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Selective Attention Warps Spatial Representation: Parallel but Opposing Effects on Attended Versus Inhibited Objects

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Abstract

Selective attention not only influences which objects in a display are perceived, but also directly changes the character of how they are perceived—for example, making attended objects appear larger or sharper. In studies of multiple-object tracking and probe detection, we explored the influence of sustained selective attention on where objects are seen to be in relation to each other in dynamic multi-object displays. Surprisingly, we found that sustained attention can warp the representation of space in a way that is object-specific: In immediate recall of the positions of objects that have just disappeared, space between targets is compressed, whereas space between distractors is expanded. These effects suggest that sustained attention can warp spatial representation in unexpected ways.

Keywords

spatial perception, multiple-object tracking, attention

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Two of the most prominent topics in the study of visual cognition are attention and spatial representation. Space is seen as the underlying medium for much of perception, whereas attention acts as a powerful filter through which people experience the world. What is the relationship between these topics? Several research programs have demonstrated ways in which spatial representation influences the allocation of attention. In the first place, it seems that people can often attend *to* locations (e.g., Posner, Snyder, & Davidson, 1980; for a review, see Cave & Bichot, 1999) and to the objects that inhabit them (e.g., Egly, Driver, & Rafal, 1994; for a review, see Scholl, 2001), and such ideas are clear in models of attention that appeal to metaphors such as spotlights or zoom lenses that move about a representational spatial medium (e.g., Eriksen & St. James, 1986; for a review of such metaphors, see Fernandez-Duque & Johnson, 1999).

Can Attention Influence Spatial Representation?

What about the reverse? Can attention also influence the representation and perception of space? This is a less intuitive possibility, given the way that space is treated as an underlying medium: If the units of attention are in some way spatial, then it would seem to follow that space must first be encoded and represented before attention can be allocated to it.

Nevertheless, there are hints from previous studies that attention may warp perceived space. One example is the attentional repulsion effect (Shim & Cavanagh, 2005; Suzuki & Cavanagh, 1997): When a bar is briefly flashed following an attentional target, the bar appears to be offset away from the target, as though attention had expanded perceived space. Similarly, precuing attention to the upcoming location of a flashed object not only causes that object to appear with higher contrast than it otherwise would (Carrasco, Ling, & Read, 2004), but also causes spatial features of the object to appear enlarged relative to the features of objects at uncued locations (Anton-Erxleben, Henrich, & Treue, 2007; Gobell & Carrasco, 2005).

The Current Study

To explore the influence of attention on the representation of spatial relationships between objects, we employed two experimental paradigms: multiple-object tracking (MOT) and a

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novel probe-detection task involving predictably moving objects. In each case, observers selectively attended to two target objects among two distractors and then reported the perceived positions of all four objects immediately after they disappeared. We did not expect large errors given the impressive localization accuracy observed in such situations (Iordanescu, Grabowecky, & Suzuki, 2009), but we thought that any systematic biases in the errors might be revealing.

We discovered two surprising effects: Selective attention to targets compresses perceived space between them, as if they were attracting each other (*selective compression*), whereas selective inhibition of distractors expands perceived space between them, as if they were repelling each other (*inhibitory expansion*). Together, these effects suggest that sustained attention actively influences spatial representation, simultaneously stretching and squeezing the representational fabric of space in counterintuitive ways.

Experiment 1: Multiple-Object Tracking

We first studied the influence of attention on spatial representation using the MOT paradigm (Pylyshyn & Storm, 1988; for a review, see Scholl, 2009). In a standard MOT task, the initial display shows a handful of identical static objects, a subset of which are cued as targets. Observers must then keep track of the targets' locations as all objects move unpredictably about the display, so that the targets can be identified when the motion ends. To explore spatial representation, we used a procedure in which the MOT displays simply offset altogether at the end of the motion, and then observers used the computer mouse to click in empty space to indicate the last seen locations of both targets and distractors. (We know of only two other studies that employed this method, both of which were designed to address very different questions: Howard & Holcombe, 2008; Iordanescu et al., 2009.) One implication of this method is that the distractors remain task relevant, and cannot be completely ignored. Nonetheless, they are still distractors in the sense that they must be selected and attended differently than the targets—and as we discovered, they are subject to very different effects.

Method

Participants and apparatus. Ten observers from the Yale University community participated in exchange for course credit or a small monetary payment. Displays were created in MATLAB using the Psychtoolbox libraries (Brainard, 1997; Pelli, 1997) and were presented on a Dell computer with a 20-in. CRT monitor. Observers sat approximately 50 cm from the screen, which subtended 44.6° × 36.3°.

Stimuli. Each trial began with four white discs (1.5°) on a black background (and always within a central "active" area of 18.2° × 18.2°), with a blue fixation dot (0.5°) at the center. The four discs initially appeared at randomly selected positions (with their centers separated by at least 3.7°), and we cued two as tracking targets by having them alternate in color (between green and black) every 167 ms for 1.67 s. The four identical objects then moved on independent unpredictable trajectories within the active region at a rate of 11°/s for 5 s (as detailed in Flombaum, Scholl, & Pylyshyn, 2008). The final positions were constrained such that each disc always landed at least 3.7°, but never more than 14.6°, from every other disc (measured from their centers).

Procedure and design. The objects immediately disappeared after the last frame of motion, and observers had to indicate their final positions via four mouse clicks—the first two for targets and the second two for distractors. Each session consisted of four practice trials (the results of which were not recorded), followed by 200 experimental trials, the order of which was uniquely randomized for each observer.

Results and discussion

Each of the two target clicks was initially matched to the closest unassigned position at which an object had actually disappeared, but these matches were then swapped whenever doing so minimized total response error. This procedure was then repeated to match distractor clicks to the two remaining unassigned objects. Tracking accuracy was calculated for each trial as the proportion of first and second clicks that matched to targets (as opposed to distractors). Overall tracking accuracy was 97.6%, ranging from 92.8% to 99.8% for individual observers, and only trials with perfect tracking were analyzed.

As a first pass toward characterizing the effects of sustained attention on spatial representation, we compared response errors within target pairs with response errors within distractor pairs. These response errors were calculated as the difference between the correct target-target distance and the reported target-target distance (mutatis mutandis for distractors), expressed as a percentage of the correct distance. These errors were signed such that positive values reflect overestimation (expansion) and negative values reflect underestimation (compression). As illustrated in Figure 1a, space between targets was significantly compressed (−9.2%), whereas space between distractors was only marginally compressed (−5.1%), and these two values differed significantly (see the top section in Table 1 for results of statistical tests on within-pair effects).

The overall compression effect could be explained in two ways: by an overall tendency to mislocalize objects toward the display's center (a *center-attraction* effect) or by a selective warping of space between the objects in a pair, independent of center attraction (a *center-independent* effect). To test for center attraction, we decomposed the response error (separately for each object) into two linear components, as illustrated in Figure 2: (a) a center-relative vector, reflecting pure error toward or away from the center of the display, and (b) a center-independent vector, reflecting error orthogonal to (and independent of) the center of the display—either in the same

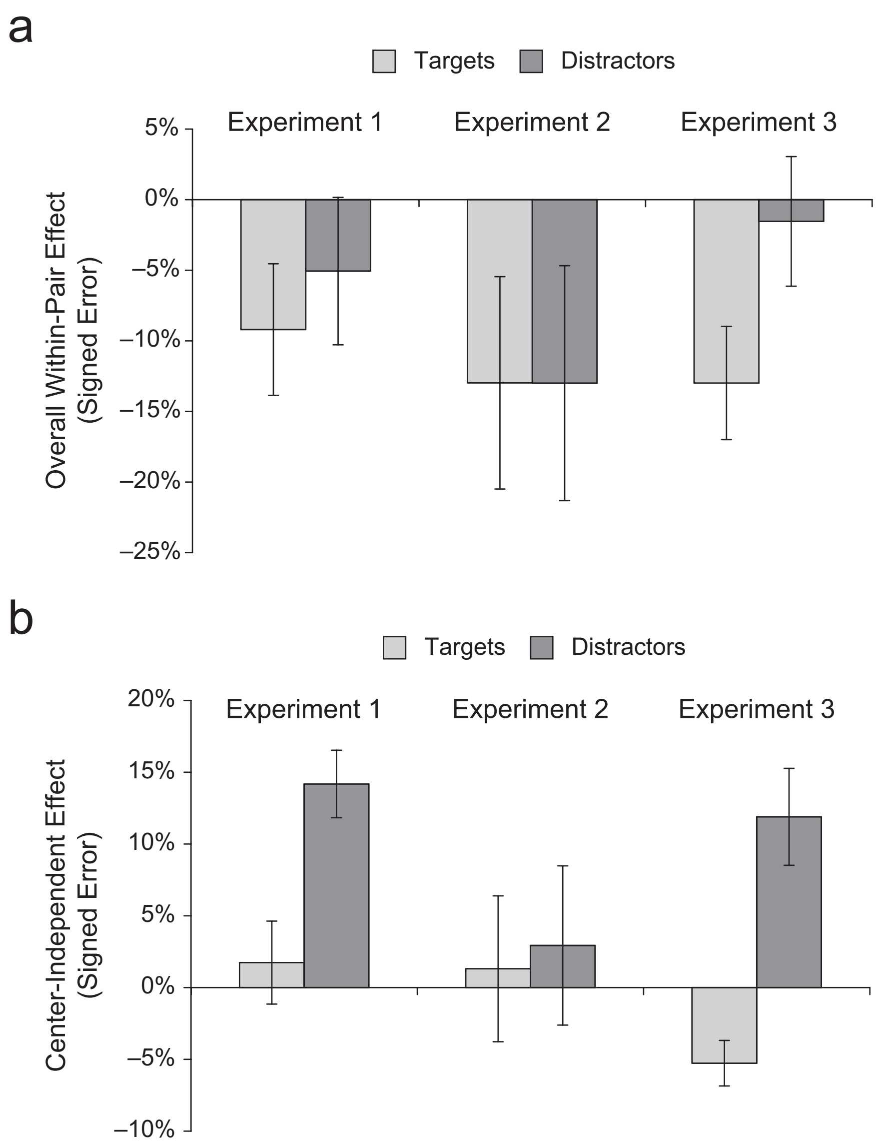

Fig. 1. Average within-pair signed error values (a) and average center-independent distortions (b) in each experiment. Positive values represent expansion effects, and negative values represent compression effects. Center-independent distortion corresponds to the average response error orthogonal to the screen's center (expressed as a signed error percentage) within each pair. Error bars represent 95% confidence intervals. For Experiment 2, "targets" and "distractors" correspond to target-equivalents and distractor-equivalents, respectively, as described in the text.

direction as the other object in the pair (negative values, indicating compression) or in the opposite direction (positive values, indicating expansion). Calculating center-relative effects (Fig. 2a) as a proportion of the true object-to-center distances (effects are also reported here in absolute degrees of visual angle) revealed compression for both targets (−10.5%, −0.75°) and distractors (−24.5%, −1.52°), with the values for distractors being larger. Statistical tests verified that the effects on targets and distractors, and the difference between these effects, were significant (see the upper section of Table 1). This center attraction could have been due to compression toward the center of gaze (Sheth & Shimojo, 2001), as this would likely often have been near the center of the display (though gaze was not constrained or measured in these studies).

To test for center-independent spatial warping, we then examined the orthogonal vectors (Fig. 2b), expressed as a proportion of the true within-pair distance, as these reflect the remaining response error after factoring out variance that could be due to center attraction. On some trials, this approach factored out some of the error that we were genuinely interested in—that is, error due to selective compression or inhibitory expansion. For example, if a pair of targets were aligned on opposite sides of the display's center, then no center-independent effect could be found because it would perfectly correlate with center attraction. In this way, our analyses were

Table 1. Results of Paired *t* Tests From All Three Experiments

Experiment and variable	Within-pair effects	Center-relative effects	Center-independent effects
Experiment 1			
Targets	$t(9) = 3.87, p = .004$	$t(9) = 6.45, p < .001$	$t(9) = 1.19, p = .265$
Distractors	$t(9) = 1.90, p = .090$	$t(9) = 8.34, p < .001$	$t(9) = 11.9, p < .001$
T – D	$t(9) = 3.15, p = .012$	$t(9) = 7.59, p < .001$	$t(9) = 8.56, p < .001$
Experiment 2			
Targets	$t(9) = 3.38, p = .008$	$t(9) = 4.68, p < .001$	$t(9) = 0.50, p = .631$
Distractors	$t(9) = 3.06, p = .014$	$t(9) = 6.63, p < .001$	$t(9) = 1.04, p = .327$
T – D	$t(9) = 0.01, p = .992$	$t(9) = 2.04, p = .072$	$t(9) = 0.45, p = .666$
Experiment 3			
Targets	$t(9) = 6.35, p < .001$	$t(9) = 4.22, p = .002$	$t(9) = 6.50, p < .001$
Distractors	$t(9) = 0.66, p = .528$	$t(9) = 8.31, p < .001$	$t(9) = 6.90, p < .001$
T – D	$t(9) = 9.39, p < .001$	$t(9) = 6.22, p < .001$	$t(9) = 9.32, p < .001$

Note: For each experiment, the first two rows show the results of *t* tests comparing the observed spatial distortion for targets and distractors (target-equivalents and distractor-equivalents in Experiment 2) with 0% error (the null hypothesis); the third row shows the results of *t* tests of the difference between the degree of spatial distortion for targets (T) and distractors (D). These tests are reported for the overall differences between the actual and reported locations (within-pair effects) and for the differences between the actual and reported locations broken down into the two linear components of distortion toward the display's center (center-relative effects) and the independent distortion orthogonal to the display's center (center-independent effects).

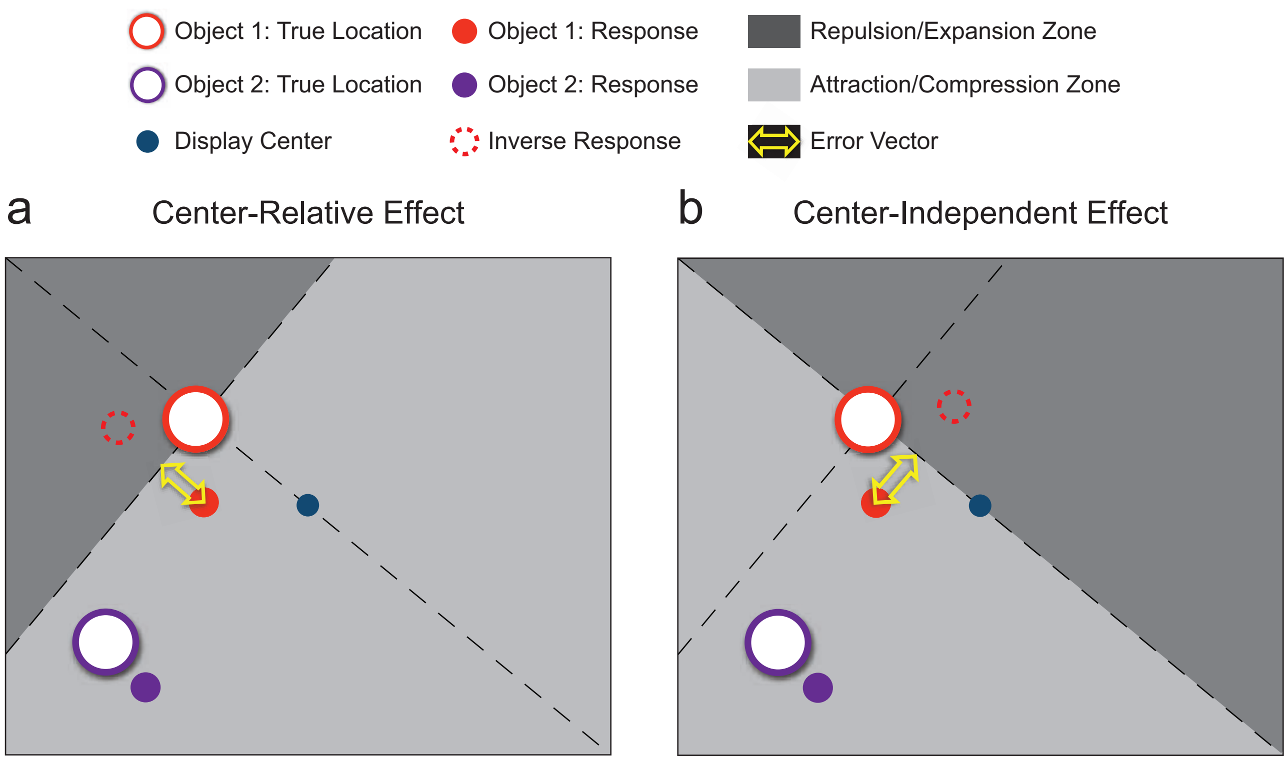

Fig. 2. Illustration of the approach used to calculate center-relative and center-independent effects. The diagrams depict the final true locations of a pair of objects and the corresponding response locations for a hypothetical trial. The axis connecting Object 1 to the center of the display and the orthogonal axis are depicted as dashed lines, and the light and dark shading indicates the zones in which a response would be considered to reflect attraction and repulsion, respectively, relative to (a) the center of the display and (b) the other object. As shown in (a), the response to Object 1 on this trial was subject to center attraction (and the inverse, center-repulsion response location is depicted as well). As shown in (b), the response to Object 1 also reflected center-independent compression (and again, the inverse response is also shown).

conservative—perhaps underestimating the magnitudes of the true effects, but also ensuring that they were due to intertarget and interdistractor effects per se.

As reported in Figure 1b, after we factored out variance that could have been due to center attraction, there was no remaining distortion of the space between targets (1.7%, 0.11°), but space between distractors was unexpectedly expanded (14.2%, 0.87°)—a novel effect we term *inhibitory expansion*. The statistical tests reported in the upper section of Table 1 verified the lack of an effect for targets and showed that the effect for distractors and the difference between values for targets and distractors were significant. The mechanisms underlying these effects are explored in the General Discussion, but we simply note here that no previously published studies of MOT have included a report of such distortions. Nevertheless, such effects could in principle have been present in many previous MOT studies, without obviously influencing tracking performance.

Experiment 2: Response-Order Control

In Experiment 1, target clicks always occurred before distractor clicks. Consequently, distractor locations had to be held for a slightly longer duration in memory, which could have contributed to spatial compression (e.g., Werner & Diedrichsen, 2002). To unconfound retention interval (earlier vs. later clicks) from selective attention (targets vs. distractors), in Experiment 2 we employed MOT trajectories identical to those used in Experiment 1 but did not require actual tracking. Instead, after the motion ended, observers localized the items by simply clicking first on the upper two objects in the final tableau (*target-equivalents*) and next on the lower two objects (*distractor-equivalents*). This task still required observers to keep track of brute spatial relationships, but without tracking per se: There was no prespecification of targets, and the identities of the upper two objects changed repeatedly and haphazardly throughout each trial.

Method

This experiment was identical to Experiment 1 except as noted here. Ten new observers participated. Trials commenced with a 1.67-s static display in which all four discs remained white (i.e., none were cued as targets). Observers were instructed to click first on the two upper object locations from the final tableau and then on the two lower locations.

Results and discussion

Response clicks were assigned to individual objects as in Experiment 1. Overall tracking accuracy was 90.0%, ranging from 75.3% to 98.3% for individual observers.[1] Again, only trials with perfect tracking were analyzed.

We analyzed the data in the same way as Experiment 1, simply substituting the first two clicks (for the upper objects) for target clicks and the second two clicks (for the lower objects) for distractor clicks.

The overall spatial warping effects, reported in Figure 1a, indicated that space between target-equivalents was significantly compressed (−13.0%), as was space between distractor-equivalents (also −13.0%), and these values did not differ. Center-attraction effects were observed for both target-equivalents (−16.4%, −1.05°) and distractor-equivalents (−23.3%, −1.58°), though the difference between these effects was only marginally significant. Center-independent spatial warping was again examined via the orthogonal response-error vectors and is reported in Figure 1b. These center-independent effects were not significant for either target-equivalents (1.3%, 0.06°) or distractor-equivalents (2.9%, −0.05°). The middle section of Table 1 reports the results of statistical tests on the within-pair, center-relative, and center-independent effects.

These results indicate that response order cannot explain the inhibitory-expansion effect observed in Experiment 1, which used identical trajectories; thus, this effect must have been due to selective attention. The center-attraction effect did persist in this control experiment, perhaps because of an interaction between global memory-based compression and the length of time spatial representations were held in memory before response (Werner & Diedrichsen, 2002).

Experiment 3: Dynamic Probe Detection

The previous experiments demonstrate that sustained attention expands perceived space between distractors during MOT. But how general is this effect? Would it apply in any dynamic context requiring selective attention, or might there be something unique in this respect about MOT? This issue is theoretically unresolved in the literature: Some researchers argue that MOT reflects the operation of a special *visual indexing* system (e.g., Pylyshyn, 2007, 2009), whereas others think that there is nothing to MOT but sustained selective attention (e.g., Scholl, 2009). In either case, the inhibitory expansion we observed could derive from the active inhibition of distractors that occurs during MOT (Pylyshyn, 2006), perhaps in combination with the dynamic reallocation of attention based on factors, such as spatial proximity (Franconeri, Jonathan, & Scimeca, 2010; Tombu & Seiffert, 2008), that change frequently and haphazardly during MOT. What seems certain, though, is that everyday visual experience frequently involves sustained attention to objects that need not be tracked, and that do not move so as to be confusable with distractors (e.g., when you attend to a traffic light while stopped at an intersection, waiting for the light to change to green).

To determine whether inhibitory expansion also occurs in non-MOT contexts, we devised a novel probe-detection task involving four discs, each of which revolved slowly (and asynchronously compared with the other discs) around its own fixed point in space while rapidly changing color. Two of the four objects were initially highlighted as targets, and observers had to detect probes (particular disc colors) on those targets as the motion proceeded. This task required sustained attention throughout the motion. At the end of the motion, the display disappeared, and observers clicked in empty space to indicate the final positions of the targets and distractors. Unlike in the MOT task, the objects' positions were fully predictable from moment to moment, and objects never closely approached each other.

Method

This experiment was identical to Experiment 1 except as noted here. Ten new observers participated. At the beginning of each trial, four white discs (1.5°) appeared. Two of these discs were immediately highlighted as targets by alternation of their color between green and black. After 1.67 s (10 color alternations for the targets), each object began to move along a circular path at a rate of 3.1°/s. Specifically, each object was positioned 0.9° from an invisible, static anchor point (unique for each object), about which that object revolved at a rate of 0.67 cycles/s. These anchor points were always at least 3.7° apart, but never more than 14.6° apart.

Each object changed colors periodically (being randomly displayed in a new color, chosen from 10 possibilities, for 250 ms, 500 ms, or 1,000 ms) throughout the motion. Between two and six times per trial (average of ~2.8), one of the target discs changed to one of two target colors (blue or red) for 167 ms, and observers were required to report these target probes by pressing a key (while ignoring target colors that appeared on distractor discs). After 10 s of motion, the entire display disappeared, and observers indicated the final positions of the objects using mouse clicks, again responding first for targets and then for distractors. Observers completed four practice trials followed by 200 experimental trials, the order of which was uniquely randomized for each observer.

Results and discussion

Probe-detection accuracy was high but not at ceiling (83.9% on average, varying from 64.5% to 92.2%), and there were a moderate number of false alarms (15.5% on average, varying from 7.3% to 25.9%). These results suggest that this task did demand sustained attention (despite the lack of confusable motion). Tracking accuracy (measured as in Experiment 1) was very high (averaging 95.8%, ranging from 79% to 100%), and only trials with perfect tracking were analyzed.

The overall spatial warping effects, reported in Figure 1a, demonstrated that represented space between targets was significantly compressed (−13.0%), whereas represented space between distractors was unaffected (−1.5%), and these values differed significantly. It is interesting to note that the difference in spatial warping between targets and distractors was much larger (11.5%) than in Experiment 1 (4.1%), $F(1, 9) = 16.607$, $p = .001$, which suggests that the probe-detection task was even more effective than MOT at inducing selection-based spatial distortion. Center attraction was also observed for both targets (−7.9%, −0.57°) and distractors (−15.9%, −1.10°), and was larger for distractors. Additionally, we observed center-independent effects, as reported in Figure 1b. As in Experiment 1, we observed inhibitory expansion for the distractor objects (11.9%, 0.81°). Surprisingly, and in marked contrast to both Experiments 1 and 2, the data revealed compression for attended targets beyond the center-attraction effect: Attended pairs were perceived as 5.3% (0.51°) closer together than they truly were, a novel effect we term *selective compression*. Additionally, both of these center-independent effects were remarkably consistent, being in the same direction for every participant. The bottom section of Table 1 reports the results of statistical tests on the within-pair, center-relative, and center-independent effects.

To the best of our knowledge, this study provides the first demonstration of attention-based compression of perceived space (in contrast to attentional repulsion; Suzuki & Cavanagh, 1997). Taken together, these results suggest that attentional modulation of perceived space is not limited to MOT, but may be a more general phenomenon.

General Discussion

Our findings provide evidence for two previously undescribed distortions of spatial representation due to selective attention—selective compression and inhibitory expansion—and suggest that attention and inhibition can exert parallel but opposing influences on spatial representation, simultaneously compressing and expanding different regions of represented space. In essence, attention appears to transform represented space in an object-based manner, rather than via a coherent transformation of the entire visual field.[2] The interaction among these effects is depicted (in caricatured form) in Figure 3, which illustrates the independence of center attraction from the expansion and compression effects.

Perception and memory

Selective compression and inhibitory expansion could reflect an influence of selective attention on on-line perception, with skewed spatial positions then being committed to memory. However, it would be consistent with the results of several prior studies of memory-based spatial distortions (Sheth & Shimojo, 2001; Werner & Diedrichsen, 2002) if these effects occurred in memory itself. It is difficult to untangle the potential effects of perception and memory (if it is even possible to do so in principle) because spatial representations in our experiments were necessarily probed via a task that required reporting from memory (albeit with a minimal load, given that responses occurred immediately after the offset of the display). Even if such distortions occur in immediate memory, however, they must still be effects *of* attention (*on* memory). This is clear from the contrast between Experiments 1 and 2, as these studies produced markedly

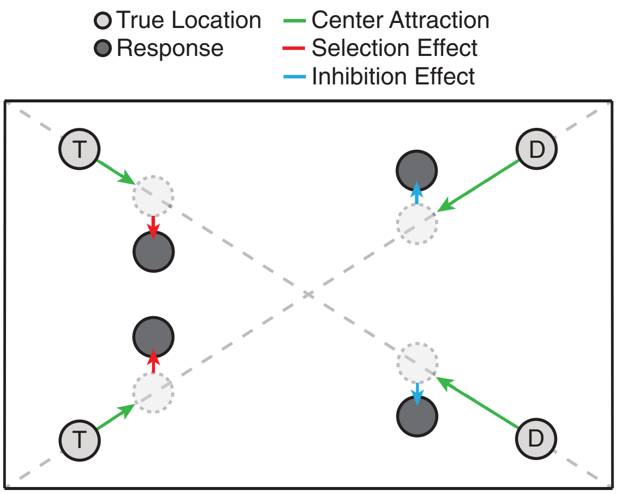

Fig. 3. Caricatured depiction of the results of Experiment 3, illustrating the independence of the selective-compression and inhibitory-expansion effects from center attraction. In this illustration, the targets (T) are located on the left in normalized space, and the distractors (D) are located on the right. Both pairs of objects are mislocalized toward the center of the screen (center attraction), and this effect is more severe for distractors than for targets. Independently of this center attraction, targets are compressed by attention toward each other (selective compression), whereas distractors are expanded by inhibition away from each other (inhibitory expansion). The overall effect is thus compression for both targets and distractors (as depicted in Fig. 1a).

distinct patterns of results, despite having equivalent memory demands.

Relationship to transient attention and grouping effects

The phenomena of inhibitory expansion and selective compression are also surprising in that they go against the grain of previous conclusions about the relationship between attention and spatial representation, based on studies of transient attentional shifts (Anton-Erxleben et al., 2007; Gobell & Carrasco, 2005; Suzuki & Cavanagh, 1997). Nearly all of these studies have suggested in one way or another that attention expands perceived space, whereas we found that selective attention can compress space (and that inhibition expands space). This difference between studies could be due to the fact that our experiments required sustained (rather than transient) attention, but it could also reflect several other factors, such as our task's requirement that subjects attend to multiple objects (rather than a single object), and attend to those objects *selectively*.

Further work will be needed to clarify the scope of such effects, however, because they do not appear to operate in all contexts: We observed reliable inhibitory expansion for both MOT (in Experiment 1) and probe detection (in Experiment 3), but selective compression was not observed with MOT. This difference between the experiments may have been due to greater attentional requirements of our probe-detection task, which required not only spatial monitoring (as with MOT) but also processing of objects' changing surface properties (i.e., colors), but this possibility will remain speculative until such spatial distortions are tested in a greater variety of sustained-selective-attention tasks.

One intriguing experiment found that observers judged the length of a briefly flashed line as longer when it appeared at an unattended location, compared with when it appeared at an attended location (Tsal & Shalev, 1996). This effect was initially interpreted in terms of transient inattention expanding perceived space. Given that the effect Tsal and Shalev reported arose from subjects comparing the perceived length of attended stimuli with the perceived length of unattended stimuli, though, it is equally possible that the effect reflected transient attention compressing perceived space. Both of these possibilities would be more similar to the selective compression and inhibitory expansion found here than to previously characterized expansionary effects of transient attentional shifts.

Another ubiquitous form of transient attentional shift occurs in the context of saccadic eye movements, and indeed, saccades have been found to distort spatial representation: A briefly presented stimulus that occurs just prior to a saccade will be mislocalized in the direction of the saccade (e.g., Ross, Morrone, & Burr, 1997). Such effects would not apply in the context of sustained attention, however, because (a) saccade-based compression appears to operate only within a very narrow temporal window (±50 ms of saccade onset), and (b) stable objects present on-screen well before the execution of a saccade are not displaced in the direction of the saccade (Ross et al., 1997).

Another potentially related class of spatial distortion effects arises from perceptual grouping in static displays. Previous studies have found that grouping can cause both spatial compression (Coren & Girgus, 1980) and expansion (Vickery & Chun, 2010; Vickery & Jiang, 2009). However, none of these previous studies manipulated grouping in dynamic displays (such as those in our studies), nor did any explicitly manipulate attention. One speculative possibility, which would relate these previous results to selective compression and inhibitory expansion, is that it was the spread of attention within or between groups that caused distortions of perceived space in these previous studies.

Neural mechanisms

We know of no existing model of attention that would readily predict the spatial warping we observed. Spatial expansion due to transient attention has typically been explained in terms of a neural model that roughly equates the number of neurons representing a spatial location with perceived size, such that attention shifts are thought to recruit additional neurons to the attended location (see Connor, Gallant, Preddie, & Van Essen, 1996), leading to overrepresentation and the subjective experience of "more space" (Suzuki & Cavanagh, 1997). Selective compression could be consistent with such a model: If some neurons that would otherwise encode the space between two objects are shifted toward those objects when they are attended, this could cause a neural underrepresentation of that intermediate space, which might then be experienced as selective compression. However, there does not appear to be any straightforward way for this model to encompass the inhibitory expansion that we consistently observed, as distractors—whether inhibited or simply less attended—would presumably receive still less neural representation than targets. Thus, inhibitory expansion may represent a higher-level effect of attention on spatial representation—one that does not derive simply from the influences of attention on receptive fields.

A concluding metaphor: sustained attention as a distorting lens?

Many popular metaphors of attention appeal to a type of clarifying process, such as illumination by a spotlight (Posner et al., 1980) or focusing by a zoom lens (Eriksen & St. James, 1986). However, the effects reported here suggest that this clarifying process may also entail a distorting cost: Attention also warps spatial representations, and does so differently depending on whether objects are selected or inhibited. This suggests another metaphor, of a wide-angle camera lens that imposes "pincushion" distortion—such that the focus of attention (near the center of the lens) is compressed, whereas the periphery (akin to distractors) is expanded.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

Notes

1. Although accuracy was lower than in Experiment 1 (a difference of 7.5%), $t(18) = 2.61$, $p = .018$, this was unsurprising, given that no constraints were placed on vertical separation. Because there were no such constraints, target-equivalents and distractor-equivalents may have occasionally been difficult to distinguish: When they were roughly horizontally aligned, observers may not have known which to click first.
2. In contrast, the center-attraction effect appeared to be independent of sustained attention, as it was observed for both targets and distractors in all experiments; it may instead be related to previously described memory-based spatial compression effects (Sheth & Shimojo, 2001).

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