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An extension of the transparent-motion detection limit using speed-tuned global-motion systems

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Abstract

When transparent motion is defined purely by direction differences, no more than two signal directions can be detected simultaneously. This limit appears to occur because higher signal intensities are required to detect transparent motion compared with uni-directional motion (Edwards, M., & Greenwood, J. A. (2005). The perception of motion transparency: A signal-to-noise limit. *Vision Research, 45,* 1877–1884). Increasing the effective signal intensities should therefore increase the number of signals that can be detected. We achieved this by adding speed differences, dividing transparent-motion signals between two speed-tuned global-motion systems. When some signals moved at appropriate low speeds and others at high speeds, up to three signals were detected. This is consistent, at least in part, with the signal-to-noise processing basis of the transparency limit. Differences in contrast polarity were also used to assess whether the limit could be extended using stimulus features without independent global-motion systems. A modest improvement in performance was obtained, suggesting that there may be multiple routes to extending the transparent-motion limit.

Keywords: Motion perception; Transparency; Global motion; Speed processing

1. Introduction

Transparent motion occurs when multiple objects move through the same region of the visual field without total occlusion. Naturally occurring examples can be seen when an animal moves behind foliage blown by wind, or when rain streams down the window of a moving vehicle. These conditions can be simulated with random-dot stimuli where two or more groups of dots move in different directions within the same aperture (e.g., Clarke, 1977). When transparency is defined purely by direction, observers are unable to detect more than two transparent-motion signal directions simultaneously (Mulligan, 1992; Edwards & Greenwood, 2005). In the present study, we investigate whether this limit can be extended to allow the detection of a higher number of transparent-motion signals.

1.1. The transparent-motion limit

To examine the perception of transparent motion, it is important to distinguish between simultaneous and sequential detection of the signal directions. Previous experiments have ensured simultaneous detection through the use of brief presentation times and tasks that require detection of all signals present. In contrast, the signals could be detected in sequence, which may be more comparable to uni-directional detection for each signal (Braddick, Wishart, & Curran, 2002). To examine the limitations of transparent-motion detection, it is therefore important to ensure simultaneous detection of the signals.

When simultaneous detection is required, observers are unable to detect more than two transparent-motion

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signals with direction differences as the sole cue to transparency (Mulligan, 1992). We have recently linked this limitation with signal-to-noise detection thresholds for transparent motion, which are three times higher than uni-directional thresholds in a comparable task (Edwards & Greenwood, 2005). This provides a basis for the transparency limit because increasing the number of transparent-motion signals decreases the maximum signal intensities. Throughout this paper, we will use *signal intensity* to refer to the proportion of dots in random-dot stimuli moving in one signal direction. For the detection of this signal, dots moving in other directions (either randomly or within other signals) will act as noise. So, when direction is the sole basis for transparency, two signals can at most be presented at intensities of 50% each. The addition of a third direction reduces signal intensities to 33%. To detect bi-directional transparency, observers in our previous study required signal intensities of 40% for each of the two signals. If detection thresholds for three signals are at least as high as those for two, it would therefore be impossible to present three signals at the required intensities within these stimuli.

1.2. Extending the transparent-motion limit

This dependence on the signal-to-noise ratio in transparent-motion stimuli is consistent with the notion that the global-motion stage is involved in setting the transparency limit (Britten, Shadlen, Newsome, & Movshon, 1993; Rees, Friston, & Koch, 2000). Within the visual system, this is the first point at which transparent motion can be represented (e.g., Snowden, Treue, Erickson, & Andersen, 1991; Qian, Andersen, & Adelson, 1994).

If the transparent-motion limit of two is the result of global-motion signal-to-noise processing, increasing the signal intensities within our stimuli should allow an extension of the limit. One means to increasing signal intensity is to distribute the transparent-motion signals between independent speed-tuned systems (Edwards, Badcock, & Smith, 1998; Snowden, 1990; Verstraten, van der Smagt, & van de Grind, 1998). In particular, Edwards et al. (1998) found that thresholds for the detection of a low-speed signal were elevated when additional low-speed noise dots were added to the stimulus, but not when additional high-speed noise dots were added. The inverse was found for high-speed detection thresholds. This suggests the existence of at least two global-motion systems: one tuned to low speeds, the other to higher speeds. Signal-to-noise processing in one system is independent of the other.

It follows that transparent-motion signals detected by one of these global-motion systems would have no effect on signal-to-noise processing in the other system. By presenting transparent-motion signals at speeds specific to either of the two speed-tuned systems, we can thus increase the effective signal intensities in our stimuli. For instance, three low-speed signals would each have a signal intensity of 33%. If one of these signals moved at a high speed beyond the sensitivity of the low-speed system, its intensity would be at 100% within the high-speed system. The intensity of the two low-speed signals would then be increased to 50% each. If the transparency limit arises due to high signal-to-noise detection thresholds at the global-motion stage, this manipulation should allow the detection of more than two signals.

Three experiments were conducted to determine whether the transparent-motion limit can be extended. Experiment 1 established the appropriate speeds to be used for each participant. In Experiment 2, we then used these speeds in transparent-motion stimuli to assess whether the speed-tuned systems could allow the detection of more than two signals. Finally, in Experiment 3 we examined whether an extension of the transparent-motion limit could occur in the absence of independent global-motion systems, using differences in contrast polarity (Edwards & Badcock, 1994).

2. Experiment 1: Sensitivity of the speed-tuned systems

We first sought to find two speeds that would be processed independently by distinct speed-tuned global-motion systems. Because there is individual variation in the sensitivity ranges of these systems (Edwards et al., 1998), it was expected that the speeds required to obtain independent processing might vary between observers. A series of global-motion tasks was performed to select the appropriate speeds, using stimuli designed to be as similar as possible to the transparent-motion stimuli of Experiment 2.

2.1. Method

2.1.1. Observers

Three observers took part in the first two experiments: one of the authors (J.A.G.) and two naïve observers. All had normal or corrected-to-normal vision, with no history of any visual disorders.

2.1.2. Apparatus

Stimuli were displayed on a Clinton Monoray monitor with a refresh rate of 120 Hz, driven by a Cambridge Research Systems VSG 2/5 in a host Pentium computer. Stimuli were viewed from a distance of 1 m, with head movements restricted by a chin rest. Observers initiated each block of trials and responded to the trials via