

# The movement of motion-defined contours can bias perceived position

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**Illusory position shifts induced by motion suggest that motion processing can interfere with perceived position. This may be because accurate position representation is lost during successive visual processing steps. We found that complex motion patterns, which can only be extracted at a global level by pooling and segmenting local motion signals and integrating over time, can influence perceived position. We used motion-defined Gabor patterns containing motion-defined boundaries, which themselves moved over time. This ‘motion-defined motion’ induced position biases of up to 0.5°, much larger than has been found with luminance-defined motion. The size of the shift correlated with how detectable the motion-defined motion direction was, suggesting that the amount of bias increased with the magnitude of this complex directional signal. However, positional shifts did occur even when participants were not aware of the direction of the motion-defined motion. The size of the perceptual position shift was greatly reduced when the position judgement was made relative to the location of a static luminance-defined square, but not eliminated. These results suggest that motion-induced position shifts are a result of general mechanisms matching dynamic object properties with spatial location.**

**Keywords:** Gabor pattern; shift; spatial representation

## 1. INTRODUCTION

The processing of motion-defined boundaries can provide depth cues in optic flow and help to break camouflage. It involves the integration of local motion signals over large areas in order to extract global changes in the motion patterns. It is necessary at the same time to maintain a localized spatial signal associated with such boundaries. Past work has investigated our ability to localize such contours (Burr *et al.* 2006; Durant & Zanker 2008). It has been shown that luminance-based motion extraction processes interact with the perceived position associated with areas of uniform motion (Ramachandran & Anstis 1990; DeValois & DeValois 1991). DeValois & DeValois (1991) compared the position of drifting Gabor patterns (sinusoidal luminance patterns bounded by Gaussian envelopes) contained within stationary

envelopes with each other and found that perceived position of the envelopes of the patterns was biased in the direction of motion. This effect shows a spatial and temporal frequency tuning. Bressler & Whitney (2005) used similar stimuli with contrast-defined motion, and also found a position bias, although with different spatial and temporal frequency tunings. It has often been suggested that second-order position coding and motion processing are carried out differently (e.g. Kingdom *et al.* 1995; Sutter *et al.* 1995; Lu & Sperling 2001). Pavan & Mather (2008) compared the two different types of motion and suggested that the separate motion mechanisms feed into separate position assignment mechanisms, with no interaction.

We ask whether perceived position can be shifted by motion, which in itself is defined by motion. To see this motion, extraction stages are needed, which differ from those for contrast-defined motion. Several layers of motion processing, larger spatial integration areas and longer integration times than luminance-defined motion (Zanker 1992), as well as arguably attentional tracking (Lu & Sperling 2001), are required. Maruya *et al.* (2008) found no effect of the motion of motion-defined contours on spatial position. Here, we investigate with a stimulus analogous to the original (DeValois & DeValois 1991) stimulus and compare the positions of two motion-defined Gabor patterns containing drifting carrier patterns (figure 1).

## 2. MATERIAL AND METHODS

### (a) Stimulus

Two motion-defined patterns (figure 1) were presented horizontally on either side of a central fixation target (at 3° eccentricity), contours oriented horizontally with their carriers drifting in vertically opposite directions. Three thousand (five dots per 1° square) randomly positioned moving black dots (1 pixel size = 0.05°; life limited to three frames) were presented on a bright grey background (73 cd<sup>2</sup> m<sup>-1</sup>). The motion axis of the dots was either horizontal (parallel to the contours) or vertical (orthogonal). The velocity of the dots (maximum 3 pixels per frame = 4.5 deg s<sup>-1</sup>) was determined by a Gabor pattern (figure 1). Sub-pixel position accuracy was calculated and rounded to the nearest pixel. Speeds below 0.3 pixels per frame were set to a random velocity between 0.3 and 3 pixels per frame; carrier speed, 1.7 pixels per frame (2.55 deg s<sup>-1</sup>); presentation time, 60 frames = 2 s (30 Hz refresh rate). A random starting phase was chosen independently for each patch. Gabor patches were 4° full width at half height. The dots were contained within a square area of 24.5° width. In experiment 3, the right-hand pattern was a 4.5° width black square outline, 0.5° thick. The experiment was approved by the Royal Holloway Psychology Department ethics committee.

### (b) Procedure

The 2AFC method of constants was used. Seven offsets were shown equally spaced between the left being higher or lower by 3°. The position of both patterns was also shifted vertically by 0.75° randomly on each trial, so the fixation point could not be used as a spatial reference. Participants indicated, using mouse buttons, which patch was higher. Eight responses were collected at each offset and a psychometric curve fitted with a logistic function, yielding the point of subjective alignment (PSA). The individual shift of a pattern was the average of the PSA offsets for opposite directions (divided by 2 when two moving patterns were compared). Four measurements were made for each condition. The four different conditions (left/right up and orthogonal/parallel) were interleaved during a block. For the judgement of the direction of motion task, the offsets were randomized and each of the conditions was shown 10 times. The participants indicated which pattern contained upward motion of the motion-defined contours, and the number of correct responses was recorded.

Electronic supplementary material is available at <http://dx.doi.org/10.1098/rsbl.2008.0622> or via <http://journals.royalsociety.org>.

Received 24 October 2008  
Accepted 5 December 2008

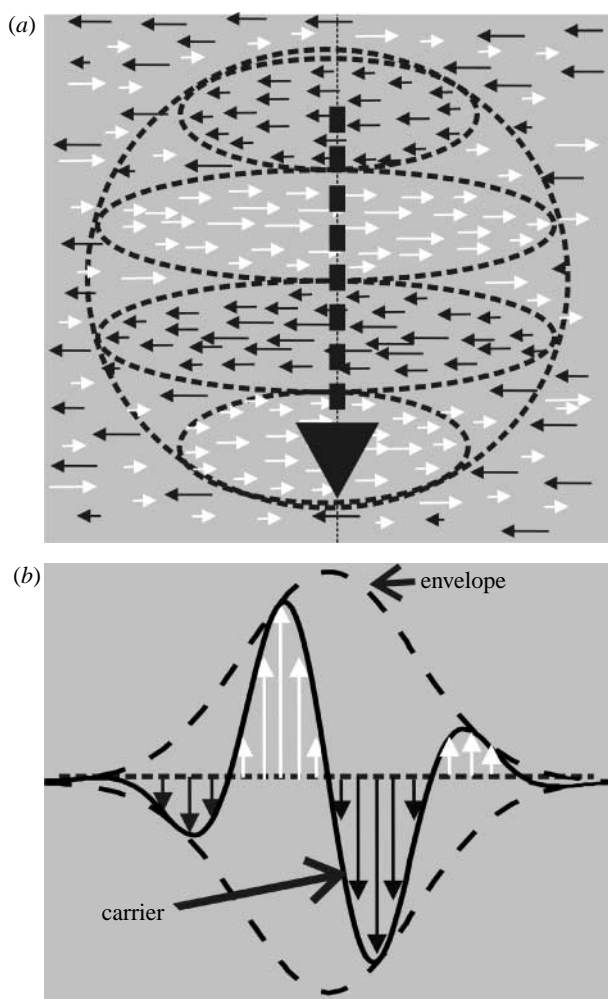


Figure 1. Illustration of the stimulus in the 'horizontal' (contour) 'parallel' (motion) condition. Black and white arrows illustrate opposite directions of motion of the black dots. (a) The large dashed arrow shows the overall direction of the motion contours. (b) A cross section of the velocity profile at the line vertically through the middle of (a). The phase change of the carrier is the 'motion of the motion'.

### 3. RESULTS

We began by finding conditions leading to sizeable positional shifts and testing how this related to the visibility of the motion of the motion-defined contours. We considered motion orthogonal and parallel to the contours. In experiment 1, we found that for a low spatial frequency of  $0.1 \text{ cycles deg}^{-1}$  of motion modulation (containing only one or two motion-defined contours at any time), there was a significant shift in perceived position. This was greater for orthogonal than parallel motion, the maximum shift being approximately  $0.4^{\circ}$ – $0.5^{\circ}$  (figure 2a).

In experiment 2, we tested with Gabors of a spatial frequency of  $0.7 \text{ cycles deg}^{-1}$  (nine contours present in one frame) and the same contour speed as in experiment 1. We found a significant perceptual shift in position of the envelopes of the Gabor patches, although the shift was reduced on the whole, and for three participants confined to dots moving orthogonally to the contours (figure 2b). This showed that the position shift is not limited to the particular stimulus conditions in experiment 1, although a wider parameter space remains to be explored.

We found a significant correlation ( $r=0.7$ ,  $p<0.05$ ) between the perceived position bias for experiments 1 and 2 and the detectability of the corresponding 'motion of the motion' direction (figure 2c): confirming that the more visible the motion of the contours, the larger the positional shift. However, we also found some points where performance on the direction judgement is at chance levels, while there remains a significant position shift, suggesting that it is not necessary to consciously perceive the motion of the contours to perceive a shift in position.

In experiment 3, we tested whether the perceived shift found with the low spatial frequency motion contours would be reduced by reducing the positional uncertainty of the spatial reference. We compared the perceived shift relative to a hard luminance-edged square as was done by Maruya *et al.* (2008)—who did not find a position shift for this motion of the motion. We found that the shift was reduced and the pattern was less consistent across participants. In general, the difference between the two types of motion was reduced; however, again, for all subjects apart from participant AS there is still a significant perceptual position shift (figure 2d).

### 4. DISCUSSION

We found that the motion of motion-defined contours can induce illusory shifts in position. This effect is particularly strong when the motion is orthogonal to the contours, when there are only a few contours visible and when the positions of two patches are being compared with each other. The perceived position shift of up to  $0.5^{\circ}$  is much larger than the shifts found in the luminance domain of around maximum 10 minarc at similar eccentricities (DeValois & DeValois 1991). This suggests that high-level mechanisms involved in extracting complex motion signals can bias perceived position, and that the magnitude of the shift could be related to the coarse-grained representation of location at these stages. The luminance-defined motion-induced shift increases with eccentricity (DeValois & DeValois 1991), which may reflect the fact of lower spatial resolution in the periphery. The coarse-grained representation associated with global motion could lead to increased positional uncertainty for the location of these stimuli. The slopes of the psychometric functions show a just noticeable difference of around 15 minarc, much higher than the accurate spatial representation in the luminance domain with a resolution of approximately 2 minarc at similar eccentricities (DeValois & DeValois 1991).

We also observed a shift (albeit much reduced and less consistent) using a first-order (luminance-defined) stimulus as reference, suggesting that the two spatial position assignment mechanisms are not completely independent of each other (figure 2d). The decrease in perceived shift with the higher spatial frequency motion carrier reflects that motion contours are less easily perceived (Watson & Eckert 1994). The size of the perceived shift increased with the saliency of motion of motion-defined contours,

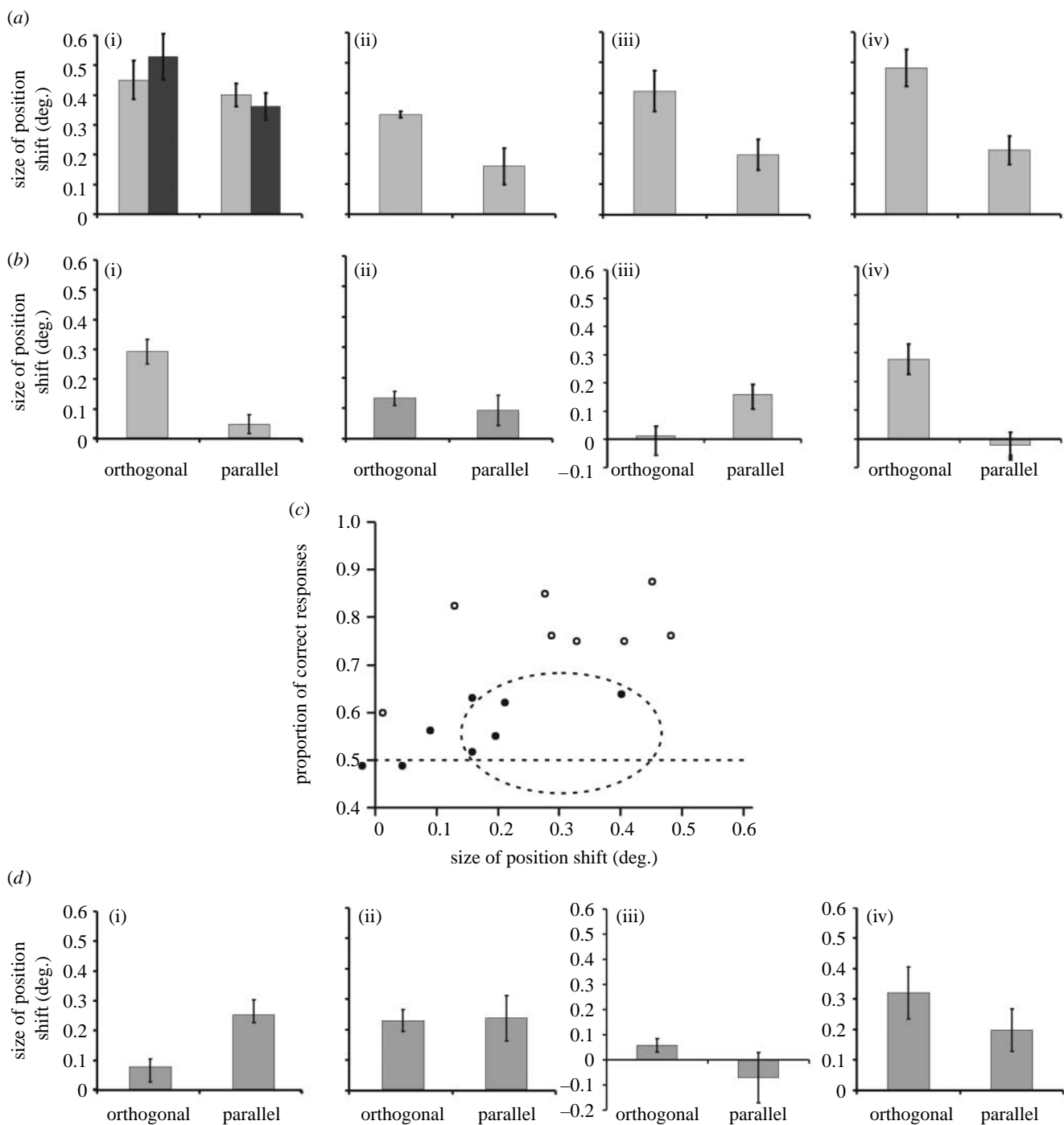


Figure 2. Measurements of the perceived position shift. Averages and SEM error bars calculated from four measurements of the psychometric function. (a) The size of the perceived position shift for the two types of contours at a low spatial frequency (0.1 cycles deg<sup>-1</sup>; grey bars, horizontal; black bars, vertical). (i) Participant SD, (ii) participant AM, (iii) participant AS and (iv) participant FH. For participant SD, two arrangements (horizontally either side of fixation or the whole screen rotated to vertically either side) of the Gabor patterns were measured. (b) Position shift for the two types of contours at a high spatial frequency (0.7 cycles deg<sup>-1</sup>). (i) Participant SD, (ii) participant AM, (iii) participant AS and (iv) participant FH. (c) Position shift from experiments 1 and 2 plotted against the corresponding detection rate of the 'motion of the motion' direction. The points are circled where performance on the direction judgement is at chance, but there is still a significant position shift (open circles, orthogonal; filled circles, parallel). (d) The position of the motion-defined Gabor envelope compared with the square frame. (i) Participant SD, (ii) participant AM, (iii) participant AS and (iv) participant FH.

suggesting that it was related to the magnitude of this higher order motion signal. Importantly, however, an awareness of the motion-defined motion direction was not necessary to produce a significant shift in perceived position (figure 2c), as was also found with luminance (Whitney 2006) and contrast-defined motion (Harp *et al.* 2007).

It is not clear why there is a larger positional shift for the orthogonal motion-defined boundaries. At these low spatial frequencies, no difference in sensitivity between the two conditions was found previously for static contours (Nakayama *et al.* 1985). On average over the trials, there is no greater upward or downward motion signal in this stimulus (as the

initial phases are randomized); however, it is possible that the axis of the motion direction of the dots corresponding with that of the direction of the motion of the contours enhances the effect.

It has been suggested that the luminance-defined motion-induced shift occurs in brain areas MT/V5 (McGraw *et al.* 2004). It has been debated whether motion-contour analysis occurs in V3 or some specialized area (Van Oostende *et al.* 1997; Zeki *et al.* 2003). The size of these position shifts coupled with the accuracy for localizing these contours (Burr *et al.* 2006) suggests a coarse position representation for these types of objects. This also suggests that motion-defined contours are processed in an area where low-resolution retinotopic information is maintained.

The position shift may be caused by the need to maintain position information, while pooling over large areas to extract the global motion that defines these contours. The finding that a comparison with the first-order static stimulus reduces the shift suggests that position is not maintained in a fixed global framework, but can be distorted locally depending on what type of stimulus is available for estimating position.

The experiment was approved by the Royal Holloway Psychology Department ethics committee.

Thanks to Andrew Meso and Tim Holmes. This work was supported by EPSRC grant EP/C015061/1.

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