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The perception of motion transparency: A signal-to-noise limit

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Abstract

A number of studies were conducted to determine how many transparent motion signals observers could simultaneously perceive. It was found that that the limit was two. However, observers required a signal intensity of about 42% in order to perceive a bi-directional transparent stimulus. This signal level was about three times that required to detect a uni-directional motion signal, and higher than was physically possible to achieve in a tri-directional stimulus (in a stimulus in which the different transparent signals are defined only by direction). These results indicate that signal intensity plays an important role in establishing the transparency limit and, as a consequence, implicates the global-motion area (V5/MT) in this process.

Keywords: Motion transparency; Global-motion

1. Introduction

A great deal of work has been devoted to trying to determine how the visual system extracts motion signals (for a review, see Smith & Snowden, 1994). Relatively little work, however, has focused on how transparent motion signals are processed. Motion transparency occurs when multiple objects move over the same region of space. Examples of motion transparency are when an animal moves through tall grass or when rain runs down the window of a moving car. Typically, at least one of the objects is spatially sparse. In these conditions, there are a number of distinct motion signals within the same region that correspond to the different objects. If the visual system can correctly segment and group these motion signals, then the transparent motion of the different objects is perceived. There are three main aims to the present study. The primary aim is to establish the number of signals that can be processed and represented by the visual system. The secondary aims are to determine the nature of the processing limit and hence where in the visual system this limit is imposed.

In addressing the question of a transparency limit, it is important to consider the different ways that the signals can be perceived. Signals can be perceived either sequentially or simultaneously. That is, it is possible to perceive each signal one at a time, or they can all be perceived simultaneously. It is only when they are perceived simultaneously that transparent motion is actually being processed, so it is that condition that is of interest in the present study (see Braddick, Wishart, & Curran, 2002 for a discussion of this issue).

Two studies have sought to establish the motion-transparency limit. Mulligan (1992, abstract only) investigated the ability of observers to identify which of two temporal intervals contained the greater number of signal directions (n versus $n+1$ signal directions). He found that only two signals could be perceived simultaneously. Mulligan ensured simultaneous perception by using the discrimination task combined with a short

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presentation time of 250 ms. A study by Andersen (1989) found that observers could reliably indicate the presence of up to three signal directions. However, that study presented stimuli for 2 s, so it is possible that observers could perceive the different signals sequentially.

An additional factor that is useful to consider when investigating motion transparency is the extent to which the different cortical motion areas are involved in representing motion transparency. Such a consideration can offer clues to the factors that contribute to the formation of the limit. It is possible that a number of processing areas impose limitations on the processing of transparent signals and that the nature of these limitations differ from area to area. Given that local-motion (V1) cells can only represent a single motion direction at a given location in space, it is clear that while these cells are obviously important in the extraction of motion signals, they cannot represent motion transparency. The first area where motion transparency could, theoretically, be represented is at the global-motion level (V5/MT). This area combines the output of many local-motion units across both space and direction and has been convincingly linked to the processing of motion transparency (e.g. Qian & Andersen, 1994; Qian, Andersen, & Adelson, 1994).

A stimulus that has been extensively used to investigate the properties of the global-motion stage is the one developed by Newsome and Pare (1988). This stimulus consists of a sequence of moving dots in which the dots are broken down into two groups: a signal group in which the dots move in the same (global-motion) direction and a noise group in which the dots move in random directions that cover the full 360°. The signal intensity is varied by altering the percentage of the dots that are signal dots. Cells in area V5 of macaques have been shown to be highly tuned to global-motion signal intensity. The response of most V5 cells increase in a linear manner with increasing signal intensity (Britten, Shadlen, Newsome, & Movshon, 1993). The performance of human observers in a signal-intensity discrimination task has been found to mirror this tuning (Edwards & Badcock, 1998). The global-motion area can be considered as performing a signal-to-noise analysis, with the signal being motion vectors in the preferred direction of the cell and the noise being motion vectors in all other directions (Edwards & Nishida, 1999). Given the involvement of the global-motion area in processing motion transparency, it is highly likely that signal intensity will play a role in determining transparency limits.

The primary aim of this study is to establish the transparency limit, and to determine whether this is a fixed limit. The approach used was similar to that used by Mulligan (1992). Observers were required to discriminate which of two temporal intervals contained the larger number of motion directions. A maximum number of five directions were used. In the stimuli, all dots moved in a signal direction. This meant that a consequence of increasing the number of directions was to reduce the signal intensity of those directions. For example, in an interval that contained a single motion direction, the signal intensity was 100%, while in an interval that contained five directions, the signal intensity was only 20%. Thus the starting point for this study was to establish that the minimum signal intensity used in the transparent conditions was greater than that required to see a single motion direction, i.e. to ensure that thresholds for the detection of a uni-directional signal, using a two temporal-interval procedure, are lower than 20%. This control assumes that signal intensities required to see transparent signals are similar to that required to see uni-directional signals. This assumption was explicitly tested in Experiment 3.

2. Experiment 1: uni-directional thresholds

Increasing the number of transparent directions results in a decrease in the signal intensity in each direction. It was therefore necessary to first establish the thresholds for the detection of a uni-directional signal to ensure that they are above the minimum signal intensity used in the transparent conditions in Experiment 2 (20%).

2.1. Method

2.1.1. Observers

Three observers were used in all experiments reported here, one of the authors (JAG) and two who were naïve with respect to the aims of the study. All observers had normal or corrected-to-normal acuity and no history of any visual disorders.

2.1.2. Apparatus

Stimuli were displayed a on Clinton Monoray monitor which was driven by a Cambridge Research Systems VSG 2/5 in a host Pentium computer. Observers' responses were recorded via a button box. The monitor had a refresh rate of 120 Hz.

2.1.3. Stimuli and procedure

Global-motion stimuli were presented within a circular aperture of 13° diameter. 120 dots were presented, giving a dot density of 0.9 dots/deg^2. The spatial step of each dot was 0.3° (eight pixels), which resulted in a speed of 6°/s. This combination of dot density and step size resulted in a low probability of false motion signals occurring (Willaims & Sekuler, 1984). The dots had a diameter of 0.2° and a Michelson contrast of 20%. The mean luminance of the display was 82 cd/m^2. A black fixation cross was presented at the centre of the viewing