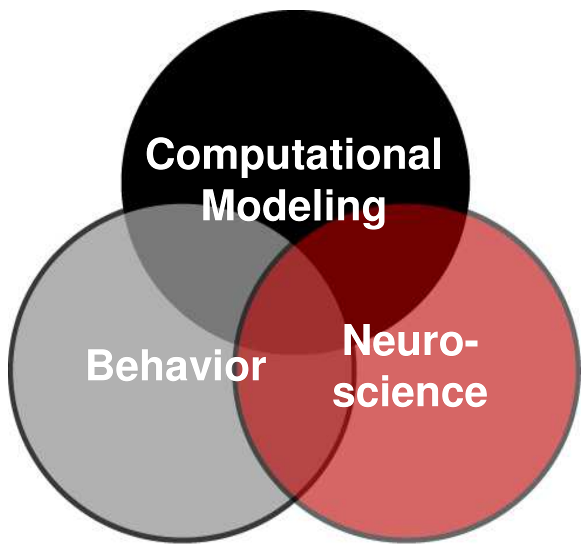
YORK UNIVERSITÉ UNIVERSITY

York Centre for Vision Research

Workshop on Perspectives for Future Directions in Computational and Mathematical Neuroscience

Levels of theory in Sensorimotor Neuroscience



General Workshop Goals:

(i) Definition of the field

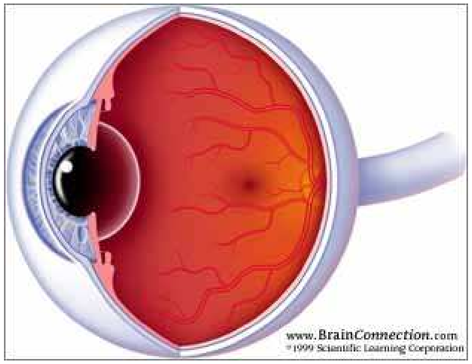
(ii) Research highlights in the field

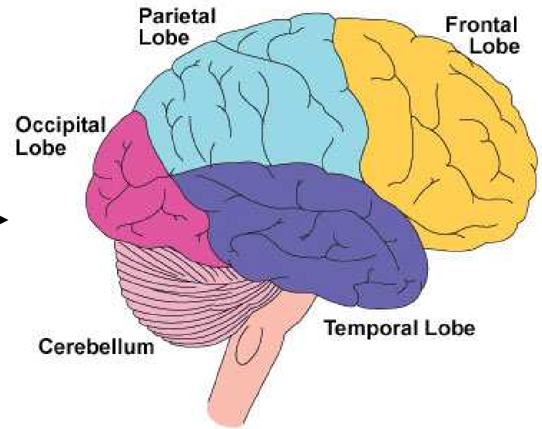
(iii) Critical considerations for someone wanting to enter the field today

(iv) Ideal type(s) of training

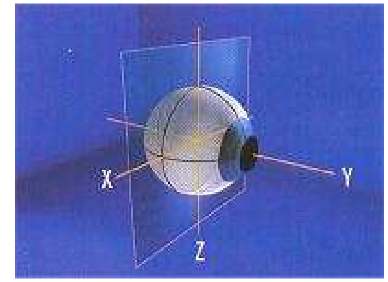
(v) Suggested changes and directions for the field.

Vision

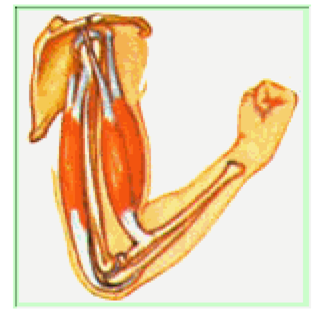




Eye Movement



Arm Movement



How do we approach this question?

The Scientific Method: Experimental tests of hypotheses

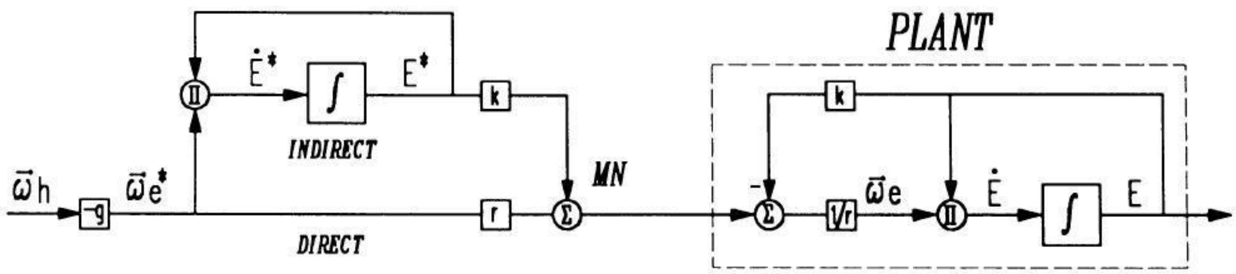
Problem: Intuitive hypotheses often do not capture the complexity of the brain and behavior

Solution: Formalize hypotheses as computational models that can be tested

Survey of Examples From My Lab:

- Role that Computational Modeling has played in our work
  - Vestibulo-ocular Reflex
  - Rapid Gaze Movements
  - Spatial Updating
  - Visually Guided Reach
- Key points:
  - Synergy between theory and experiment
  - Predictive power of models as formal Hypotheses
  - Moving between different levels of theory

3-D VOR Model (1988-1991)



Crawford & Vilis (1991) *J. Neurophysiol.*

Predictions

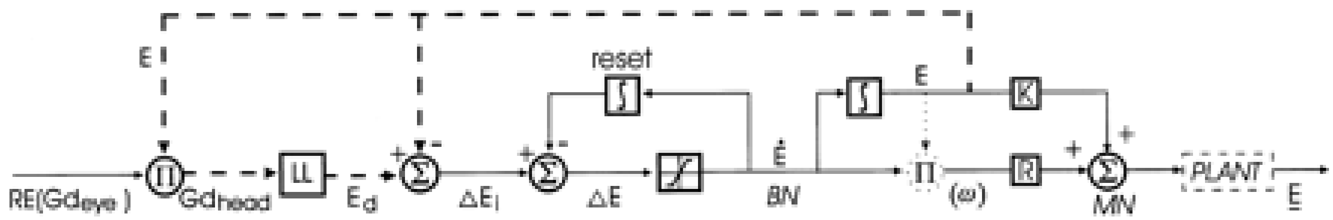
1) eye rotates about same axis as head during VOR
2) VOR violates Listing's law of eye

Crawford JD, Vilis T. (1991) Axes of eye rotation and Listing's law during rotations of the head. *J Neurophysiol* 65:407-23.

3) need a three-dimensional 'neural integrator'

Crawford JD, Cadera W, Vilis T. (1991) Generation of torsional and vertical eye position signals by the interstitial nucleus of Cajal. *Science* 252:1551-3.

3-D Saccade Model (1993-1997)



Crawford (1994) *J. Neurosci.;* Crawford & Guitton (1997) *J. Neurophysiol.*

Predictions

1) brainstem ‘coordinates’ align with Listing’s plane

Crawford JD. (1994) The oculomotor neural integrator uses a behavior-related coordinate system. *J Neurosci.* 14:6911-23.

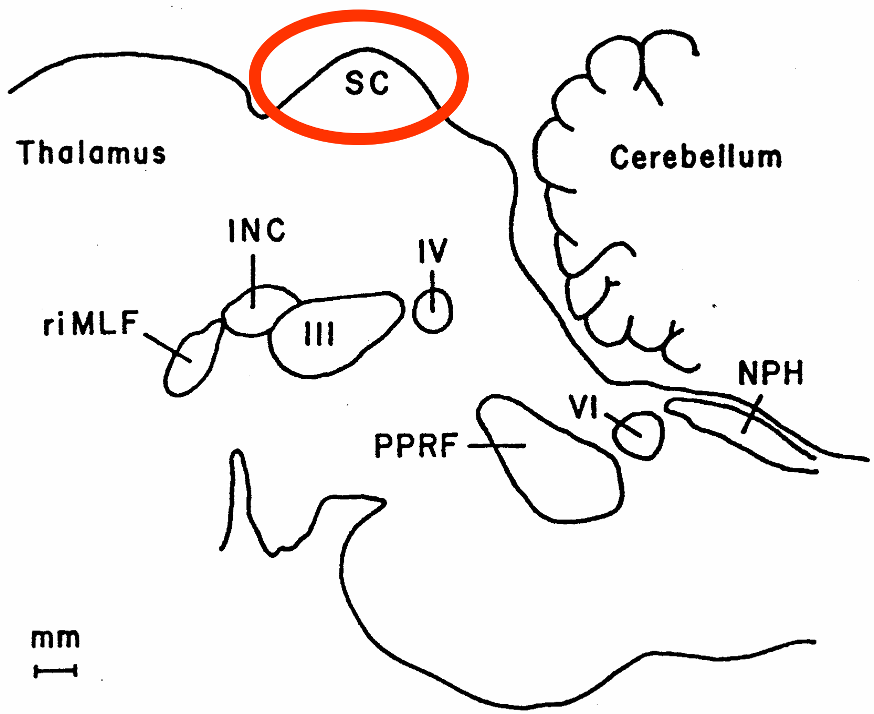
2) saccade generator accounts for initial eye orientation.

Klier EM, Crawford JD. (1998) Human oculomotor system accounts for 3-D eye orientation in the visual-motor transformation for saccades. *J Neurophysiol.* 80:2274-94.

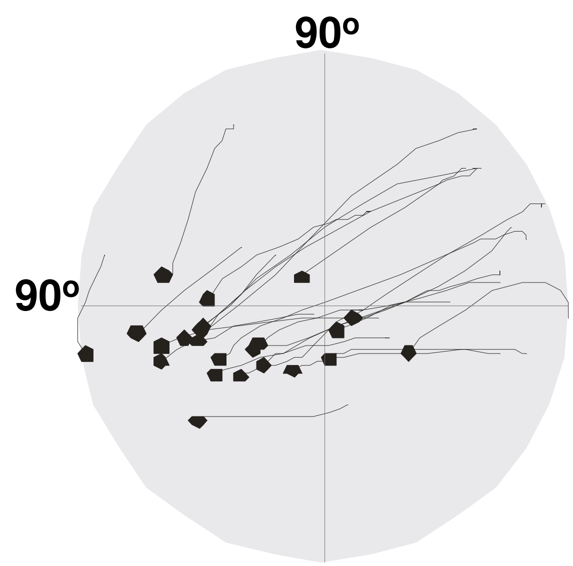
3) superior colliculus has an eye-centered map of space

Klier EM, Wang H, Crawford JD. (2001) The superior colliculus encodes gaze commands in retinal coordinates. *Nat Neurosci.* 4:627-32.

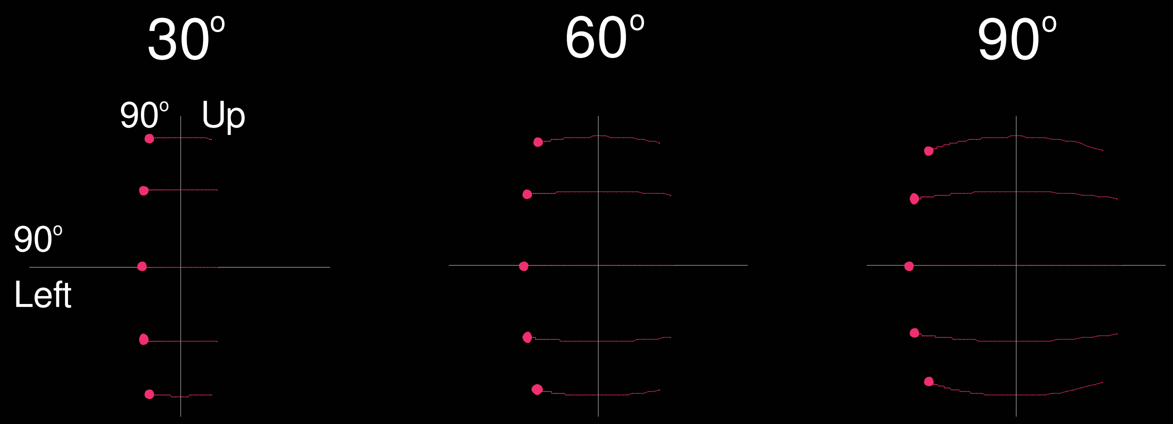
Gaze Coding in Superior Colliculus (SC)

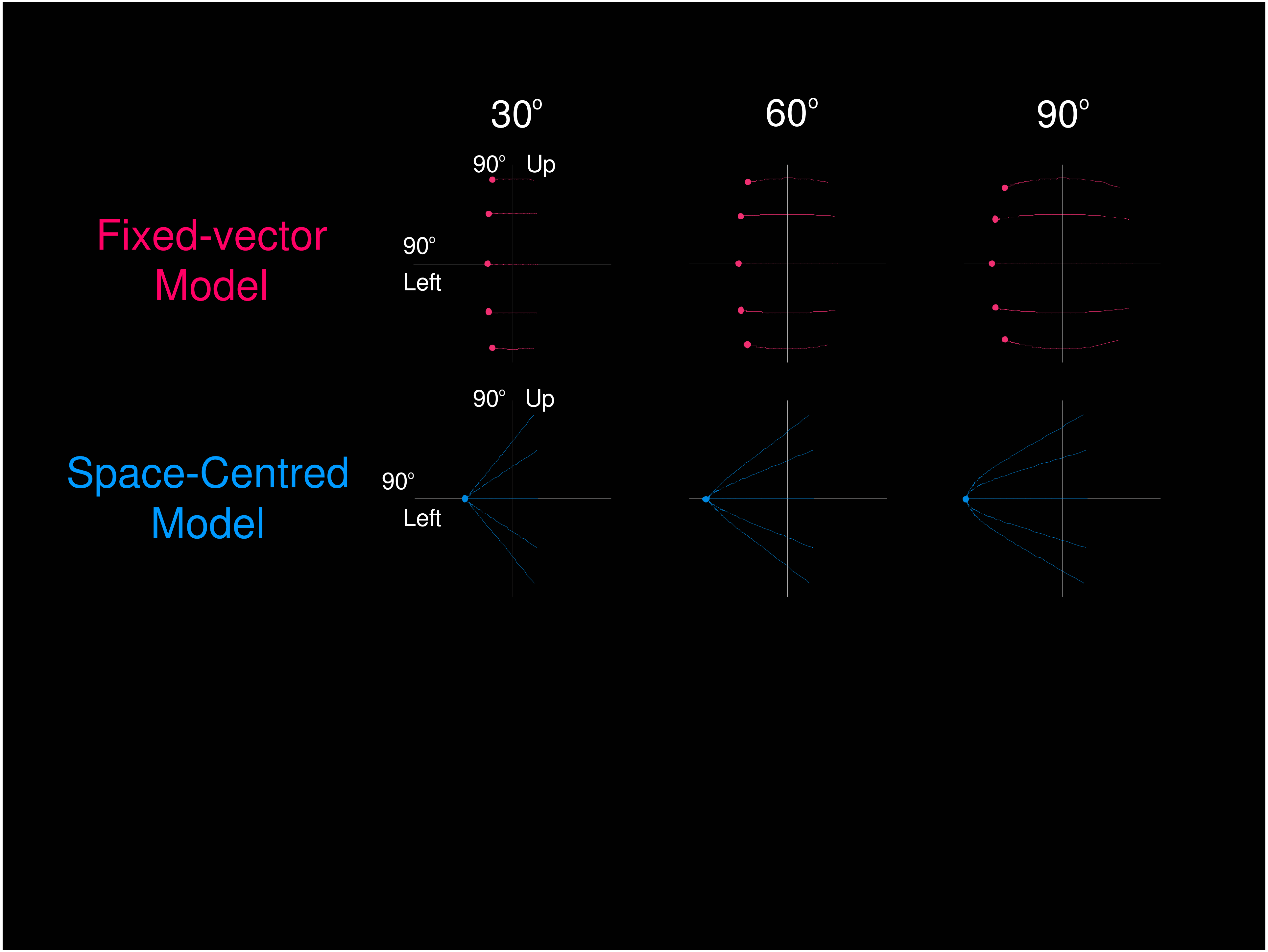


Gaze Shifts
During SC Stimulation

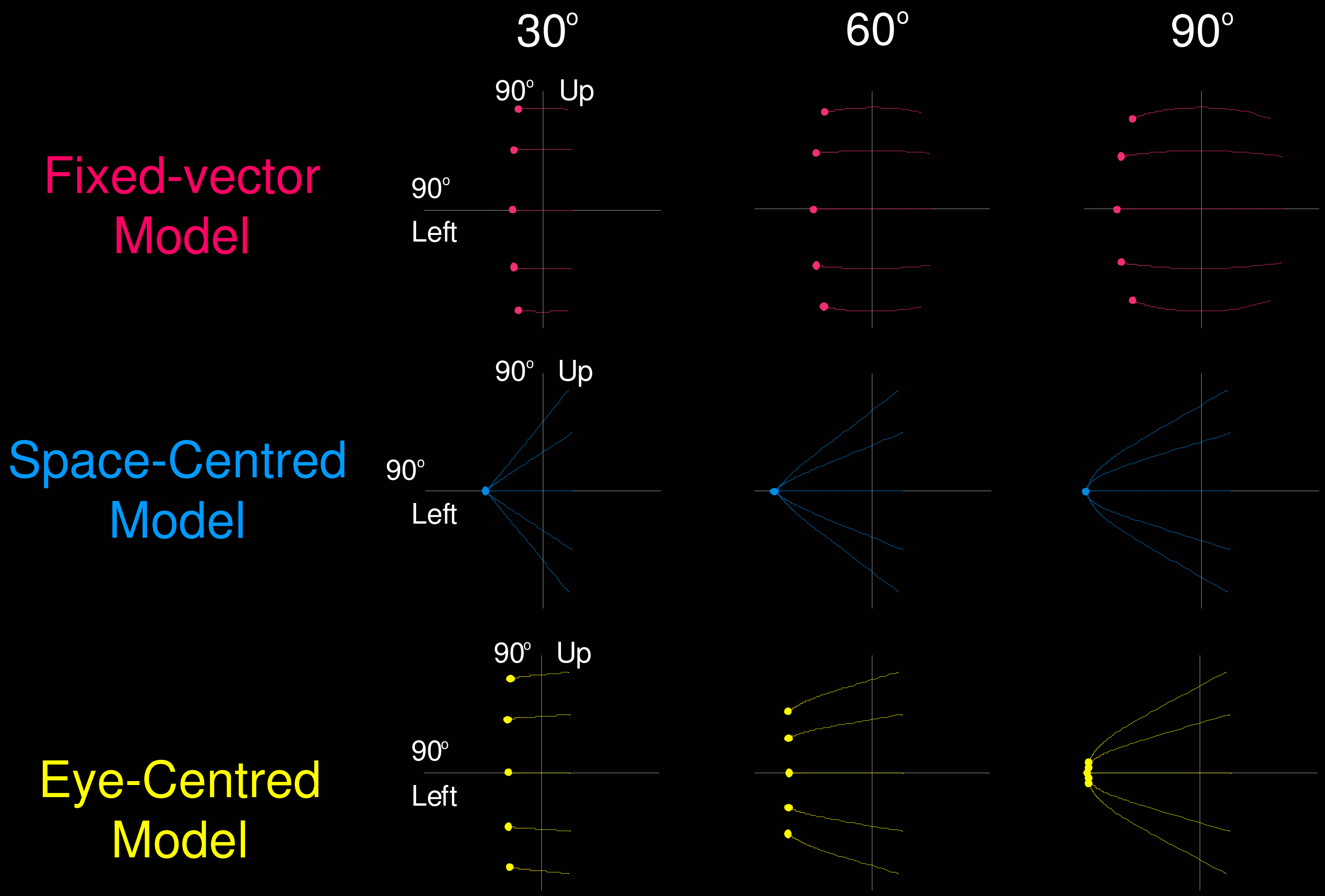


Fixed-vector Model



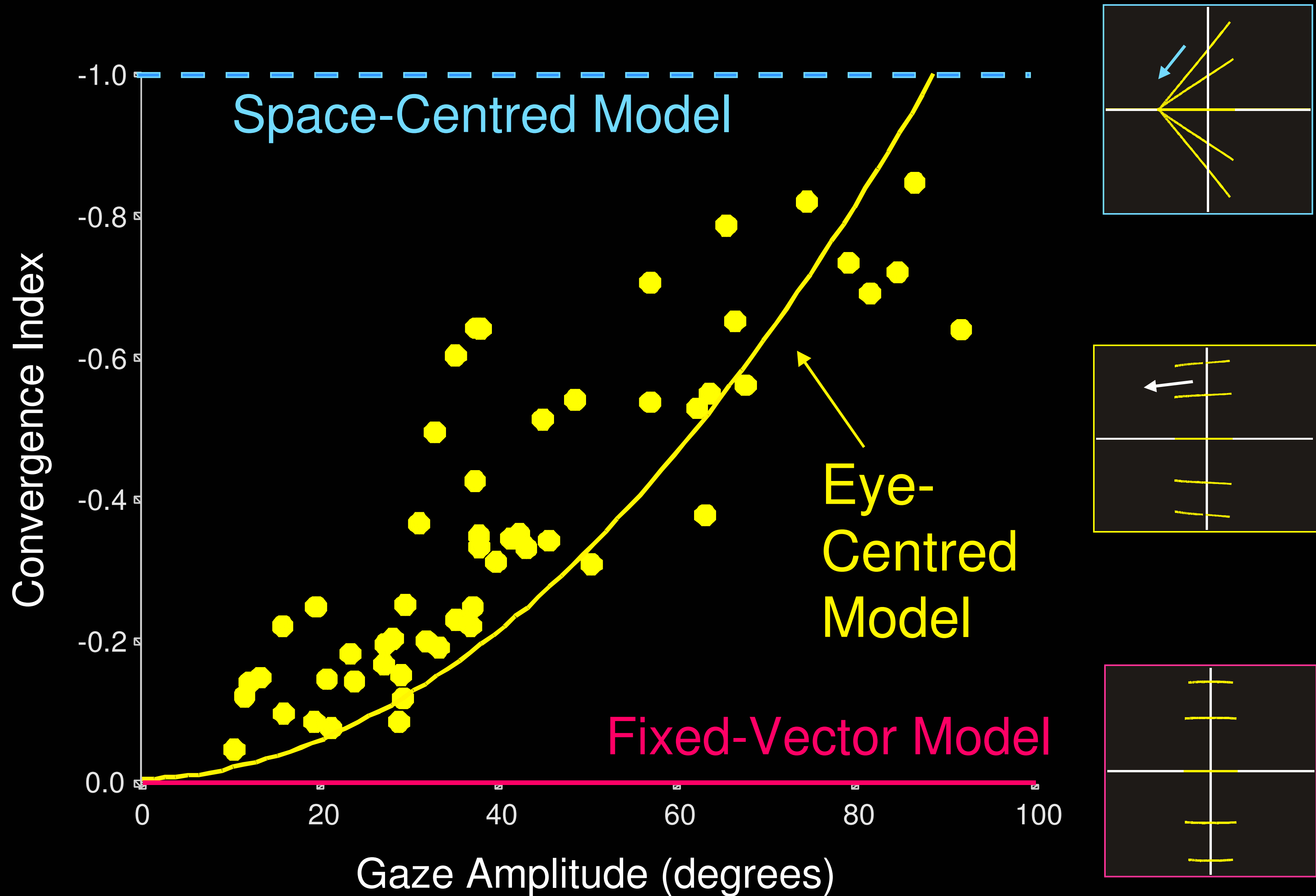


30°
60°
90°
Fixed-vector Model
Space-Centred Model
90° Up
90° Left
90° Up
90° Left

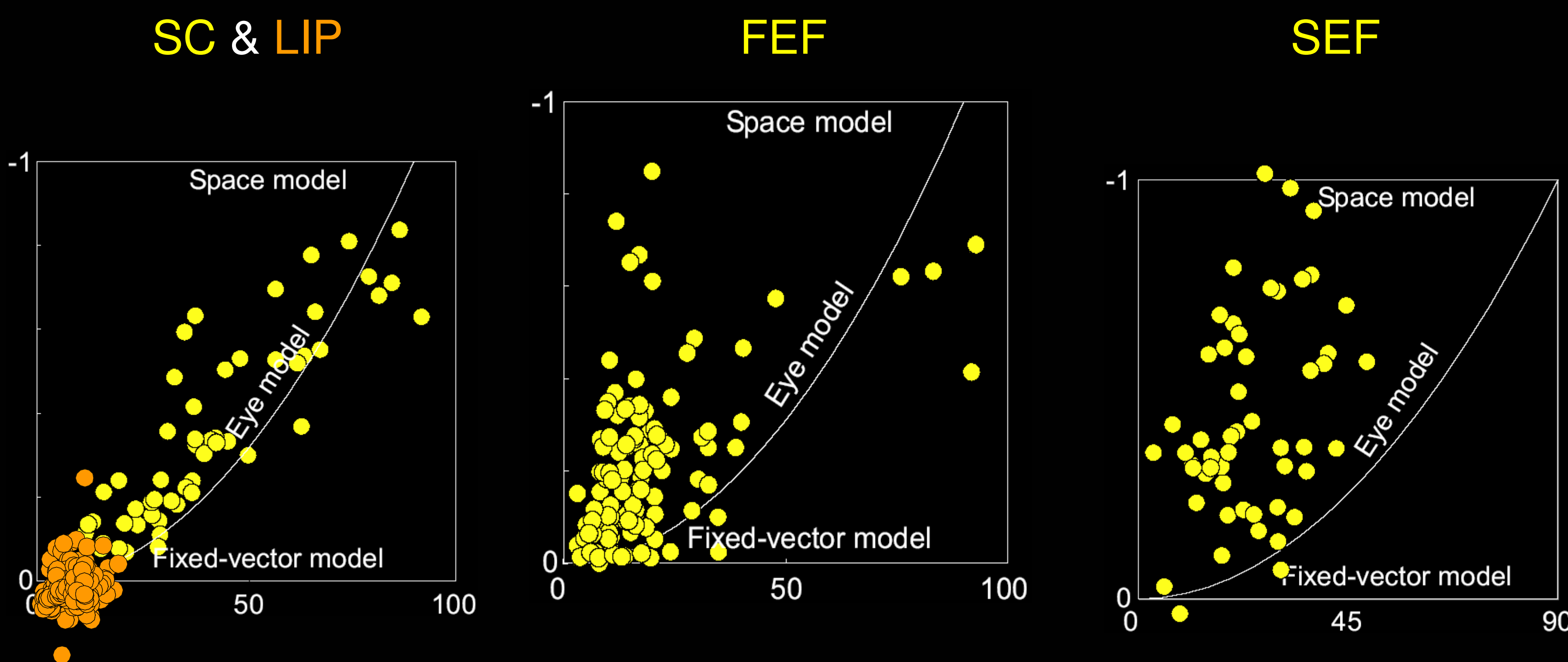


(Crawford & Guitton *J. Neurophysiol.* 1997)

(Stimulation Data: Klier et al. *Nature Neuroscience*, 2001)



Comparison across brain sites

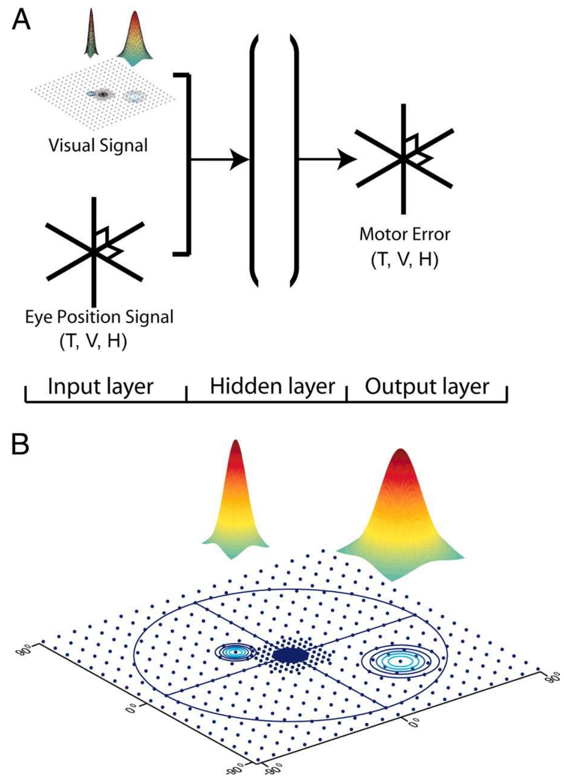


Eye-centered RF
(Klier et al. 2001 *Nature Neurosci.)*

Transition between SC and SEF

Multiple RFs
(Martinez-Trujillo et al. *Neuron* 2004)

Neural Net Version (2001-2005)

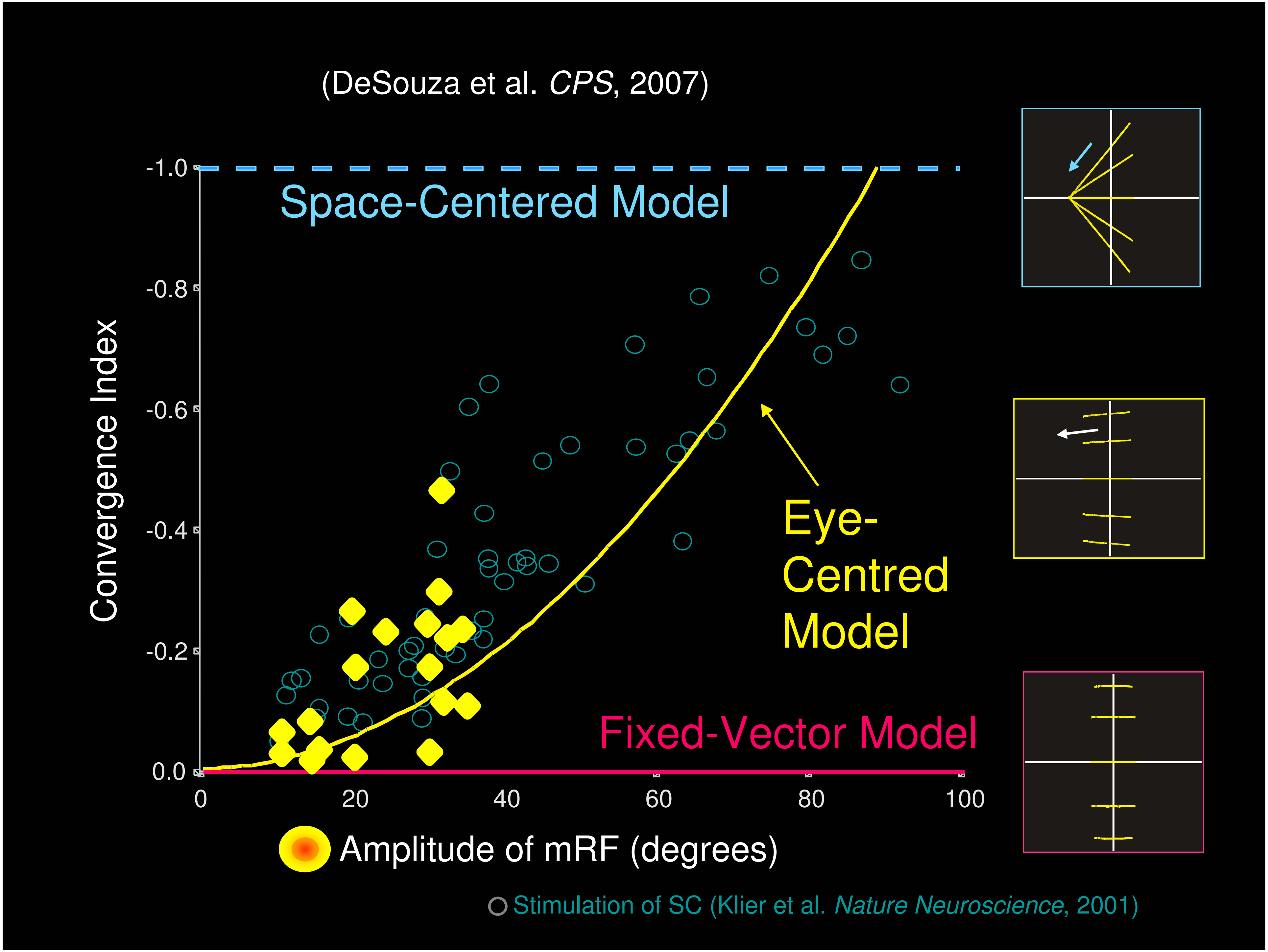


Smith & Crawford (2005)
J. Neurophysiol.

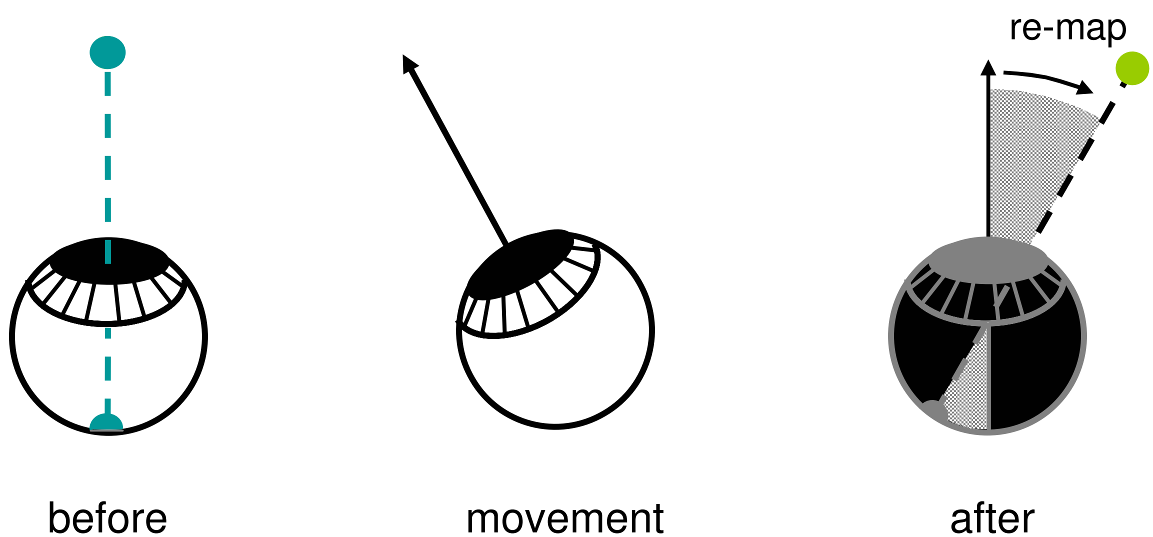
Predictions

1) superior colliculus units have eye-centered receptive fields with non-linear eye position modulation

DeSouza, J.F.X., Yan, X., Blohm, G., Wang, H., & Crawford, J.D. (2006). Gaze position effects and position-dependent motor tuning in primate superior colliculus (SC) neurons during head-unrestrained visually guided movements. *Society for Neuroscience Abstracts.*


(DeSouza et al. *CPS*, 2007)
Space-Centered Model
Eye-Centred Model
Fixed-Vector Model
Convergence Index
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
0
20
40
60
80
100
Amplitude of mRF (degrees)
Stimulation of SC (Klier et al. *Nature Neuroscience*, 2001)

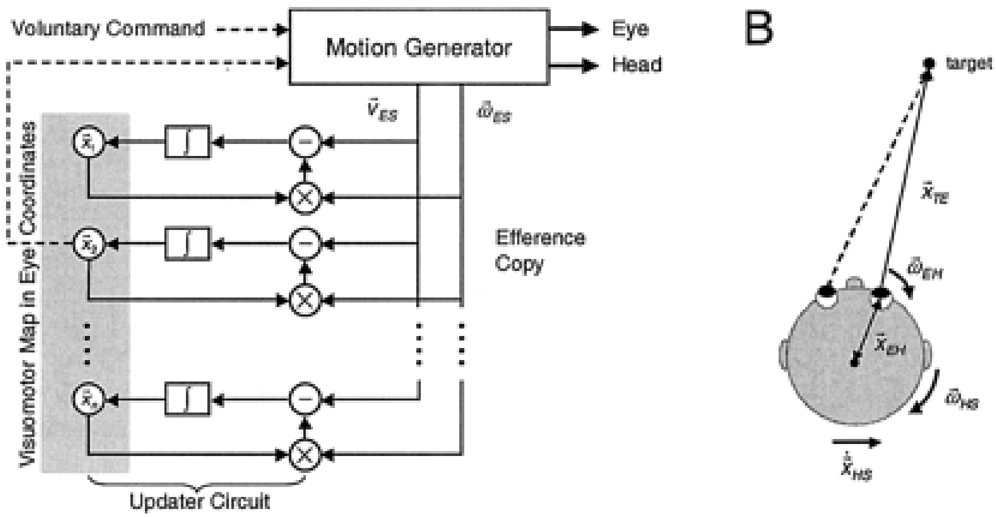
Spatial Updating & 'Remapping'



Spatial Updating Models (1999-2003)

Smith et al. (2001)
J. Neurophysiol.

Medendorp et al.
(2002, 2003)
J. Neurosci.



Predictions

1) parietal cortex activity ‘updated’ during eye movements

Medendorp WP, Goltz HC, Vilis T, Crawford JD. (2003) Gaze-centered updating of visual space in human parietal cortex. *J Neurosci*. 23:6209-14.

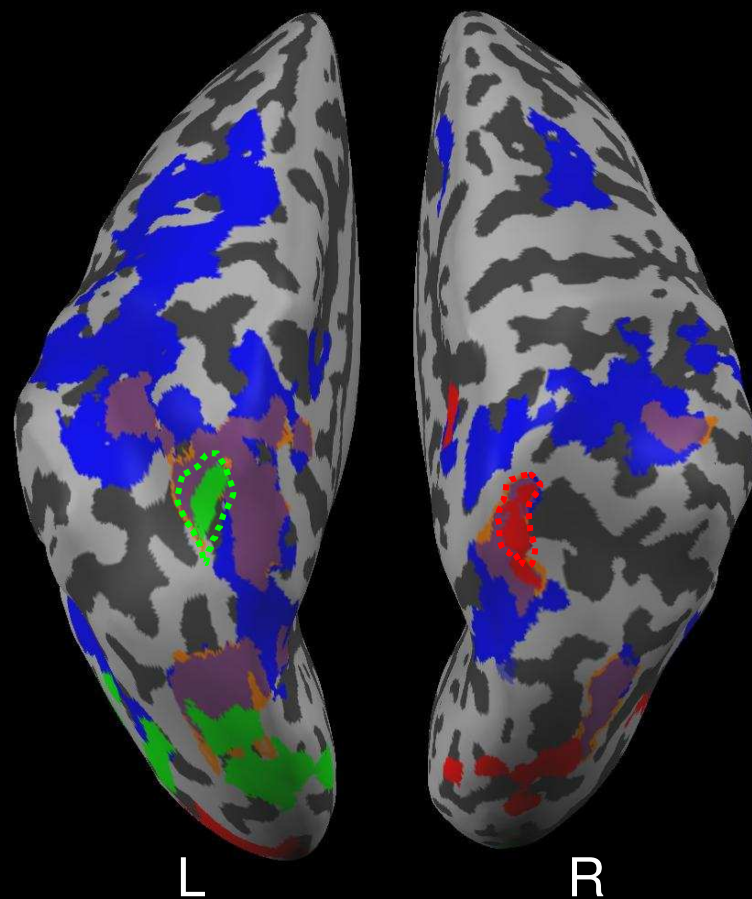
Pointing Topography

Rightward Pointing   Leftward Pointing

Saccades

Pointing

Both



Medendorp et al.
J. Neuroscience
2003

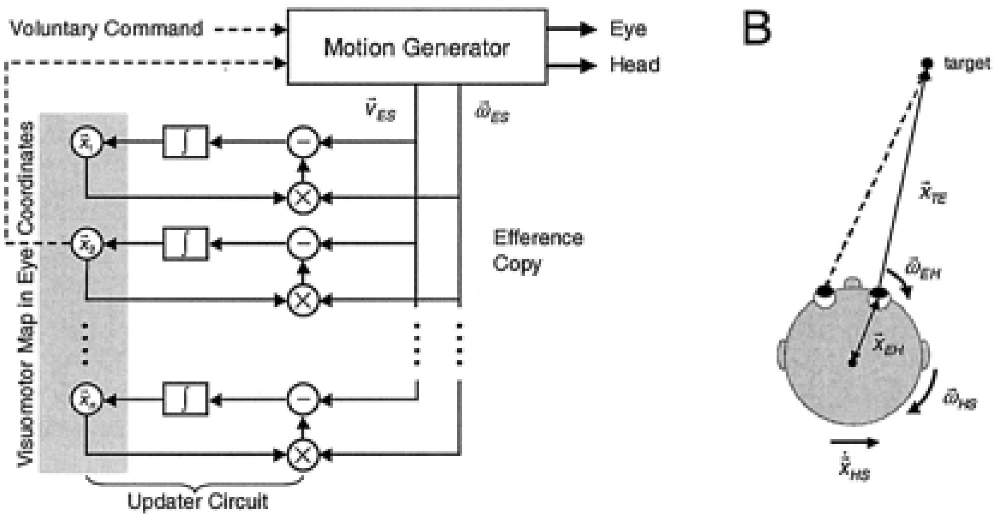
Medendorp
et al.
J. Neuroscience
2003

Does this spatially-selective activity remap during saccades?

Spatial Updating Models (1999-2003)

Smith et al. (2001)
J. Neurophysiol.

Medendorp et al. (2002, 2003)
J. Neurosci.



Predictions

1) parietal cortex activity 'updated' during eye movements

Medendorp WP, Goltz HC, Vilis T, Crawford JD. (2003) Gaze-centered updating of visual space in human parietal cortex. *J Neurosci*. 23:6209-14.

2) parietal damage leads to eye-centered deficits in reaching

Khan AZ, Pisella L, Vighetto A, Cotton F, Luaute J, Boisson D, Salemme R, Crawford JD, Rossetti Y. (2005) Optic ataxia errors depend on remapped, not viewed, target location. *Nat Neurosci*. 8:418-20.

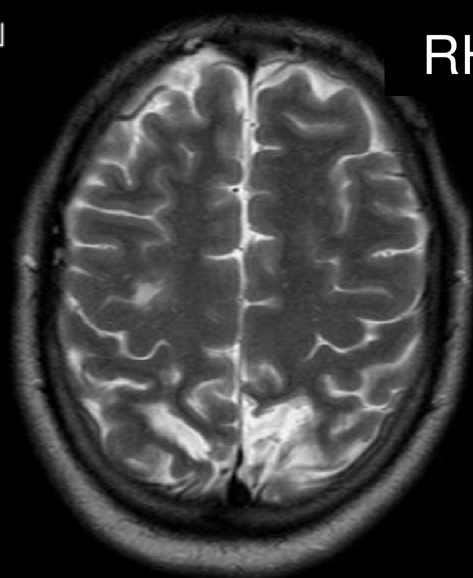
A. Khan et al.
Nature Neuroscience
2005

O.K.

RH

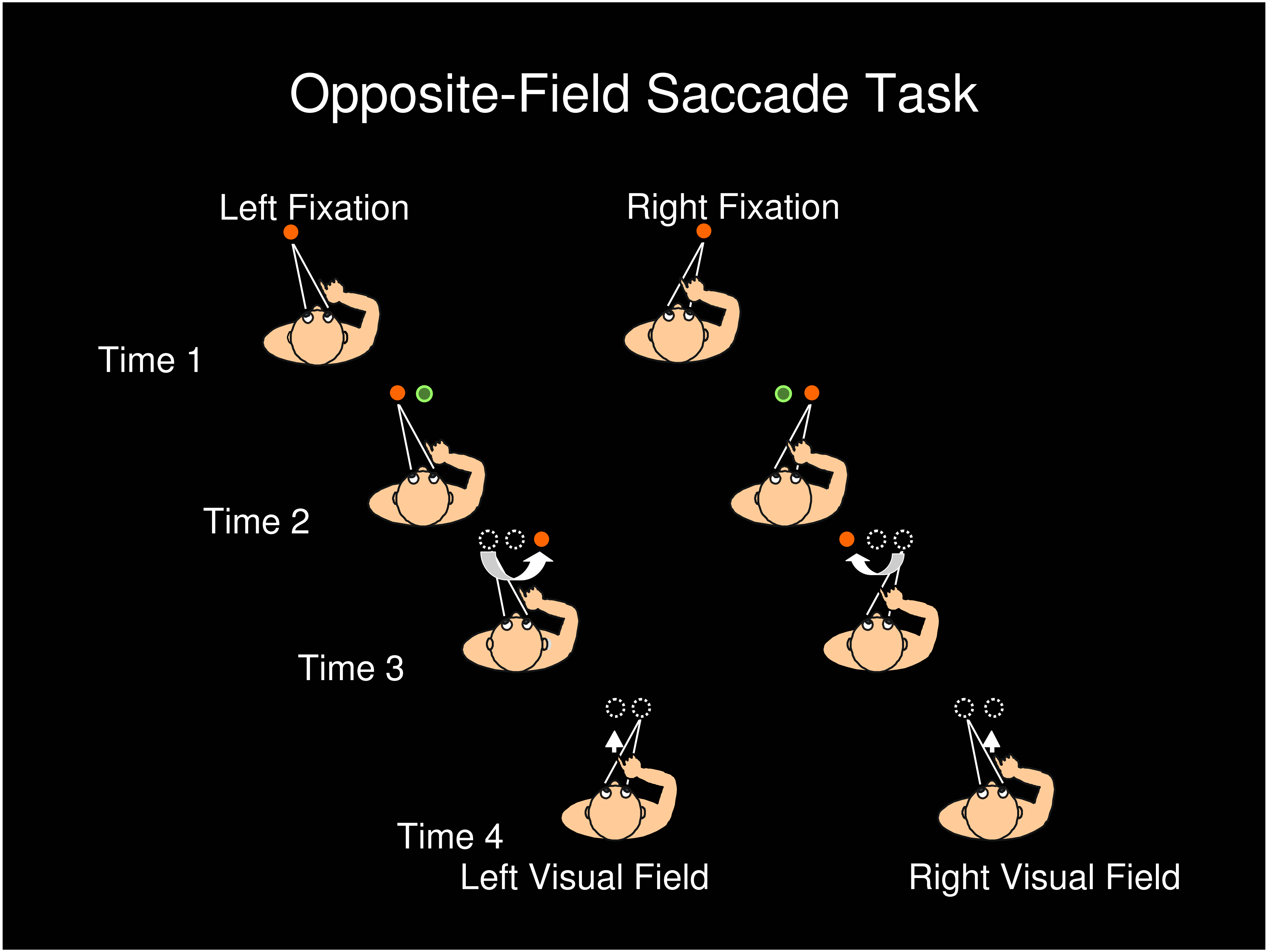
- 39 year-old right-handed male
- Right Parietal Cortex Lesion

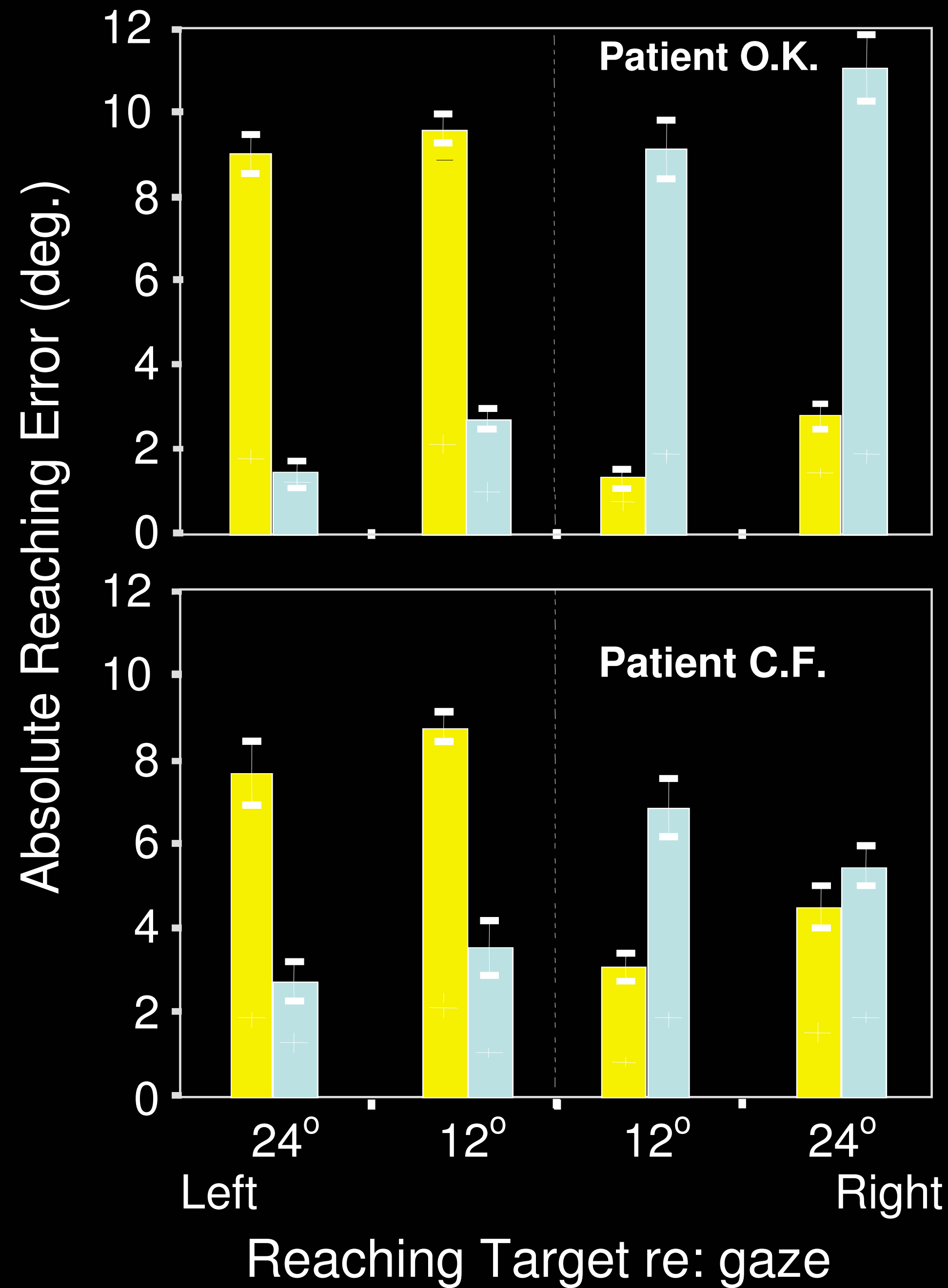
C.F.



RH

- 27 year-old right-handed male
- Bilateral Damage
- Unilateral (Right Parietal) OA


Opposite-Field Saccade Task
Left Fixation
Right Fixation
Time 1
Time 2
Time 3
Time 4
Left Visual Field
Right Visual Field



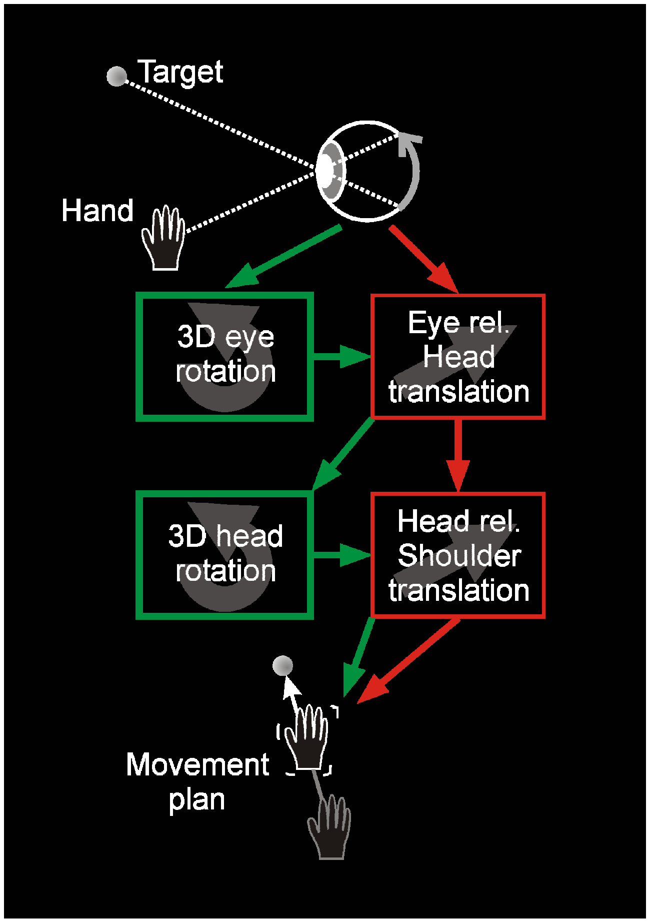
A. Khan et al.
Nature Neuroscience
2005

Fixation Task

Opposite Field Saccade Task

(Target in initial gaze coordinates, before Saccade)

Visually-Guided Reach (2005-2007)



Blohm and Crawford (2007) *Journal Of Vision*

Predictions

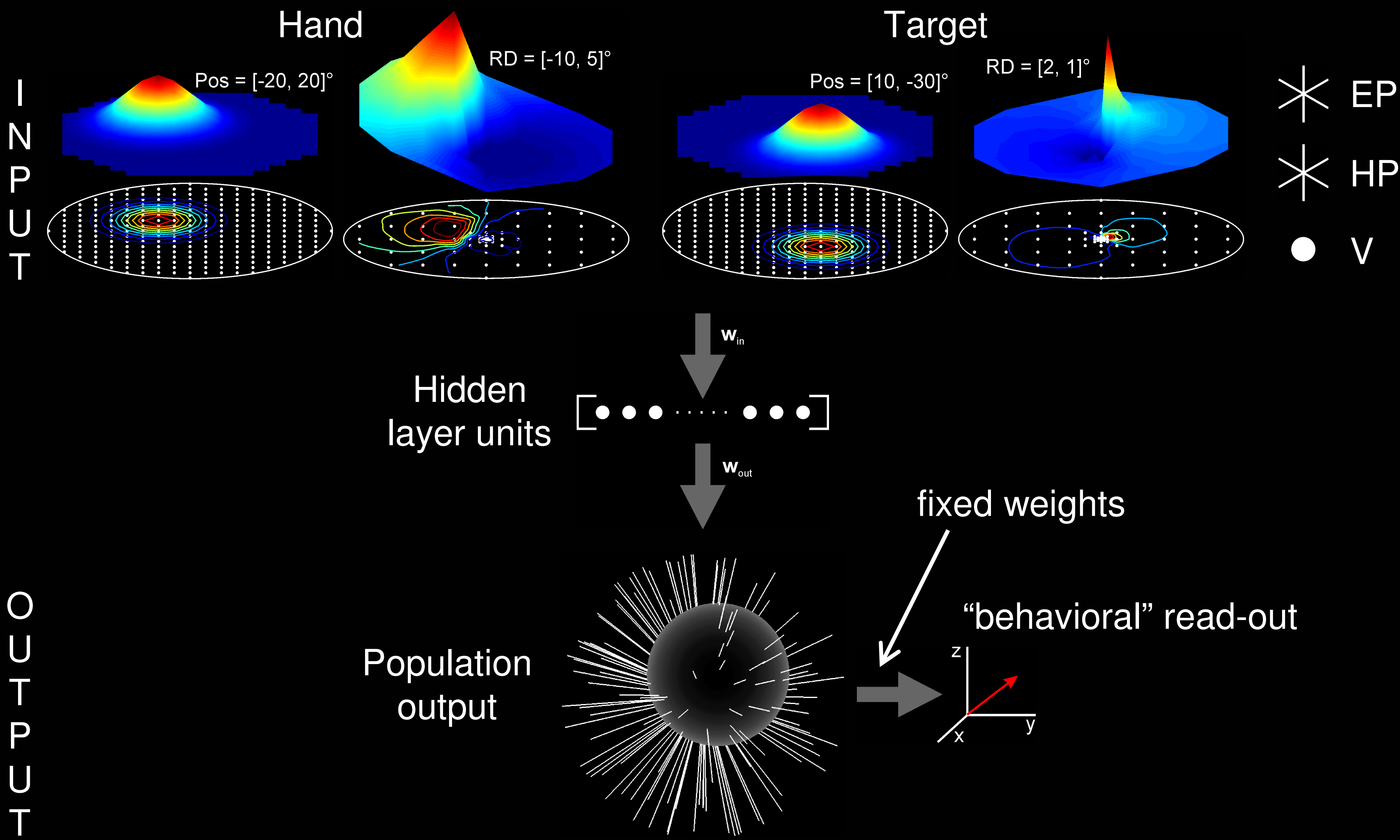
1) Optimal Reaching in Normal Subjects

Blohm, G. and Crawford, J.D. (2007) Geometric Computations for Visually- guided reaching in 3-D Space *The Journal of Vision*.

2) Specific parametric deficits in stroke patients with frontal / parietal damage

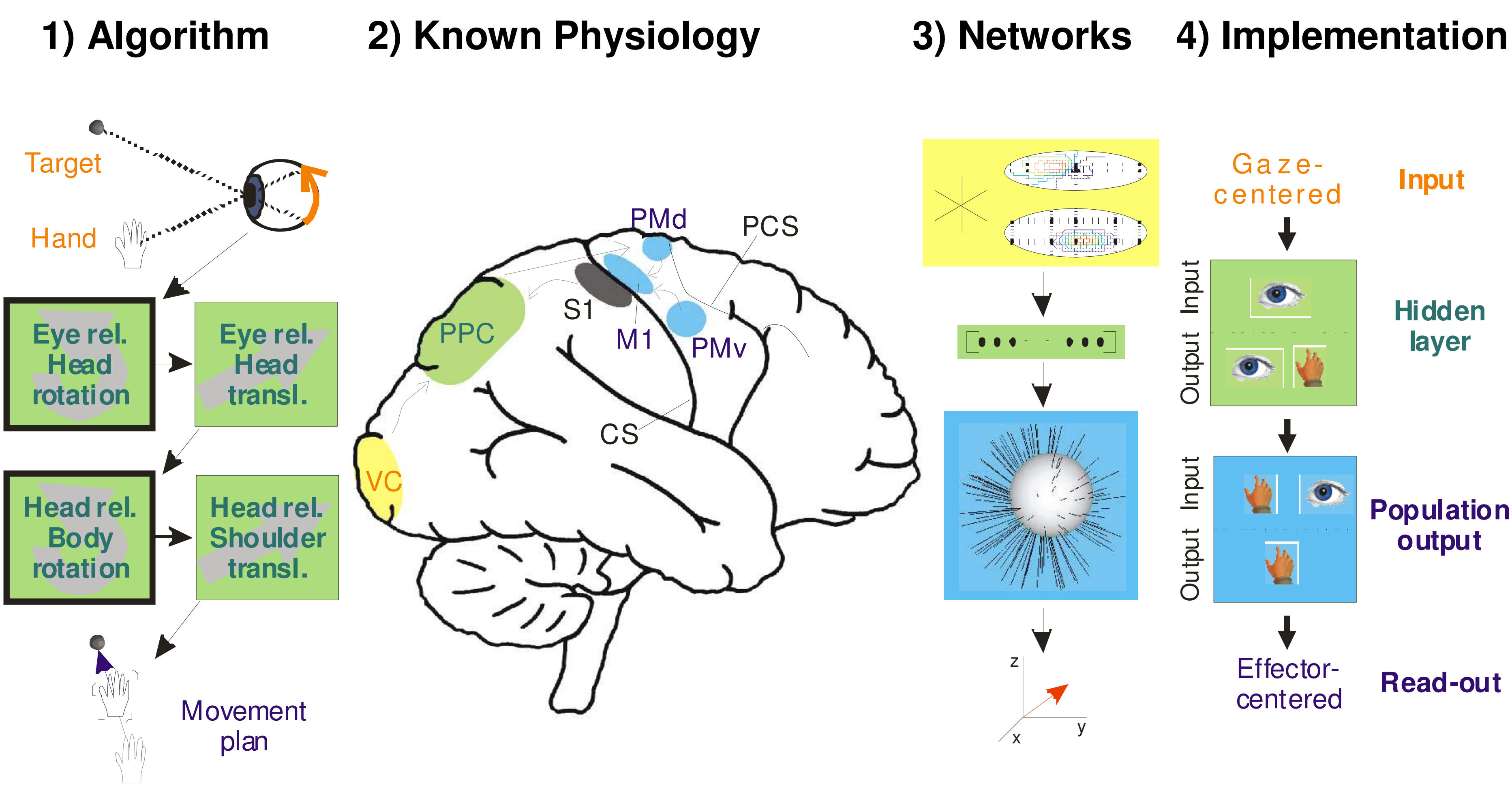
Currently Being Investigated.

Neural Network Version (2006-2007)



Blohm and Crawford (2006) *Soc. Neurosci. Abst.*

Moving Between Different Levels of Theory of Brain Function



General Workshop Goals:

(i) Definition of the field

‘Systems Level’ Sensorimotor Research:

- ‘Black Box’ models of sensorimotor algorithms
- ‘Neural Network’ Models
- Quantification of data…motion analysis, spikes etc.

General Workshop Goals:

(ii) Research highlights in the field

(just a few examples):

1) Models have provides us with testable framework to understand Mechanisms of
   - 3-D VOR
   - Spatial Frames for Gaze Coding
   - Spatial Updating for saccades & pointing
   - Visually-Guided Reach

2) Related mathematical tools for data analysis

General Workshop Goals:

(iii) Critical considerations for someone wanting to enter the field today

1) What do we already know?

2) What do we not know?

3) Can I design models that will have an impact on

- Basic experimental work
- Clinical applications

4) How will I realize those applications?

General Workshop Goals:

(iv) Ideal type(s) of training

1) Training environments that provide more than one approach (theoretical & experimental)

2) Training environments that provide a synergy between theory and experimentation

- **Within projects**
- **As part of collaborative ventures**

General Workshop Goals:

(v) Suggested changes and directions for the field.

1) More synergy between theory and experiment!

2) Better communication (and mutual appreciation) between theorists, experimentalists, and clinicians

3) Better understanding of the relationships between different 'levels' of theory & experiment

e.g., a formal theory of how sensorimotor algorithms are distributed within networks

Crawford Lab

ACKNOWLEDGEMENTS

@YORK

Mike Smith

Pieter Medendorp

Gunnar Blohm

Gerry Keith

CIHR IRSC

Canada Research Chairs

Canada Foundation for Innovation
Fondation canadienne pour l'innovation

NSERC CRSNG

Ontario