Distinct neural selectivity for 3D directions of visual motion.

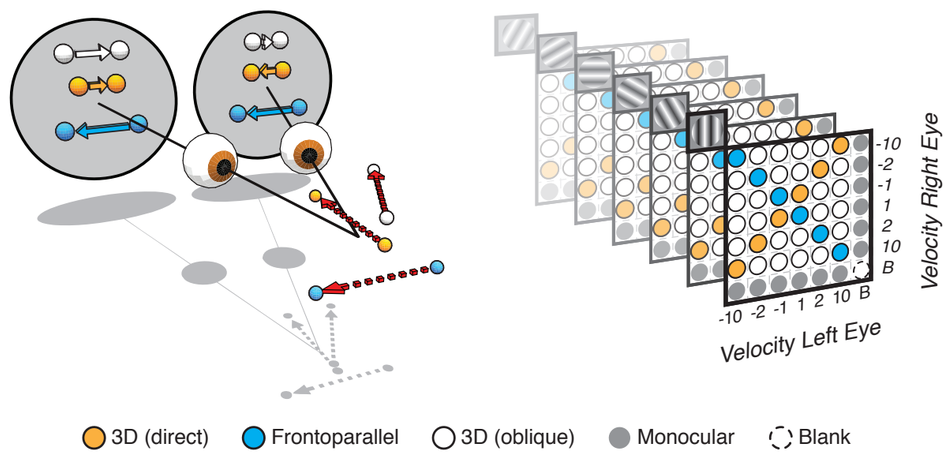
Thaddeus B. Czuba[1], Alexander C. Huk[2], Lawrence K. Cormack[2], Adam Kohn[1]

[1] Dominick P. Purpura Department of Neuroscience, Albert Einstein College of Medicine,
[2] Center for Perceptual Systems, Departments of Neuroscience & Psychology, The University of Texas at Austin

3D motion produces different motion signals in the two eyes

(Euclid, 300 BC)

- Mounting behavioral evidence for distinct 3D motion mechanisms
  (Cumming & Parker 1994; Shioiri et al., 2000; Rokers et al., 2008; Czuba et al., 2011)
- fMRI evidence for 3D motion selectivity in human MT & MST
  (Rokers et al, 2009)
- Surprisingly little electrophysiological evidence for binocular 3D motion mechanisms
  (Zeki, 1974; Cynader & Regan, 1982; Maunsell & Van Essen, 1983b; Poggio & Talbot, 1981, Spleers et al. 1990; Sanada & DeAngelis, SfN 2012)
- Neurons in primate area MT selective for components of binocular 3D motion cues
  - Static disparity & Frontoparallel (2D) motion.
    (Maunsell & Van Essen, 1983a)



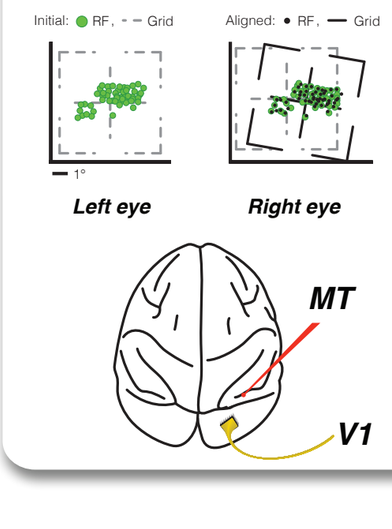
Do MT neurons encode 3D motion?

- Measure binocular motion tuning with stimulus ensemble spanning physiological and behavioral sensitivities
  (Beverley & Regan, 1975; Maunsell & Van Essen, 1983a; Czuba et al., 2010)
  - Drifting binocular gratings
  - Fully crossed matrix of monocular velocities
  - Extensive disparity controls & assessment
- Understand how 3D tuning:
  - Relates to known frontoparallel & disparity sensitivity
  - Arises from the combination of inputs to the two eyes

Displays & recording

- Binocular presentation via mirror stereoscope & dual CRT displays
- Extracellular recording from anesthetized macaque
  V1: 96 channel 'Utah' array (Blackrock Systems)
  MT: 7 tetrode/electrode array (Thomas System)

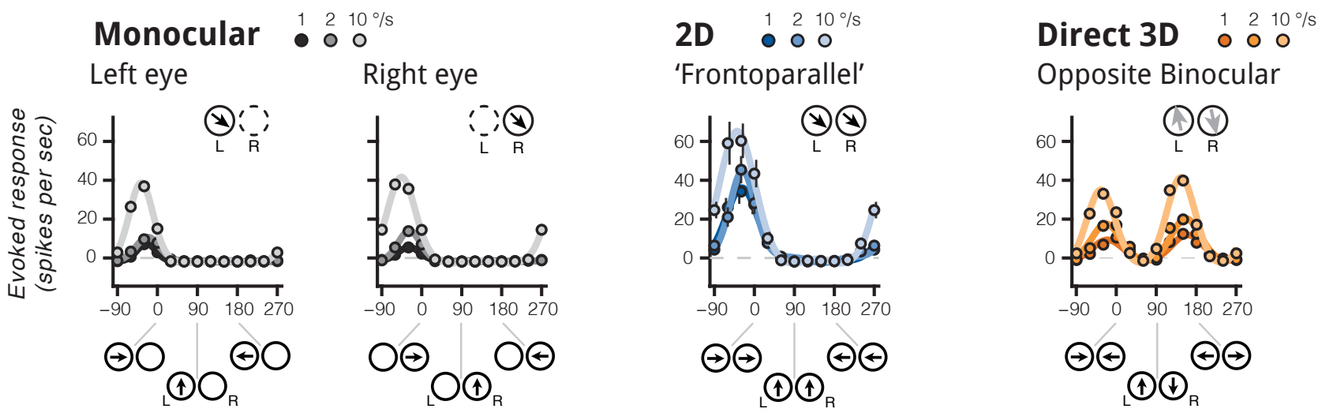
Functional Binocular Alignment



- Problem of vergence drift under general anesthesia
- Simultaneous V1 array implant (96-channel 'Utah' array)
- High-res monocular V1 receptive field (RF) maps
- Matrix transform [x, y, θ] to align RFs
- Translation & rotation to align binocular stimul

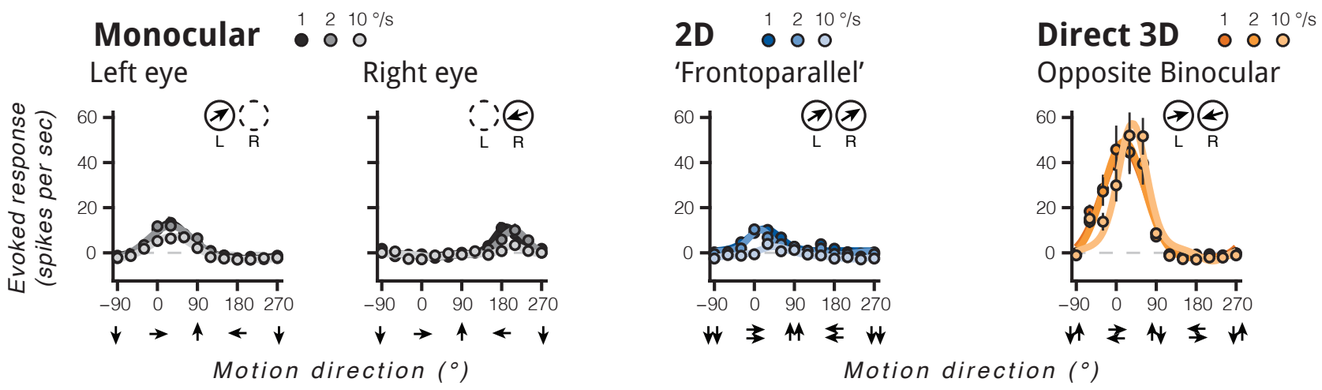
Binocular tuning characteristics & example cells

Classic 2D motion tuned cell



- Monocular response predictive of 2D motion
- Bimodal (non-selective) 3D motion response

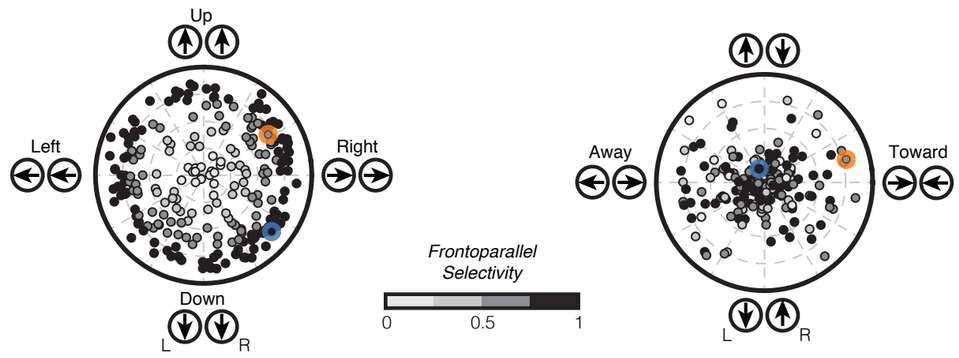
Distinct 3D motion tuned cell



- Different direction preference between eyes
- Strong directional tuning for 3D motion

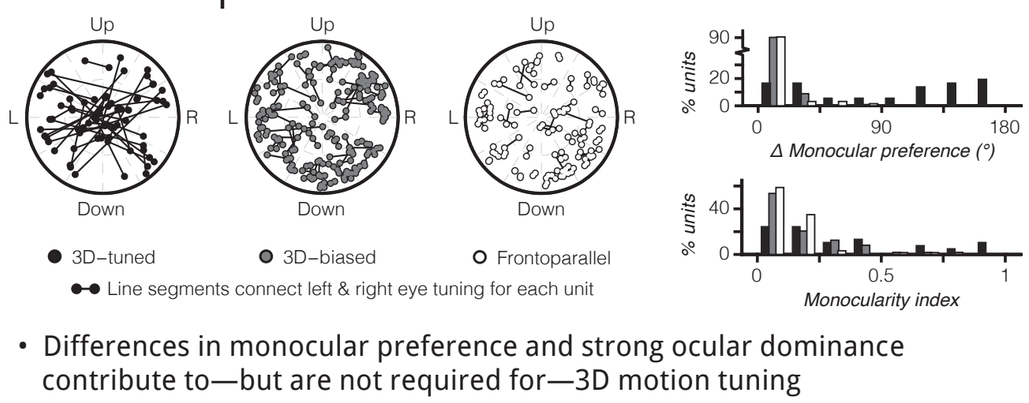
Tuning across MT population (n=236)

- 2D motion selectivity typical of MT
- Selectivity for Direct 3D motion biased for horizontal motions



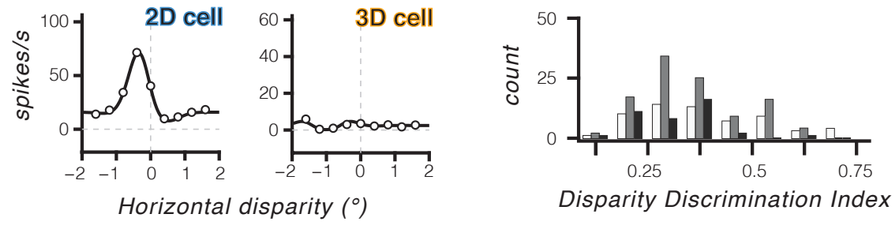
Is 3D tuning predicted by component selectivity?

Monocular preference & ocular dominance



- Differences in monocular preference and strong ocular dominance contribute to—but are not required for—3D motion tuning

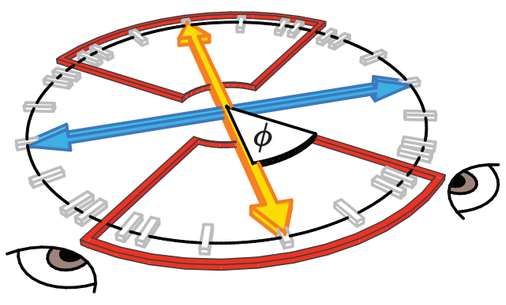
Static disparity tuning is not predictive of 3D tuning



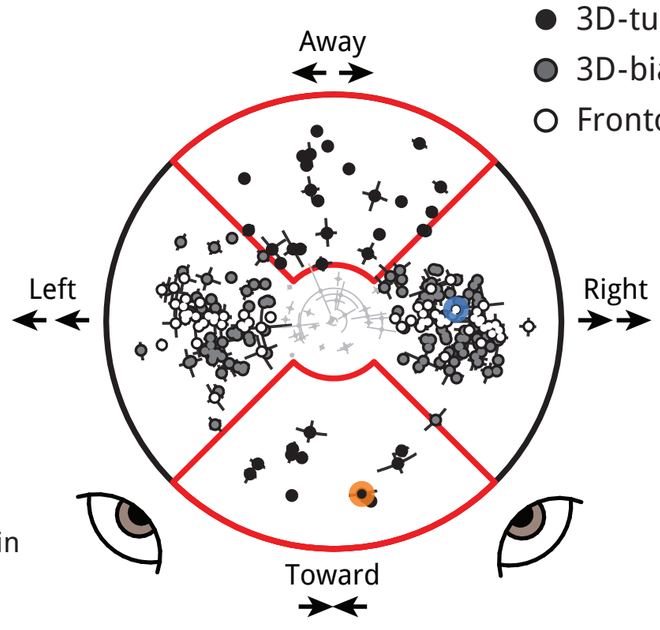
Binocular motion tuning in 3D direction space

- 3D direction computed from ratio of monocular velocities

$$\phi = \operatorname{atan2}\left(V_{RE},\ V_{LE}\right) - \frac{\pi}{4}$$



- Trajectories span a plane through depth
- 89% of recorded units were well tuned in this space (210 of 236)



- 3D-tuned (17%)
- 3D-biased (53%)
- Frontoparallel (30%)

Clear and distinct 3D motion tuning in primate MT

- 70% of MT units encode 3D motion
- Overrepresentation of trajectories directly approaching/receeding

3D tuning is independent of known sensitivities for frontoparallel motion & static disparity

Mechanisms involve:

- Distinct direction preference in the two eyes
- Nonlinear binocular interactions

Published article: Czuba, et al., Area MT Encodes Three-Dimensional Motion., J. Neurosci. (2014).

www.visualstimul.us

Contact: czuba@utexas.edu