Human smooth pursuit eye movement responses to visual, auditory, and imagined target motion

Anton E. Krukowski, Durand R. Begault, Elizabeth M. Wenzel, and Leland S. Stone. NASA Ames Research Center, Moffett Field, CA

I. Introduction

It is widely believed that a moving visual target is required to drive robust smooth pursuit eye movements. However, some studies have reported low-gain pursuit of moving auditory targets (Hashiba et al, 1996; Paige et al, 2000; Krukowski et al, 2001). Here, we explore the possibility that this auditory pursuit might be a response to the motion of an imagined target, by comparing pursuit responses under 3 conditions: combined visual and auditory motion, auditory motion, and an imagined-motion condition in which the trajectory is cued only by brief, stationary, auditory presentations at its end points. We have also explored the dependence of pursuit under these 3 conditions to variations in amplitude and temporal frequency.

II. Methods

- Comparison of oculomotor tracking responses under 3 conditions: combined auditory and visual motion (A+V), purely auditory motion (A), and imagined target motion cued by an auditory "metronome" (I).
- A virtual 3D auditory sound source generated the illusory motion of a sampled real sound source (ringing of a small bell) delivered through stereo headphones.
- Stimulus motion consisted of horizontal sinusoidal oscillation (at either 0.1, 0.2, 0.3, or 0.4Hz).
- In Experiment 1, each block of 24 trials consisted of a sequence of A+V, A and I trials, with the 4 stimulus frequencies randomly interleaved (2 repetitions x 4 frequencies x 3 stimulus types); all trajectories had an amplitude of 30 degrees.
- In Experiment 2, each block of 27 trials consisted of the same sequence of stimulus types (A+V, A, I), with 3 frequencies (0.1, 0.2, 0.4 Hz) and 3 amplitudes (30, 15, 7.5 degrees) randomly interleaved (1 repetition x 3 frequencies x 3 amplitudes x 3 stimulus types).
- The metronome cue for imagined motion consisted of brief (Exp 1: 150ms; Exp 2: 300ms) stationary presentations of the same bell sound, jumping between the 2 extrema at one of the same frequencies, thereby providing the same spatial and temporal information as A albeit without any auditory motion.
- The task for the metronome control was to move the eyes as smoothly as possible between the two end points, phase locked with sound presentations.
- Individualized head-related transfer functions (HRTFs) were measured and used for each observer.
- HRTFs combine interaural timing and intensity differences (ITDs & IIDs) as well as binaural spectral cues.
- Three human observers (one naïve) participated in the two experiments.
- Pupil position of the left eye was monitored using an ISCAN 726 infra-red video-based eye-tracker sampling at 240Hz.
- Visual stimulus was a laser point source back projected onto a screen, manipulated with mirror galvanometers.
- Pursuit amplitude and phase was computed by Fourier analysis of the de-saccaded velocity traces.
- Means and standard deviations calculated for each observer over 3 blocks in both experiments.

References

Hashiba, M., Yasui, K., Watabe, H., Matsuoka, T., & Baba, S. (1996) Acta Otolaryngol (Stockh); Suppl 525: 151-154.
Krukowski, A. E., Begault, D. R., Wenzel, E. M., & Stone, L. S. (2001) Soc. Neuro. Abs. 404.15.
Paige, G.D., Avissar, M., Macuga, K.L., & Giffi, J.T. (2000) Soc. Neuro. Abs. 26: 1713.

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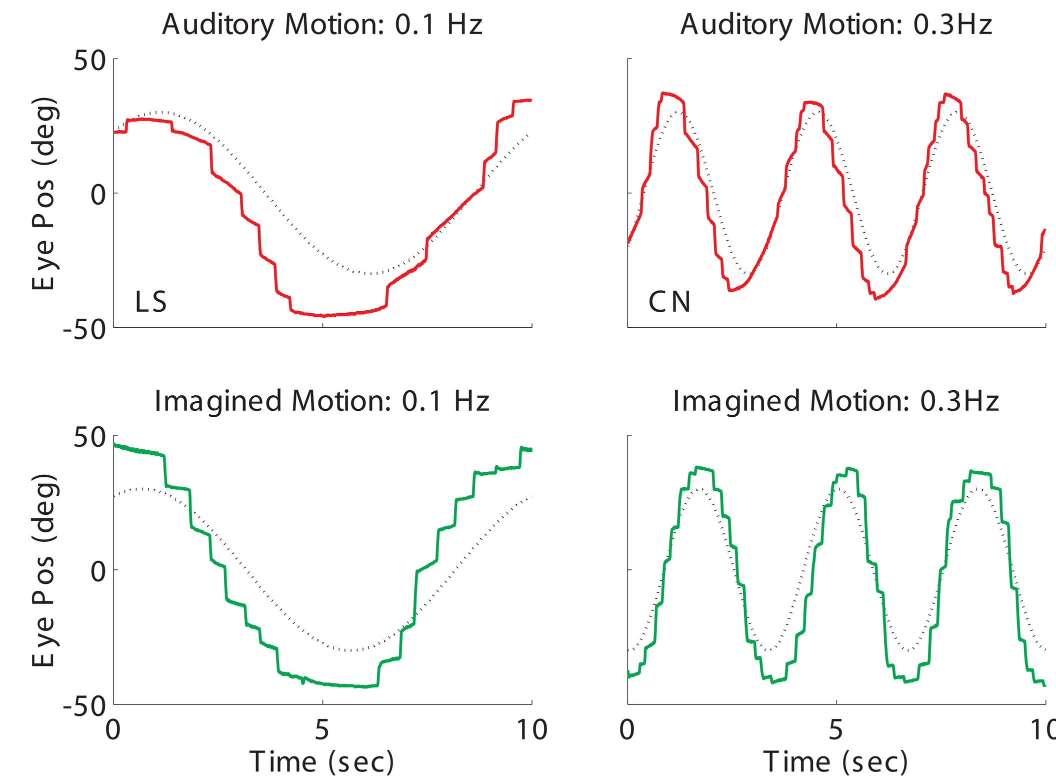
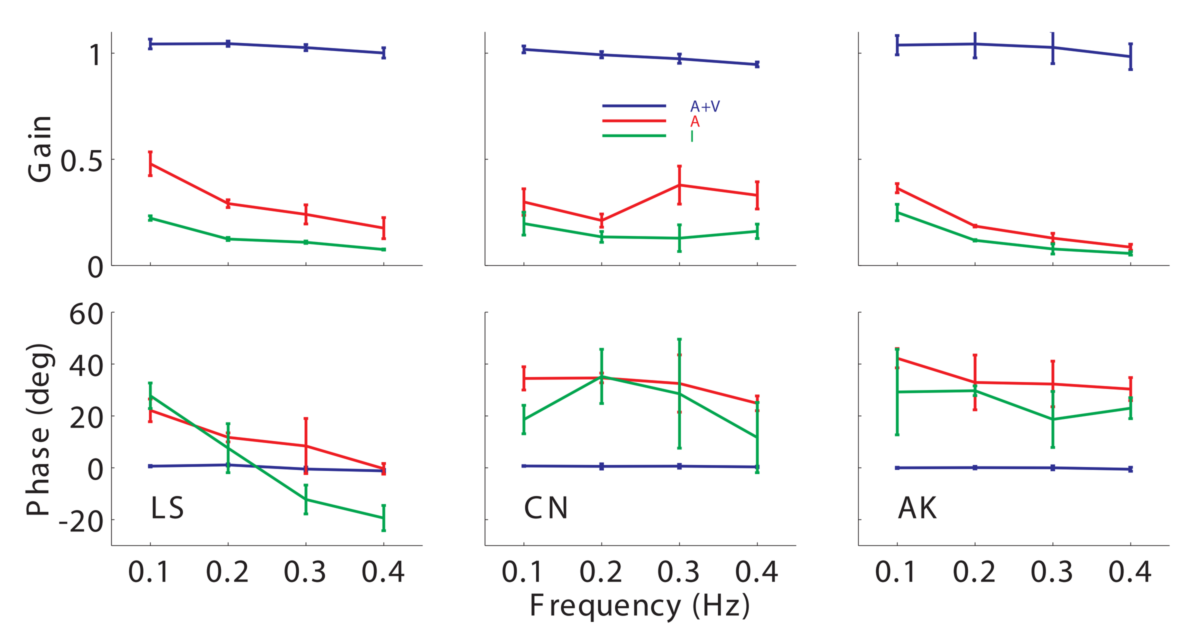
III. Experiment #1: Bode Analysis

Raw Data



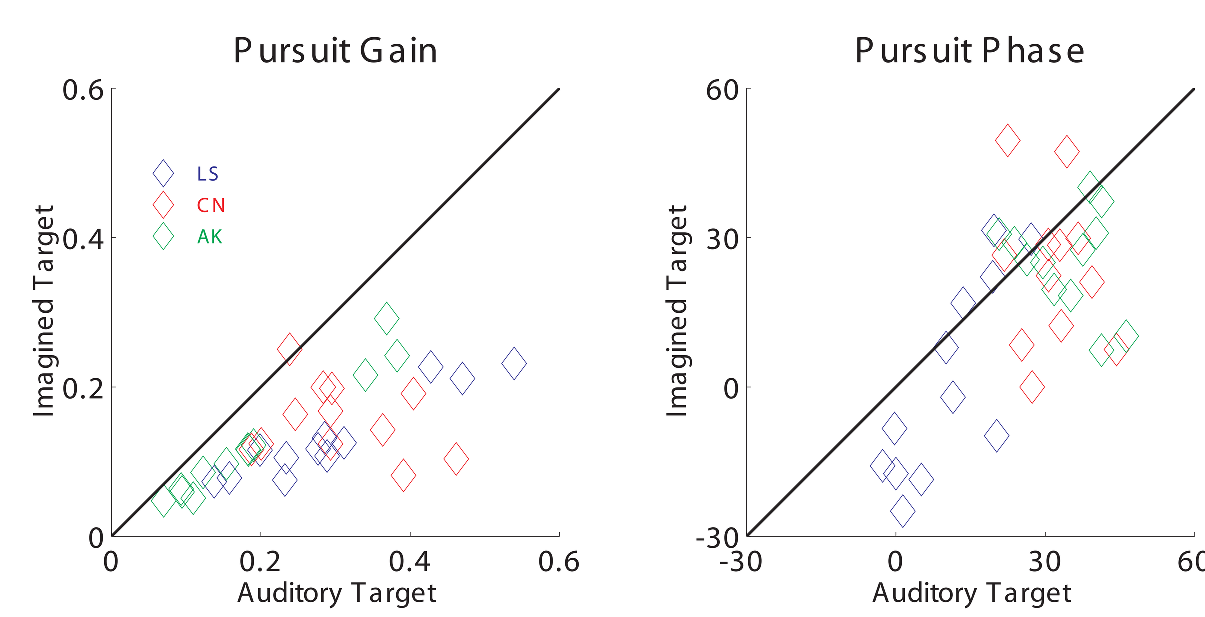
- Smooth (pursuit) epochs between jumps (saccades) for auditory & imagined motion

Pursuit Bode Plots



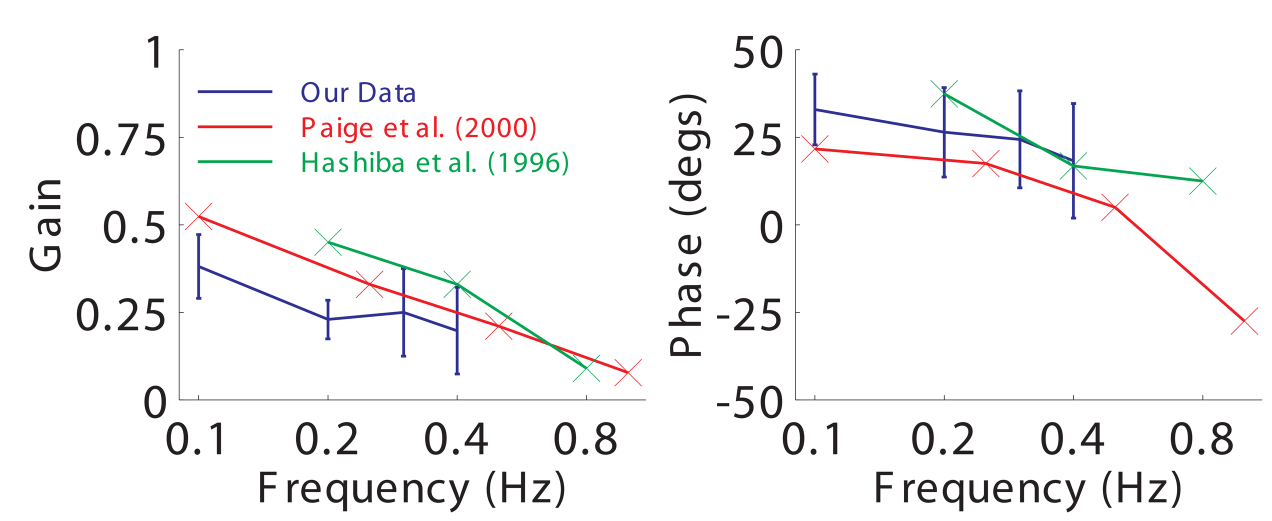
- Pursuit of auditory & imagined motion is reliable, albeit with low gain & phase lead

Auditory vs. Imagined Pursuit



- Pursuit of imagined motion has lower gain than auditory pursuit
- Pursuit of imagined motion has greater phase lag than auditory pursuit

Virtual vs. Real Auditory Pursuit

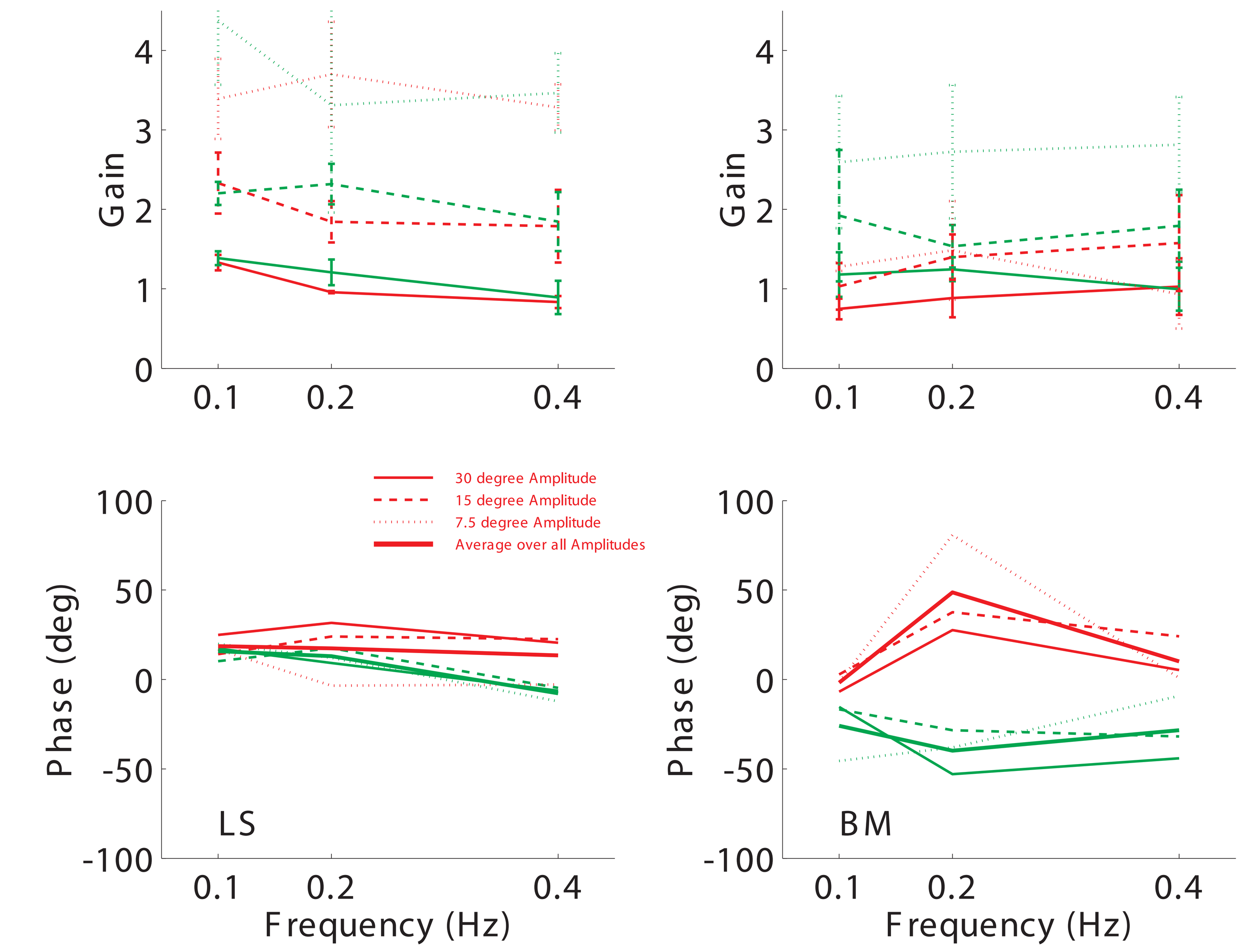


- Pursuit of our virtual sound source is consistent with previous results with real sources

Summary: Auditory pursuit is better than one can imagine

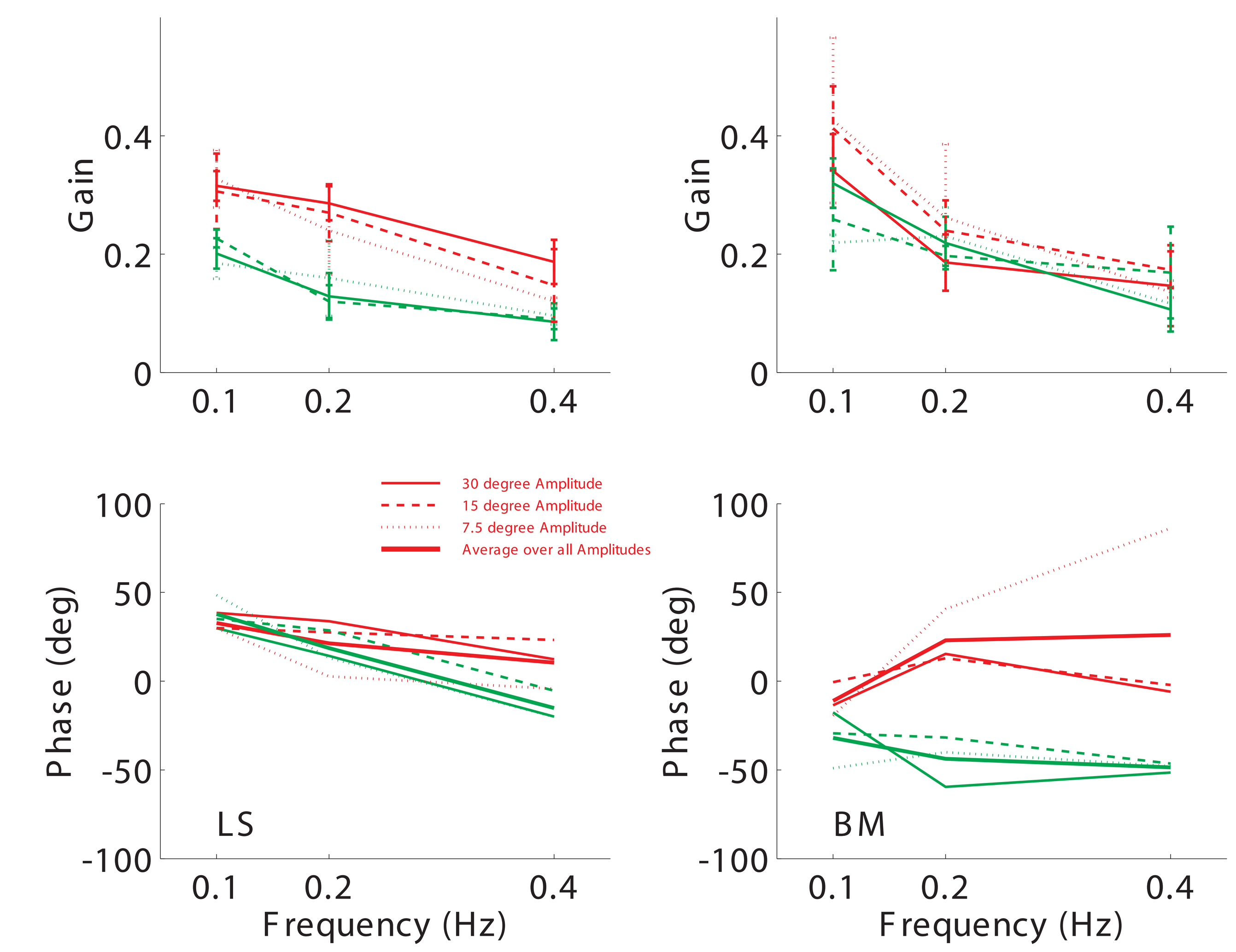
IV. Experiment #2: Effect of Amplitude

Full Tracking Response



- Inter-subject variability, with some observers systematically overshooting the amplitude of the target trajectory.

Normalized Pursuit Bode Plots



- When normalized for inappropriate overall tracking amplitude, pursuit gain appears consistent across stimulus amplitudes.

Summary: Auditory pursuit is still robust even when displacement information is poor.

V. Conclusions

Pursuit of auditory motion cannot be accounted for by pursuit of imagined motion across a range of stimulus frequencies and amplitudes.

Pursuit of imagined motion, cued by sparse timing and displacement information alone without any real motion, can be reliable, although with lower gain than that of auditory motion.

Even observers with little access to information about target displacement can exhibit robust auditory pursuit, suggesting independent access to information about target velocity.

The use of virtual auditory sources will allow future studies to compare the auditory information (ITD, IID and spectral cues) used to support pursuit and localization.