Moving in a Fog: Stimulus contrast affects the perceived speed and direction of motion

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Abstract - **Moving cars give the illusion of slowing down in foggy conditions, because low contrast reduces perceived speed.. A grey square that drifts horizontally across a surround of black and white vertical stripes appears to stop and start as it crosses each stripe, because its contrast keeps changing. A moving square whose vertical and horizontal edges have different contrasts will show illusory distortions in perceived direction. Contrast also affects the apparent amplitude and salience of back-and-forth apparent motion. Also, a line of black and white dots on a gray surround moves in illusory directions, because of a mismatch in the contrasts along and across the dotted line. Thus, motion signals in the early parts of the visual system are profoundly altered by stimulus luminance and contrast. This suggests that motion is coded by the relative firing rates of neural channels tuned to "fast" and "slow" motion.**

INTRODUCTION

Fog kills, and statistics prove it. Some examples: On October 11th, 2002, a multiple-vehicle accident in Sheboygan county, Wisconsin, resulted in 10 fatalities due to "white out" conditions in dense fog on I-43. On November 4th, 2002, nearly 200 cars and big-rig trucks collided in heavy fog on the Long Beach Freeway, injuring dozens of people, including nine critically. A mangled mess of cars, vans and big-rig trucks shutdown the freeway, about 25 miles south of Los Angeles, for nearly 11 hours. Authorities said some motorists were driving too fast for the foggy conditions. Estimates are that cars were moving at 25 to 35 mph. On December 28th, 2002, seventy vehicles piled up in dense fog on a freeway outside Houston, Texas, with 31 injuries.

In the state of Wisconsin alone, about 1,200 vehicle accidents occur each year when dense fog is a factor. This results in about 16 deaths and 700 injuries. Nationally, an average of 950 people die in winter-related road accidents each year. Many of these accidents can be avoided.

What can be done? Often fog simply makes other cars invisible. Motorists do not see them and crash into them, and visual science can do nothing about this, although IQ testing might help. But at other times fog makes other cars somewhat less visible without hiding them completely, and other motorists misjudge them. Here visual science can perhaps make a useful contribution. Many anecdotes suggest that during a fog, other cars and also one's own car appear to move more slowly than their actual speeds. My recent findings attribute both phenomena to the fact that objects *appear to move more slowly when they are low in contrast,* as they are in a fog. (Note: 'Contrast' refers throughout this paper to the measurable stimulus property of differences in luminance. It does not refer to the 'simultaneous contrast', or illusory brightness induction, that is caused by lateral inhibition.) In a fog, other cars are reduced in contrast so they appear to be going more slowly than they really are. Also, a driver judges his own speed largely by visual cues from the landscape as it slides past him, often viewed through the side windows of the car in peripheral vision. Fog reduces the contrast of the passing landscape, so it appears to slip by him more slowly and he believes that he himself is driving slowly.

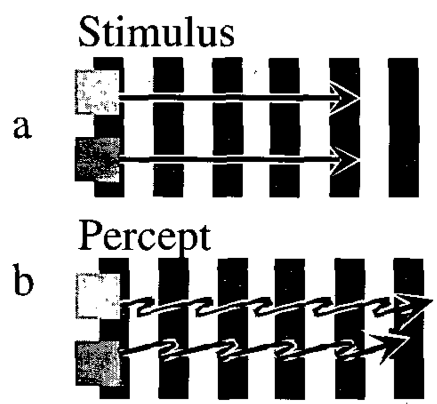

Figure 1. The footsteps illusion. A light and a dark grey square move together at constant speed across stationary stripes. As they alternately change from high to low contrast, they seem to alternate between high and low speeds.

RESULTS

It is known that apparent speed varies with contrast [1--4]. I have found some novel and direct demonstrations of these illusory changes in apparent speed. Two squares, one of them light grey and the other one dark grey, moved horizontally at constant speed across a stationary surround of vertical stripes (Fig. 1). Each square was exactly two stripe widths in diameter, so that its front and back edges always lay on the same colour (black or white). I found that the two squares appeared to stop and start in alternation, depending upon their local contrast. When the dark grey square lay on white stripes it had high contrast (dark versus white) and appeared to speed up momentarily. When it lay on black stripes it had low contrast (dark versus black) and appeared to slow down. The opposite was true for the light grey square. Consequently the two squares appeared to speed up and slow down in alternation, like a pair of walking feet. So I called this the 'footsteps illusion' [5, 6]. In this display you see the contrast altering the apparent speed in real time. The illusion is very strong, particularly in peripheral vision, where the squares can appear to stop dead and re-start, about once every second or so

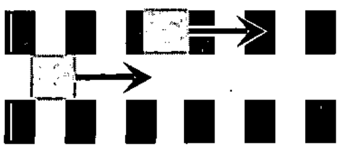

Figure 2. The upper square shows the footsteps illusion because its leading and trailing edges change contrast as it traverses the stripes. The lower square shows no illusion because only its irrelevant top and bottom edges change in contrast.

I examined which parts of the surround and of the moving squares cause the footsteps illusion. I moved the squares along a narrow horizontal 'railway track', so that only the front and back edges of the squares contacted the stripes. The illusion was still present in full force (Fig. 2a). Then I moved the squares along a narrow 'clear track' cut through the stripes, so that only the top and bottom edges of the squares contacted the stripes. The illusion vanished (Fig. 2b).

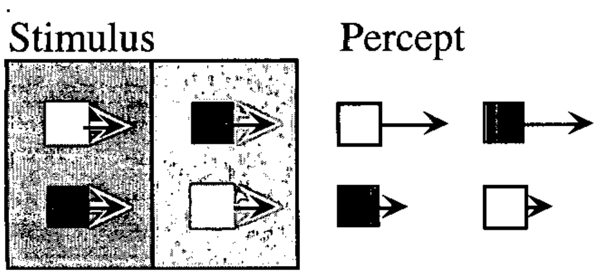

Figure 3. All squares jump back and forth through exactly the same distance. However, the top squares have higher contrasts against their surrounds, so they appear to move further than the bottom squares.

Contrast affects not only smooth real movement, but also stroboscopic apparent movement. A black square and a dark white square, one above the other, jumped back and forth horizontally through a distance of one-quarter of the square's width. On a dark surround, the white square appeared to jump through a greater distance, because it had a higher contrast. On a light surround, the black square appeared to jump through a greater distance, because now it was the square with higher contrast. This was particularly true in peripheral vision. Here the contrast affects the apparent amplitude of motion, not its apparent speed. This was a true motion illusion; it was not simply a mis-perception of the position of the two end-points of the motion, because separate experiments showed that the judged positions of stationary squares were not affected by contrast.

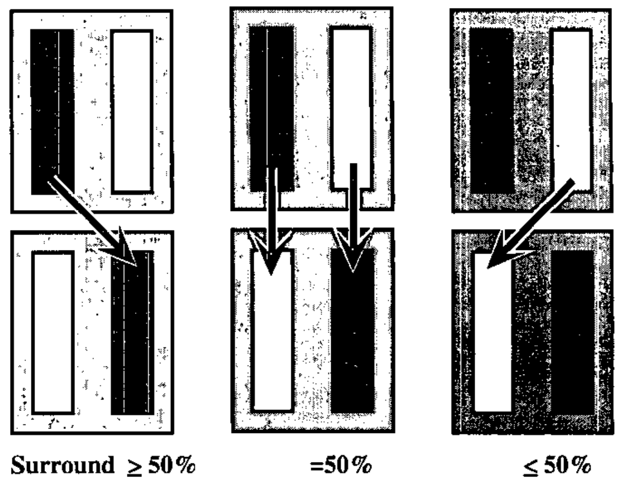

Figure 4. A black and a white bar abruptly exchange luminances. On a light grey surround (left), the black bar appears to jump, but on a dark grey surround (right), the white bar appears to jump. In other words the bar with the higher contrast against the surround appears to jump.

Here is another case of contrast affecting stroboscopic motion. Suppose that two vertical bars, one black and one white, lie side by side but not touching on a grey surround. Suddenly the black bar becomes white and at the same instant the white bar becomes black (Fig. 4). What will this look like? Will an observer see the two bars simply exchanging luminances? Or will the black bar appear to jump to the right? Or the white bar to the left? Or will both bars appar to jump past each other in opposite directions? It turns out that the result depends upon the luminance of the surround [7--9]. On a light grey surround, the black bar appears to jump, but on a dark grey surround, the white bar appears to jump. In other words the bar with the higher contrast against the surround appears to jump. I showed, in experiments that I shall not detail here, that the two bars generated motion signals in opposite directions, but the stronger signal predominated in a winner-take-all outcome. An analogous case would be two overlapping, superimposed gratings of vertical bars drifting in opposite directions. Both gratings have the same speed and spatial frequency. If they also have the same contrast, an observer sees a counterphase grating that flickers in place. However, if (say) the rightward grating has a higher contrast, one sees next motion to the right. Once again the two opposed motion signals compete and the stronger one wins.

If a black and a white bar exchange luminances on a mid-grey surround, one sees either two equal and opposite motions, or else no net motion. The mid-grey at which this happens is halfway between black and white. But 'halfway' can have more than one meaning – it could refer to either the arithmetic or the geometric mean of black and white. If black and white were equal to 1% and 100% of some reference luminance, then the arithmetic mean would be 50.5%, while the geometric mean would be 10%. It turns out that the halfway point at which the motion disappears is near 50%, not 10%. This may seem surprising in that nearly all visual functions apply a log transform to input luminances. However, the explanation is simple. On a surround grey level of 50.5%, it is easy to calculate that a white bar and a black bar have equal Michelson contrasts, although of opposite polarities. Thus, motion strength in these competitive situations depends upon the Michelson contrast of the moving objects. In the footsteps illusion described earlier, we also measured the mid-grey level at which a moving square shows no change in apparent speed as it moves from a black to a white surround. This critical luminance is also close to 50%, so that the Michelson contrast of the grey square remains the same as it moves alternately across a black and white surround.

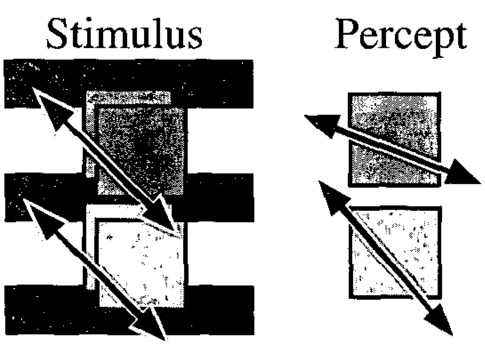

Figure 5. Squares jumping obliquely. On left, the positions of the squares at times T1, T2 are shown overlapping. Actual jumps were oblique at 45°, but different contrasts on vertical and horizontal edges altered the perceived motion paths (right).

Contrast-based motion illusions can be applied to different parts of a single moving object. Two squares, one light grey and the other dark grey, jumped back and forth obliquely, at 45° from the vertical, across a horizontally striped surround (Fig. 5). The squares were placed so that their top and bottom edges contacted black stripes, whereas their left and right edges contacted white stripes. So the dark grey square's top and bottom edges contacted a black surround and had low contrast. This reduced the effective vertical component of the dark square's oblique motion. Its left and right edges contacted a white surround and had high contrast. This enhanced the horizontal component of its motion. The result was that the dark square appeared to move back and forth between 10 o'clock and 4 o'clock. The opposite was true for the light square, which appeared to move back and forth between 11 o'clock and 5 o'clock. So contrast could alter the perceived direction of motion, as well as its perceived speed. Fortunately this does not usually happen on the road. It would be as if painting one wing of a car black and the other wing white made the whole car appear to move obliquely.

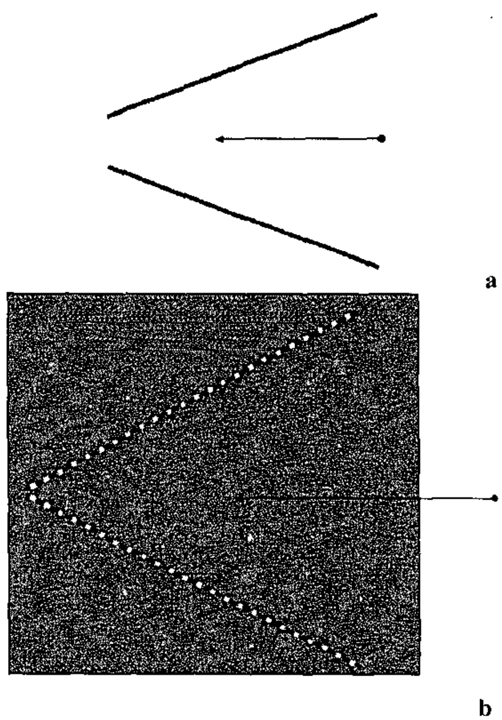

Figure 6. Dotted lines. **a,** Control condition: Move a pen tip to the left along the arrows, and the lines appear to converge inwards. **b,** experimental condition: these lines appear to move outwards.

Here is another way in which contrast of different parts of an object can affects its perceived direction of motion [10--12]. Figure 6a shows two lines forming a shallow V. Put a pen tip at the tail of the arrow and move the pen to the left, toward the tip of the arrow. Or simply hold the pen tip stationary and move the page to the right under the pen. Gaze at the pen tip but attend to the two lines. They will appear to move closer together. This is not surprising because the lines really are closer to the fovea when the pen is shifted to the left. But now do the same for the two dotted lines in Figure 6b. These lines appear to move *outwards*.

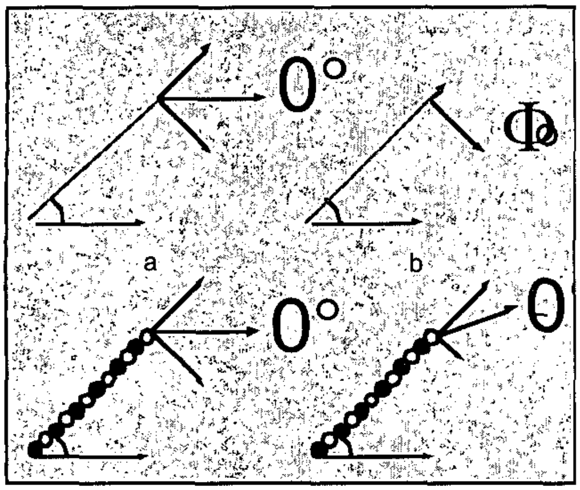

Figure 7. a, When an oblique black line moves horizontally to the right (top arrow), its motion can be decomposed into one vector along the line and another at right angles to the line (oblique arrows).

b, Since a straight line is invariant under motion along its axis, the vector along its axis is not perceived. Only the orthogonal vector is seen, and the line appears to move at right angles to its own length in direction Φ.

c, a moving dotted line can be similarly decomposed into two vectors

d, Now the vector along the axis is seen, or even overestimated, whilst the orthogonal vector is underestimated. Motion is perceived in a direction θ, closer to the line's orientation.

Here is the reason: When a long, straight line moves, its motion is ambiguous because the component of motion along its length produces no changes at the retina. In other words, a straight line is invariant under motion along its own length. If a 45° oblique black line moves horizontally to the right, its motion can be decomposed into a component along its length, which is not seen, and a component at right angles to its own length. Result: The line is perceived as moving obliquely down, at right angles to its own length (Fig. 7a, b). But when a 45° oblique dotted line moves to the right, its motion can again be decomposed into two components, one along its length and the other at right angles to its own length. For the dotted line, however, the contrast along its own length (between black dots and white dots) is about twice as high as the contrast at right angles to its own length (between black dots and the mid-grey surround, or between white dots and the mid-grey surround). So the motion along the line's length, instead of being invisible, is highly visible and high in contrast, so that it predominates over the motion across the line (Fig. 7c, d). The resulting perceived motion is the vector sum of these two components, and the line is perceived as moving almost parallel to its own length

DISCUSSION

All these contrast-based illusions of motion are compatible with models of motion coding that use velocity-tuned neural units, each tuned to a different range of speeds. Such units have been found in primate MT [13--16]. Let us briefly compare motion coding to color coding. The retina contains three types of cones, namely R, G and B, sensitive respectively to long, medium and short wavelengths. The cones have broad, overlapping spectral sensitivity curves, so that a given wavelength stimulates more than one cone type, and each wavelength is coded neurally as the ratio of firing in different cones. For instance, a particular yellow might stimulate the R and G cones equally. If the luminance of the yellow increased, then so would the firing rate of the R and the G cone – but by an equal amount, so that the firing ratio R/G would successfully encode a particular yellow despite changes in luminance. However, this compensation for luminance changes is not perfect, and in fact hues do tend to change their appearance, moving toward yellow and blue, and away from green and purple, as the luminance in increased [17] This is the Bezold Brucke illusion [18] and probably reflects a nonlinearity in which the firing rate in one cone, or more likely in one opponent-color pathway, increases more rapidly with luminance than another. The contrast illusions described in the present paper may simply be motion analogs of the Bezold-Brucke effect, in which a medium velocity might stimulate a "slow" and a "fast" detector equally. In a perfect system, changes in stimulus contrast would increase the firing of a "slow" and a "fast" detector by exactly the same amount, so that the firing ratio Fast/Slow would successfully encode a particular medium speed despite changes in contrast. However, this compensation for changes in contrast may not be perfect. I suggest that the apparent increases in speed with contrast arise because responses of "fast" detectors grow more rapidly with contrast than do "slow" detectors. Note that colors show small illusory changes with luminance, whereas in our displays motion shows large illusory changes with contrast.

A series of papers by Grossberg and his colleagues [19-21] offer a far more sophisticated approach along these lines. Their neural network model represents visual velocity as a distributed population code of speed tuned units, in which the size of a unit's receptive field is correlated with its preferred speed. A key aspect of their model is that larger cells need to have higher thresholds, and that they compete in specific, albeit simple, ways. Their multiple broadly speed-tuned detectors explain a great deal of data about speed estimation and discrimination, and in particular the relationship between contrast and perceived speed. The authors successfully simulated data from Thompson et al showing that higher contrast increases perceived speed. Moreover, their model can be extended to cover motion grouping and vector coding of motion [22].

Drive carefully in the fog.

ACKNOWLEDGMENT

Supported by grants from the UCSD Dept of Psychology and Academic Senate.

REFERENCES

[1] Thompson P , "Perceived rate of movement depends on contrast," *Vision Research* 22 pp. 377-380, 1982

[2] Stone LS, Thompson P. "Human speed perception is contrast dependent," *Vision Research* 32: pp. 1535-49, 1992

[3] Thompson P, Stone L S, Swash S "Speed estimates from grating patches are not contrast-normalized," *Vision Research* 36 pp. 667-674, 1996

[4] Thompson P, Stone L S "Contrast affects flicker and speed perception differently," *Vision Research* 37 pp. 1255-1260, 1997

[5] Anstis SM, "Footsteps and inchworms: illusions show that contrast affects apparent speed. *Perception* 30(7): pp. 785-94 2001

[6] Anstis SM, "Levels of motion perception," In: Harris L, Jenkin M (Eds): *Levels of Perception*, 2003

[7] Anstis SM, Mather G. "Effects of luminance and contrast on direction of ambiguous apparent motion," *Perception* 14(2): pp. 167-79, 1985

[8] Mather G, Anstis S. "Second-order texture contrast resolves ambiguous apparent motion," *Perception* 24(12): pp. 1373-82, 1995

[9] Anstis Anstis SM, Smith DR, Mather G. "Luminance processing in apparent motion, Vernier offset and stereoscopic depth," *Vision Research* 40(6): pp. 657-75, 2000

[10] Ito H, Anstis SM "Motion aftereffects from illusory movements of second-order contours," Presentation at the European Conference on Visual Perception, Glasgow, Scotland, 2002

[11] Ito H, Anstis SM "Anomalous movements of dotted contours," unpublished

[12] Cavanagh P, Anstis S. "The boogie-woogie illusion," *Perception*.; 31(8): pp. 1005-11, 2002

[13] Allman J, Miezin F, McGuinness E, Direction and velocity specific response from beyond the classical receptive field in the middle temporal visual area (MT) *Perception* 14, 105-126, 1985

[14] Maunsell JHR, Van Essen DC, "Functional properties of neurons in idle temporal visual area of the macaque monkey. I. Selectivity for stimulus duration, speed, and orientation. *J Neurophysiology* 49(5); pp. 1127-1147, 1983

[15] Mikami A, Newsome WT, Wurtz RH, "Motion selectivity in macaque visual cortex. II. Spatiotemporal range of directional interactions in MT and V1. *J Neurophysiology* 55(6); pp. 1328-1338, 1986

[16] Zeki SM, "Functional organization of a visual area in the posterior bank of the superior temporal sulcus of the rhesus monkey. *J Physiol* (Lond) 236: 546-573, 1974

[17] Fry,GA.The Bezold-Brucke phenomena at the two ends of the spectrum. *Am J Optom Physiol Opt* Dec;60(12): pp. 977-81, 1983

[18] Pridmore RW, "Bezold-Brucke hue-shift as functions of luminance level, luminance ratio, interstimulus interval and adapting white for aperture and object colors," *Vision Research* Nov;39(23): pp. 3873-9, 1999

[19] Chey, J., Grossberg, S., and Mingolla, E,. "Neural dynamics of motion processing and speed discrimination," *Vision Research*, 38, pp. 2769-2786, 1998

[20] Grossberg, S and Rudd, M, "Cortical dynamics of visual motion perception: Short-range and long-range apparent motion," *Psychological Review*, 99, pp. 78-121, 1992

[21] Chey,J., Grossberg, S. and Mingolla, E, "Neural dynamics of motion grouping: From aperture ambiguity to object speed and direction," *J Opt Soc Am*, 14, pp. 2570-2594, 1997

[22] Grossberg, S., Mingolla, E. and Viswanathan, L, "Neural dynamics of motion integration and segmentation within and across apertures," *Vision Research*, 41, pp. 2521-2553, 2001