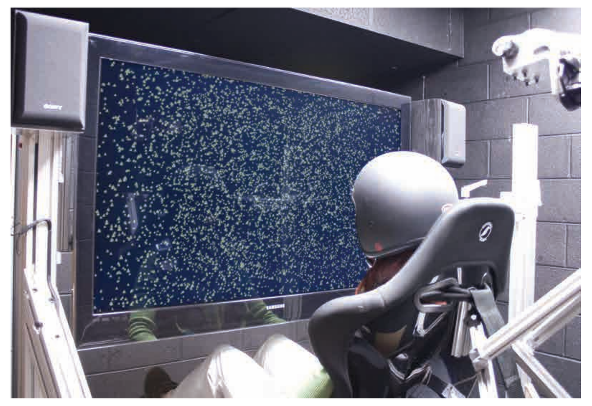
# Visual Motion Profile Has Minimal Effect on Visual-Vestibular Multisensory Integration

Miguel A. Yakouma[3], Eric Anson, PhD[1], and Benjamin T. Crane, MD, PhD[1,2,3]
University of Rochester Departments of Otolaryngology[1], Neuroscience[2], and Bioengineering[3]



## Abstract

**Background**:
Visual motion is ambiguous in that it can either represent external motion or self-motion. Visual-vestibular integration is most advantageous during self-motion. It has previously been shown that visual-inertial integration occurs only when they have a consistent direction and good temporal alignment. The current experiment tests the hypothesis that the visual motion needs to have a motion profile consistent with the inertial motion.

**Methods**
Twenty healthy human subjects (mean age 20 ± 3 years, 13 female) experienced 2 seconds of translation which could be left or right of center. A 6-degree-of-freedom (6-DOF) motion platform was used to deliver the inertial motion stimuli while a 55" color display delivered the apparent visual motion. Inertial headings were paired with a synchronized 2 s duration visual headings that were presented at relative offsets of 0°, ±45°, ±60°, and ±75°. In some trials the visual motion was consistent with the inertial motion and in other trials it was inverted – it started at the peak velocity, decreased to zero mid stimulus, then accelerated back to the peak velocity.

Subjects judged the direction of the inertial heading as either left or right of midline. Visual-vestibular integration was determined by measuring the bias in inertial heading towards the visual stimulus.

**Results**
A visual optic flow stimuli biased inertial heading perception in the direction of the visual stimulus. When the velocity profile of the visual stimulus matched the velocity profile of inertial motion the inertial stimulus was biased 10.0 ± 1.8° (mean ± SE) with a 45° visual offset, 8.9 ± 1.7° with a 60° offset and 9.3° ± 2.5 ± with a 75° offset. When the visual stimulus was inverted so it was inconsistent with the inertial motion the respective biases were 6.5 ± 1.5°, 5.6 ± 1.7°, and 5.9 ± 2.0°. Thus, the biases with the inverted stimulus were significantly smaller ($p < 0.05$, t-test across all offsets), although the inverted visual stimulus still demonstrated the known pattern of decreasing influence as the relative offset to inertial heading increased. When the subjects were examined individually, there were six subjects where the type of visual stimulus made essentially no difference in heading perception (<1°), while in the most extreme subjects the difference was 10°. However in 17/20 subjects the bias towards the visual stimulus was greater when the visual stimulus matched the inertial motion profile. Thus, some subjects seemed to consider the velocity profile of the visual stimulus in multisensory integration while others did not.

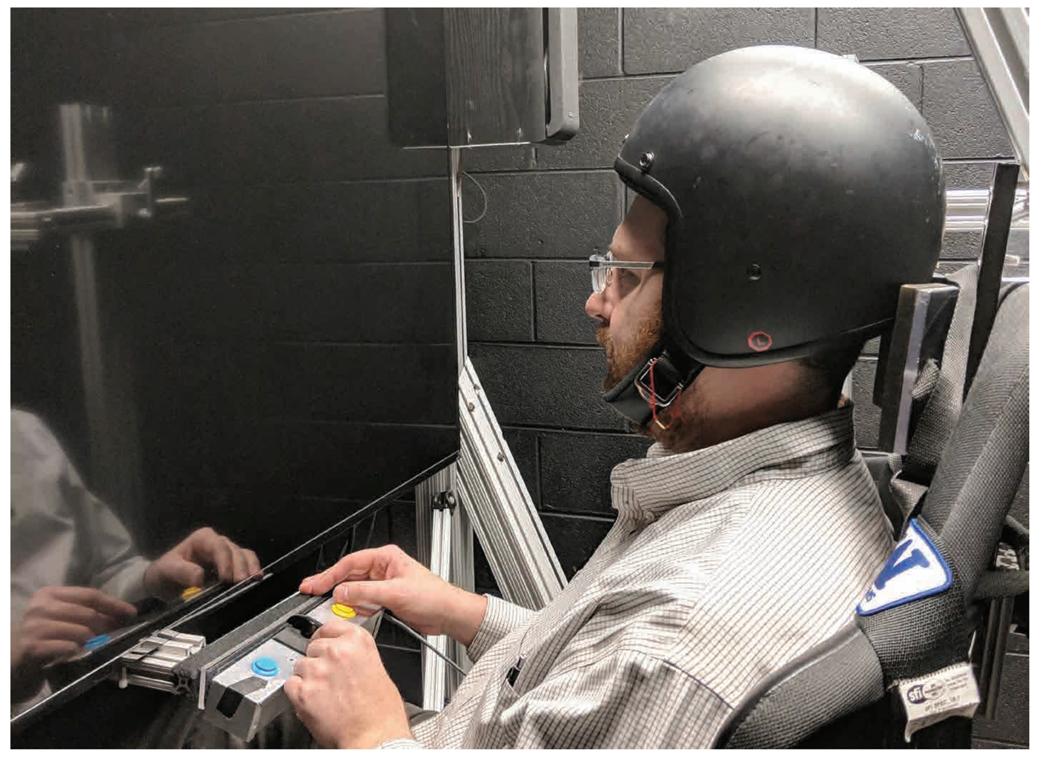
**Conclusions**
The visual stimulus has a greater and more consistent effect when its velocity and acceleration match the inertial stimulus, but the effect was small and not present in all subjects.

## Introduction

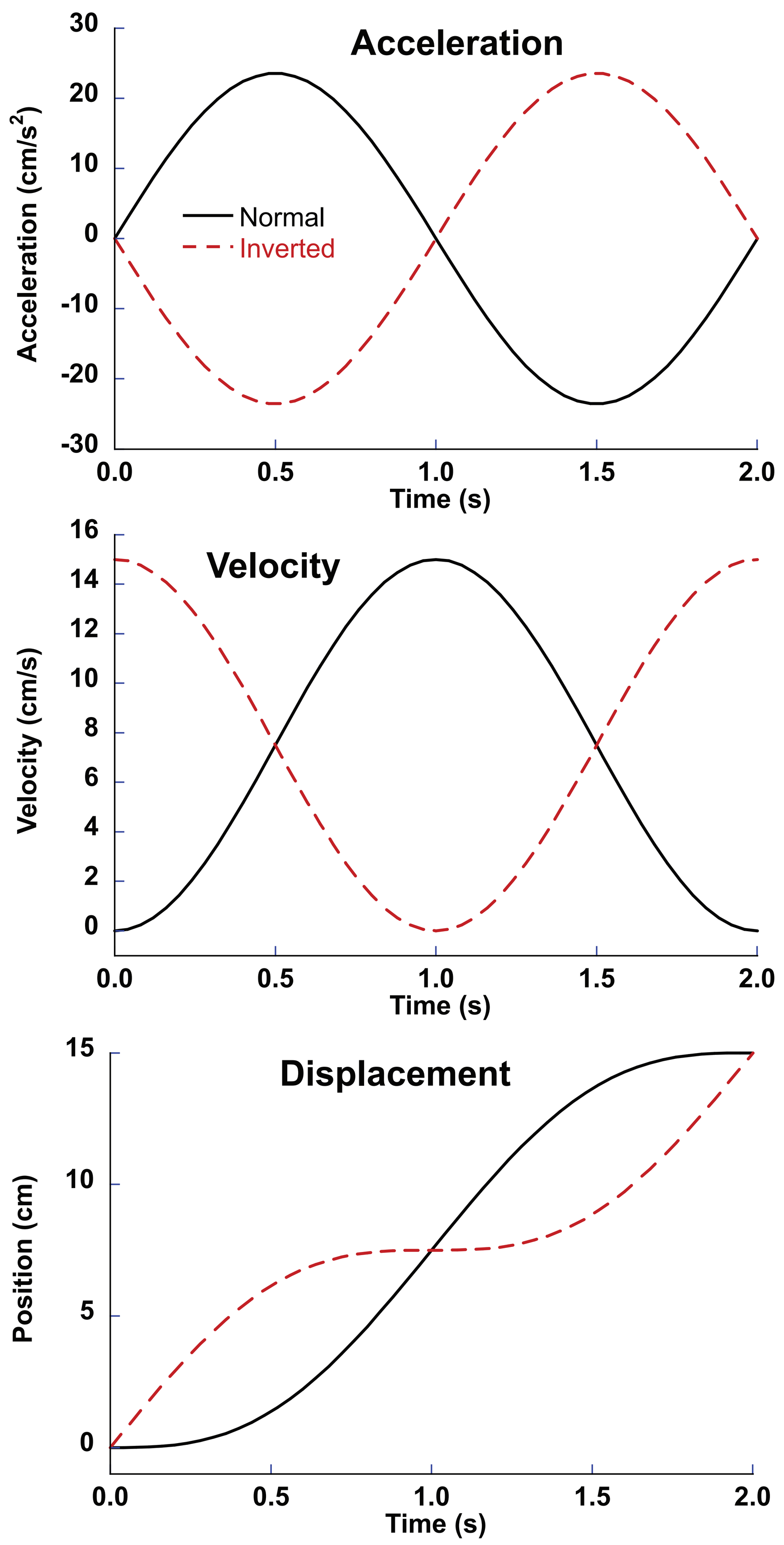
Multisensory integration should occur when two stimuli share common causation. Visual motion is ambiguous in that it can represent object motion or self-motion. For visual and inertial cues to be integrated they must share self-motion as the common causation. There have been found to be situations when visual-inertial stimuli aren't integrated: When visual and inertial stimuli aren't temporally aligned they aren't integrated[1] and they aren't integrated when separated by more than 90°[2]. For visual and inertial stimuli, common causation is only plausible if the visual stimulus has an acceleration and velocity profile that is consistent with the inertial stimulus, but experimentally the effect of the motion profile has been more ambiguous. A previous study in which subjects were asked to judge if a stimulus was straight ahead or offset it was found that some subjects did not integrate the visual stimulus because it was thought to be inconsistent with the inertial stimulus[3]. However, a subsequent study, that varied the visual motion profile, demonstrated visual-inertial integration occurred equally well and in a statistically optimal manner when the velocity profile of the visual stimulus was just a constant velocity and when it matched the inertial stimulus[4]. The differences between these may be much longer duration stimulus (around 10s) used in the earlier study. A subsequent study looked at the effect of stimulus duration and found that longer stimuli tended to weigh the visual component of heading more[5]. The current study focus on shorter duration (2s) stimuli such as those where it was previously shown that the velocity profile didn't matter[4]. However, it was thought that there may be some limits to the velocity profile that could be integrated, so instead of using a constant velocity profile we inverted the velocity to make it as inconsistent as possible while still maintaining the motion that was consistent with the same distance.

This experiment looked at the potential influence of the motion profile. It was felt that when the visual motion profile was inconsistent with the inertial motion profile it would be more likely to be perceived as external motion and not integrated. The following related hypotheses were tested:

1) A larger separation of visual-inertial heading directions will be integrated when the stimuli have consistent motion profiles.
2) The influence of the visual stimulus on inertial heading perception will be minimized when the visual motion profile is inconsistent with inertial motion.

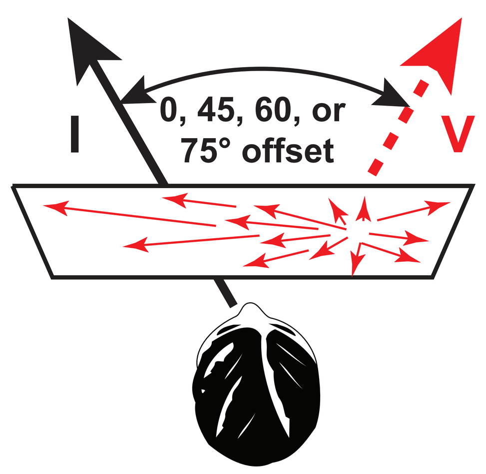


The experimental set up. Subject was seated with the head fixed using a helmet. Audible white noise was used during the stimulus presentations. Each stimulus presentation included visual and inertial motion. After each stimulus presentation, subjects were asked to judge the direction of the the inertial stimulus on as left or right of straight ahead in a two alternative forced choice (2AFC) task. Every trial block included randomly interleaved stimuli that were not offset or offset in either direction. No feedback was given.



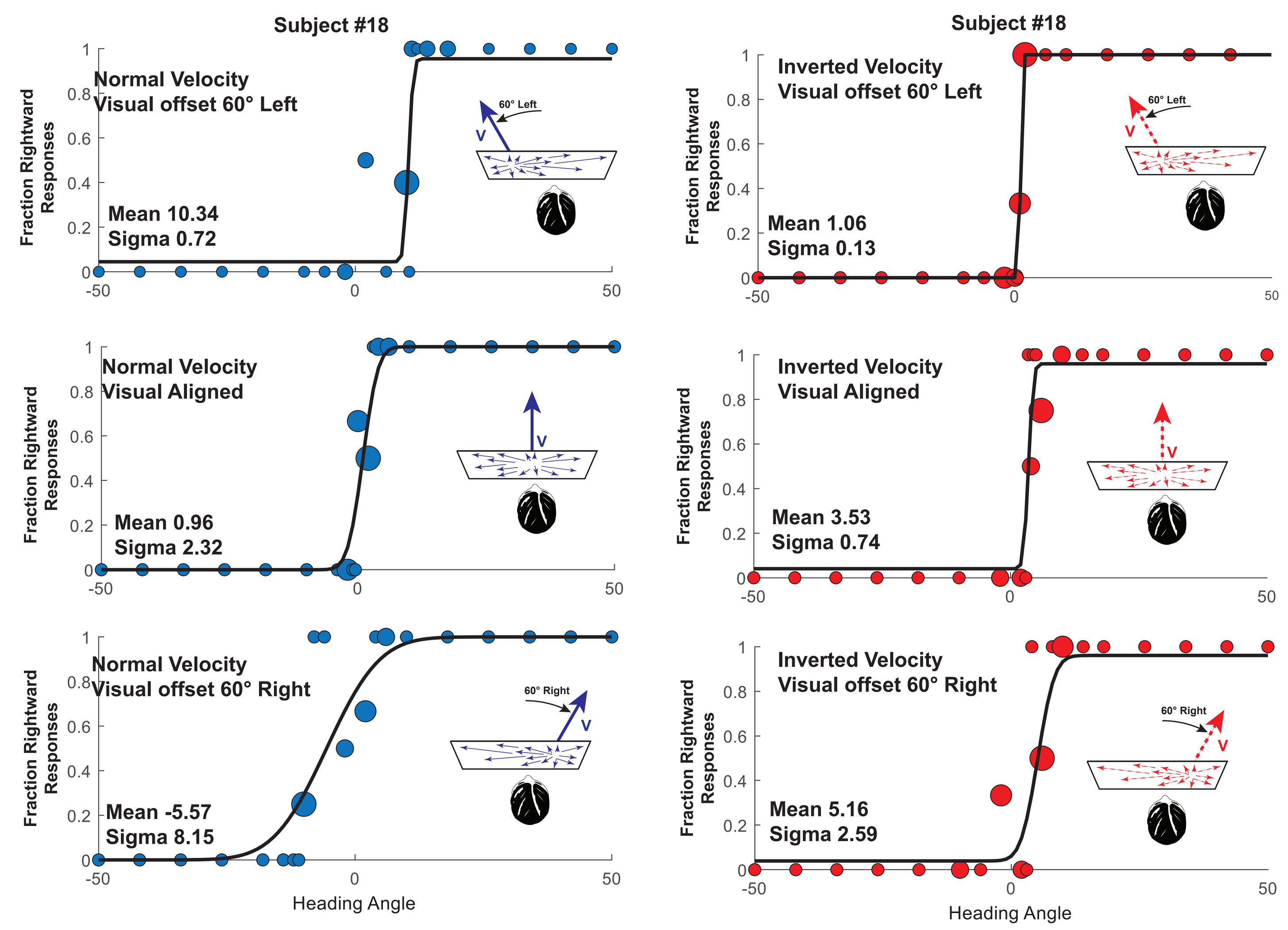

Every trial block included stimuli in which the visual motion profile matched the inertial motion (**normal**) and trials in which it was inverted. The overall displacement was similar in both. In inverted trials the velocity started at its peak value decreased to standstill then increased to its peak value again. This type of motion profile (**inverted**) would be consistent with an inertial movement in which the subject was moving at the start and end of the stimulus which was inconsistent with what occurred and would not be possible in our laboratory. However both stimuli where the same duration and were synchronous.

The visual stimulus was presented at 70% coherence to encourage the subjects to try to report the inertial stimulus only as they were directed.

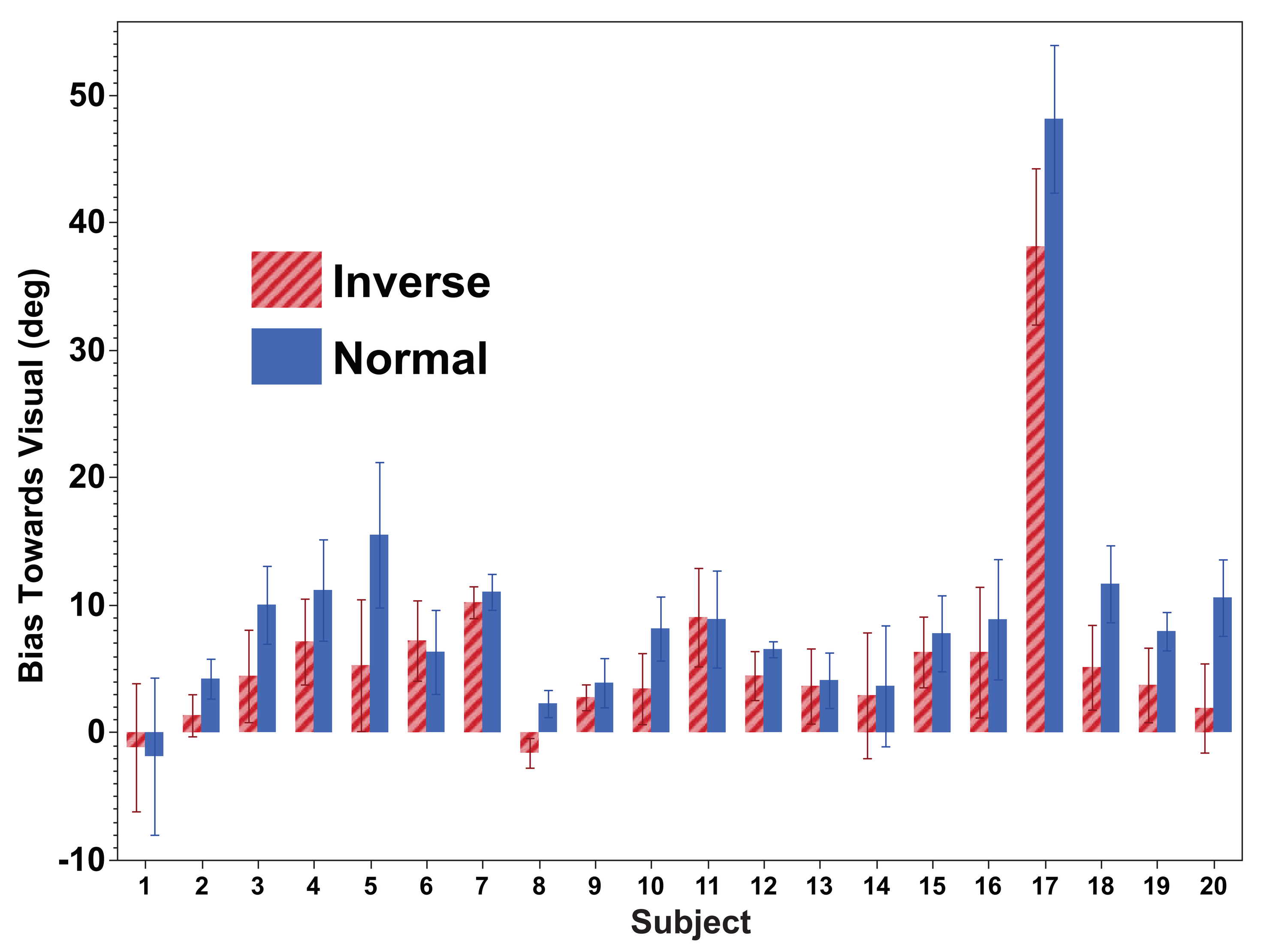



Every trial block included stimulus presentations in which the visual motion profile matched the inertial motion (**normal**) and trials in which it was inverted. Every subject completed 3 blocks of trials. Every block included 1/3 of trials in which the visual and inertial stimuli were directionally aligned, 1/3 where the visual was offset to the right, and 1/3 were the visual was offset to the left. During each block the offset was the same at ±45, 60, or 75°.

At the start of the trial the inertial stimulus was ±50°, which could reliably be reported as left or right of midline by all subjects. The direction of subsequent stimuli were adjusted using a staircase.

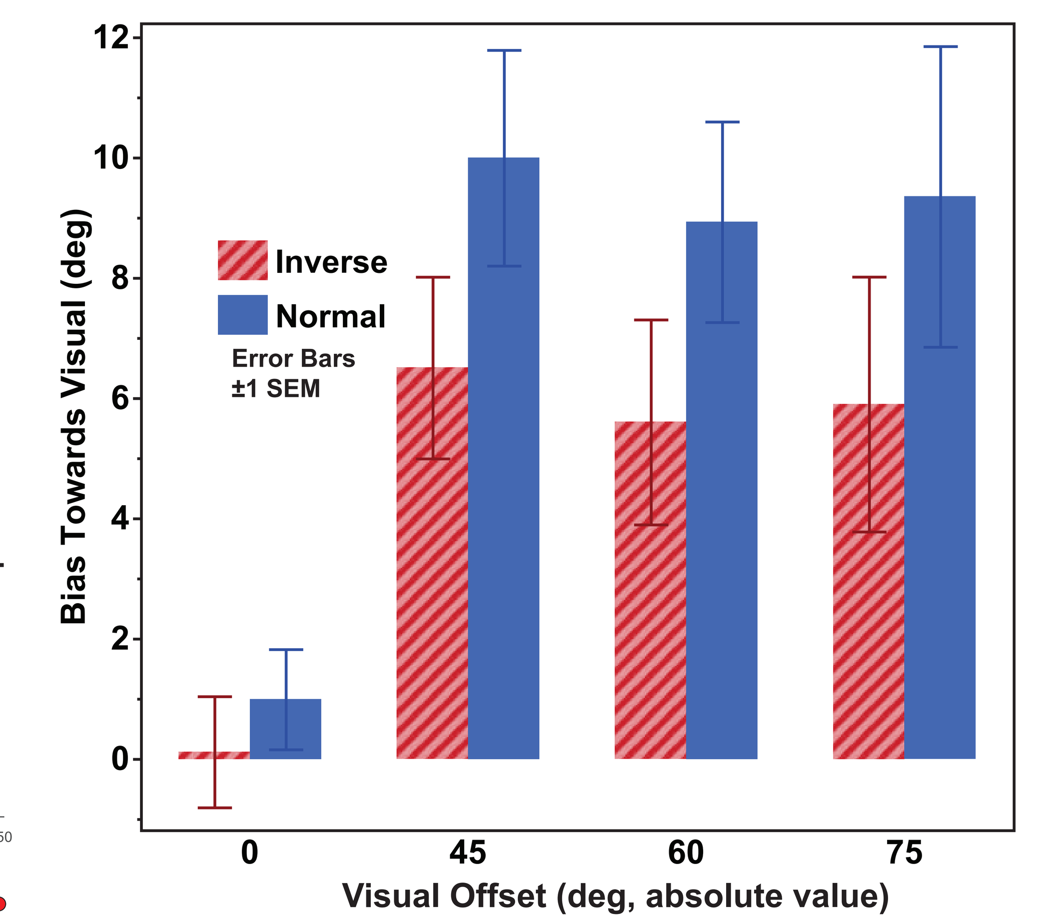



Sample data from an individual subject (#18).




Data by subject across the three non-zero offsets. Two subjects (#1, 8) demonstrated effectively no influence of vision on heading perception. Sixteen subjects had effects in which the effect of vision was diminished when an inverted velocity profile was used. Two subjects (#6, 11) the inverted velocity had a slightly larger effect. Error bars represent ±1 SEM.

### Effect of Visual Offset




When each individual angle was examined separately there was no statistical significance ($p > 0.05$) for all. When combied (2-tailed T test) $p = 0.027$

## Summary

1. Visual heading has a larger effect on initial heading perception when the visual stimulus velocity profile is consistent with the inertial stimulus. Although there was some effect of the motion profile (unlike the previously tested constant velocity visual motion), the effect was small.

2. Visual headings influence inertial heading perception even when there is a large amount of separation between the headings. The effect occurred over a similar range for both normal and inverted visual velocities.

3. The findings were similar across most subjects. As with other visual-intertial integration experiments there was a small fraction subjects who had a large effect while there was also a fraction that had a minimal effect.

## References

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## Support

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