Perception, 2009, volume 38, pages 1405 – 1409

doi:10.1068/p6383

LAST BUT NOT LEAST

Illusory movement of dotted lines

Hiroyuki Ito, Stuart Anstis¶, Patrick Cavanagh§
Department of Visual Communication Design, Kyushu University, 4-9-1, Shiobaru, Minami-ku, Fukuoka-shi, 815-8540, Japan; ¶ Department of Psychology, University of California San Diego, 9500 Gilman Drive, La Jolla, CA 92093-0109, USA; § Laboratoire de Psychologie de la Perception, Université Paris Descartes, UFR Biomédicale des Saints-Pères, 45 rue des Saints-Pères, 75270 Paris, France; e-mail: ito@design.kyushu-u.ac.jp, sanstis@ucsd.edu, patrick.cavanagh@parisdescartes.fr
Received 10 February 2009; in revised form 9 March 2009

Abstract. When oblique rows of black and white dots drifted horizontally across a mid-grey surround, the perceived direction of motion was shifted to be almost parallel to the dotted lines and was often nearly orthogonal to the real motion. The reason is that the black/white contrast signals between adjacent dots along the length of the line are stronger than black/grey or white/grey contrast signals across the line, and the motion is computed as a vector sum of local contrast-weighted motion signals.

Please examine figures 1 – 5. Hover a stationary pencil point above each figure and move the page slowly to the right, or else move the fixated pencil point slowly to the left. View from close-up, since the effects are best in peripheral vision. In the control condition of figure 1 the two oblique lines appear to move inwards, consistent with the retinal stimulation, since the lines really do move inwards toward the fovea as the pattern moves to the right.

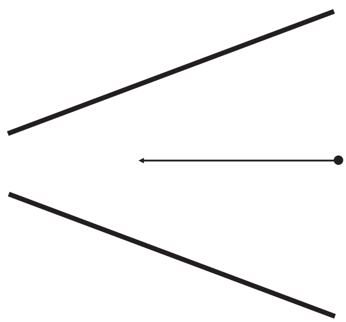

Figure 1. Control condition: put a pen tip on the black spot and move it to the left, tracking it with your eyes. Result: lines appear to move inwards, consistent with the retinal stimulation.

However, the dotted lines in figure 2 appear to move outwards (away from each other) as the pattern moves to the right.

Figure 3 shows that the dotted lines need not be black and white, but can be low-contrast light and dark-grey, provided that they straddle the surround luminance. When the pattern moves left and right behind the fixation point, it appears to move up and down, and conversely when it moves up and down it appears to move left and right.

Figure 4 shows a minimum stimulus for the illusory motion, made from adjacent pairs of black and white dots. When the pattern moves horizontally, some dots seem to move upwards, others downwards, at right angles to their actual motion.

Compare this with Pinna and Brelstaff's (2000) motion illusions, which are also based on the motion of oblique luminance components.

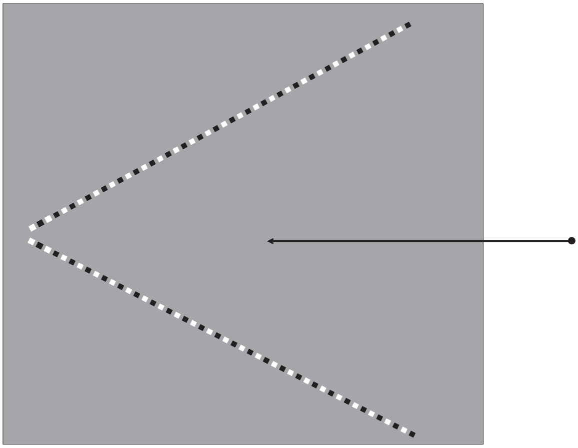

Figure 2. When the eyes move to the left, dotted contours appear to move outwards, opposite to the prediction from retinal stimulation. A movie version including a moving fixation spot is available on the *Perception* website at http://dx.doi.org/10.1068/p6383

Figure 3. Oblique dotted lines. A movie version is available on the *Perception* website.

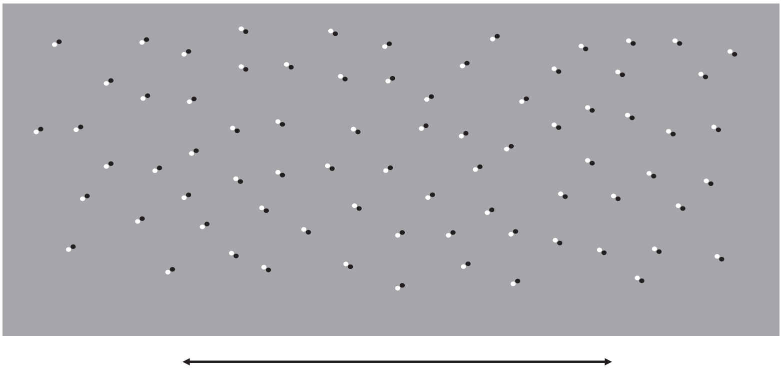

Figure 4. A minimum stimulus for illusory motion. When the eyes move horizontally across the obliquely oriented pairs of black and white dots, the dots seem to move up and down. A movie version is available on the *Perception* website.

Figure 5 shows illusory motion during horizontal movements and demonstrates that the virtual contour need not be dotted or oblique. But the spatial offsets do introduce oblique local luminance components.

We argue that contrast determines vector strength. When the grey level of the surround is midway between that of the light and dark dots, the contrast along the line (black/white) is twice the mean signed contrast across the line (mean of black/grey and white/grey). Since high-contrast motion looks faster and more salient than low-contrast motion (Thompson 1982; Anstis 2001, 2004; Howe et al 2006), we propose that the high-contrast motion component along a dotted line is over-estimated, distorting the perceived direction so that it looks more parallel to the orientation of the line.

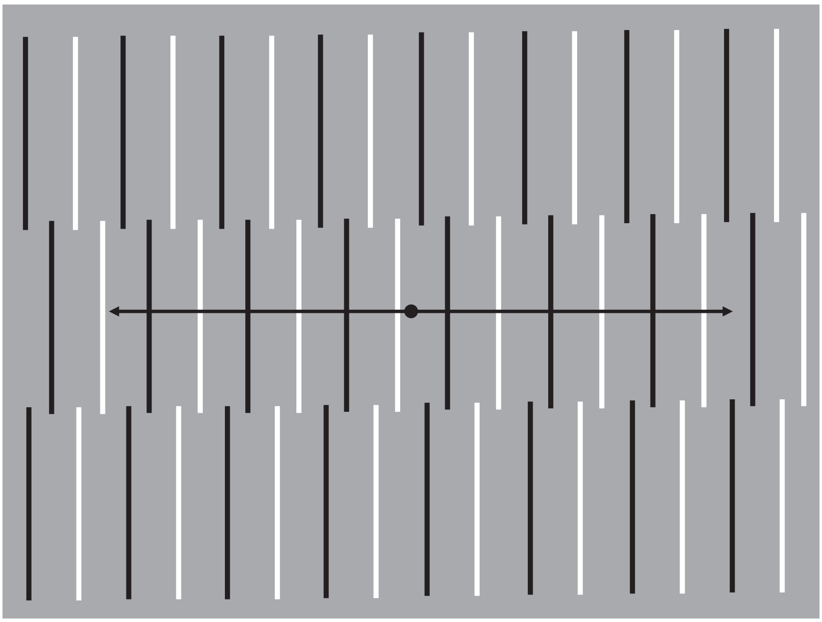

Figure 5. Phase edges need not be oblique. A movie version is available on the *Perception* website.

A moving line can be decomposed into two motion vectors, one parallel to the line and one orthogonal to it. For a solid black (real) line, the motion signal across the line is stronger than the motion signal along the line, which in fact tends toward zero, so orthogonal motion is seen. But for a dotted line, the motion signal along the line is stronger than the motion signal across the line, so the perceived motion will tend to a direction parallel to the line. To test this, we moved 45° oblique lines, either dotted or solid black, horizontally at a rate of 4.2 deg s^{-1} across uniform grey surrounds of various luminance levels. Two observers (HI and SA) viewed the oblique lines of figure 3 through an annular window of inner and outer diameters 4.9 deg and 14.1 deg in a textured screen, and adjusted a centrally placed arrow to match the perceived directions.

Figure 6 shows the results. The *x*-axis was the surround luminance as a percentage of 'white' (30 cd m^{-2}). Dashed curve shows the physical contrast ratio:

$$\frac{\text{black/white contrast along dotted line}}{\text{mean signed contrast of black/grey and white/grey dots against the surround}} \, .$$

This ratio peaked when the surround grey was midway between the dot luminances.

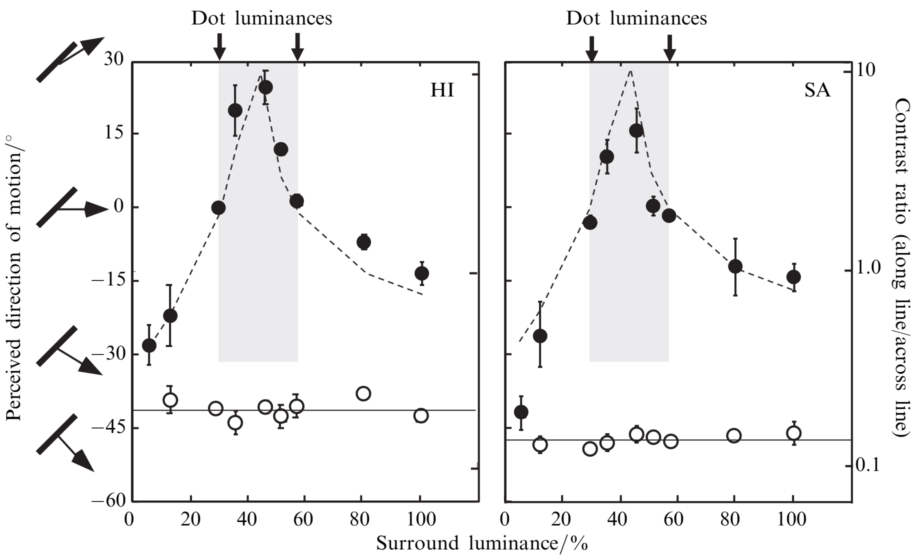

Figure 6. Dashed line: physical ratio of Michelson contrasts along/across the dotted lines (right-hand scale). Solid symbols: perceived directions of the moving dotted lines (left-hand scale) as a function of surround luminance. Open symbols: control, solid black moving lines, showing no motion illusion. Illusion was maximum when the dot luminances straddled the surround luminance (grey rectangles).

Solid symbols show the psychophysical perceived direction of movement. The illusion was highly correlated with the contrast ratio, as we predicted.

In sum, the motion was distorted most when the grey level of the surround lay between those of the light and dark dots.

Note that the stimulus geometry—the layout of the dots, the line separations, and the drift rates—was the same on every trial. So if the stimulus geometry were the only factor, the perceived motion would be the same whatever the surround luminance. This was approximately true for the black control lines, but it was emphatically not true for the experimental dotted lines. So the perceived direction of motion owed as much to relative stimulus contrast as to stimulus geometry. Incidentally, the contrast along the black control lines was always zero, so the motion ratio and perceived direction of motion never changed.

Next, we made the dotted lines vertical on a fixed mid-grey surround (44%) and moved them in 16 different physical directions that were 22.5° apart. Again observers reported the perceived directions with an adjustable matching arrow. To rule out individual biases, we used a dark-grey surround to obtain control data, and we subtracted these controls from the experimental results.

Results are shown in figure 7, collapsed down from 360° into a single quadrant. A vertical line that moved at 45° was perceptually shifted toward the vertical, with a perceived direction only 30° away from the vertical. Furthermore, a line moving at 22.5° from the vertical appeared to move at only 2.5° away from the vertical! So the illusions were substantial, especially for lines moving nearly parallel to their own orientation. However, lines that actually moved along, or orthogonal to, their own length, showed no illusions.

In conclusion, we attribute the motion illusions to interactions between two motion vectors: strong, high-contrast boundaries between adjacent black and white dots along the lines; and weaker, lower-contrast boundaries between the dots comprising the line and the mid-grey surround (see also Cavanagh and Anstis 2002). This is consistent with a motion-energy model (Adelson and Bergen 1985), in which motion energy is

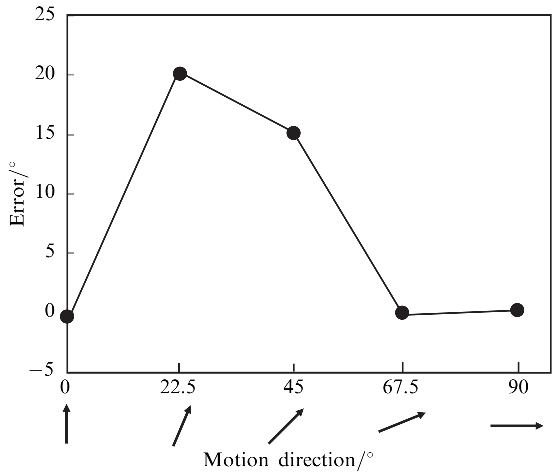

Figure 7. Errors in judging motion of vertical dotted lines (mean of two observers × 8 readings). Perceived directions of motion looked much closer to vertically upward than they really were. 45° motion was perceptually shifted 15° toward vertical, and 22.5° motion was shifted by 20°, looking practically vertical. A demonstration movie is available on the *Perception* website.

proportional to contrast; but in our case the energy is computed not simply in opposite directions ($E_L - E_R$) but in all 360° directions. Thus visual motion makes a contrast-weighted summation of local motion vectors in all directions.

These findings could have implications for road safety. 'Safety' markings on roads and guard rails often consist of black and white stripes or checks. A driver moving almost parallel to such markings could easily misjudge the direction of his own travel by up to 20°, with potentially hazardous results.

Acknowledgments. HI and SA were supported by a Grant-in-Aid for Scientific Research (20300048, 19653083, and 19103003) provided by the Japanese Ministry of Education, Culture, Sports, Science, and Technology, Japan. SA also thanks UCSD for granting him a Sabbatical. PC possesses a Chaire d'Excellence at the Université de Paris.

References

Adelson E H, Bergen J, 1985 "Spatiotemporal energy models for the perception of motion" *Journal of the Optical Society of America A* **2** 284 – 299

Anstis S, 2001 "Footsteps and inchworms: Illusions show that contrast modulates apparent speed" *Perception* **30** 785 – 794

Anstis S, 2004 "Factors affecting footsteps: contrast can change the apparent speed, amplitude and direction of motion" *Vision Research* **44** 2171 – 2178

Cavanagh P, Anstis S, 2002 "The boogie-woogie illusion" *Perception* **31** 1005 – 1011

Howe P D, Thompson P G, Anstis S M, Sagreiya H, Livingstone M S, 2006 "Explaining the footsteps, belly dancer, Wenceslas, and kickback illusions" *Journal of Vision* **6** 1396 – 1405

Pinna B, Brelstaff G J, 2000 "A new visual illusion of relative motion" *Vision Research* **40** 2091 – 2096

Thompson P, 1982 "Perceived rate of movement depends on contrast" *Vision Research* **22** 377 – 380