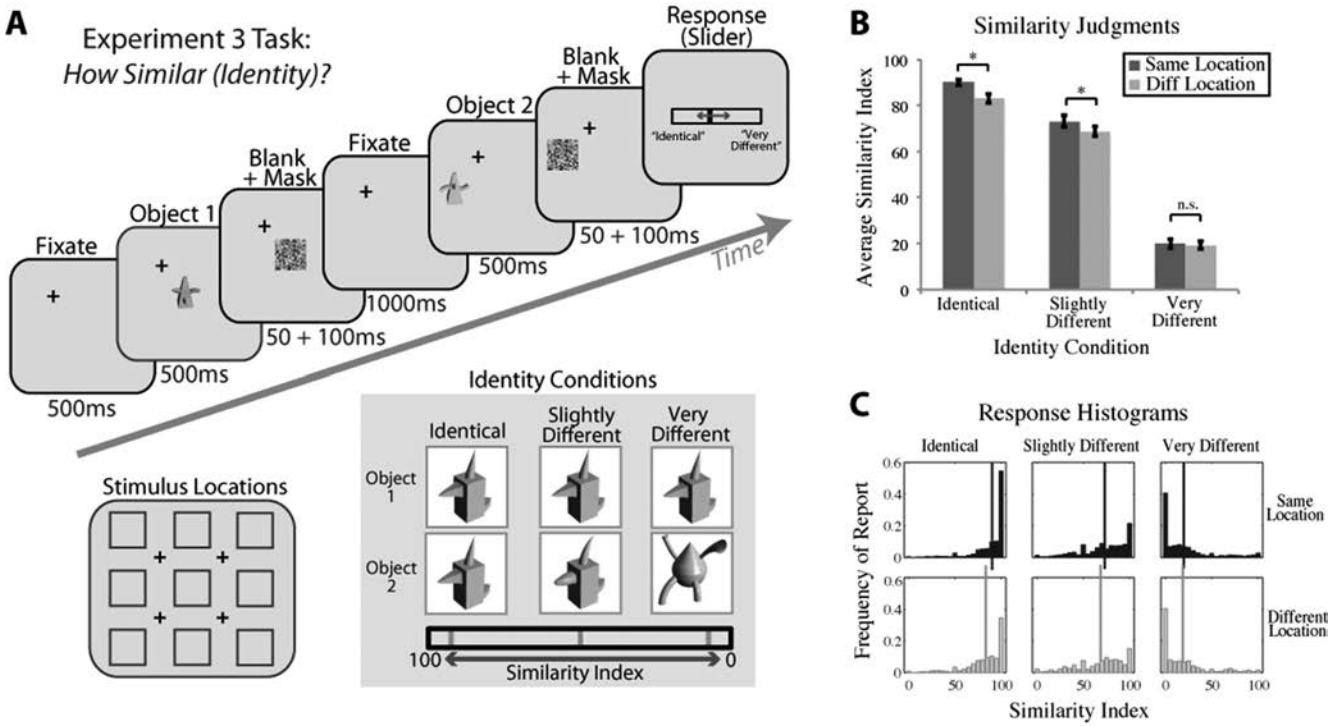

Figure 3. Experiment 3 methods and results. (A) A sample trial is illustrated. The task was the same as in Experiment 1 (see Figure 1), but subjects made a graded similarity judgment instead of a binary same/different task. To respond, subjects moved the response slider to the left or right to indicate "how similar" the two objects were. Insets illustrate possible stimulus locations (same as in Experiment 1) and sample stimuli from each identity condition: "identical," "slightly different" (drawn from the same morph family), and "very different" (drawn from different morph families). (B) Similarity judgments (average similarity index on a scale of 0–100, with 100 being most similar), broken down by identity and location conditions. Error bars are standard error of the mean; asterisks indicate $p < .05$ (paired t tests). (C) Response histograms (cumulative across subjects) showing the distribution of similarity ratings for each of the six conditions. Vertical lines indicate the means of the distribution. $N = 22$. Diff = different.

center of the scale, and subjects used the left/right arrow keys to move the slider along the scale. They were instructed to take as much time as they wanted, and to press the spacebar to enter their rating and go on to the next trial. Slider position was discretized into 21 intervals; these were converted into a "similarity index" ranging from 0 (*most dissimilar*) to 100 (*most similar*).

We calculated the mean similarity index for each subject and Location × Identity condition. We also plotted histograms of the full distribution of similarity ratings for each subject and condition. These histograms were inspected to verify that subjects were using the full similarity scale and to exclude the two subjects noted above who instead made categorical judgments.

Subjects completed 10 blocks of 30 trials each (five per condition: same/slightly different/different identity by same/different location).

Results

Average similarity index for each of the six conditions is plotted in Figure 3B. There was a significant main effect of identity, $F(2, 42) = 592.78$, $p < .001$, $\eta_p^2 = .97$, confirming that subjects were appropriately rating similarity as greatest for identical pairs, followed by "slightly different" pairs, followed by "very different" pairs. Critically, there was both a main effect of location, $F(1, 21) = 22.55$, $p < .001$, $\eta_p^2 = .52$, and a Location × Identity interaction, $F(2, 42) = 7.74$, $p = .001$, $\eta_p^2 = .27$. Planned comparisons revealed a significant location effect for identical, $t(21) = 6.09$, $p < .001$, $d = 1.30$, and slightly different pairs, $t(21) = 3.37$, $p = .003$, $d = 0.92$, but not for very different pairs, $t(21) = 0.53$, $p = .599$, $d = 0.11$. Moreover, the location effect was significantly greater for slightly different versus very different pairs, $t(21) = 2.61$, $p = .016$, $d = 0.56$.

Figure 3C shows response histograms for each of the six conditions pooled across subjects. Mirroring the average similarity index data in Figure 3B, the distributions of responses shifted along the similarity index spectrum as pairs went from identical to slightly different to very different, with location effects apparent for identical and slightly different conditions.

Discussion

In Experiment 3 we tested whether location would still bias identity responses if we used a task that did not require a "same" versus "different" response. Subjects used a sliding scale to make

graded similarity responses between each pair of objects. Subjects reliably rated both the identical and slightly different objects as more similar when they were presented in the same location versus different locations, replicating the bias we found with the same/different response paradigm and arguing for a perceptual rather than response-level account of the congruency bias. We noted above that a perceptual-level account would make two key predictions: Subjects should rate objects appearing in the same location as more similar (not just more likely to respond "same"), and this effect should be strongest when the task is perceptually difficult. The results supported both predictions. Importantly, not only was there a main effect of location on the similarity ratings, but there was a significant interaction with identity condition. We found a significant location effect when the task was perceptually challenging (identical and slightly different), but not when the differences between objects were very obvious (very different). The inclusion of the slightly different pairs is what likely made the identical pairs challenging; if differences in objects were always very different, the location effect may have been mitigated.

These findings make an important theoretical distinction: that object location can influence the perception of object identity when a task is difficult, but location information does not otherwise override obvious identity information.

Experiment 4

Reverse Task: Does Identity Information Influence Location Judgments?

Experiments 1–3 revealed a spatial congruency bias, where irrelevant location information can bias identity judgments. Is this bias a special property of object location, or do incongruent object properties mutually interfere with each other? To test this question, in Experiment 4 we reversed the task and had subjects perform a location discrimination task, asking whether we would find a similar congruency bias for irrelevant identity information.

Subjects performed two tasks in interleaved blocks: same/different identity (where location was irrelevant) and same/different location (where identity was irrelevant). The stimuli were identical in both tasks, with the same four conditions (same/different identity by same/different location) appearing equally often. To equate the tasks for difficulty, stimulus morph distance (identity task) and spatial separation distance (location task) were staircased independently during practice blocks. The staircased distances were used for both tasks, meaning there were only small differences in object location and object identity when different. A full hemifield mask was used for both tasks to mask both identity and location information.

On the basis of Experiment 2, we predicted that we would replicate the location congruency bias in the identity task, even with small differences in location. The key question was whether we would find an analogous bias in the location task driven by congruent object identity.

Method

Subjects. Twenty-two subjects (13 female, nine male; mean age = 18.59 years; range: 18–27) participated in this experiment; one additional subject completed the study but was excluded for poor task performance (accuracy < 50%).

Stimuli, task, and design. Stimuli, task, and design (see Figure 4A) were similar to those in Experiments 1 and 2, with the following exceptions: Subjects performed two tasks: an identity task and a location task. The same task was performed for a block

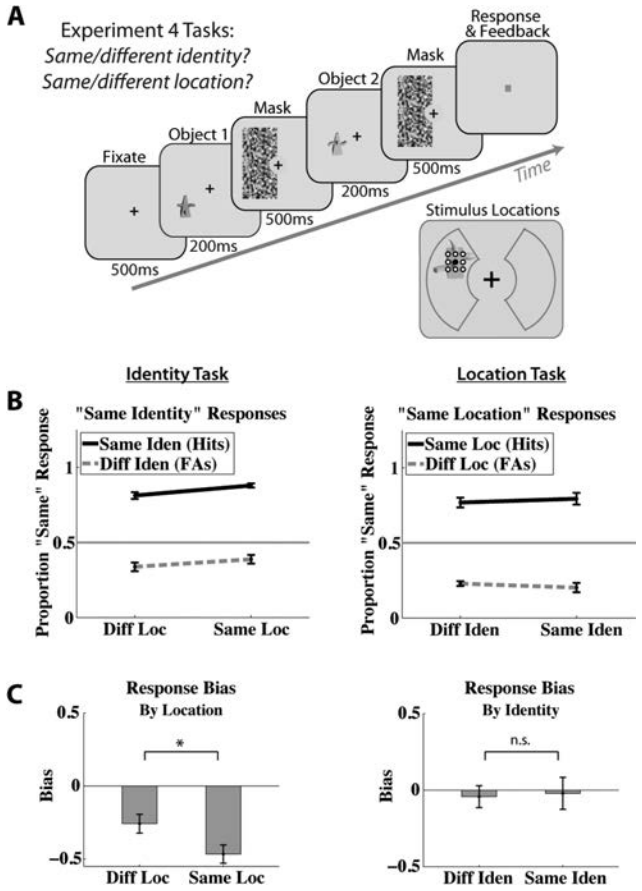

Figure 4. Experiment 4 methods and results. (A) A sample trial is illustrated. While fixating, subjects saw two sequential object presentations in the periphery, followed immediately by hemifield masks. Subjects performed one of two tasks, on alternating blocks. In the identity task they judged same/different identity (location was irrelevant), and in the location task they judged same/different location (identity was irrelevant). The stimuli were presented identically for both tasks; they just differed in the attended dimension. Both identity and location differences were near threshold. Inset illustrates the possible stimulus locations. Object 1's location was chosen randomly from anywhere within the two partial annuli, and Object 2's location was either identical or differing by a small (staircased) amount; black dot indicates Object 1 center, and white dots indicate possible locations (centers) for Object 2. Identity differences were also small (within morph family, as in Experiment 1). (B) Proportion of "same identity" responses for the identity task and "same location" responses for the location task, broken by relevant and irrelevant dimension. Black line shows hits, and gray dashed line shows false alarms (FAs). Chance is 50%. (C) Response bias (criterion) on the identity task plotted for same and different location and on the location task plotted for same and different identity. Error bars are standard error of the mean; asterisks indicate $p < .05$ (paired t tests). $N = 22$. Iden = identity; Diff = different; Loc = location.

of 20 trials. Subjects performed alternating blocks of each task: The starting task was counterbalanced across subjects. To remind subjects of which task they were in, they were given an instruction screen at the beginning of each block, and the word *Identity* or *Location* was additionally presented on the feedback screen after each trial.

Subjects always fixated a cross at the center of the screen, and stimuli were presented within a partial annulus ranging from 3° to 5° eccentricity and $\pi/5$ to $-\pi/5$ polar angle above/below the vertical meridian. Stimuli were presented in the left hemifield on half the trials and the right hemifield on the other half, randomly intermixed. The location of the first stimulus was chosen randomly from within the prescribed range; the second stimulus occurred at either the identical location or offset by the staircased distance in the *x* and/or *y* directions (eight possible directions, chosen randomly). The masks covered the full hemifield (with a semicircular cutout so the fixation cross would always be visible) to mask both location and identity information, so that we could use identical stimulus displays for both tasks.

Stimulus location was defined by the center of the object. All objects filled the same 5° × 5° image template, but because objects differed in shape, the center of mass may have been slightly different for different objects. For this reason, when object identity was "different," we only used two objects from the same stimulus morph family. Within the same family all objects had the same midline "body," and we instructed subjects to focus on the body of the object when discriminating location.

Location and identity differences were independently staircased with an adaptive QUEST (Watson & Pelli, 1983) procedure during training blocks. Subjects first completed one practice block of each task at an "easy" level to orient them to the task, followed by two training blocks of each task during which the staircase was conducted. These staircase values were then fixed for the main blocks. If, however, performance on a certain block dropped below 65% or above 85%, the threshold was adjusted prior to the next block.

Finally, Experiment 4 used shorter stimulus and delay times (200 ms per stimulus, followed by 500-ms mask/delay), which had the benefit of allowing us to test the robustness of the effect reported in the previous experiments. For each task, subjects completed six blocks of 20 trials each (five trials per condition: same/different identity by same/different location).

Results

Figure 4B illustrates the proportion of "same identity" responses for the identity task and "same location" responses for the location task.

Bias. In the identity task, subjects were again influenced by irrelevant location information; response bias (see Figure 4C) was significantly greater for same location than for different location, $t(21) = 2.34$, $p = .029$, $d = 0.50$. However, we did not see a similar effect when the task was reversed: Irrelevant identity information did not bias location judgments in the location task, $t(21) = -0.26$, $p = .800$, $d = 0.05$. We performed a Task × Irrelevant Dimension ANOVA on the bias scores, where irrelevant dimension was defined as location for the identity task and identity for the location task. The interaction was significant, $F(1, 21) = 4.54$, $p = .045$, $\eta_p^2 = .18$, confirming a significant difference in congruency bias between the two tasks. There was also an overall main effect of task, $F(1, 21) = 18.41$, $p < .001$, $\eta_p^2 = .47$, suggesting an overall greater bias to report "same" in the identity task.

Sensitivity. The d' scores were not significantly affected by the irrelevant dimension in either task (see Tables S3 and S4): effect of location on identity task, $t(21) = -1.05$, $p = .305$, $d = 0.22$; effect of identity on location task, $t(21) = -1.21$, $p = .242$, $d = 0.26$; interaction, $F < 1$.

Priming. RT priming (see Tables S3 and S4) for the irrelevant dimension was found in both tasks. In the identity task, RTs were significantly faster for same versus different location, $F(1, 21) = 14.92$, $p = .001$, $\eta_p^2 = .42$, and in the location task, RTs were significantly faster for same versus different identity, $F(1, 21) = 9.41$, $p = .006$, $\eta_p^2 = .31$. There was no significant Task × Irrelevant Dimension RT interaction ($F < 1$).

Discussion

In Experiment 4 subjects performed alternating blocks of identity and location tasks. Although RT priming was found for both tasks, the congruency bias was only found in the identity task. As in Experiments 1 and 2, two objects appearing in the same spatial location were more likely to be judged as having the same identity. But two objects of the same identity were not more likely to be judged as having the same location. The asymmetric nature of the bias argues further against a generic response-level explanation and suggests there is something special about location information.

Experiment 5

Other Tasks: Does Location Bias Color Judgments?

Across four experiments we found that object location biases judgments of object identity. This congruency bias appears to be selectively driven by location information, but how robust is it? The previous experiments all tested the influence of location on identity (shape) judgments. In Experiment 5 we tested the influence of location on color judgments. Subjects saw two sequentially presented colored squares and were asked to judge whether they were the same or different color. Stimulus color was chosen from 180 colors along an isoluminant color wheel, and color differences were staircased for each individual. Trials were equally distributed among four conditions (same/different color by same/different location).

Method

Subjects. Sixteen subjects (12 female, four male; mean age = 23.53 years; range: 18–44) participated in this experiment.

Stimuli, task, and design. Stimuli, task, and design (see Figure 5A) were identical to those in Experiment 1, with the following exceptions: Rather than the novel objects, the stimuli presented were colored squares (0.82° × 0.82°). The color of the first stimulus was chosen randomly on each trial from 180 possible colors (evenly distributed along a circle in CIE $L^*a^*b^*$ color space, centered at L = 70, a = 20, b = 38, radius = 60). The second stimulus was either identical in color or differed by a subject-specific threshold difference (determined during a training block and adjusted after each main block if necessary to keep perfor-

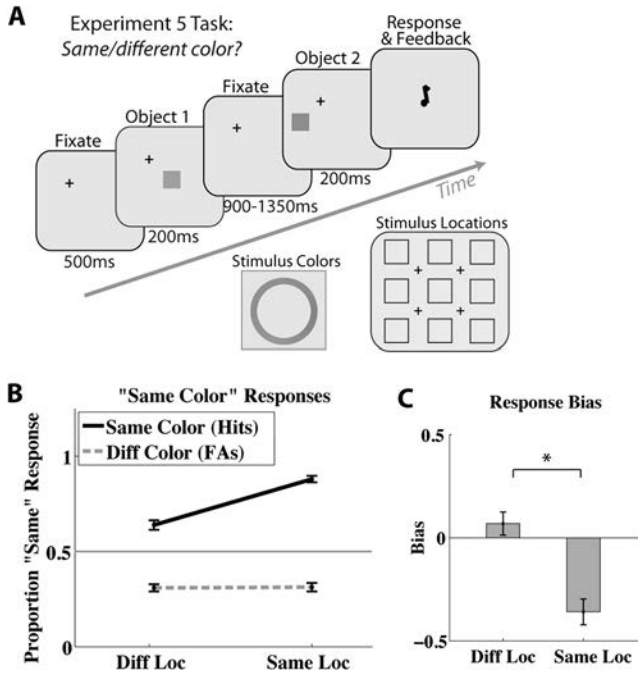

Figure 5. Experiment 5 methods and results. (A) A sample trial is illustrated. Subjects saw two colored squares in sequence, presented in the periphery. The task was to judge same/different color; location was irrelevant. Color differences were staircased for each subject (possible stimulus colors illustrated in left inset). Stimulus locations (right inset) were the same as in Experiment 1. Subjects received auditory feedback in this experiment. (B) Proportion of "same color" responses, broken down by location and color. Black line shows hits, and dashed gray line shows false alarms (FAs). Chance is 50%. (C) Response bias (criterion) on the color task plotted for same and different location. Error bars are standard error of the mean; asterisk indicates $p < .05$ (paired t tests). $N = 16$. Diff = different; Loc = location. See the online article for the color version of this figure.

mance between 70% and 80%). When different, the direction of the difference along the color wheel (clockwise or counterclockwise) was chosen randomly from trial to trial.

Each stimulus was presented for 200 ms, separated by either 900- or 1,350-ms delay (same as in Experiment 1, but without a mask). Stimuli appeared at two possible eccentricities (7.7° and 17.3°), balanced across conditions. Neither delay nor eccentricity influenced the key results, so data are collapsed across both. Subjects were given auditory feedback on each trial (different frequency beeps indicating correct or incorrect). Subjects completed 15 blocks of 16 trials each (four per condition: same/different color by same/different location).

Results

Figure 5B illustrates the proportion of "same color" responses by location.

Bias. We found a significant increase in response bias (see Figure 5C) when objects shared the same location, $t(15) = 8.53$, $p < .001$, $d = 2.13$.

Sensitivity. In this task, there was also a significant effect of location on d' (see Table S5), $t(15) = -9.43$, $p < .001$, $d = 2.36$, with sensitivity also increased for same versus different location.

Priming. RT (see Table S5) on the color task was also significantly facilitated when the two stimuli were presented in the same versus different location, $F(1, 15) = 30.78$, $p < .001$, $\eta_p^2 = .67$.

Discussion

In Experiment 5 subjects performed a same/different color task instead of a same/different identity (shape) task. We replicated the spatial congruency bias seen in all of the earlier experiments. Additionally, in this task we saw a sensitivity enhancement when colors were presented in the same location, similar to the sensitivity boost that co-occurred with the bias in Experiment 2.

Experiment 6

Multiple Irrelevant Object Properties: Color, Shape, and Location?

The previous five experiments all demonstrated a robust response bias driven by irrelevant location information. Experiments 4 and 5 suggest that the bias is both robust across tasks and specific to location. To address a few remaining concerns and more thoroughly test whether location is special in creating this bias, we conducted Experiment 6.

In Experiment 6 the stimuli consisted of objects that could vary in shape, color, and location. Subjects performed two tasks in alternating blocks: a shape task (relevant dimension = shape; irrelevant dimensions = color, location) and a color task (relevant dimension = color; irrelevant dimensions = shape, location).

The purpose of this experiment was twofold: (a) Would we still see a location bias in the presence of additional irrelevant object properties? (b) Would the shape and color information bias each other, or is the bias specific to location?

In Experiment 4 we had used threshold-level differences in both identity (shape) and location so that we could use identical stimuli for both tasks. With these small differences, we still found a location bias, but no analogous shape bias. However, it is possible that shape/identity information may in fact bias other object properties, if the shape differences were more pronounced. Thus, in Experiment 6 we used large differences for the irrelevant object properties.

Method

Subjects. Twenty-one subjects (13 female, eight male; mean age = 21.33 years; range: 18–31) participated in this experiment; two additional subjects completed the study but were excluded for poor task performance (accuracy < 50%).

Stimuli, task, and design. Stimuli, task, and design (see Figure 6A) were identical to those in Experiment 4, with the following exceptions: Stimuli varied in shape, color, and location. The objects from Experiments 1 and 2 were converted into flat, two-dimensional shapes filled with a uniform color. Color values were chosen according to the same procedures as in Experiment 5. The two tasks that the subjects performed were a same/different shape task and a same/different color task (presented in alternating blocks, as in Experiment 4). Subjects were explicitly instructed to

ignore the irrelevant dimensions and only judge the task-relevant property.

For each task we used subtle (thresholded) differences for the task-relevant property, as before; shape and color differences were independently staircased during training blocks and adjusted between task blocks if necessary. However, the amount of difference for the irrelevant properties was fixed at a larger, easily discernible level (10° visual angle for irrelevant location differences, 30° in color wheel space for irrelevant color differences, and a shape from a completely different morph family for irrelevant shape differences). In other words, in the shape task we used small differences in shape but large differences in color and location; in the color task we used small differences in color but large differences in shape and location. Figure 6A illustrates sample stimuli for each task.

Stimuli were presented for 500 ms each and masked (masks were colored with a random color value at each pixel location to mask both shape and color information), and were separated by a 1,000-ms interstimulus interval. During each trial's feedback period, subjects were also presented with a cue word reminding them of the current task (*COLOR* or *SHAPE*). For each task, subjects completed five blocks of 32 trials each (four per condition: same/different shape by same/different color by same/different location).

Results

Figure 6B illustrates the proportion of "same shape" responses for the shape task and "same color" responses for the color task, broken down by relevant and irrelevant dimensions.

Bias. Response bias for each Location × Color condition in the shape task and Location × Shape condition in the color task are reported in Tables S6 and S7. To better illustrate the main effects, Figure 6C plots response bias for each task separately for each dimension (collapsing across the other dimension).

Bias scores were subjected to a three-factor ANOVA with task, location, and "other irrelevant dimension" as factors. Results revealed a significant main effect of location, $F(1, 20) = 21.42$, $p < .001$, $\eta_p^2 = .52$, replicating the spatial congruency bias. In contrast, there was no significant main effect of other irrelevant dimension ($F < 1$). There was also no significant main effect of task ($F < 1$), but there was a significant Task × Location interaction, $F(1, 20) = 6.97$, $p = .016$, $\eta_p^2 = .26$, driven by a stronger spatial congruency bias in the shape versus color task. The only other significant interaction was a Location × Other Irrelevant Dimension interaction, $F(1, 20) = 5.03$, $p = .036$, $\eta_p^2 = .20$, revisited below.[1]

To explore these interactions further, we ran two-factor ANOVAs separately for each task. Consistent with the three-factor ANOVA reported above, the separate two-factor ANOVAs confirmed that the location bias was significant in both tasks—main effect of location: $F(1, 20) = 19.41$, $p < .001$, $\eta_p^2 = .49$, for shape task, and $F(1, 20) = 6.40$, $p = .020$, $\eta_p^2 = .24$, for color task. There was no significant main effect of color bias on the shape task, $F(1, 20) = 1.49$, $p = .237$, $\eta_p^2 = .07$), nor of shape bias on the color task ($F < 1$).

Sensitivity. The d' scores (see Tables S6 and S7) were also submitted to a three-factor ANOVA. There was a significant main effect of location, $F(1, 20) = 12.18$, $p = .002$, $\eta_p^2 = .38$, indicating an increase in sensitivity for same versus different location. The main effect of other irrelevant dimension was not significant ($F < 1$), although there was a Task × Other Irrelevant Dimension interaction, $F(1, 20) = 7.27$, $p = .014$, $\eta_p^2 = .27$. The separate two-factor ANOVAs for each task revealed that color did not affect sensitivity in the shape task, $F(1, 20) = 2.13$, $p = .160$, $\eta_p^2 = .10$, but shape did affect sensitivity in the color task, $F(1, 20) = 5.05$, $p = .036$, $\eta_p^2 = .20$. Interestingly, however, the shape sensitivity effect was in the opposite direction, with sensitivity decreased for same versus different shape. The effects of shape on the color task are examined more thoroughly in the Discussion.

Priming. In the shape task, RT priming (see Table S6) was found for both location, $F(1, 20) = 7.65$, $p = .012$, $\eta_p^2 = .28$, and color, $F(1, 20) = 6.31$, $p = .021$, $\eta_p^2 = .24$, along with a Location × Color interaction, $F(1, 21) = 8.03$, $p = .010$, $\eta_p^2 = .29$. In the color task, RT priming (see Table S7) was found for shape, $F(1, 20) = 9.76$, $p = .005$, $\eta_p^2 = .33$, but surprisingly not for location ($F < 1$). Overall subjects were faster on the color task than the shape task, $F(1, 20) = 68.60$, $p < .001$, $\eta_p^2 = .77$.

Discussion

This experiment set out to test two questions: whether the location bias would remain robust in the context of additional irrelevant object dimensions and whether these additional dimensions (shape and color) would bias each other. The pattern of results on the shape task was unambiguous. We replicated and extended the previous location bias; placing objects in the same location increased the likelihood of "same shape" responses. Irrelevant color information, on the other hand, produced no such bias. Color information had some influence on RT priming, but only location information actually biased the responses.

The pattern of performance on the color task was a bit less clear-cut, but statistically the key findings mirrored those of the shape task. We again found a location bias for the color task, although it was weaker than in the shape task—likely because it was moderated by an interaction with shape: The location bias was only present when the colored objects were the same shape. In Experiment 5 we found a strong location bias for color judgments, but the colors were always presented as squares with identical shape information. Thus it is possible that large differences in object shape might disrupt the location bias for color judgments.[2]

An additional effect we saw in the color task was an effect of shape on sensitivity, although the effect went in the opposite direction one might expect: When objects were the same shape, performance was worse. Although this effect seems at first counterintuitive, it may in fact be a result of the finding that the location bias was only seen when shape was the same. On different shape trials, there was no bias, so conflicting location information did not

[1] In the color task, the location bias was moderated by a Location × Shape interaction, $F(1, 20) = 4.80$, $p = .040$, $\eta_p^2 = .19$. Post hoc t tests revealed that for the color task, the location bias was significant when objects were the same shape, $t(20) = 3.24$, $p = .004$, $d = 0.71$, but not when they were different shapes, $t(20) = 0.19$, $p = .855$, $d = 0.04$. In the shape task, there was no significant Location × Color interaction ($F < 1$); the location bias was evident regardless of color condition.

[2] Color did not interact analogously on the shape task, although it is unclear whether this difference reflects something meaningful about the tasks and/or feature interactions, or a more trivial difference (e.g., if the irrelevant shape differences were more obvious than the irrelevant color differences; we only explicitly matched performance for the task-relevant dimension).

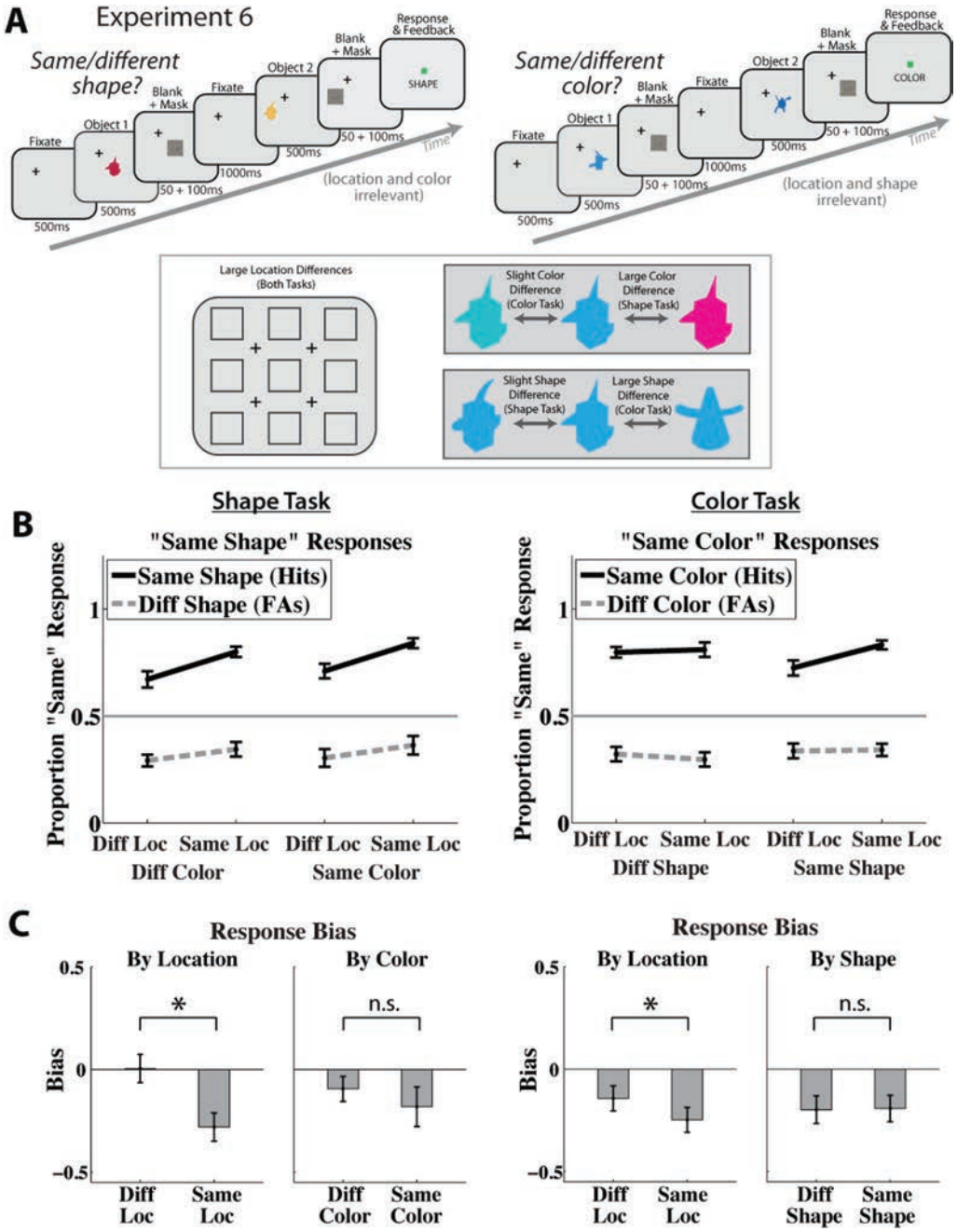

Figure 6. Experiment 6 methods and results. (A) A sample trial is illustrated for each task. While fixating, subjects saw two sequential colored objects in the periphery, followed by colored masks. Subjects performed one of two tasks, on alternating blocks. In the shape task they judged same/different object shape (location and color were irrelevant), and in the color task they judged same/different object color (location and shape were irrelevant). Inset: In the shape task we used slight (near threshold) differences in shape but large differences in color and location. In the color task we used slight (near threshold) differences in color but large differences in shape and location. Fixation and stimulus locations were the same as in Experiment 1. (B) Proportion of "same shape" responses for the shape task and "same color" responses for the color task, broken by relevant and irrelevant dimensions. Black lines show hits, and dashed gray lines show false alarms (FAs). Chance is 50%. (C) Response bias (criterion) on the shape task plotted for same and different location (collapsed across color) and same and different color (collapsed across location). For the color task, bias is plotted for same and different location (collapsed across shape) and same and different shape (collapsed across location). Error bars are standard error of the mean; asterisks indicate $p < .05$ (paired t tests). $N = 21$. Diff = different; Loc = location.

interfere with performance. But on same shape trials, performance was worse on incompatible location trials, which reduced the average accuracy.

Despite this more nuanced role of shape information in the color task, it is notable that shape information itself did not bias the color judgments. Across both tasks the only object property that generated a bias was location, providing further evidence that the congruency bias is specific to object location.

General Discussion

The six experiments presented above reveal a novel and robust phenomenon: a congruency bias that is driven uniquely by location information. When participants must judge whether the identity of two objects is the same or different, object location influences judgments in two key ways. First, as has been previously reported, objects in the same location may benefit from shared spatial attention resources, leading to RT priming (Maljkovic & Nakayama, 1996; Tsal & Lavie, 1993), and in some cases enhanced sensitivity (reviewed in Kravitz, Vinson, & Baker, 2008). The second way in which location information influences identity judgments has not, to our knowledge, been reported previously: We found that placing objects in the same versus different location *biased* the identity judgments. When objects were presented in the same location, subjects were more likely to report the objects as having the same identity. The bias was strongest when objects were in the same location and weakened as the distance between objects increased. Critically, our results suggest a special role for location information in generating this bias. While location information biased judgments of identity (shape) and color, identity information did not bias location judgments, and shape and color information did not bias each other.

It is important to note that our results do not imply that these other features have no influence on object judgments. Indeed, we often found RT priming effects when objects shared the same identity/features, and we occasionally saw increases in sensitivity for these other object properties as well. But the congruency bias was only driven by location information, and it was present for location in every experiment we tested. The bias was sometimes accompanied by an increase in sensitivity for same versus different location, but in some cases we found a pure bias, with subjects more likely to correctly judge object identity as the same when true (hits), but also more likely to incorrectly judge them as the same when they were actually different (false alarms).

Neural Implications

Our results carry implications for the neural representations of object location and identity. A fundamental question is to what extent "what" and "where" information is processed separately in the brain. The idea of a strict dichotomy between two visual streams (Goodale & Milner, 1992; Mishkin et al., 1983; Ungerleider & Mishkin, 1982) has been increasingly debated, with recent functional magnetic resonance imaging and neurophysiology studies supporting a more nuanced take (Carlson et al., 2011; Cichy et al., 2011; Golomb & Kanwisher, 2012; Hung, Kreiman, Poggio, & DiCarlo, 2005; Kravitz et al., 2010; Schwarzlose et al., 2008; Zachariou, Klatzky, & Behrmann, 2014). The congruency bias reported here invites the possibility that object identity may never be represented fully independently of location.

Relatedly, a central tenet of object recognition is that representations in higher order visual areas become increasingly invariant (or tolerant) to changes in lower level properties such as location, viewpoint, size, etc. (DiCarlo & Cox, 2007; Grill-Spector et al., 1999; Hung et al., 2005). Our results can be taken as evidence against pure location "invariance" (where representations are identical across locations), consistent with recent arguments that location "tolerance" (where relative preferences are preserved across locations) is a better characterization of the neural architecture underlying object recognition (e.g., Kravitz et al., 2008; Rust & DiCarlo, 2010).

Theoretical Accounts of the Congruency Bias

In the remainder of the Discussion, we consider several possible theoretical explanations for this novel finding. Why would objects presented in the same location be more likely to be judged as the same identity? While RT priming effects could be explained by attentional orienting (speeding processing to locations recently attended), and retinal/neural variability or persistence could account for sensitivity effects (better discrimination of two objects in the same location), both of these accounts predict an increase in performance, not a shift in bias. What, then, could be driving the spatial congruency bias?

1. Response interference. A response interference account would suggest that the irrelevant location information is interfering with subjects' responses by providing conflicting response options, for example, as in the Simon or Stroop tasks (Lu & Proctor, 1995; Simon, 1990; Stroop, 1935). In other words, we could imagine that if the subject detected an object property (e.g., location) was the same, he or she might be unable to suppress the response to that property, even if it was not task relevant and could lead to incorrect responses.

However, Experiments 3 and 4 argue against this account. When the response-level conflict was eliminated in Experiment 3, objects in the same location were still consistently rated as more similar in identity than objects in different locations. Moreover, in Experiment 4 we found that location biased identity responses but identity did not bias location responses. This asymmetry was particularly striking because both location and identity dimensions were relevant on different trials, a scenario in which subjects would be expected to be most susceptible to response-level interference from the irrelevant dimension.

2. Evidence accumulation. Another possible explanation for the congruency bias is something akin to evidence accumulation. In a difficult, perceptually uncertain task, perhaps subjects accumulate evidence about "sameness" from multiple object dimensions, not just the relevant dimension. That is, if both identity and location were the same, there might be more overall evidence for "sameness," leading subjects to be more likely to report "same identity." But this account would predict an increase in reporting "same location" as well, a pattern we did not see in Experiment 4. We also failed to find reliable evidence for cumulative effects in Experiment 6, where each object had three manipulable dimensions (shape, color, location; see supplemental materials, "Supplemental Analyses").

3. Spatiotemporal contiguity. Spatiotemporal contiguity is known to be a robust cue that aids object recognition. For example, when an object moves behind an occluder and a second object

emerges, maintaining spatiotemporal contiguity, we tend to perceive it as a single object, even if the features have obviously changed (Burke 1952; Flombaum, Kundey, Santos, & Scholl, 2004; Flombaum & Scholl, 2006). Likewise, artificially altering spatiotemporal regularities has been shown to "break" object recognition (Cox, Meier, Oertelt, & DiCarlo, 2005; Li & DiCarlo, 2008).

In the current study, we found that shared location alone was enough to generate a bias toward perceiving objects as the same, even without temporal contiguity (there was a 1- to 2-s blank delay between objects) and without training with specific object pairs. Additional experiments (see Figure S2) suggest that the bias persists across delays of up to several seconds and does not seem to be affected by changes in mask presence or duration. Thus, it is possible that the bias relies more on spatial contiguity than temporal contiguity, an idea that warrants further exploration.

4. Object files and location indices. Location has long been proposed to play a special role in feature binding, serving as an index or cue to assign different features to the same object (e.g., Kahneman et al., 1992; Leslie et al., 1998). If object files are defined by location, then it is logical that our visual systems would use location as a cue for distinguishing and accessing different items. One could imagine that if two objects appeared sequentially in the same location, the default may be to rely on their shared location index to assign them to the same object[3] (unless they are very clearly different, as in Experiment 3).

Such an account fits with a recent study by Pertzov and Husain (2013) demonstrating a special role of location information in accessing items from working memory. In the Pertzov and Husain study, if two objects had been displayed in the same location during the study phase, subjects were more likely to mistakenly report a feature of the wrong (unprobed) object during a memory test, than if the two objects had been displayed in different locations. As in our study, this effect was specific to object location; objects that shared the same color did not induce these memory errors.

5. Location as a privileged feature. While the location index account posits that location information is used to define and access objects, a more general account could be that location is simply a more privileged feature, and when two objects share the same privileged feature (and perhaps thus more neural similarity), they are more likely to be perceived as the same. The idea that location is special, or privileged, compared to other object properties has been supported by asymmetries in a variety of behavioral tasks (Cave & Pashler, 1995; Chen, 2005, 2009; Pertzov & Husain, 2013; Tsal & Lavie, 1988, 1993). Location can be thought of as privileged in the neural sense as well, being a fundamental organizing principle of the visual system, with neurons at the earliest levels of processing coding for location.

The spatial congruency bias not only provides evidence that location is special, but suggests that this privilege may result in irrelevant location information being automatically encoded with and bound to other object properties, biasing their perceptual judgments. It remains to be seen whether this bias is truly automatic or simply a default that could be overridden with sufficient motivation or task demands.

6. Ecological relevance/long-term learning. A final possibility is that subjects' responses may be based on implicitly learned assumptions about the world. At first glance our spatial congruency bias seems counterproductive, since perception is biased rather than improved. But from an ecological standpoint, perhaps this does make sense in most situations. In the real world, location is generally a reliable cue for "sameness." Our visual systems may have developed to take advantage of these regularities and assumptions, so we may be more likely to assume that two objects are the same when they are presented in the same location and the difference in identity is subtle.

Conclusion

In conclusion, we report a novel phenomenon—a spatial congruency bias—demonstrating a fundamental influence of object location on identity and feature representations. When two objects are presented in the same spatial location, they are more likely to be perceived as having the same shape or color. In terms of theoretical explanations, our data rule out the response interference and evidence accumulation accounts, and the spatiotemporal contiguity account is only partially consistent. Although the exact mechanisms remain to be discovered, the final two theoretical accounts (location as an index or privileged feature for object recognition), along with the ecological argument, seem most harmonious with our data.

That being said, we know of no prior theory or result that claims (or even proposes) that simply because two objects occupied the same location, their identities or features are perceived as more similar. The congruency bias suggests that the influence of location on object recognition may be even more extensive than previously thought, and the full extent to which this finding influences theoretical and neural accounts of object recognition remains to be seen. The apparent robustness of the spatial congruency bias suggests that it may be useful as a simple behavioral measure to probe further unanswered questions about the binding process, including what type of location information is bound, when in the processing stream binding occurs, and even whether binding may be enhanced or diminished in certain clinical populations.

[3] The concept of shared location indices could also help explain why a recent study by Zachariou, Klatzky, and Behrmann (2014) found that irrelevant location information did not interfere with shape comparisons. Although they only tested RT and accuracy (not bias), a more intriguing difference could be the fact that their location information was based on relative location (distance) between objects and reference lines. Subjects were to compare two pairs of objects presented simultaneously on opposite sides of the screen, so their objects never actually occupied the same spatial location, and thus would not be expected to invoke a shared location index.

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Call for Nominations

The Publications and Communications (P&C) Board of the American Psychological Association has opened nominations for the editorships of **Developmental Psychology** and the **Journal of Consulting and Clinical Psychology** for the years 2017–2022. Jacquelynne S. Eccles, PhD, and Arthur M. Nezu, PhD, respectively, are the incumbent editors.

Candidates should be members of APA and should be available to start receiving manuscripts in early 2016 to prepare for issues published in 2017. Please note that the P&C Board encourages participation by members of underrepresented groups in the publication process and would particularly welcome such nominees. Self-nominations are also encouraged.

Search chairs have been appointed as follows:

- **Developmental Psychology,** Suzanne Corkin, PhD, and Mark Sobell, PhD
- **Journal of Consulting and Clinical Psychology,** Neal Schmitt, PhD, and Annette LaGreca, PhD

Candidates should be nominated by accessing APA's EditorQuest site on the Web. Using your Web browser, go to http://editorquest.apa.org. On the Home menu on the left, find "Guests." Next, click on the link "Submit a Nomination," enter your nominee's information, and click "Submit."

Prepared statements of one page or less in support of a nominee can also be submitted by e-mail to Sarah Wiederkehr, P&C Board Search Liaison, at swiederkehr@apa.org.

Deadline for accepting nominations is January 7, 2015, when reviews will begin.