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Space Constancy *vs* Shape Constancy

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Abstract

The perceived distance between objects has been found to decrease over time in memory, demonstrating a partial failure of space constancy. Such mislocalization has been attributed to a generalized compression effect in memory. We confirmed this drift with a pair of remembered dot positions but did not find a compression of perceived distance when the space between the dots was filled with a connecting line. When the dot pairs were viewed eccentrically the compression in memory was substantially less. These results are in line with a combination of factors previously demonstrated to cause distortion in spatial memory — foveal bias and memory averaging — rather than a general compression of remembered visual space. Our findings indicate that object shape does not appear to be vulnerable to failures of space constancy observed with remembered positions.

Keywords

Shape constancy, space constancy, perception *vs* action, foveal bias, memory averaging

1. Introduction

We perceive the world through a buffer of constancy mechanisms. These perceptual mechanisms take the assumption that many objects in the outside world do not normally change and tolerates or compensates for contradictory sensory information. For example, objects are assumed to remain the same colour (colour constancy), size (size constancy) and shape (shape constancy) and not to spontaneously stop existing (object constancy) despite changes in illumination sources, retinal image size, perspective and occlusion that could be taken to indicate otherwise. Similarly, the layout of objects in space is generally assumed to be constant and when a per-

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son moves, they perceive themselves to be moving relative to a stable world (space constancy).

When constancy mechanisms fail they result in illusions in which things that are indeed constant appear to change. Size and space constancy can produce errors when sensory information about distance and motion are inaccurate (see Burgess, 2008 for a review). Even without intervening self-motion, space constancy fails over time and the remembered locations of objects drift over time (Hubbard and Ruppel, 2000; Kerzel, 2002a, 2002b; Mateeff and Gourevich, 1983; Musseler *et al.*, 1999; O'Regan, 1984; Sheth and Shimojo, 2001; Uddin *et al.*, 2005; van der Heijden *et al.*, 1999).

The shape of an object could also be regarded as a simple volume of space. This study addresses the question of whether the locations of points that form a shape are subject to the same mislocalization in memory that they suffer if they are regarded as isolated points. If they are, the remembered shape of an object would become distorted in a manner predictable from the failures of space constancy. Furthermore, since the drift of remembered locations in memory can depend on their position within the visual field (Kerzel, 2002b), distortion of the shape of a remembered object would depend on the position of its parts in the visual field.

There are at least three types of distortion that cause violations of space constancy. Firstly, the perceived location of a stationary target can drift towards the fovea (foveal bias) (Kerzel, 2002a, 2002b; Mateeff and Gourevich, 1983; Musseler *et al.*, 1999; O'Regan, 1984; Sheth and Shimojo, 2001; Uddin *et al.*, 2005; Van der Heijden *et al.*, 1999). Secondly, there is a pull of a remembered target towards salient visual landmarks in the scene (Hubbard and Ruppel, 2000; Sheth and Shimojo, 2001; Werner and Diedrichsen, 2002). And thirdly, the remembered location of multiple objects visible at the same time are pulled towards each other, an effect termed memory averaging (Hubbard and Ruppel, 2000; Kerzel, 2002a; but see Kerzel, 2002b). Although they might not all operate in the same direction at the same time, these distortions in stored object location correspond to a general collapse of remembered space in on itself and have been thought to represent a general compression of space in memory (see Sheth and Shimojo, 2001).

However, if the locations of two points are structurally connected they do not seem to undergo this compression effect: shape constancy seems to resist the failures of space constancy. For example, a study by Wearden *et al.* (2002) sought to determine if 'subjective shortening' — a compression effect typically associated with memory for duration (Spetch and Wilkie, 1983) — could be extended to visuo-spatial representations. In their study, participants were presented with a sample and comparison line stimuli between 9.4 and 12.8 cm (retinal size unobtainable) and then again after a variable delay of up to 10 s. Although they did confirm compression for duration judgments, Wearden *et al.* (2002) did not find the visual distortion of the perceived length of a remembered line that would be expected from a generalized compression of remembered space. However they did not test for all three types of distortion.

In the present study we compare remembered spatial locations that were occupied either by separate, independent objects (separate dots) or that were tied together by a continuous boundary (a line formed by the same dots joined together). The method used was designed to facilitate a compression effect towards a fixation point for both dots and line-ends and thus determine the existence of a generalized compression of space. Thus, we looked to see if the failures of space constancy were expressed in parallel failures of shape constancy (Experiment 1). We find that distortions of space constancy are not expressed in shape constancy and may be explained by a combination of foveal bias and memory averaging (Experiment 2). We conclude that space constancy and shape constancy may involve functionally separate encoding and retrieval processes.

2. Experiment 1

2.1. Method

2.1.1. Participants

Eleven participants (six female, five male, mean age = 25, range 23–29 yrs), all undergraduate or graduate students, volunteered or were paid $10/hour if they were not members of the authors' lab. All participants signed an informed consent form and had normal or corrected-to-normal vision. This study was conducted according to the procedures outlined in the York University ethics code.

2.1.2. Apparatus

Stimuli were created with a Dell Dimension 8100 PC running Matlab version 7 release 14 in conjunction with the Psychophysics Toolbox extensions version 2.54 (Brainard, 1997; Pelli, 1997). A 21" Sony Trinitron flatscreen monitor was used for the display viewed at a distance of 31.5 cm. A chin-rest was used to stabilize the position of the participant's head during the experiment.

2.1.3. Stimuli

Line and dot stimuli were presented at a luminance of 60 cd/m^2 against a background of 0.3 cd/m^2. Dot stimuli were created by removing a length between the ends of the line stimuli leaving two squares (0.5° × 0.5°). Line stimuli were 0.5° wide. Distances between line and dot endpoints were varied congruently (see procedure below). Participants fixated at the centre of the screen in a dark room. The screen edge was hardly visible in the periphery at an eccentricity greater than 70° and thus was unlikely to be used as a metric or reference by participants.

2.1.4. Procedure

A forced-choice paradigm was used in which participants had to judge whether the endpoints (line) or points (dots) of a comparison stimulus were further apart or closer than a previously viewed sample stimulus of the same type (lines or dots). At the beginning of a trial, a fixation cross which subtended 1° appeared for 0.3 s followed by a random delay of between one and two seconds during which the

screen was blank. Participants were then presented with a sample stimulus which could be either a single line or a pair of dots separated laterally, equidistant from the fixation. Sample stimuli were presented for 0.3 s. Inter-stimulus intervals (ISIs) between sample and comparison stimuli were 0.5, 0.75, 1 or 2 s during which the screen was blank. When the comparison stimulus appeared, it remained visible until a response was made. Participants were instructed to press '1' on the keyboard number pad if the comparison stimulus appeared 'shorter' than the sample stimulus. That is, if the comparison line was shorter in length or if the distance between the ends of the comparison dots was less than the remembered sample distance. Conversely, participants were instructed to press '2' if the comparison distance appeared 'longer'. These definitions of 'shorter' and 'longer' were made clear to the participants. Auditory feedback was given to the participants in the form of a 0.6 s tone played through a standard pair of PC speakers or through a pair of headphones in both dot and line conditions. Feedback was given when participants responded correctly. When the sample and comparison stimuli were the same, feedback was given randomly, i.e., 50% of the time. The stimulus sequence is illustrated in Fig. 1.

There were seven Δ values (Δ = difference in length between dot or line endpoints) ranging from $-3°$ to $3°$ (positive means the distance in the comparison was shorter than in the sample) in $1°$ steps. To display a given Δ, the sample was $35.7° + \Delta/2$ and the comparison was $35.7° - \Delta/2$. Each combination was presented 10 times. The total number of trials was 2 (stimulus type: line or dot) $\times$ 7 (sample–comparison Δ) $\times$ 4 (ISIs) $\times$ 10 repetitions = 560. Conditions were presented randomly and divided into two experimental sessions of 280 trials each. Each session took approximately 20 min to complete.

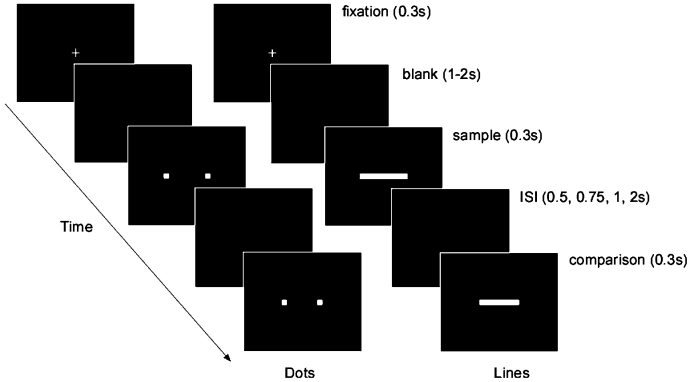


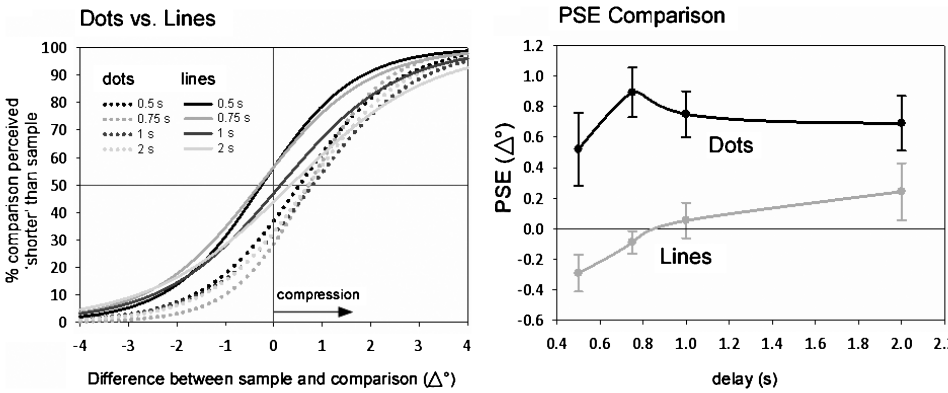
Figure 1. Dot and line stimulus sequences. Each trial was initiated with a fixation cross for 0.3 s. A blank-screen delay followed for between 1 and 2 s and then the sample stimulus appeared for 0.3 s. Upon offset of the sample, a blank screen was displayed for the duration of the inter-stimulus interval (ISI) which was between 0.5 and 2 s. The comparison stimulus was then displayed until the participant responded either 'longer' or 'shorter' than the sample. The illustration depicts trials for which the distance between the endpoints is shorter in the comparison than in the sample (defined as a positive Δ).

2.1.5. Data Analysis

The percentage of instances that the comparison stimulus was judged as appearing 'shorter' than the sample was derived for each participant and plotted as a function of the difference in length (sample − comparison) for each ISI for both line and dot stimuli. Logistic functions were fitted to these data using the equation: $y = 100/(1+\exp(-(\Delta-\Delta_0)/b))$ where b is the standard deviation, and Δ_0 is the point of subjective equality (PSE) — the Δ at which the comparison stimulus was equally likely to be judged longer or shorter. All regressions accounted for at least 97% of the variance in the dependent variable ($r^2 > 0.97$). Positive Δ values indicate sample stimuli that were shorter than comparison stimuli. Thus, a positive shift of the PSE indicates a condition where the remembered length of a longer sample stimulus was equal to a shorter comparison stimulus (compression effect), while a negative shift represents expansion in memory.

2.2. Results of Experiment 1

Figure 2A shows the logistic curves plotted through the mean percentage of times the comparison was judged shorter expressed as a function of the difference in length between the sample and comparison stimuli for the four delays for both lines (lines) and dots (dots). The PSE values for the dot stimuli became increasingly positive as ISIs increased up to a duration of 1 s. Logistic functions were also fitted to each participant's data separately to derive individual PSE values to be used for t-tests to compare the different conditions. To test for significant shifts in PSE,



(A) (B)

Figure 2. (A) Best fit logistic curves plotted for dot and line conditions (dot conditions are represented as dotted lines) for each delay time. Curves were fitted to the data for each condition using the percentage of instances participants selected the comparison stimulus as being shorter (dots closer together) than the sample stimulus. The PSE indicated when the comparison stimulus was regarded as the same length as the standard. Positive shifts of PSE values away from 0 indicate compression effects. (B) PSE comparisons. PSE values were averaged across each participant and are plotted with standard errors as a function of the delay time. Mean dot PSEs were more positive than a test value of 0 and more positive than the mean line condition PSEs at each delay.

directional, one-sample t-tests were conducted on the dot and line stimuli against a test value of 0 (veridical judgment) at each delay. A Bonferroni correction was used to control for type-1 errors. Using this adjustment provides a revised probability criterion (an alpha criterion) of $0.5/4 = 0.0125$ (Bonferroni correction). None of the PSE values for the line stimuli (solid lines in Fig. 2A) were significantly different from 0 ($p > 0.0125$). The shift for the 0.5 s dot condition (black dots in Fig. 2A) was marginally significant ($t(10) = 2.35$, $p = 0.02$). The PSEs for the 0.75, 1 and 2 s dot conditions were significantly greater than 0 (0.75 s: $t(10) = 5.4$, $p < 0.001$; 1 s: $t(10) = 4.6$, $p < 0.001$; 2 s: $t(10) = 3.4$, $p < 0.01$).

To determine if PSE values were significantly higher for dot stimuli than line stimuli at each ISI, planned paired-sample t-tests were also conducted on the individual participant PSE values using Bonferroni control ($\alpha = 0.0125$). The mean PSE values for the dot stimuli were consistently greater than those observed for the line stimuli except at the 2 s retention interval, which was only marginally significant (0.5 s: $t(10) = 3.2$, $p = 0.01$; 0.75 s: $t(10) = 5.4$, $p < 0.001$; 1 s: $t(10) = 3.3$, $p < 0.01$; 2 s: $t(10) = 2.1$, $p < 0.06$). These data are illustrated in Fig. 2B.

2.3. Discussion of Experiment 1

The data obtained from the dot conditions are consistent with the results of Sheth and Shimojo (2001) as they demonstrate a tendency for the distance between two visual targets to decrease in memory. If this were a general compression of space, however, such compression should be observed with all visual stimuli. The results of the line conditions did not show compression over the two second retention period and were thus consistent with Wearden *et al.* (2002). These observations suggest that the 'compression' phenomenon was specific to points that were separated in space. Object shape (in this case, lines) did not appear compressed over the same time period. We now consider two alternative explanations to the distortion observed with the remembered positions of the dot stimuli, foveal bias and memory averaging.

2.3.1. Foveal Bias

An alternative explanation to compression may be that mislocalization of dot stimuli may result from foveal bias (Mateeff and Gourevich, 1983, 1984). Perceptual displacement of briefly presented peripheral targets has previously been observed such that the perceived location of objects migrate towards the fovea over time (see also Kerzel, 2002b; Uddin *et al.*, 2005). Unlike in some previous studies which demonstrated foveal bias (e.g., Mateeff and Gourevich, 1983, 1984), we did not use a constantly visible fixation point. However, foveal bias has been found to occur without the presence of an actual fixation marker (Van der Heijden *et al.*, 1999; see also Uddin *et al.*, 2005). Since the fixation position is likely to have remained salient as a result of covert orienting (Rizzolatti *et al.*, 1987; see Corbetta and Shulman, 2002 for a review), foveal bias would result in a perceived displacement of each dot, separately, towards the implied fixation point.

2.3.2. Memory Averaging

Bias in the dot condition may have also resulted from the effect of memory averaging (Hubbard and Ruppel, 2000; Kerzel, 2002a) between the target locations. Memory averaging results in bias of the remembered location of a stimulus towards other locations in the display. This effect is similar to what has previously been termed 'the global effect', by which the location of several possible saccadic eye movement targets are averaged (Coeffe and O'Regan, 1987; Findlay, 1982; Jacobs, 1987). An account of the data as resulting entirely from memory averaging differs from what would occur as a result of foveal bias because it suggests perceptual displacement of the remembered dot stimuli towards each other and not a separate perceived displacement of each stimulus towards a third location (i.e., the fixation). Both memory averaging and foveal bias are illustrated in Fig. 3.

Memory averaging and foveal bias are not, however, incompatible sources of mislocalization. The bias in the remembered dot locations may be completely attributable to either effect or to some combination of both. In order to measure the effects of each factor on the misperceived dot locations we repeated the experiment with the dots not centered on a fixation point.

3. Experiment 2

Experiment 2 was conducted to discriminate between the effects of foveal bias and memory averaging on the perceived positions of dot stimuli within spatial memory. Dot pairs were presented randomly to the right or left of a central fixation point. Any bias resulting from memory averaging would manifest itself as the remembered distance between the dots becoming smaller with increasing delays, as in Experiment 1 (Fig. 3). Foveal bias would, however, displace the remembered location of both dots

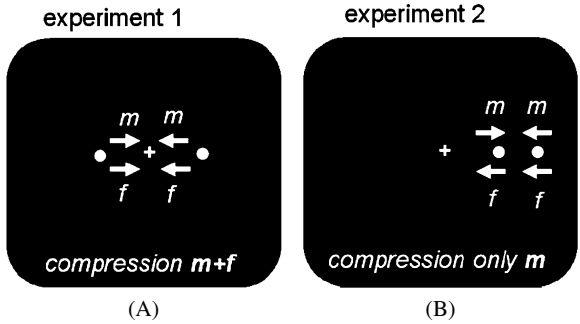


Figure 3. Predictions of foveal bias and memory averaging. The remembered position of dot stimuli in Experiment 1 (A) may have been mislocalized towards the centre of the display (central fixation point shown by the +) as a result of either or both memory averaging (arrows labelled 'm') and foveal bias (arrows labelled 'f'). In Experiment 2 (B) the stimuli are displaced to either the left or right (right condition shown) of the fixation, resulting in different effects of memory averaging and foveal bias on the remembered positions of the stimuli. Foveal bias will shift the remembered stimuli toward the centre (+), and only memory averaging will result in a displacement of the remembered dots towards each other.

in the pair towards the central fixation location and not significantly contribute to any difference in the perceived distance between them.

3.1. Method

3.1.1. Participants

Eleven participants (six female, mean age = 28, range 22–43 years) volunteered or were paid $10/hr if they were not students of the authors' labs. Seven of those who participated in the first experiment also participated in Experiment 2. All participants signed an informed consent form and had normal or corrected-to-normal vision. This study was conducted according to the procedures outlined in the York University ethics code.

3.1.2. Apparatus

All conditions were carried out using the same apparatus as in Experiment 1. The parameter settings on the monitor remained unchanged.

3.1.3. Procedure

The forced-choice procedure used in the first experiment was also used for the current task. All aspects of the experiment were as for Experiment 1, with the exception that the dot pairs were displaced such that the midpoint between them was $+/-20°$ to the left or right of the centre of the monitor. Stimuli were presented randomly to one side or the other. Participants were instructed to maintain gaze at the location of the central fixation cross at all times. The stimulus sequence is illustrated in Fig. 4.

As in Experiment 1, participants were instructed to press '1' on the keyboard number pad if the comparison stimulus appeared 'shorter' than the sample stimulus. Conversely, participants were instructed to press '2' if the comparison distance appeared 'longer'. These definitions of 'shorter' and 'longer' were consistently made clear to the participants.

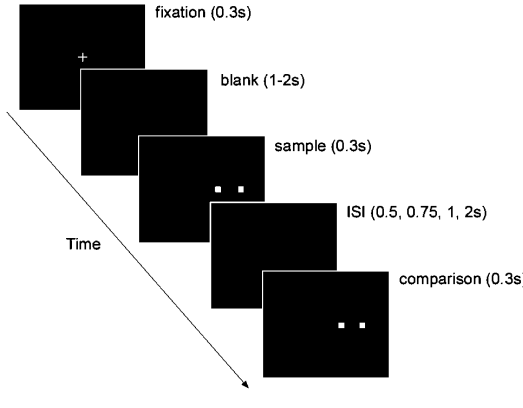


Figure 4. Dot stimulus sequence for Experiment 2: the midpoint between the dot pairs was randomly displaced either to the right or left of the central fixation marker. All other spatial parameters were identical to those used in Experiment 1. The sequence illustrates a sample trial for which the dot pair was displaced to the right side of the observer.

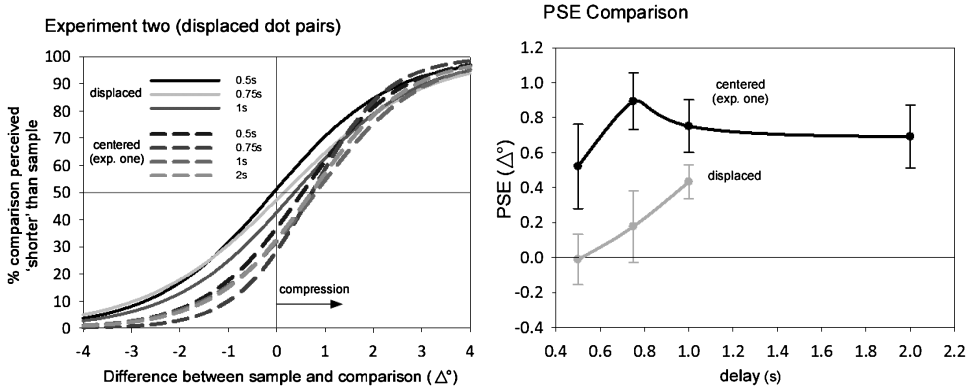
The separations between the dots had the same 7 Δ values as in experiment one, ranging from −3° to 3° in 1° steps. The total number of trials was 7 (sample–comparison Δ) × 3 (ISIs) × 10 repetitions = 210. Presentation side (left or right) was recorded as a variable.

3.2. Results of Experiment 2

PSE values for all participants at each delay were obtained for both left and right hemisphere stimulus presentations and compared using paired-samples t-tests. The comparisons yielded no significant differences between presentation sides ($p > 0.05$). Figure 5 shows the logistic fits to the pooled mirror symmetric data at each delay from 0.5 to 1 s. No differences in PSE values between stimulus hemispheres were observed in paired-sample t-tests for each delay ($p > 0.05$). All regressions accounted for at least 98% the variance in the dependent variable ($r^2 > 0.98$). For each delay condition, mean PSEs at which the sample and comparison distances were judged equal for each participant were obtained and compared with a test value of 0 using a one-sample t-test with Bonferroni type-1 error correction. A significant bias was found only for the 1 s delay condition ($t(10) = 4.3$, $p < 0.01$). The remembered positions of the dots were significantly closer to each other after a 1 s delay.

3.3. Discussion of Experiment 2

When pairs of dots were presented both to one side of fixation the results were consistent with those obtained in Experiment 1 — the remembered distance between



(A) (B)

Figure 5. Memory averaging *vs* foveal bias. (A) Logistic regressions fitted to the percentage of instances comparison dot stimuli in experiment two (displaced relative to fixation) were judged as shorter than sample dot pairs. For comparison purposes, the logistic regressions obtained in experiment one (centered dot pairs) are shown as dashed lines. Positive values on the abscissa represent a compression effect and negative values represent expansion. (B) PSE comparisons. PSE values were averaged across each participant and are plotted with standard errors as a function of the delay time. The PSE for displaced dot stimuli showed a significant shift in the direction of a compression effect only at the 1 s delay interval.

the dots decreased over time. However, the overall magnitude of this distortion was smaller at each delay compared to when the dot pairs were positioned symmetrically around the fixation point in the centre of the screen. The smaller magnitude of the drift effect indicates that the implied compression effect found by Sheth and Shimojo (2001) and confirmed in Experiment 1 are likely to result from a combination of memory averaging and foveal bias of the remembered locations of the stimuli. If only foveal bias were involved then there would be no significant compression effect under the conditions of Experiment 2 because the remembered location of both dots in the pair would drift in the same direction, towards the centre of the display, and at the same rate assuming that the strength of the bias does not vary with eccentricity. Museller *et al.* (1999) have shown that participants tend to increasingly foveally mislocate the remembered midposition of an extended target placed in the periphery, relative to a central fixation point. However, the parameters they used are not comparable with the present study (e.g., maximal delay of 112 ms, 6.5° eccentricity). Moreover, their data suggest that differences in the magnitude of any foveal bias between the dots in the present experiment would be insignificant. Even if the more eccentric dot drifted more or less than the more central one towards the fixation point, foveal bias would still play a role. Alternatively, if there were no foveal bias and only memory averaging were involved then the size of the effect would be the same for both configurations. Thus, the diminished compression effect that occurred in Experiment 2 suggests that foveal bias and memory averaging both contributed to the drift of remembered target locations in Experiment 1.

3.3.1. Additive Model

Figure 6 depicts the perceived locations of the dot stimuli for both experiments and fits the data with a simple model. The mean PSE values for Experiment 2 are fitted using an exponential function representing the effect of memory averaging only, as displacement of the remembered location of dot pairs towards each other in this experiment could not arise from foveal bias (assuming foveal bias was approximately equal for both eccentricities). The time constant of the function was 0.6 s and the asymptote occurred at 0.3°. The PSE values obtained from Experiment 1 are fitted using the sum of two exponential functions describing both the effects of memory averaging (with the same parameters as fit the experiment two data) and foveal bias. The time constant associated with foveal bias (0.2 s) and the asymptote, which occurred at 0.5°, indicate a faster and larger effect of mislocalization attributable to foveal bias. The regressions account for 80% of the variability in the data ($r^2 = 0.8$).

4. General Discussion

Experiments 1 and 2 reveal systematic distortion in spatial memory for remembered locations such that the locations of separate objects move towards each other in memory, apparently confirming a general compression of perceived space and a partial failure of space constancy. The results of Experiment 1 are in agreement

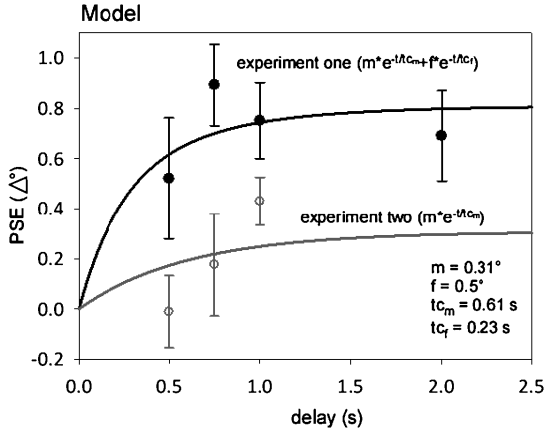


Figure 6. PSEs for the dot stimulus conditions over the range of delay intervals in Experiment 1 (filled circles) and Experiment 2 (open circles) fitted by the exponential functions shown. Mislocalization of remembered dot positions in Experiment 2 is expressed as the result of only memory averaging and is fit with a single function (grey line). Distortion of the remembered positions in Experiment 1 are modeled as resulting from both memory averaging and foveal bias (black line). Memory averaging and foveal bias time constants (tc_{m} and tc_{f}) and asymptotes (m and f) are shown in the bottom right of the figure.

with previous investigations and support the bias of remembered object locations towards salient landmarks, in this case a central fixation point (Van der Heijden *et al.*, 1999; see also Posner, 1980; Zhaoping, 2008).

Experiment 1 also demonstrates that although remembered object locations are distorted, the shape of objects is not affected as it would have been if the points that make up the shape remained vulnerable to such bias. The results of this experiment therefore do not support a general collapsing of perceptual space in memory. Experiment 2 revealed that the distortion of perceived locations may instead be predicted by a combination of the effects of foveal bias and memory averaging; the remembered line length, however, did not seem vulnerable to either of these influences.

4.1. Failure of Space Constancy and Maintenance of Shape Constancy

The results of Experiment 2 indicated that mislocalization resulting from foveal bias is greater than the bias attributable to memory averaging but that both played a role. The data are well described using exponential functions to predict the amount of distortion after a given interval, attributable to either effect — see Section 3.3. The magnitude of the displacement of the remembered positions of the dots found in this study resulting from memory averaging is comparable with the data obtained by Hubbard and Ruppel (2000) who found displacements of approximately 0.19° at the time of recall (although, additional mislocalization attributable to foveal bias may have occurred — see Kerzel, 2002b). However, observers in their study were able to respond immediately after the target was terminated and not after a delay period as in the current study. The regressions obtained in our model are consistent

with the results of Kerzel (2002b) who found mislocalizations attributable to foveal bias that were between approximately 0.2 and 0.6° after a 260 ms retention interval. Our data are also comparable with the results of Sheth and Shimojo (2001) who found drifts of the remembered position of dot stimuli to be between approximately 0.2 and 0.5° after a 2 s delay interval.

When the dot stimuli were connected with an intervening line, participants remembered perception of the endpoints (the dot stimuli in essence) remained accurate as there was no mislocalization that could not be attributed to chance, similar to the findings of Wearden *et al.* (2002). This result suggests the process responsible for distorting the locations of the dots when they are unconnected cannot distort the shape of whole objects. Thus, there appears to be a failure of space constancy in memory, but not a failure of shape constancy.

4.2. *Coding of Space* vs *Shape*

The encoding of locations in space is subserved primarily by the visual dorsal stream (often termed the 'where/how' stream). Within this stream information processing is predominantly used to code location and to guide reflexive, goal-directed actions, such as orienting movements (Goodale and Milner, 1992). Specifically, dorsal stream activity is necessary for tasks that involve online visuomotor processing associated with guiding motion towards an object; for example, visuomotor processing used for object prehension (Culham *et al.*, 2003). These tasks typically require continuously updating spatial visual input for controlling action (Milner and Goodale, 1995). Thus, memory for these locations is not generally part of the control system for guiding action. A target's position can change instantly and unpredictably, and thus it is more efficient to generate a motor program at the time when action is required (while the targets are visible) rather than storing a potentially infinite number of locations that may never be used and updating them to compensate for any changes in the observer's position (see Westwood and Goodale, 2003).

Visual processing that engages memory occurs in the ventral stream which plays a larger functional role in object processing ('what' stream). Ventral visual areas encode patterns and are essential for object identification and recognition (Goodale and Milner, 1992; also see Breitmeyer and Ogmen, 2006), tasks which inherently require memory. Thus the demands on object and spatial working memory are very different. They have also been found to activate different neural systems (Courtney *et al.*, 1996). Additionally, human memory for object shape is resilient to changes in position, light levels, clutter or visual angle (see Pasupathy, 2006 for a review) although the perceived locations of objects, as previously reviewed, is quite vulnerable to errors related to changes in eye position, head position, whole-body translation and rotation.

The distinction between shape and position processing found herein suggests further experiments to dissociate shape and size. Shape and size are functionally equivalent for our line task, as we did not additionally measure changes in perceived

line width. Thus, further insight may be gained by using isotropic stimuli such as circles to determine if distortions occur between vertical and horizontal dimensions. Such a condition would distinguish perceived shape and size.

Although it is possible that both dot and line tasks could be accomplished either egocentrically or allocentrically, spatial localization is essentially an egocentric task in which locations are coded relative to the self (Westwood and Goodale, 2003; see Milner and Goodale, 1995). Shape processing on the other hand involves an allocentric, object-based reference frame (Marr and Nishihara, 1978; Sekuler and Swimmer, 2000). Thus, we could conclude that ego-space is compressed and vulnerable to error whereas allocentrically coded shape can be remembered accurately.

4.3. Comparison of Mislocalization of Remembered Object Position with Saccadic Compression

Although smaller in magnitude, the mislocalization of remembered dot stimuli ($\sim$0.8° maximum) such that they tend to collapse towards each other and the fovea is reminiscent of the compression observed near the time of saccades ($\sim$10° maximum in Ross *et al*., 1997) (see Ross *et al*., 2001 for a review). This may suggest a similar failure of space constancy under the two conditions (waiting and saccades). In the event of saccades, space seems to compress not towards the fovea but towards the projected endpoint of the saccade (see Ross *et al*., 2001). This is consistent with the interpretation of the compression associated with saccades as resulting from neural processes anticipating the new location of the fovea (Lappe *et al*., 2000). Interestingly, saccadic compression, like the spatial compression investigated in the present study, appears to preserve shape features despite the compression of space towards the saccade endpoint, indicating a prevalence of shape constancy (Lappe *et al*., 2006).

5. Conclusions

The perceived location of objects is distorted in memory. This distortion comprises a tendency to drift towards the fovea and a tendency for memory averaging. Neither of these tendencies, however, appears to distort the shape of an object. In this study, the only difference between the dot and line conditions is addition of a luminance boundary which extends from one dot to another. Bounding separate locations in this simple manner may engage robust encoding and retrieval processes that tend to resist distortion and facilitate action and perception.

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