Induced movement: The flying bluebottle illusion

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Two small objects (flies) followed identical circular orbits. However, a large background that circled around behind them in different phases made one orbit look twice as large as the other (size illusion) or made the circles look like very thin horizontal or vertical ellipses with aspect ratios of 7.5:1 or more (shape illusion). The nature of the perceptual distortion depended upon the relative phase between the movements of the background and those of the flies. Brief snatches of the moving background that added up to a circular motion were also effective.

Keywords: induced movement, motion perception, illusion

Introduction

The perceived motion of moving objects can be profoundly affected by a moving background. We shall show some illusions based upon this.

Duncker (1929) first investigated induced movement. An everyday example is the moon that seems to sail along behind moving clouds. However, the moon's perceived motion is not entirely convincing; observers can see that the moon is not moving even as they experience a form of motion. We shall present much more convincing illusions. Duncker noted that a moving target appears to move opposite to the background motion so that a target moving downward across a background that moves to the right appears to drift down to the left. The Duncker illusion can affect both saccades (Zivotofsky, 2004; Zivotofsky, White, Das, & Leigh, 1998) and hand-pointing movements (Soechting, Engel, & Flanders, 2001) that are aimed at the remembered position of a target.

Loomis and Nakayama (1973) suggested that induced motion, or motion contrast, in which a surround moving in one direction induces a perception of the opposite motion in neighboring region, is a velocity analogue of brightness contrast. Burt and Sperling (1981) implemented this by subtracting the mean motion of the entire field from every moving object within it.

Vector decomposition

Johansson (1950) pointed out that when a friend waves to you from a train, his or her hand traces out a horizontally extended sine wave relative to the earth. However, that is not what you see. The visual system decomposes the movement into the linear motion of the train plus an up-and-down movement of the hand. Again, a single light on the rim of a rolling wheel traces out a cycloidal path in the dark, which is what an observer perceives. However, if a light is added at the center of the wheel, an observer immediately decomposes this into the linear motion of the whole wheel, plus a circular motion of the point on the rim around the center of the wheel (Johansson, 1974).

The most sophisticated and complex form of vector decomposition occurs in "biological motion," when a walker in a dark room has a small light attached to each joint (hip, knee, ankle, etc.). An observer can instantly recognize the complex pattern of motions as a walking human (Johansson, 1950, 1975) and can even estimate the walker's gender within a few seconds (Cutting, Proffitt, & Kozlowski, 1978; Pollick, Kay, Heim, & Stringer, 2005).

Experiment 1

Movie 1 shows a control condition in which two bluebottles each move along clockwise trajectories of the same diameter. They are in counterphase, one being at 12 o'clock when the other is at 6 o'clock, but they both move in the same direction, and it is easy to see that their two trajectories are the same size. The background is stationary.

However, in Movie 2, the flying bluebottles are superimposed upon a moving background. Although the orbits of both flies are the same size, the left-hand orbit looks subjectively about twice as big as the right-hand orbit. In fact, naive students have expressed considerable surprise and disbelief on seeing this illusion and have sometimes attempted to measure the trajectories with a ruler.

It is the moving background that changes the apparent size of the trajectories. The background moves along a rotary path, which by itself is not rotating, like a sponge on a window cleaner's hand. The background and the two bluebottles all move clockwise but in different phases. The

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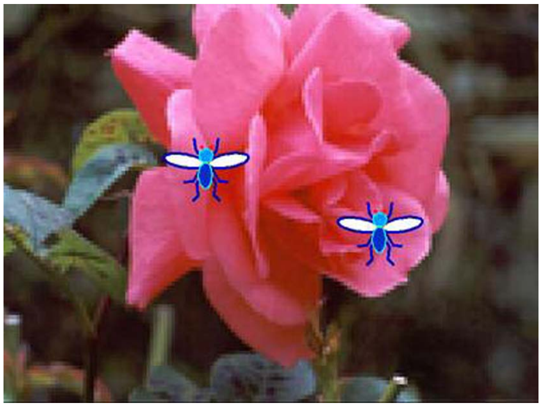


Movie 1. Control condition. The two circular orbits are correctly seen as being the same size. Click on the image to view the movie.

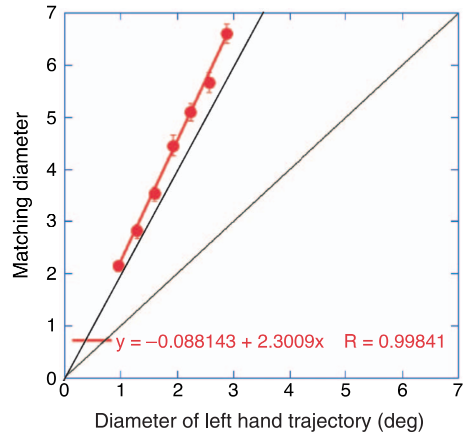


Figure 1. The background and the left-hand spot followed counterphase orbits of the same size, ranging between 1 and 3 deg of visual angle. The left-hand spot's orbit was subjectively matched (by adjusting the in-phase right-hand orbit) and was consistently judged to be 2.3 times bigger than it really was.

circular orbit of the background is in phase with the right-hand bluebottle, and this possibly diminishes the perceived path of the latter. It is in counterphase with the left-hand bluebottle, and this greatly exaggerates its path; it is the motion of the left-hand fly relative to the background that increases the apparent size of its orbit.

In practice, to measure the illusion, we optimized the real-time plotting smoothness by reducing the stimulus to its bare essentials, and the bluebottles in a landscape were replaced by two small crosses (+) circling against a moving regular lattice of white spots that were spaced 1.75 deg apart horizontally and vertically. The rotation rate was 0.54 revolutions per second. The stimuli were programmed in Macromedia Director and shown on a monitor screen controlled by a Macintosh computer. The screen resolution was 1,280 × 854 pixels, and the display was viewed from a distance of 57 cm in a dimly lit room. Free eye movements were permitted. One observer was the first author, but all the other observers were experimentally naive.

We set the background to move in counterphase with the left-hand trajectory and in phase with the right-hand trajectory. This made the left trajectory look much bigger than the right trajectory, although they were actually the same size. Next, the observer nulled out this subjective difference by expanding the physical size of the right-hand trajectory with the aid of a computer mouse until the two trajectories appeared to be subjectively equal in size. A mouse click then recorded the setting for later offline analysis. The background and the left-hand spot always had the same sized orbit but of opposite phase within a trial, and their diameters were randomly set on each trial to be equal to 1, 1.3, 1.6, 1.9, 2.24, 2.6, or 3 deg of visual angle.

Results (mean of five trials × five observers) are shown in Figure 1. Figure 1 shows that, over the whole range of sizes used, the observers' overestimation of the left trajectory led them to set the right-hand trajectory to just over twice the physical diameter of the left-hand trajectory. Vertical lines show ±1 *SE,* but they are hard to see because they were barely larger than the plotting symbols. A straight line gave an excellent fit to the data, with R = .998. The line of slope equal to +1 shows the prediction

Movie 2. Size illusion. The moving background makes the left orbit look about twice as big as the right orbit. Click on the image to view the movie.

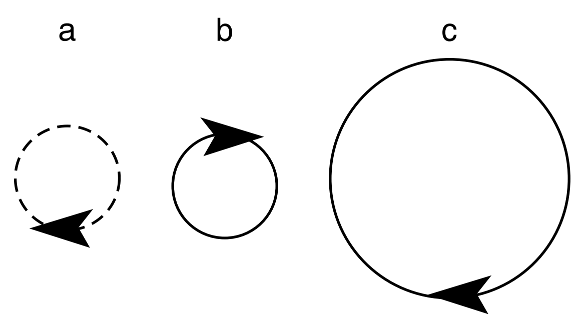


Figure 2. (a) Background's orbit (dashed line). (b) Actual orbit of spot that moved in counterphase to the background. This was judged to be equal in size with the right-hand orbit (c) when this was set 2.3 times bigger. Drawing is to scale. Arrowheads show physical phases of the three orbits. Absolute size of stimuli varied on different trials.

for veridical perception. The line of slope equal to +2 shows the prediction for perception only of relative motion between the left trajectory and the background. The data appear to lie very close to this prediction.

This is a really large illusion; Figure 2 is a to-scale drawing of the amplitude of the background orbit (dotted) of the left-hand fly (middle circle) and the circular orbit of the right-hand fly that was set to match the middle circle, although its diameter is 2.3 times greater. For veridical perception, all three circles would have been the same size.

The bluebottle illusion is a manifestation of motion contrast or induced movement. When observers attempted to judge the moving flies, they actually perceived them relative to the background, and they discounted or ignored the movements of the background itself. In ambiguous situations like this, the motion is generally ascribed to the smaller objects (the flies), which are more likely to be actually moving in the natural world.

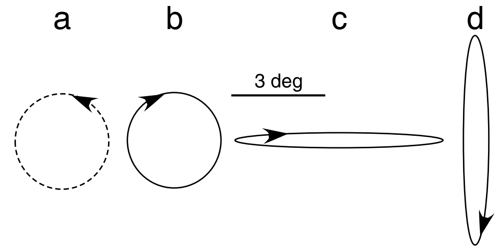
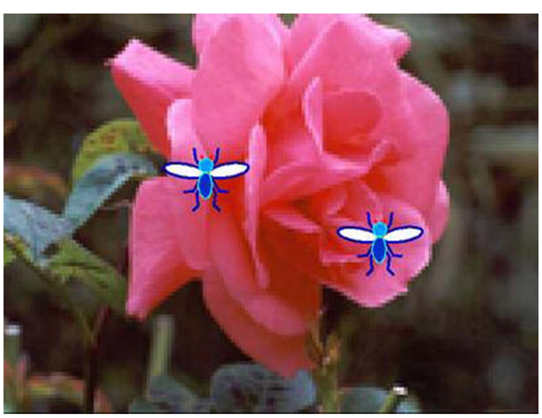


Figure 3. Scale drawing showing that when a spot's clockwise circular orbit (b) lay on a counterclockwise background orbit (a, dashed line) that was out of phase with its horizontal component, it was judged as matching a wide ellipse (c) with an aspect ratio of 14:1. When the background was out of phase with its vertical component, it was judged as matching a tall ellipse (d) with an aspect ratio of 7.5:1. Drawing is to scale. Scale bar shows 3 deg of visual angle.

Experiment 2

In Movie 3, the background moves counterclockwise, opposite to the clockwise-circling flies; both these circular orbits had a diameter of 3 deg of visual angle. We arranged for the left-hand fly to be in phase with the background at 3 o'clock and at 9 o'clock; this meant that the horizontal components of the fly and the background were in phase, while the vertical components were in counterphase. Thus, both moved left and right together, but one moved up as the other moved down. This greatly enhanced the vertical motion of the fly, and it appeared to move up and down around a thin vertical ellipse. The other fly's orbit was in phase with the background at 12 o'clock and at 6 o'clock so that their vertical components were in phase but their horizontal components were in counterphase. Thus, both moved up and down together, but one moved left as the other moved right. This enhanced the horizontal motion of the right-hand fly, and it appeared to move left and right around a thin horizontal ellipse.



Movie 3. Shape illusion. The background moves counterclockwise, making the left fly seem to move left and right, and the right fly seem to move up and down. Click on the image to view the movie.

Observers adjusted the width and height of the right-hand orbit, by moving the computer mouse in the x and y planes, until the right orbit appeared to have the same size and shape as the left orbit. (The computer allowed them to set the height and width independently to any desired value, even down to zero.) A mouse click recorded the setting for later offline analysis. On each trial, the computer randomly set the phase of the background to match either the horizontal or the vertical component of the left orbit's motion.

Results (mean of five trials $\times$ seven observes) are shown in Figure 3. Figure 3 shows that the circular orbit of the left-hand spot was grossly distorted perceptually into a very thin ellipse with an aspect ratio of 7.5:1 or 14:1. The orientation of this apparent ellipse, vertical or horizontal, depended upon the relative phase between the movements of the background and left spot. Specifically, when the 3 deg circular orbit was in counterphase to the horizontal component of the background, it was perceptually stretched horizontally by a factor of 2.2 and compressed vertically by a factor of 6.3 so that observers matched it to a wide ellipse that was 0.8 deg tall and 6.3 deg wide (aspect ratio = 14:1). Conversely, setting the circular orbit into counterphase with the vertical component of the background subjectively compressed the orbit horizontally by a factor of 3.5 and expanded it vertically by a factor of 2.1 so that it matched a tall ellipse that was 6.7 deg tall and 0.5 deg wide (aspect ratio = 7.5:1; Figure 3).

Hence, the circular orbit appears to expand along one axis but appears to shrink along the orthogonal axis. Why were the illusions so large? Note that Experiments 1 and 2 contained a double dose of illusion, which affected the standard and the matching ellipse/circle in opposite directions. For instance, a moving background could simultaneously enhance the vertical motion of the left-hand orbit and the horizontal motion of the adjustable right-hand orbit, and this would double the effective illusion. It is analogous to comparing a Muller–Lyer line with outward fins to a second line with inward fins, rather than to a naked line. It is also analogous to comparing colors induced into two gray squares, one on a red surround and one on a cyan surround, instead of comparing a red surround to a neutral surround.

Remember that the left and right orbits are in counterphase to each other; hence, the background simultaneously enhances the vertical motion of (say) the left orbit and the horizontal motion of the other orbit. Thus, when the two orbits are circular, they look subjectively like two ellipses, one stretched vertically and the other horizontally, which effectively double the illusion. If the left orbit looks like a vertical ellipse, then the right-hand orbit must first be physically compressed to overcome its own apparent horizontal stretch before it is then expanded vertically to match the apparent heightening of the left ellipse. In other words, the left orbit undergoes a genuine subjective heightening, but the ostensible narrowing of the left orbit is actually an apparent widening of the right-hand, matching orbit.

We predict that because the orbits in Experiment 1 subjectively expanded to circles of about twice their physical size, the orbits in Experiment 2 should apparently double in height or in width. Because the illusion was effectively doubled by our matching procedure, as just described, we expected that the matching ellipses would have an aspect ratio of 4:1; that is, they would be doubled in height and halved in width (or vice versa). In fact, for unknown reasons, our results were much stronger than this, with matching aspect ratios between 7.5:1 and 14:1.

A subtraction algorithm (Burt & Sperling, 1981) would fit our results quite well; as flies moved against the background, their perceived motion would be approximately doubled, as we found. Subtraction is a simple, low-level, "dumb" algorithm, easy to apply to local motion with constant speed and direction but not to the more complex motions seen in everyday life.

Eye movements are not crucial to the illusions. A tracking eye movement along a given trajectory will act physically to subtract that component from the moving stimulus; for instance, tracking the axle point in a Johansson rotating wheel dot display will produce a circular trajectory on the retina. In the same way, if one tracks the moving background in Movies 2 and 3, then the only remaining component would correspond to the doubling effect reported. However, the reader can readily verify, by fixating a stationary pencil point laid against the screen, that the illusion is not materially reduced when the eyes are still.

Other displays

Two other movies are not shown because the file sizes would be prohibitively large. In both, the background rotated at 90% of the rate of the flies so that the background and flies moved slowly in and out of phase. This set up a slow beat frequency so that in the continuous version (not shown) of Movie 2, the orbits of the left and right flies appeared to wax and wane in size alternately with a repetition period of 20 s. In the continuous version (not shown) of Movie 3, the orientation of the two orbits started as horizontal on the left and vertical on the right, but these orientations slowly rotated through a series of oblique orientations until the left orbit looked vertical and the right orbit looked horizontal.

Experiment 3

Interrupted background motion

In Experiment 3, the background motion was broken up into short segments, as illustrated in Figure 4. In Figure 4a, a circle is broken up into a polygon of 36 sides (arrowed), with each side subtending 10 deg (360/36) at the center of the polygon. This polygon could define the circular orbit of a background, but instead, a duplicate set of these 36 arrows has been assembled in the center of the polygon as the radii of a tiny porcupine or asterisk. Now, each radius in the asterisk, taken in clockwise sequence, represents the motion of a background texture, and the lengths of the lines are proportional to the distances traveled. Instead of a single background that moved around along complete circles subtending 2 deg of visual angle, a new background was randomly selected from a set of eight candidate textures, 36 times per revolution, that is, after the equivalent of 10 deg of angular rotation. Thus, Texture 0 moved vertically upward through a distance of 21 arcmin of visual angle ($2 \times \pi \times 2$ deg/36), taking a time of 167 ms. It was then replaced by a new unrelated texture (Texture 1) that

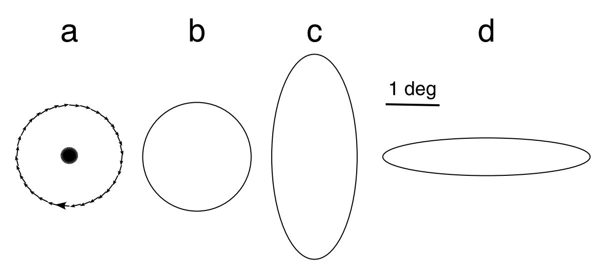


Figure 4. (a) Scale drawing. Instead of the background moving around the arrowed circle, a series of randomly chosen textures moved along linear paths only 21 arcmin long, shown in the center of the circle. Direction of movements stepped clockwise around a circle. (b) Actual counterclockwise circular orbit of left-hand spot. (c, d) Ellipses set by observers to match the appearance of the circular orbit in Panel b. The aspect ratios of these two ellipses are 2.4:1 and 1:5.7.

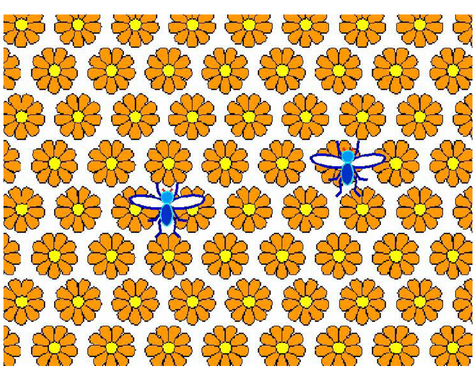
moved upward through 21 arcmin at an angle 10 deg clockwise from vertical. Then, a new texture (Texture 2) moved up at an angle of 20 deg, Texture 3 at 30 deg …, Texture 35 at an angle of 350 deg—in other words, 10 deg counterclockwise from vertical. The sequence then repeated indefinitely. This meant that instead of a continuously circling background, there were only brief snatches of approximately linear motions, whose directions stepped progressively around a circle, and each texture moved through only a small distance, 21 arcmin or about 3% of a circumference, before it was replaced by a fresh texture. This sequence of movements would have been parallel to a single background following a rotary orbit, but the sequence deliberately eliminated any continuity of motion, position, or pattern. Movie 4 offers a reduced version of the stimulus but with only 8 instead of 36 texture changes per revolution.

The textures were brightly colored lattices of stars, flowers, bull's-eyes, and the like, taken from the texture palette of the Deneba Canvas drawing program. We examined whether this background sequence of interrupted motions would suffice to induce a shape illusion.

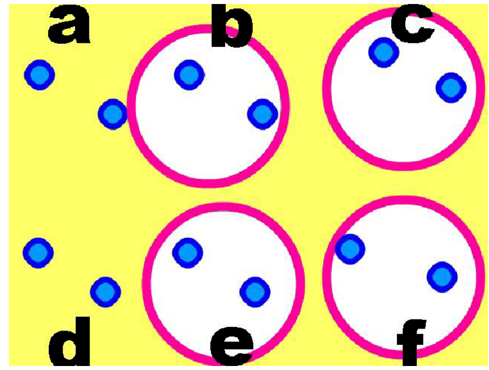
Method

The method recreated the shape illusion of Experiment 2 but with the new interrupted motion sequence for the background. This background motion stepped around clockwise while the two spots moved counterclockwise, in counterphase to each other. As before, the moving backgrounds made the left-hand circular orbit look like a vertical or horizontal ellipse on alternate trials, determined by the relative phase between the left-hand target and the background. Observers adjusted the height and width of the right-hand orbit with a mouse until the two orbits appeared to be of the same size and shape. A mouse click recorded the settings for later analysis.

Results are shown in Figure 4. Figure 4 shows that the interrupted motion could generate a substantial shape illusion because the circular orbits were perceived as



Movie 4. Shape illusion from a sequence of very brief linear motions that step gradually clockwise. Click on the image to view the movie.



Movie 5. Summary. Pairs of dots rotating clockwise (a and d). Clockwise surround (b) makes left orbit look larger (c). Counterclockwise surround (e) makes dots appear to move up and down or left and right (f). Click on the image to view the movie.

ellipses with aspect ratios of 2.4:1 (vertical) and 1:5.7 (horizontal; mean of four observers $\times$ five trials). Note that the perceived changes in the orbit dimensions were up to 30 times larger than the small inducing motions of the background textures.

Thus, the sequence of very small texture motions produced a very large cumulative change in the perceived orbit because each briefly drifting segment of background had a brushing effect upon the test spot that was local in time, and a sequence of these brushes could propel the spot indefinitely, in the same way a long sequence of short broom strokes can sweep dust across a carpet.

Conclusions

Movie 5 summarizes our main findings. Parts a and d show pairs of dots rotating clockwise. When the surround also rotates clockwise, in phase with the right-hand dot (Part b), the orbit of the left-hand dot is greatly overestimated (Part c). When the surround rotates counterclockwise (Part e), the dots appear to move up and down or left and right (Part f).

The illusion could elucidate a more general mechanism not only restricted to motion computation. For example, it is instructive to compare motion perception with brightness perception. Loomis and Nakayama (1973) suggested that motion contrast is a velocity analogue of brightness contrast. However, not all instances of induced motion are caused by local lateral inhibition between motion pathways. Johansson's (1950, 1974, 1975, 1977) key idea is that the visual system analyzes motion into common and relative components. Johansson's pupil, Bergström (1994), applied the same idea to brightness perception, proposing a vector decomposition that analyzes reflected light into common and relative components. This provides a way of splitting the retinal image into layers and distinguishes between illumination and reflectance in the proximal stimulus, leading to an extraction of 3-D form. Adelson (2000) has reviewed similar ideas, and there is plenty of evidence that high-level perceptual organization can induce far greater changes in perceived brightness than any low-level interaction process could achieve (Adelson, 1993; Gilchrist, 1994). In the domain of motion, our experiments may well indicate that long-range interactions across the retinal image can generate very substantial illusions of motion that cannot be attributed to local lateral inhibition.

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References

Adelson, E. H. (1993). Perceptual organization and the judgment of brightness. *Science, 262,* 2042–2044. [PubMed]

Adelson, E. H. (2000). Lightness perception and lightness illusions. In M. Gazzaniga (Ed.), *The new cognitive neurosciences* (2nd ed., pp. 339-351). Cambridge, MA: MIT press.

Bergström, S. S. (1994). Color constancy: Arguments for a vector model for the perception of illumination, color, and depth. In A. Gilchrist (Ed.), *Lightness, brightness, and transparency* (chap. 6, pp. 257–286). Hillsdale, NJ: Lawrence Erlbaum.

Burt, P., & Sperling, G. (1981). Time, distance, and feature trade-offs in visual apparent motion. *Psychological Review, 88,* 171–195. [PubMed]

Cutting, J. E., Proffitt, D. R., & Kozlowski, L. T. (1978). A biomechanical invariant for gait perception. *Journal of Experimental Psychology: Human Perception and Performance, 4,* 357–372. [PubMed]

Duncker, K. (1929). Über induzierte Bewegung. *Psychologische Forschung, 12,* 180–259.

Gilchrist, A. (1994). Introduction: Absolute versus relative theories of lightness and perception. In A. Gilchrist (Ed.), *Lightness, brightness, and transparency* (chap. 2). Hillsdale, NJ: Lawrence Erlbaum.

Johansson, G. (1950). *Configurations in event perception*. Uppsala: Almqvist and Wiksell.

Johansson, G. (1974). Vector analysis in visual perception of rolling motion. A quantitative approach. *Psychologische Forschung, 36,* 311–319. [PubMed]

Johansson, G. (1975). Visual motion perception. *Scientific American, 232,* 76–88. [PubMed]

Johansson, G. (1977). Spatial constancy and motion in visual perception. In W. Epstein (Ed.), *Stability and constancy in visual perception*. New York: Wiley.

Loomis, J. M., & Nakayama, K. (1973). A velocity analogue of brightness contrast. *Perception, 2,* 425–427. [PubMed]

Pollick, F. E., Kay, J. W., Heim, K., & Stringer, R. (2005). Gender recognition from point-light walkers. *Journal of Experimental Psychology: Human Perception and Performance, 31,* 1247–1265. [PubMed]

Soechting, J. F., Engel, K. C., & Flanders, M. (2001). The Duncker illusion and eye–hand coordination. *Journal of Neurophysiology, 85,* 843–854. [PubMed] [Article]

Zivotofsky, A. Z. (2004). The Duncker illusion: Intersubject variability, brief exposure, and the role of eye movements in its generation. *Investigative Opthalmology & Visual Science, 45,* 2867–2872. [PubMed] [Article]

Zivotofsky, A. Z., White, O. B., Das, V. E., & Leigh, R. J. (1998). Saccades to remembered targets: The effects of saccades and illusory stimulus motion. *Vision Research, 38,* 1287–1294. [PubMed]