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 0.5º, 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 judgment 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.

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 localised spatial signal associated with such boundaries. Past work has investigated our ability to localise 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, De Valois & De Valois, 1991). DeValois and 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 and Whitney (2005) used similar stimuli with contrast-defined motion, and also found a position bias, although with different spatial and temporal frequency tuning. It has often been suggested that second-order position coding and motion processing are carried out differently e.g. (Sutter et al., 1995, Kingdom et al., 1995, Lu & Sperling, 2001). Pavan and 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 if 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), are required as well as arguably attentional tracking (Lu & Sperling, 2001). 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 and DeValois (1991) stimulus and compare the positions of two motion-defined Gabor patterns containing drifting carrier patterns (see Figure 1).

2. Methods

Stimulus

Two motion-defined patterns (Figure 1) were presented horizontally on either side of a central fixation target (at 3º eccentricity), contours oriented horizontally with their carriers drifting in vertically opposite directions. 3000 (5 dots per 1º square) randomly positioned moving black dots (1 pixel size = 0.05 deg; life limited to 3 frames) were presented on a bright grey background (73 cd^2/m). The motion axis of the dots was either horizontal (parallel to the contours) or vertical (orthogonal). The velocity of the dots (maximum 3 pixels/frame = 4.5 deg/s) 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/frame were set to a random velocity between 0.3 and 3 pixel/frame. Carrier speed: 1.7 pixels/frame (2.55 deg/s). Presentation time: 60 frames = 2s (30 Hz refresh rate). A random starting phase was chosen independently for each patch. Gabor patches were 4º full width at half height. The dots were contained within a square area of 24.5º width. In experiment 3 the right hand pattern was a 4.5º width black square outline 0.5º thick. The experiment was approved by the Royal Holloway Psychology Department ethics committee.

Procedure

2AFC method of constants was used. 7 offsets were shown equally spaced between the left being higher or lower by 3º. The position of both patterns was also shifted vertically by 0.75º 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 two when two moving patterns were compared). Four measurements were made for each condition. The four different conditions (left/right up, orthogonal/parallel) were interleaved during a block. For the judgment of the direction of motion task the offsets were randomized and each of the conditions was shown 10 times. Participants indicated which pattern contained upward motion of the motion-defined contours, the number correct was recorded.

3. Results

We began by finding conditions leading to sizeable positional shifts and testing how this related 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 cycles/deg 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, maximum shift of around 0.4º-0.5º (See Figure 2a).

In experiment 2 we tested with Gabors of a spatial frequency of 0.7 c/deg (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 judgment is at chance levels, whilst 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 Mayura et al. (2008) - who did not find a position shift for this “motion of 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 AS there is still a significant perceptual position shift (see 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 the when positions of two patches are being compared to each other. The perceived position shift of up to 0.5° is much larger than the shifts found in the luminance domain of around maximum 10 minarc at similar eccentricities (De Valois & De Valois, 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 grain representation of location at these stages. The luminance-defined motion-induced shift increases with eccentricity (De Valois & De Valois, 1991), which may reflect the fact lower spatial resolution in the periphery. The coarse 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 around just 2 minarc at similar eccentricities (De Valois & De Valois, 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, suggesting 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 (see 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 upwards or downwards motion signal in this stimulus (as the initial phases are randomised), 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 MT/V5 (McGraw et al., 2004). It has been debated whether motion-contour analysis occurs in V3 or some specialised area (Zeki et al., 2003, Van Oostende et al., 1997). The size of these position shifts coupled with the accuracy for localising 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, whilst pooling over large areas to extract the global motion that defines these contours. The finding that a comparison with 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.

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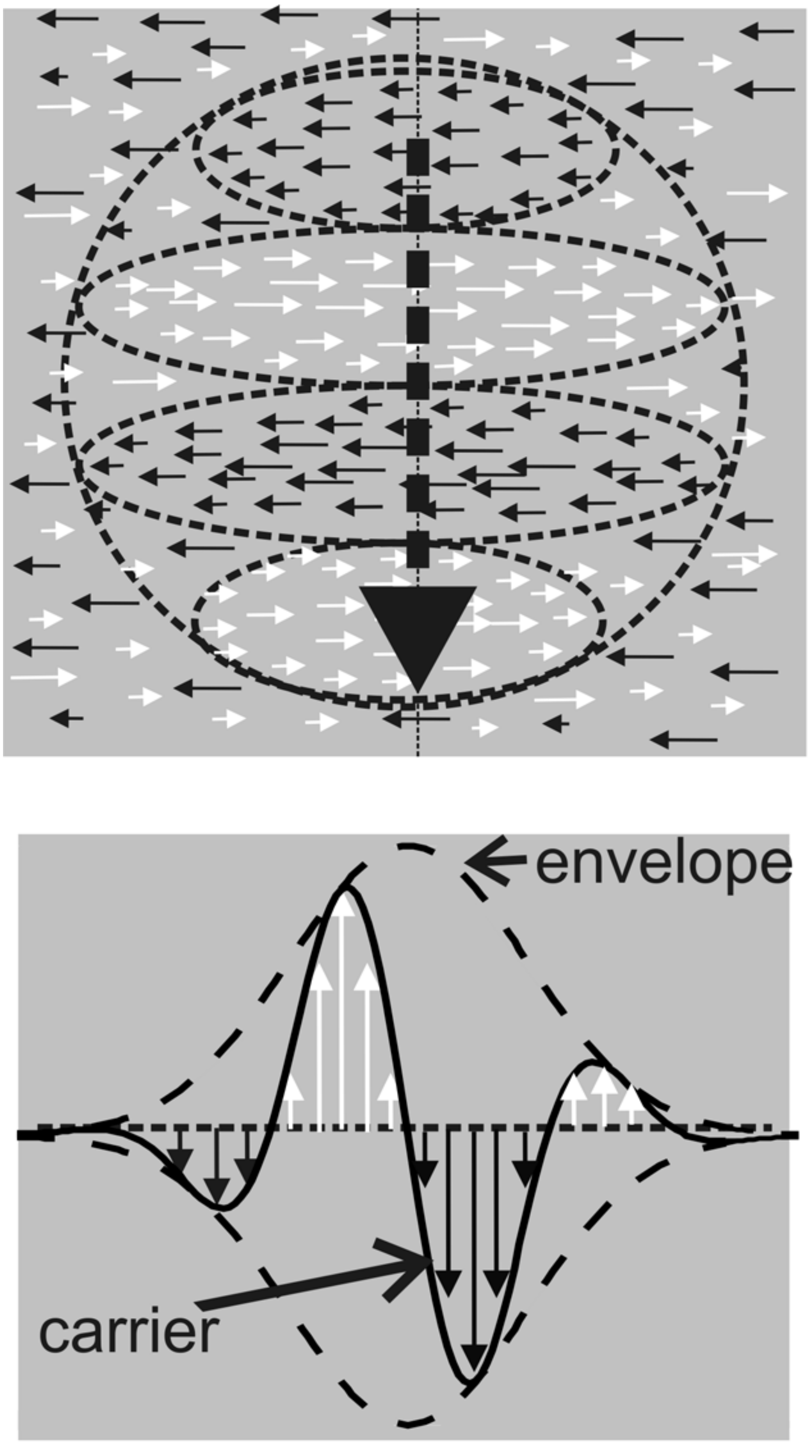

Figure 1. Illustration of the stimulus in the “horizontal” (contour) “parallel” (motion) condition. Black and white arrows illustrate opposite directions of motion of the black dots. Top panel: The large dotted arrow in the top panel shoes the overall direction of the motion contours. Bottom panel: A cross-section of the velocity profile at the line

vertically through the middle of the top image. The phase change of the carrier is the "motion of the motion".

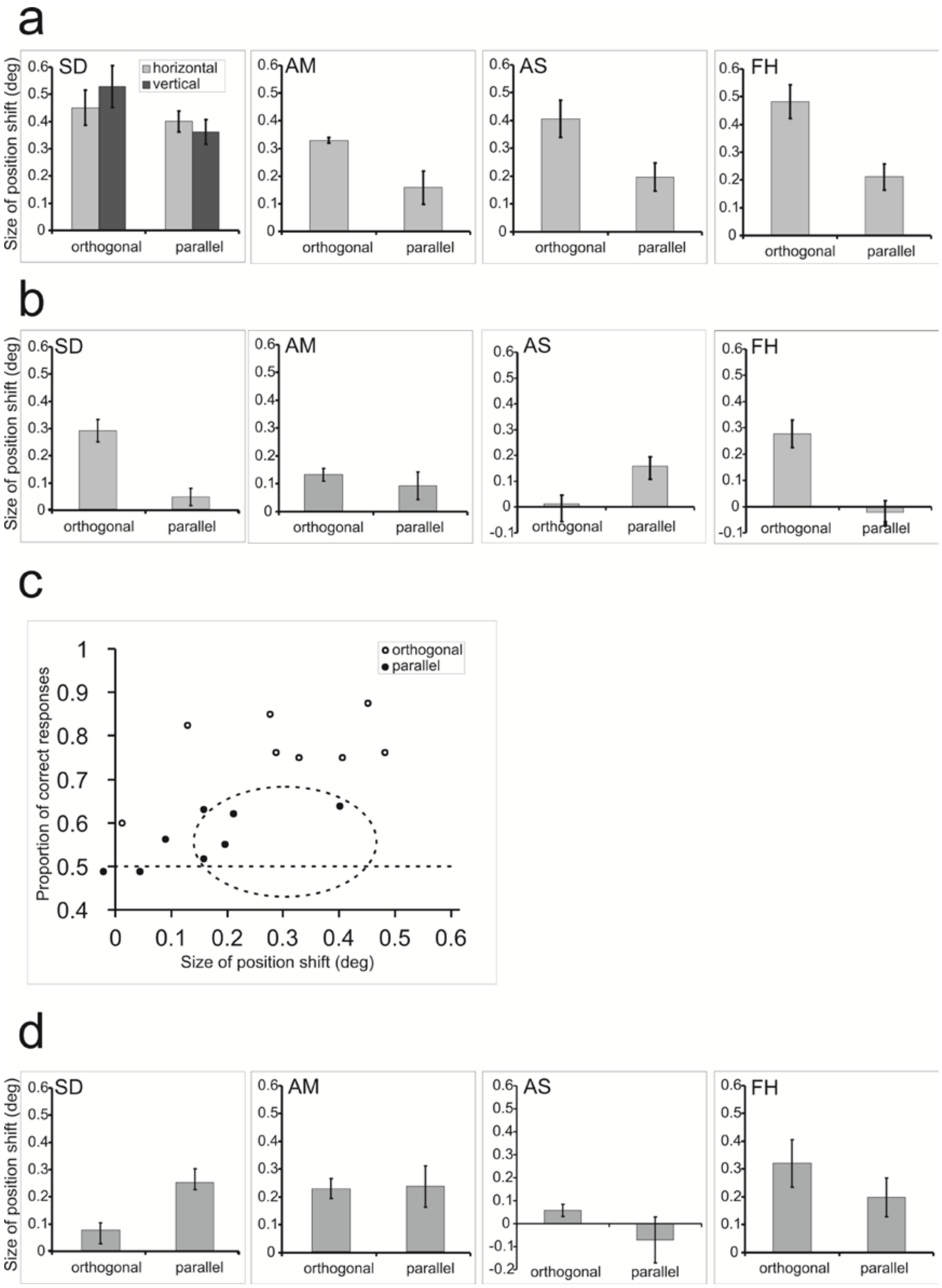

Figure 2. Measurements of the perceived position shift. Averages and SEM error bars calculated from four measurements of the psychometric function

(a) The size of the perceived position shift for the two types of contours at a low spatial frequency (0.1 cycles/degree). For 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/degree). (c) Position shift from experiment 1 and 2 plotted against the corresponding detection rate of the “motion of the motion” direction. Circled are the points where performance on the direction judgment is at chance, but there is still a significant position shift. (d) The position of the motion-defined Gabor envelope compared with the square frame.