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Motion Parallax: Perceiving Depth with Virtual Dihedral Angles

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Motion Parallax: Perceiving Depth with Virtual Dihedral Angles

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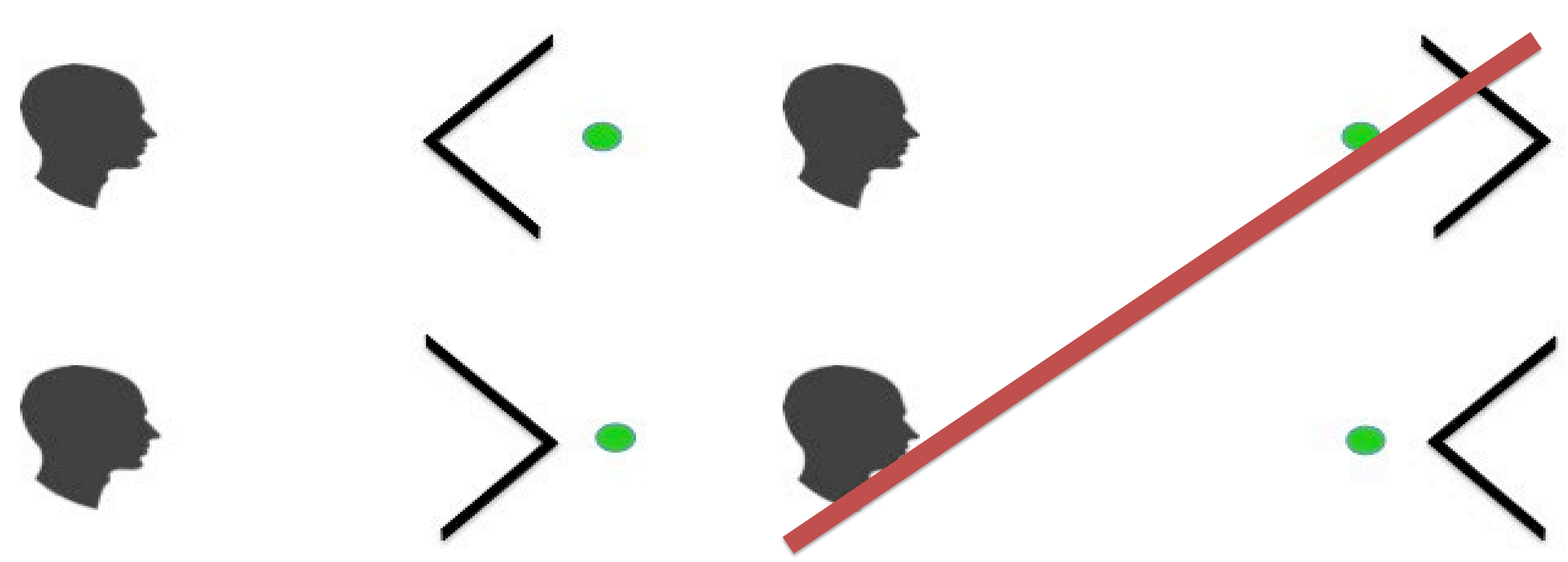
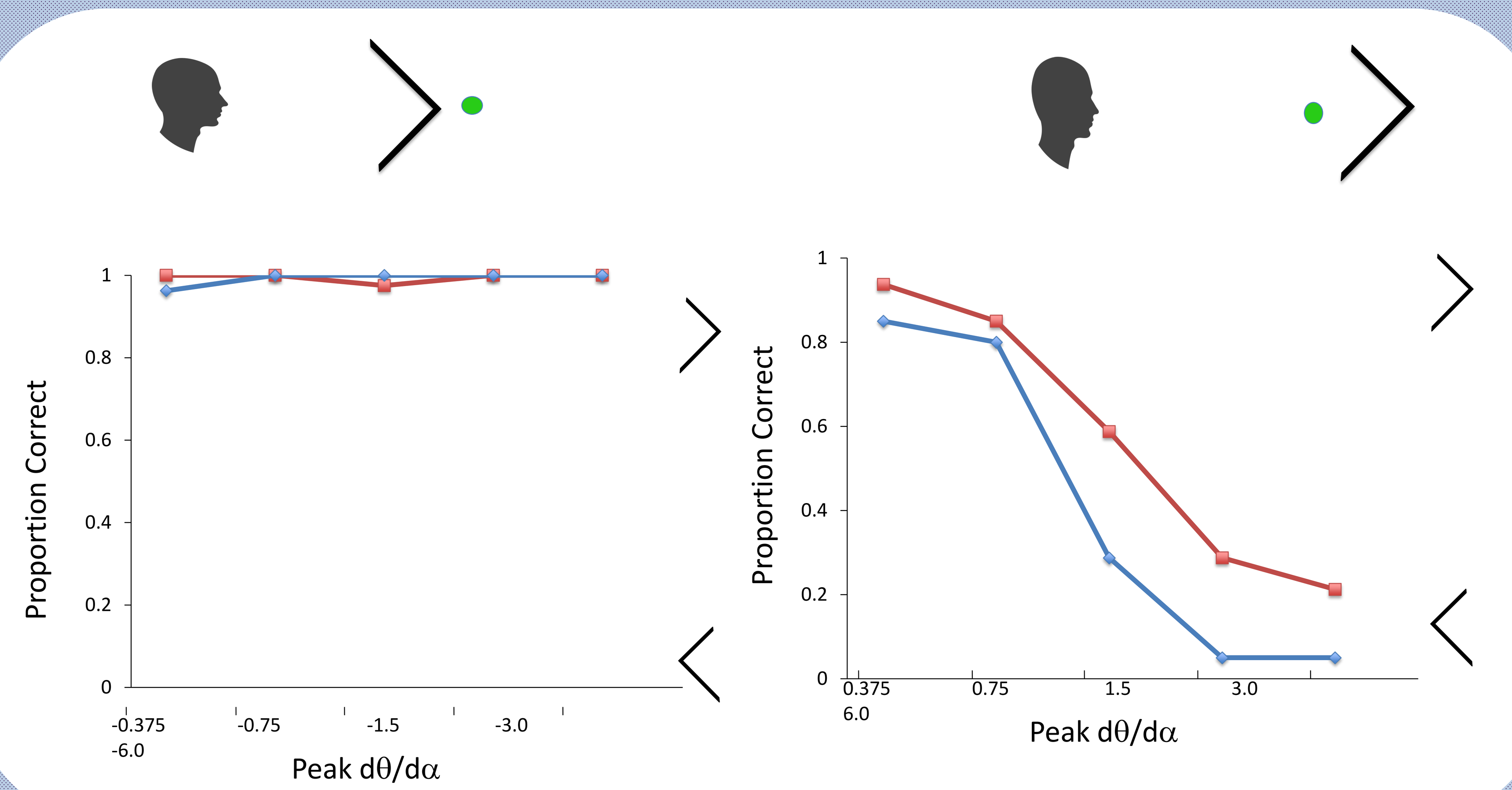
Introduction

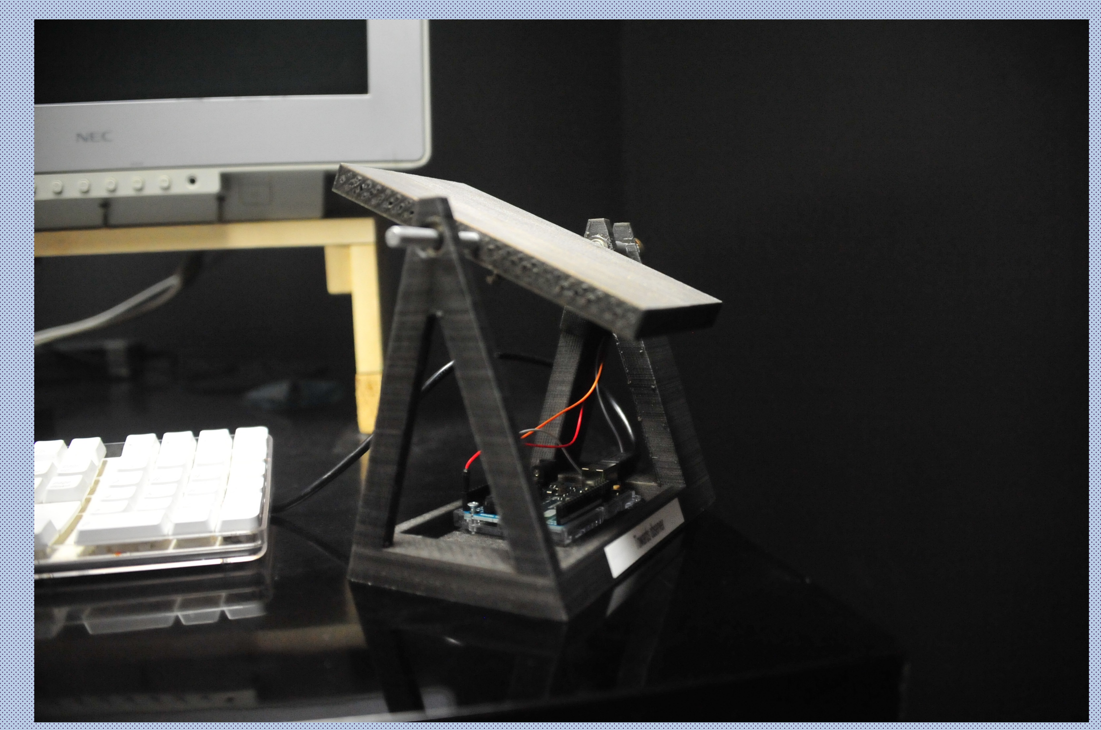
- **Our goal is to understand how people perceive visual depth information.**
- **Here we explored how the visual system uses motion information to recover the slant of a virtual surface when viewing virtual stimuli.**
- **The difficulty is determining the separate effects of:**
    - **errors in the motor response of indicating slant with a hand gesture**
    - **errors in the actual perception of depth from motion parallax stimuli**
- **The previous experiment (see our other poster) demonstrated that viewers are very orderly, but inaccurate, in reporting correct slant with real, physical stimuli**

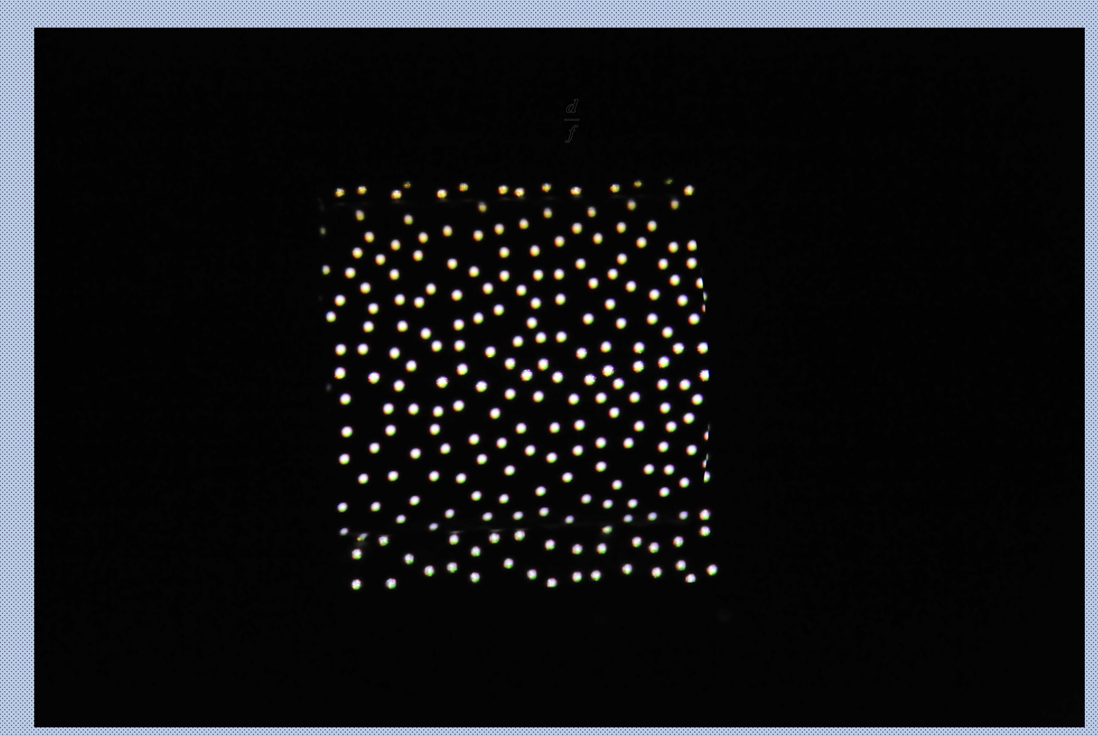
Methods

- **Participants viewed translating random-dot stimuli presented on a computer screen.**
- **The sole source of depth information came from the visual motion parallax cue.**
- **While viewing the stimulus, participants reported the perceived slant of the surface with hand position.**
- **This hand position was recorded electronically to computer with a potentiometer.**
- **To separate the perceptual (input) error from the response (output) error, these slant responses were corrected with the results from the first experiment.**
- **The result should tell us what the actual perceived slant from the motion parallax stimulus.**
- **From this slant we can estimate the amount of depth perceived in the stimulus.**



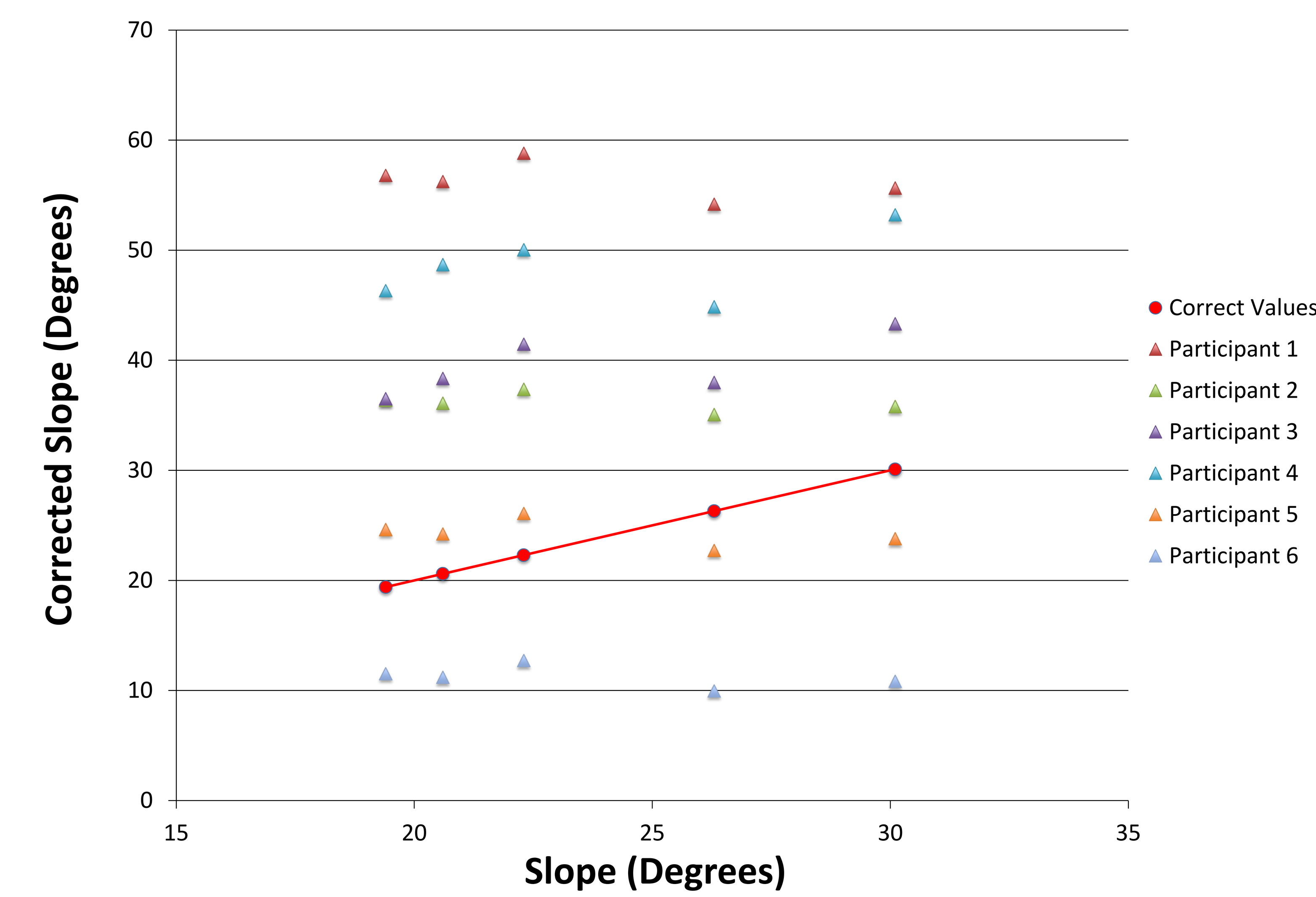




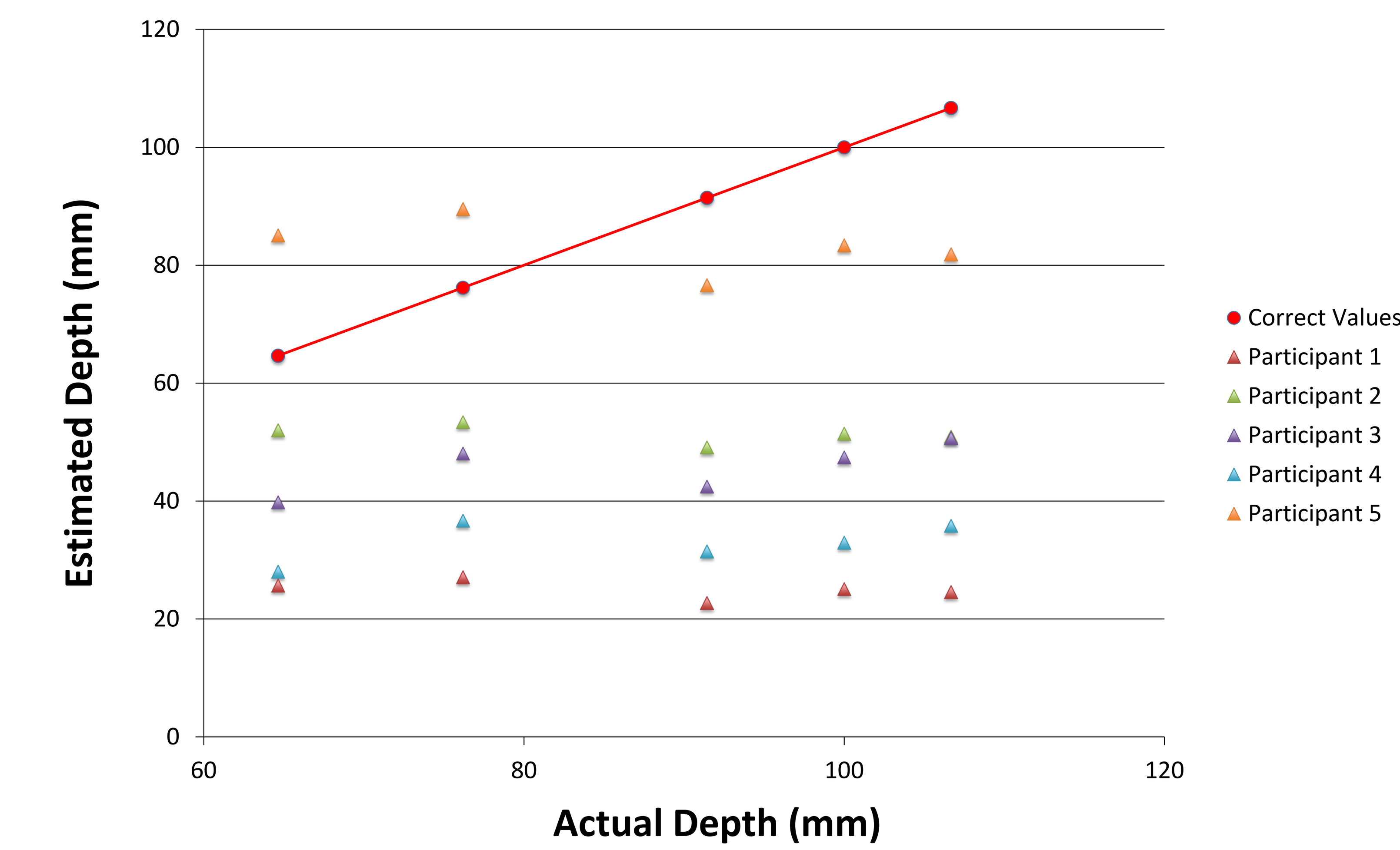


Results

Virtual Angle Corrected Slope Versus Slope



Virtual Angle Estimated Depth Versus Depth



Discussion

- **Most participants underestimated the slant, although the correction from the physical experiment suggested that much of this was due to motor response error, not just perceptual error.**
- **Overall, participants were quite stable in perceiving depth portrayed by motion in the virtual display, despite changes in the stimulus parameters.**

Understanding the cause of perceptual depth-sign ambiguity with dihedral angles created with motion parallax

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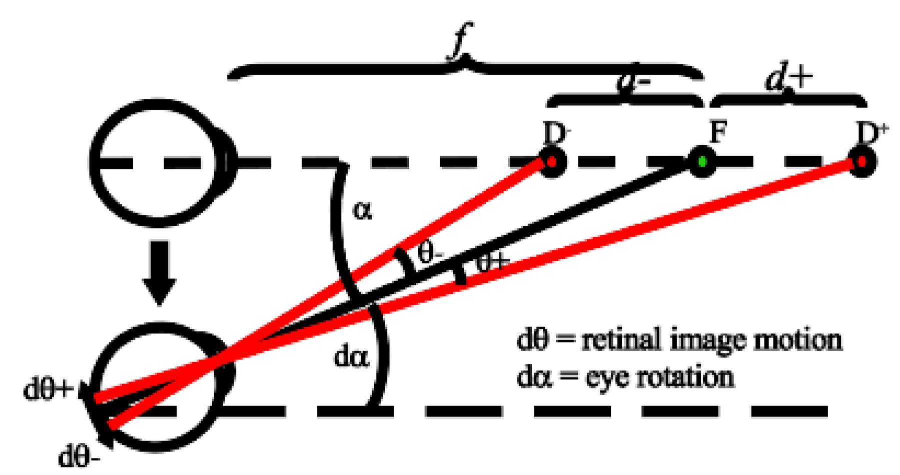
Background

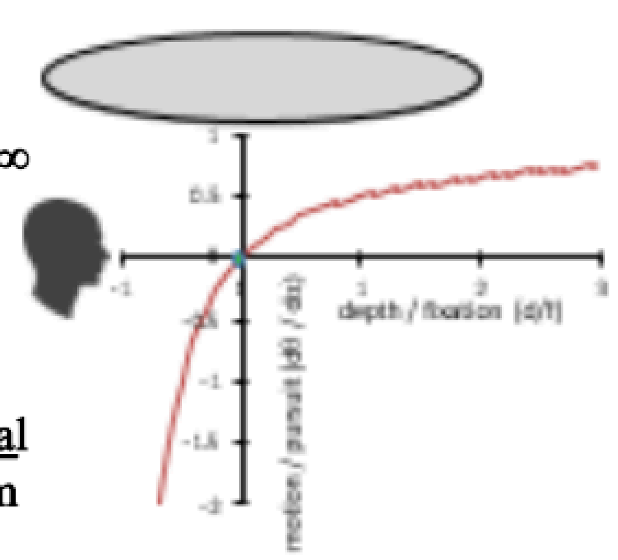
Goal: To understand why previous studies [1-4] reported perceptual depth-sign ambiguity with computer generated motion parallax stimuli.

The Motion/Pursuit Law (M/PL) provides the precise geometric relationship between two distal cues (F, D), fixation distance (*f*) and relative depth of a point in space (*d*), and two proximal cues, retinal image motion (dθ) and an internal pursuit signal (dα), with the function [5, 6]:

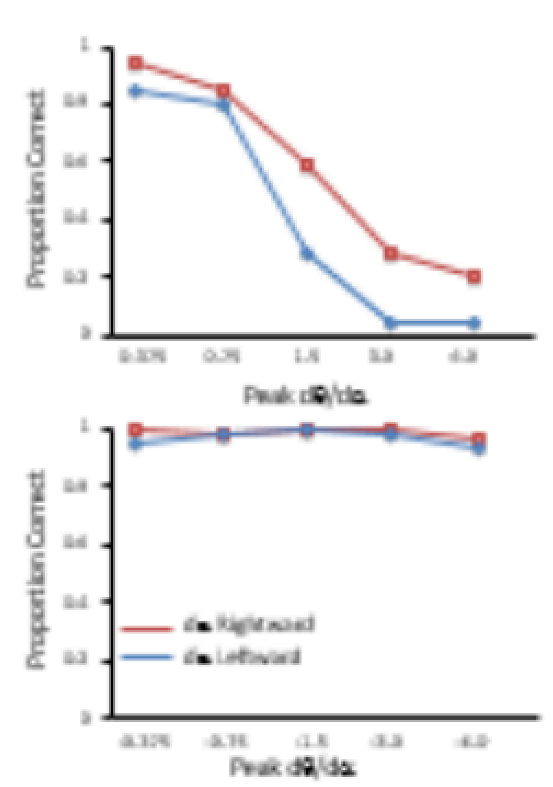


$$\frac{d}{f} = \frac{d\theta/d\alpha}{1 - d\theta/d\alpha}$$

A graph of motion/pursuit ratio (M/PR) (dθ/dα) vs. relative depth (*d/f*) illustrates limits: *d-* is limited to *–f* as -dθ/dα goes to ∞ (lower limb of red line) but as d+ goes to ∞, dθ/dα < 1 (upper limb of red line). However, computer generated MP stimuli can attempt to depict parameters with dθ/dα > 1 (grey oval), meaning an unnatural or impossible stimulus for the visual system viewing a rigid scene.



Using a 2AFC depth-sign task, we previously found [7] that perceived depth from MP was depth-sign reversed when parameter values created stimuli with dθ/dα > 1 (right side of upper panel). This corresponds to stimuli with parameter values in the grey region in the figure above. That is, as dθ/dα approaches 1, d+ approaches ∞: a very deep stimulus. And when dθ/dα > 1, d+ would become impossibly deep. The visual system appears to solve this situation by reversing the perceived depth-sign of the stimulus. No perceptual ambiguity is expected, or found, with stimuli having the same stimulus parameters in near depth (lower panel).

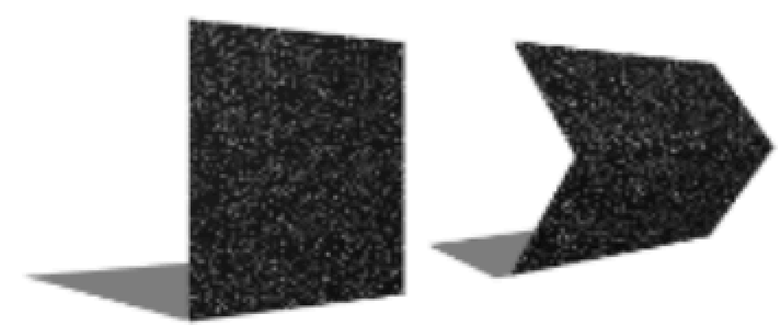


Here, as in [7], we use perceived slant of dihedral angles to assess perceived depth from MP. Consider as perceived depth increases, slant should approach horizontal whereas a stimulus with no depth should be perceived as a vertical surface. Are these perceptual depth-sign reversals accompanied by changes in perceived depth magnitude as determined with perceived slant?

Hypothesis: Depth-sign becomes ambiguous or reverses when stimulus M/PR (dθ/dα) > 1, and this depth-sign reversal is accompanied by a change in perceived depth magnitude.

Method

Physical and Virtual dihedral angles: Stimuli depicted dihedral angles with the horizontal vertex pointing towards or away from the observer (1, 2). All stimuli, physical and virtual, subtended a visual angle of 10.6º x 10.6º when viewed from 40 cm.



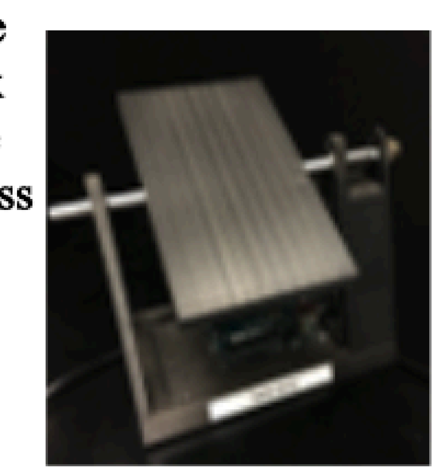
Physical stimuli: Generated with grey PLA filament depicting a dihedral angle between 30º and 150º (x = 75 mm, y = 75 mm, z = 10 – 138 mm). Stimuli were mounted to a background board. The stimuli were illuminated with an LED array ~ 3200 lux (298 fc) and viewing was through a square aperture controlled by a ferro-electric shutter.

Virtual stimuli were generated in Matlab [8,9] and presented on a 21" CRT @ 120 Hz(8, 9). The virtual random-dot MP stimuli used M/PR gradients to depict the two slanted planes with varying relative depth magnitudes (60-110 mm) and therefore varying slants (19º - 30º) for stimuli nearer than fixation depth. For stimuli using the same stimulus parameters farther than fixation, stimuli with peak M/PR of 0.375 and 0.75 have depth of 183mm and 1067mm and slants of 11.5º and 2º respectively. Stimuli with peak M/PR > 1 cannot be properly described with the Motion/Pursuit Law.

Motion (dθ): The two sloping surfaces creating the angles were generated by interpolating dot velocities between 1 and 3 deg/sec. The minimum velocity could be at the vertex or at the top/bottom edges. In each stimulus dots moved in the same direction, leftward or rightward. A fixation point was drawn at the center of the stimulus.

Pursuit (dα): Stimuli initially translated laterally, leftward (-dα) or rightward (+dα) at 0.5, 1, 2, 4, or 8 deg/sec. dθ and dα in same directions denote negative M/PR, dθ and dα in opposite directions denote positive M/PR. M/PRs had a range between -6 and 6.

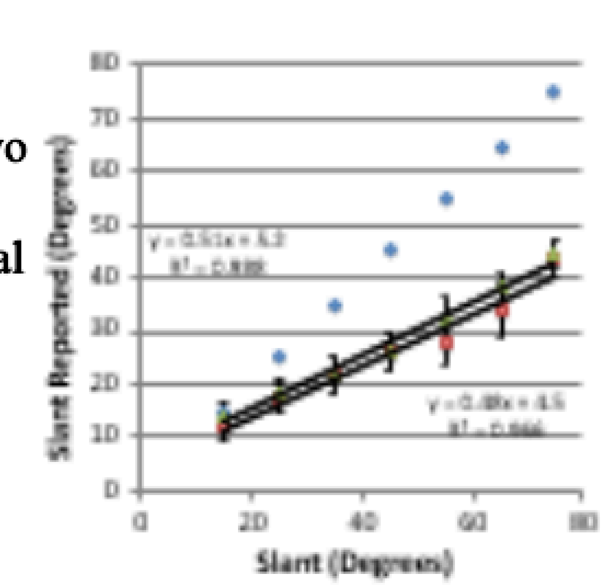
Measures: A rotating palm-plate was used to indicate the slant of the top (vertex towards) or bottom (vertex away) surface of the angle. Every trial began with the hand in the flat 0º position. Observers used a key press to indicate which surface they were matching.



Observers: 7 naïve observers completed 20 trials in each of the 54 different stimulus combinations.

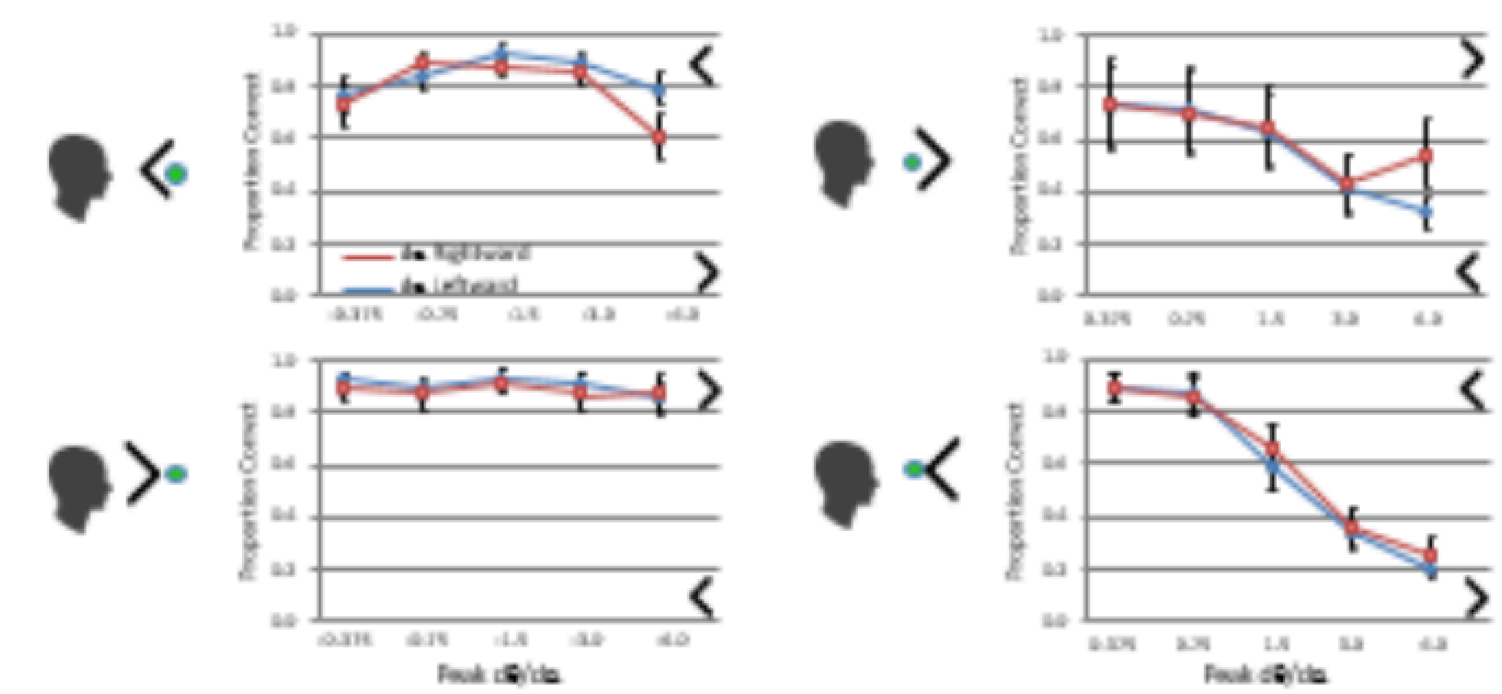
Results

Physical Stimuli. Observers underestimated slant of the physical stimuli by half (individuals varied between 0.3-0.7). The two lines show vertex towards (upper) and away. Because an underestimate of slant with virtual stimuli would be misinterpreted as an increase in perceived depth, for each observer the reported slants of virtual MP stimuli were corrected with linear functions derived from their report of the slant with physical stimuli.



Results

Virtual Stimuli. The figures below show the depth-sign reports made for stimuli nearer (left panels) and farther than fixation (right panels). Stimuli could depict the vertex farther from fixation (upper panels) or nearer than fixation (lower panel) compared to the outer parts of the stimulus. Depth sign reports did not vary with M/PR for near stimuli, but did change for far stimuli when the M/PR ≥ 1.



Knowing that observers underestimate slants (see results for Physical Stimuli) observer's reported slant was "corrected" with a linear function derived from each's physical stimulus results. Each of the 20 trials, in the 40 conditions, was sorted into "correct" and "incorrect" based on depth sign report. Slants were averaged in each of the conditions, across dα direction, and vertex direction. For each observer a Sign Test (binomial) was used to compare the reported slant magnitudes across all conditions in which there were perceptual sign reversals, and for conditions in which "far" stimuli were perceived near. None were significant ($p = 0.97 – 0.34$). The mean difference in reported slant magnitudes across depth sign reversals was only 3.3º (1.8º - 7.5º).

Conclusion

Depth-sign does reverse when stimulus M/PR (dθ/dα) > 1, but the depth-sign reversal is not accompanied by a change in perceived depth magnitude.

As predicted by the M/PL the visual system correctly assesses depth sign from MP across the range of negative M/PR values but fails to correctly assess depth with M/PR > 1. In such cases the visual system appears to perceptually "reverse" the *d+* to a *d-*. Moreover, results are not due to high pursuit velocities giving low pursuit gains: Larger M/PR values are found with lower pursuit velocities (*remember dα, pursuit, is in the denominator*).

The M/PL model for motion parallax provides a possible explanation for why some reports suggested that MP was a reliable relative depth cue. The explanation is that these studies may have unknowingly employed unnatural stimulus conditions (high dθ, low dα)for a rigid object, generating M/PR values for which the visual system produces an anomalous result.

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