Eye movements to motion-defined and luminancedefined forms

Ram Mani[1*] and Eileen Kowler[1]
[1]Department of Psychology, Rutgers University, Piscataway, New Jersey 08854
kowler@rci.rutgers.edu

[*]Rutgers Undergraduate Research Fellow

Abstract

A prominent area of inquiry in neuroscience and vision is the binding problem: how does one account for the brain integrating the different features of an object (e.g. luminance, velocity, color, and texture) when it has been shown repeatedly that separate areas of the brain code for separate features of the object. To approach this question, we characterized eye movements (more specifically, saccades) to forms defined by luminance and forms defined by motion. Luminance-defined form (LDF) is a visual stimulus that is distinguished from its background due to a difference in luminance between it and the background. Motion-defined form (MDF) is a visual stimulus created by moving components within the form in one direction and having the components of the form's background move in the opposite direction. Saccades to MDF were very similar to those of LDF, meaning saccades to both types of form were highly correlated with target location. This novel discovery demonstrates that the oculomotor system can make accurate eye movements to MDF. Secondly, it was shown that saccadic endpoints were biased in the direction of dot motion of MDF. This global illusory shift in target position caused by local motion agrees with perceptual literature (Regan, 1993). Thirdly, saccades made to MDF while the subject was told to ignore a simultaneously presented LDF were biased in the direction of the offset LDF. Results indicate that saccades and MDF will be useful tools in studying the binding problem and that there may be a hard-wired tendency to bind features to create single a "object."

Introduction

Saccades are voluntary eye movements that allow the viewer's fovea to jump quickly from point A to point B. The purpose of the fovea (the central region of the retina) is to allow for the utmost acuity in visual perception. Thus, saccades allow the eye to quickly focus on a spatially displaced point or object. Saccadic eye movements are crucial for certain daily visual tasks, such as reading, scanning an object, and visual search and drift.

A question that arises in study of neuroscience is how do we integrate the different properties of a stimulus into one mental image. Psychophysical and neurophysiological evidence has shown convincingly that the different attributes of an object -- shape, color, motion, texture, orientation -- are handled by separate

neural systems (Regan, 1993). There are advantages in this specialization, but the perception process is incomplete if our brains leave the object fragmented.

Scientists have called this question the "binding problem," which basically asks how does the brain integrate the different attributes of an object so that we are able to form a single perception of the object. We have set out to investigate the binding problem by analyzing saccades to motion-defined (MDF) and luminance-defined form (LDF).

Rationale

LDF is an object that differs from its background in luminance. MDF is an object that differs from its background due to motion of its internal elements. Past psychophysical / oculopathology work by a collaborator (D. Regan - York University) has shown that perception of MDF is handled by a neural system independent of that which handles LDF.

Since MDF is a novel target for saccadic localization experiments, we first needed to establish that saccades could be directed to it. We compared saccadic localization of MDF to saccadic localization of LDF.

We then attempted to discern how the visual and oculomotor systems handle luminance and motion-defined form simultaneously by having the subject saccade to MDF in the presence of LDF at different eccentricities and offsets. If the visual system tends to automatically bind LDF and MDF into a single object, it may prove difficult to saccade to MDF and ignore LDF. Implications in how the brain spatially aligns motion and contrast of objects and how our visual attention deals these two attributes are investigated.

Methods

Subject

1 subject (EK) was tested. EK is a highly experienced eye movement subject. EK is myopic and a corrective lens was used to keep stimuli in sharp focus.

Instrumentation

Microsoft C was used to write the programs that generated the bitmapped stimulus. The stimulus was generated by digital-to-analog converters and shown on a display monitor (Tektronix 608, P4 phosphor) located directly in front of the subject's right eye. Two-dimensional movements of the right eye were recorded by a Generation IV SRI Double Purkinje Image Tracker (Crane & Steele, 1978).

Experiments 1 & 2 (LDF & MDF, respectively)

Fixation cross was presented to subject. It consisted of a vertical and a horizontal line, each consisting of consecutive 5 dots, perpendicularly intersecting each other at their midpoints. When ready, subject tapped finger response button to present stimulus. The conditions were: target and background offset by +/- (228, 240, or 252 min arc) AND target offset from background by +/- (0, 15, 30 min arc). Presentation of the stimulus lasted for 2 seconds. 10 sessions of 100 trials each were recorded over 2 days.

Experiment 3 (LDF & MDF simultaneously)

Procedure was the same as Experiments 1 & 2. Stimulus was different. MDF was offset by +/- (0, 15 min arc) from the background center. Simultaneously, LDF was presented and offset either 30 min arc to the left of MDF, to the right of MDF, or completely overlapping MDF. Instructions were to saccade to MDF and ignore LDF.

Results & Discussion

As expected, saccades to LDF alone were highly correlated with target location (figures 3 & 4). Saccades to MDF alone were found to be quite similar to saccades to LDF alone. This reveals that the oculomotor system can make accurate eye movements to MDF, a novel discovery.

Saccadic endpoints were biased in the direction of dot motion, even though the MDF target itself remained stationary (figures 5 & 6). The apparent *global* illusory shift in target position caused by *local* motion agrees with anecdotal evidence present in previous perceptual literature (Regan 1993).

Saccades to MDF were pulled in the direction of the LDF (figures 7 & 8). The subject was not able to ignore LDF entirely, despite attempts to do so. This result tells us that attention devoted to MDF is also drawn to LDF when the conflicting luminance attribute is present.

Conclusions & Implications

1. Luminance and motion-defined forms are processed separately in the brain. We have shown that *both* are effective saccadic targets. The oculomotor system may thus be receiving signals from more than one sensory processing area. The main questions now are how and where these signals are combined.

2. The illusory displacement of the MDF in the direction of dot motion caused a shift in saccadic endpoints. Saccades will be a useful tool to study the origin of this illusion of global motion.

3. It was hard for the subject to saccade to MDF and ignore overlapping LDF. This difficulty may reflect a hard-wired tendency to bind attributes to create a single "object." Further experiments using adaptation paradigm (Deubel, 1995) will explore the binding process.

Acknowledgments

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References

Crane H.D. and Steele C.S. (1978) Accurate three-dimensional eyetracker. Applied Optics, 17, 691-705.

Deubel H. (1995) Separate adaptive mechanisms for the control of reactive and volitional saccadic eye movements. Vision Research, 23/24, 3529-3540.

Regan D. (1993) Detection and discrimination of motion-defined and luminancedefined two-dimensional form. Spatial vision in humans and robots. Cambridge University Press.

Figure 1. Luminance-defined form (LDF).

LDF was created by increasing the luminance of the target (inner square) over that of the background. The contrast was above threshold, with luminance of the target being 4-8 times greater than that of the background (background = 18.7 cd / m^2). Target and background are both squares, with target side of 2 degrees in length and background side 4 degrees. Dots are not to scale. A dot is about 2 minutes of arc in diameter. Possible locations for dots were every 5 minutes of arc . Only about 20% of the possible locations for each object were occupied by dots, resulting in a dot density of about 29 dots/deg^2).

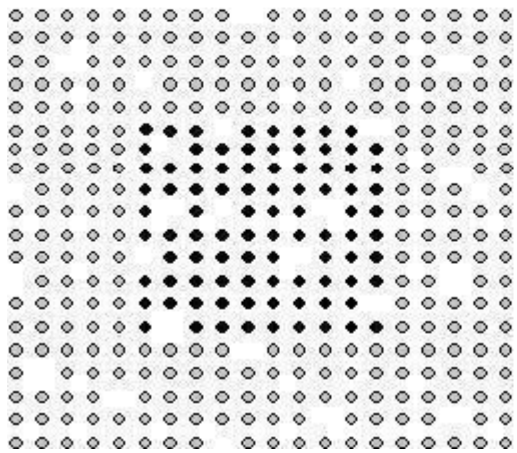

Figure 2. Motion-defined form (MDF).

Darker dots are used in this figure to differentiate target from background. In the experiments, ALL dots were of the SAME luminance. Opposing horizontal velocities of target and background dots were used to create the MDF form. Dimensions and dot spacing/density were the same as used in LDF. Dot speed was 1 degree / sec. Target dots that hit border wrapped around to the other side of target. Background dots skipped over the target and wrapped to the other side of the background when reaching its border.

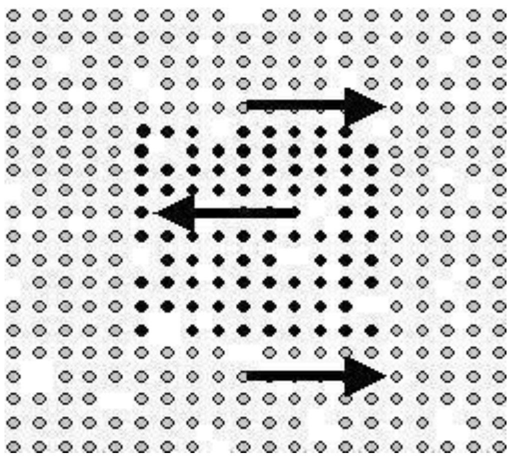

Figure 3. Saccades to LDF alone.

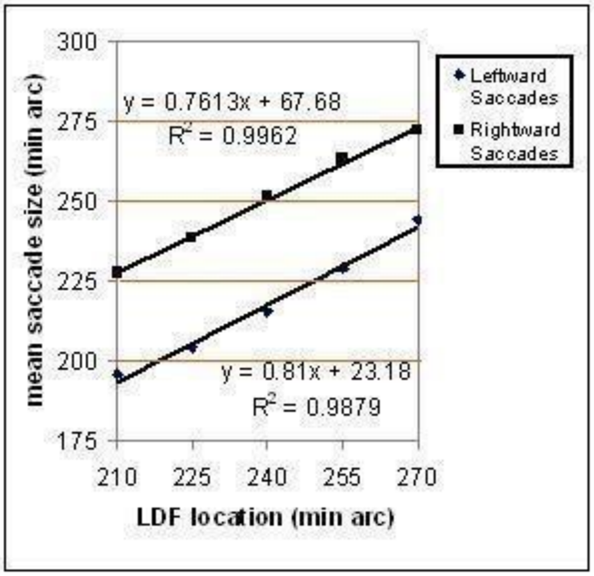

Figure 4. Saccades to MDF alone.

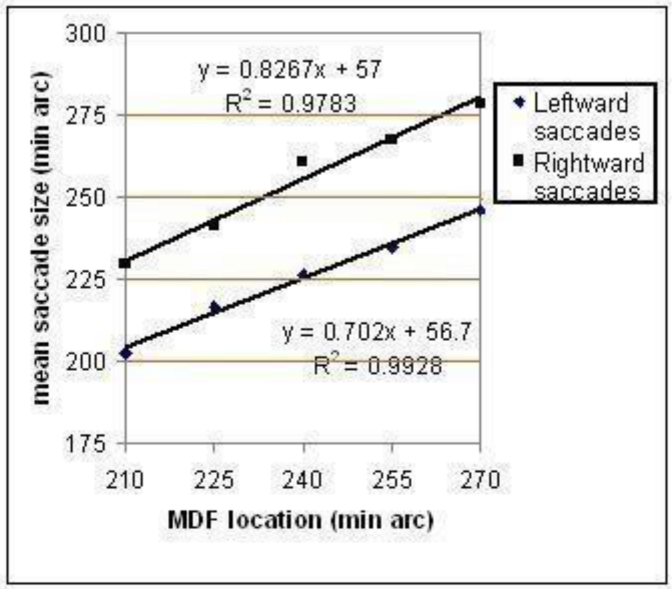

Figure 5. Leftward saccades to MDF alone: effect of direction of dot motion

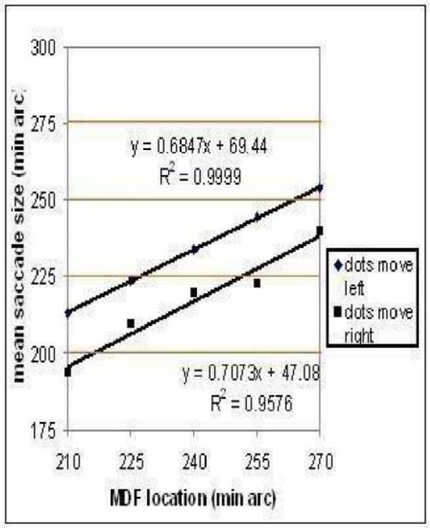

Figure 6. Rightward saccades to MDF alone: effect of direction of

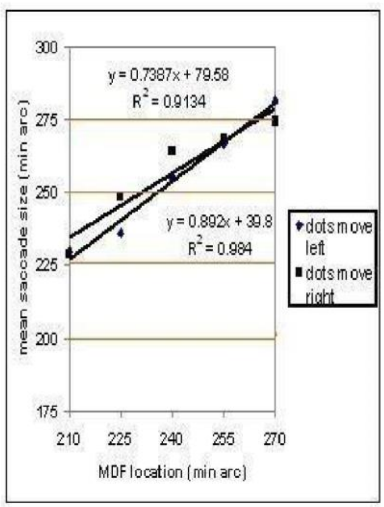

Figure 7. Leftward saccades to MDF in presence of LDF.

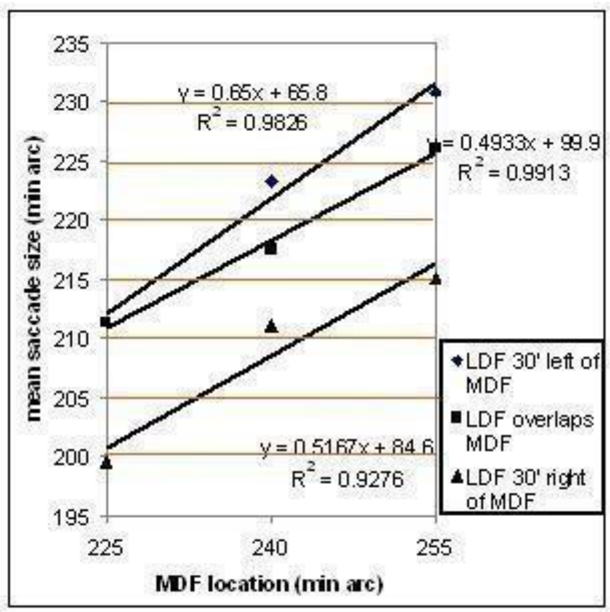

Figure 8. Rightward saccades to MDF in presence of LDF.