Brain and Behavior Underlying Human Spatial Navigation

Elizabeth R. Chrastil
Department of Geography

Kavli Institute for Theoretical Physics
Workshop on Sensory Navigation
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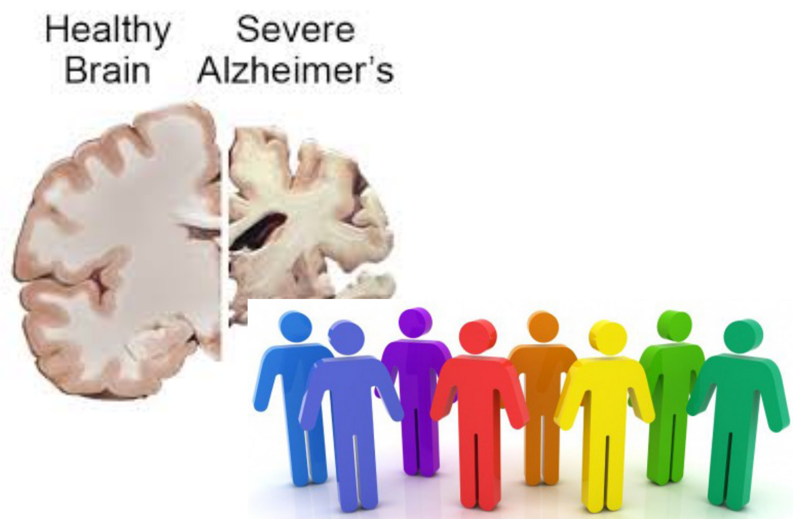
Why Study Navigation?

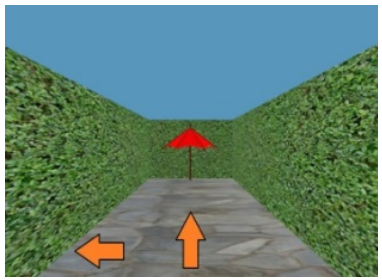
Wayfinding and Guidance

Human Health

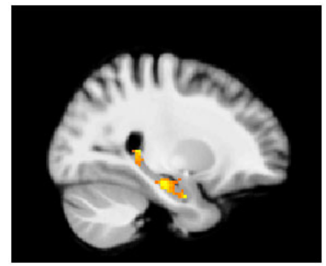


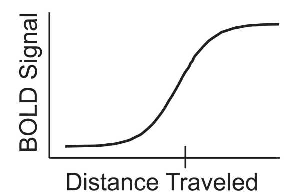
Approach

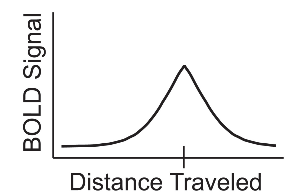
Cognition



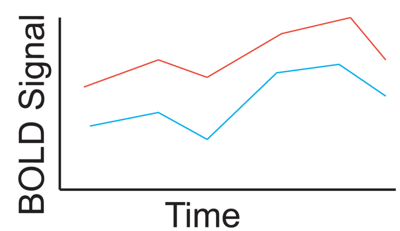
Neuroscience







Spatial Knowledge
Information
Cognitive Processes
Neural Substrates



Questions

- What is the structure of spatial knowledge?
  - Cognitive graphs
- How can we learn new environments?
  - Active learning
- How does the human brain track locations during self-motion?
  - Path integration
- What sources of visual and body-based information contributes to human path integration?

- How do individuals differ in their spatial abilities?
- How does the brain process spatial information?

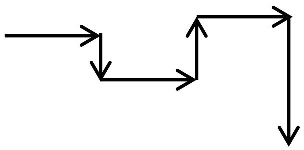
FROM COGNITIVE MAPS TO COGNITIVE GRAPHS

What is the structure of spatial knowledge?

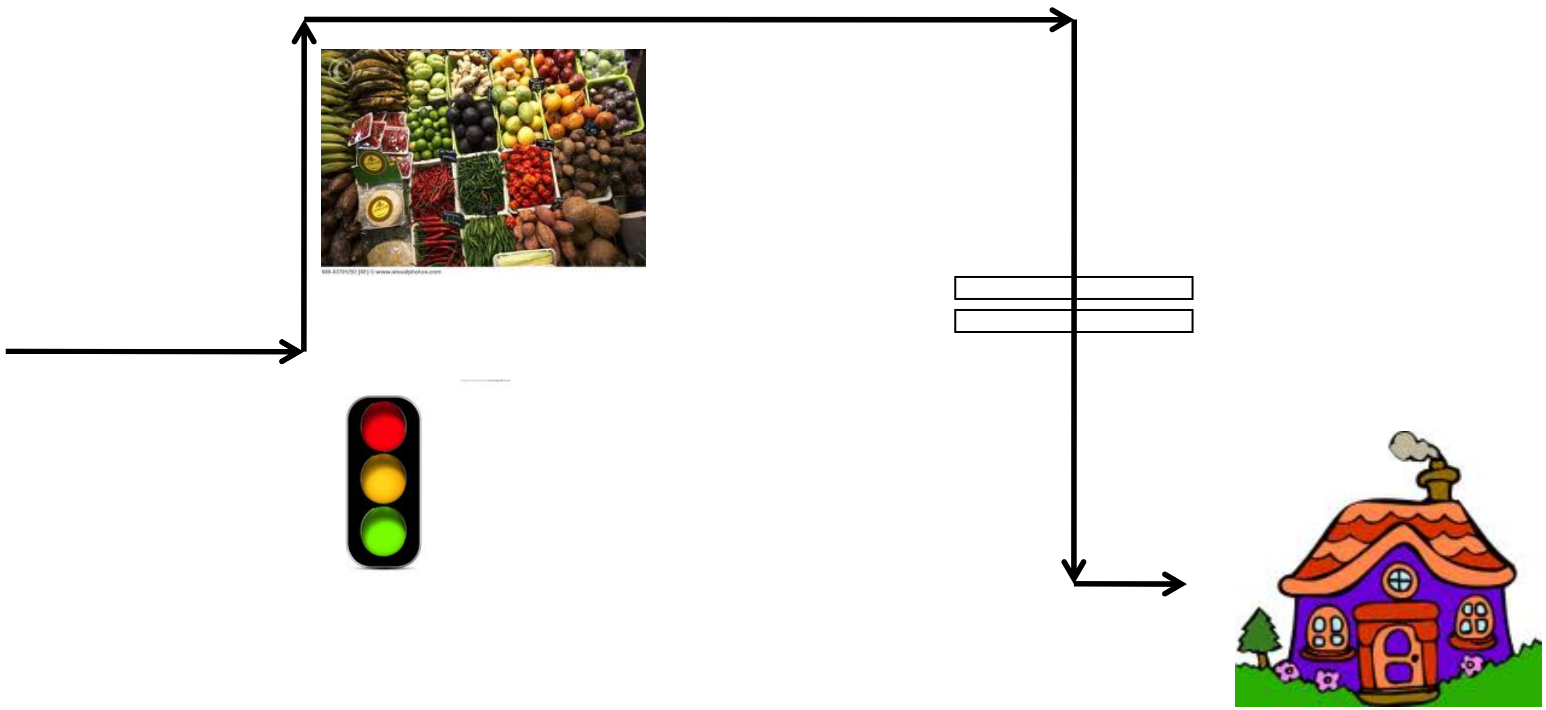
Types of Spatial Knowledge

- Landmark
  - Salient objects or locations that provide navigational cues

Types of Spatial Knowledge

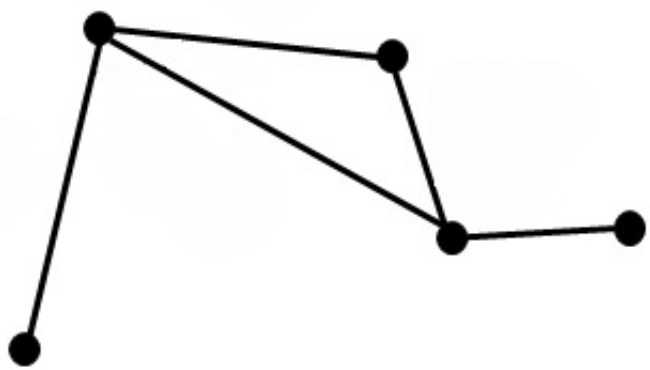


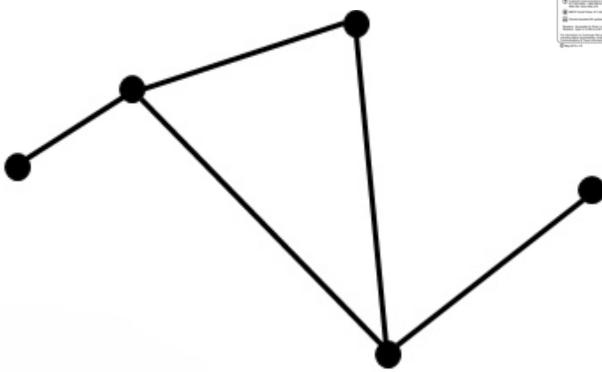
- Route
  - Series of place-action associations



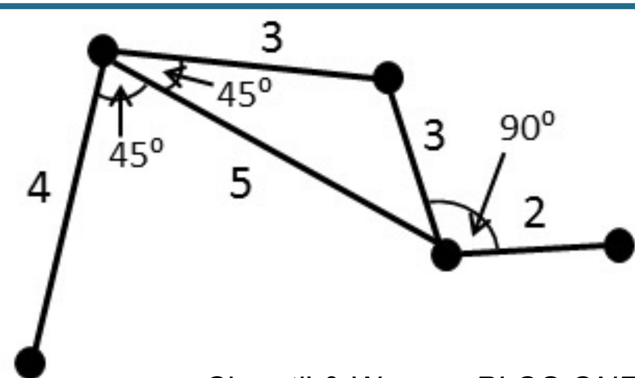
Types of Spatial Knowledge

- Graph
  - A network of place nodes linked by path edges





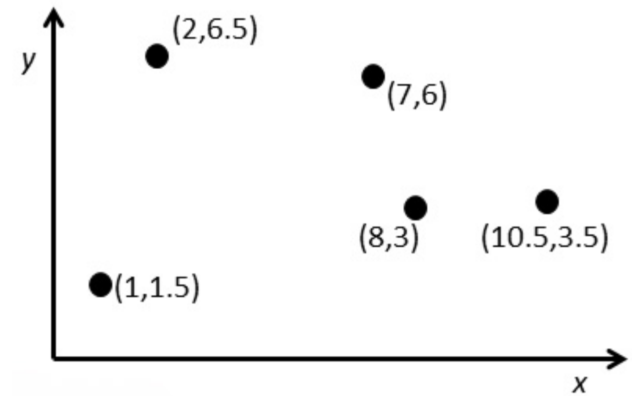
- Labeled Graph
  - Local metric information
  - Coarse, contains biases

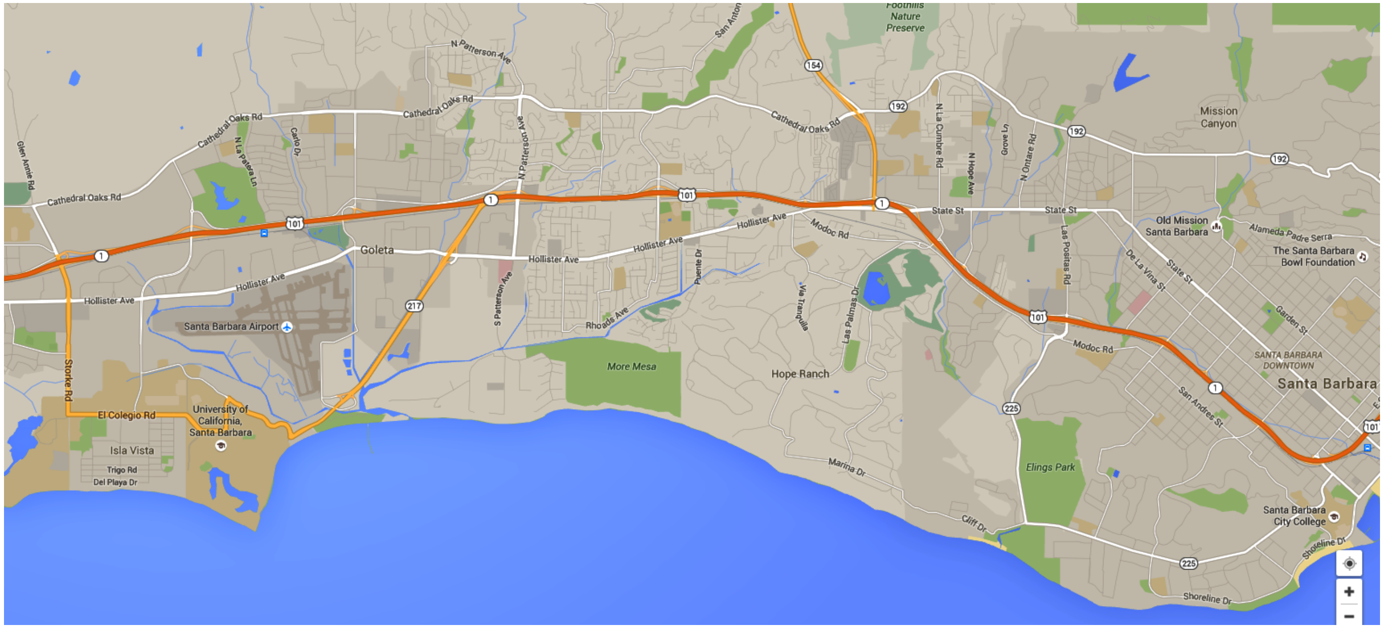


Chrastil & Warren, *PLOS ONE*, 2014

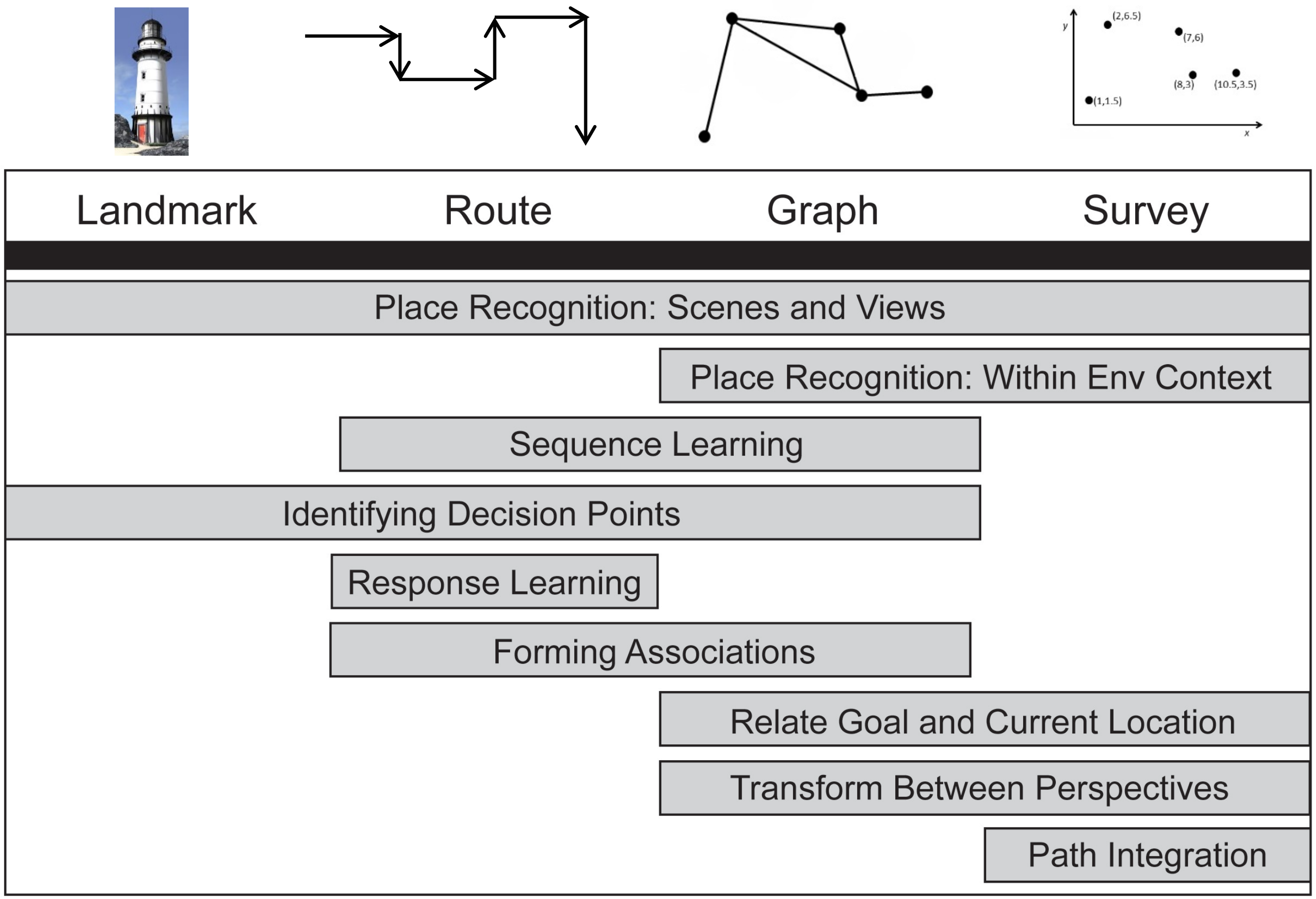
Types of Spatial Knowledge

- Survey
  - Maplike knowledge metric distances and angles between locations
  - Enables shortcuts





Cognitive Processes Involved



Chrastil, *Psychonomic Bulletin & Review*, 2013

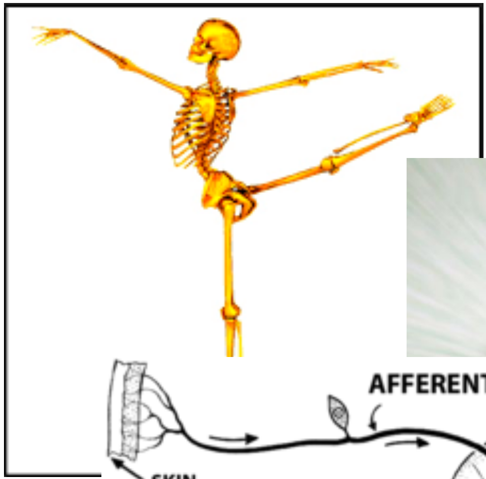
HOW CAN WE LEARN NEW ENVIRONMENTS?

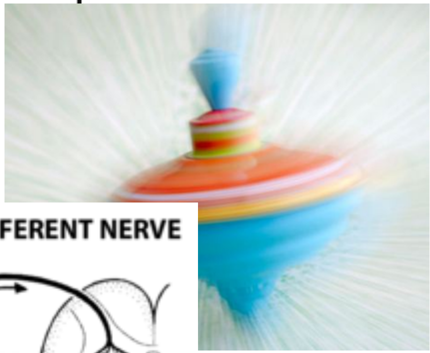
How does active navigation contribute to spatial learning?

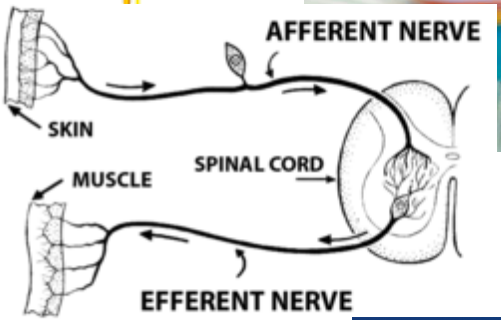
What is “Active”?

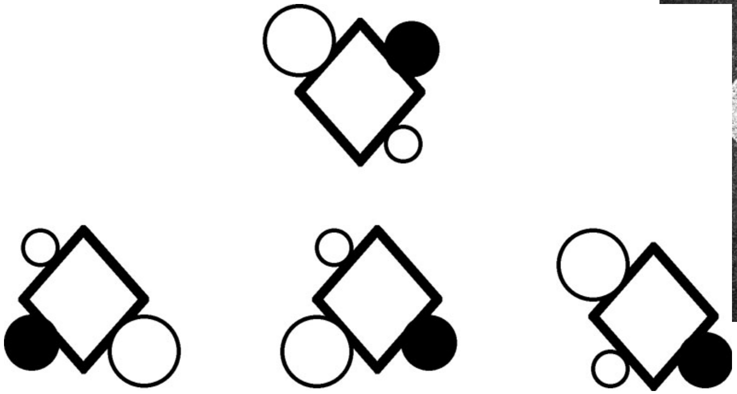
- Physical Activity
  - Proprioception
  - Vestibular information
  - Efferent motor commands

- Cognitive Activity
  - Allocation of attention
  - Cognitive decision-making
  - Mental manipulation



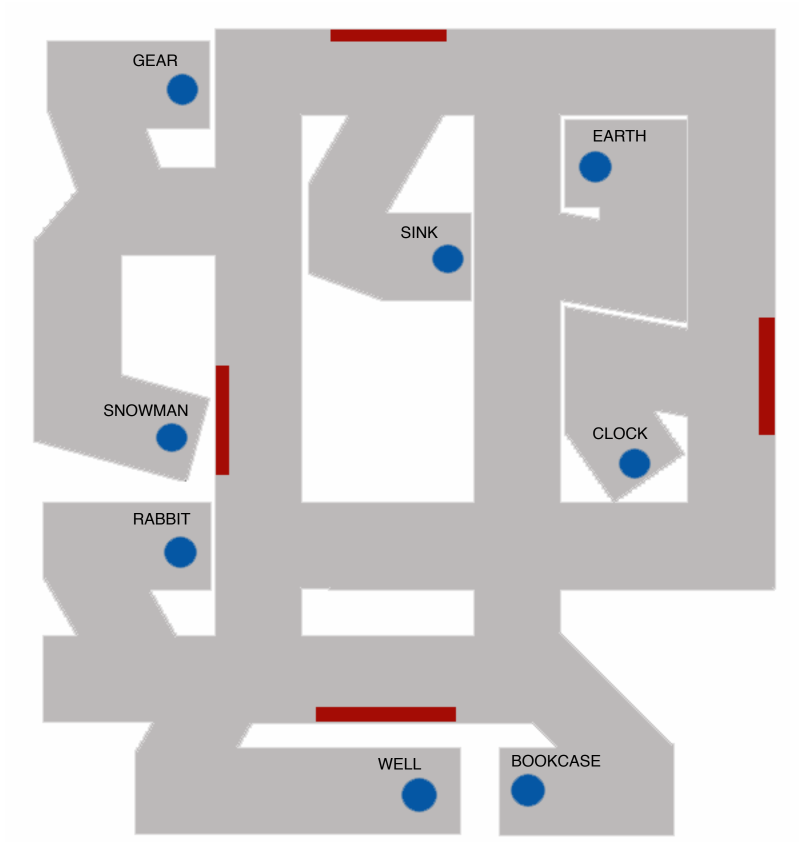




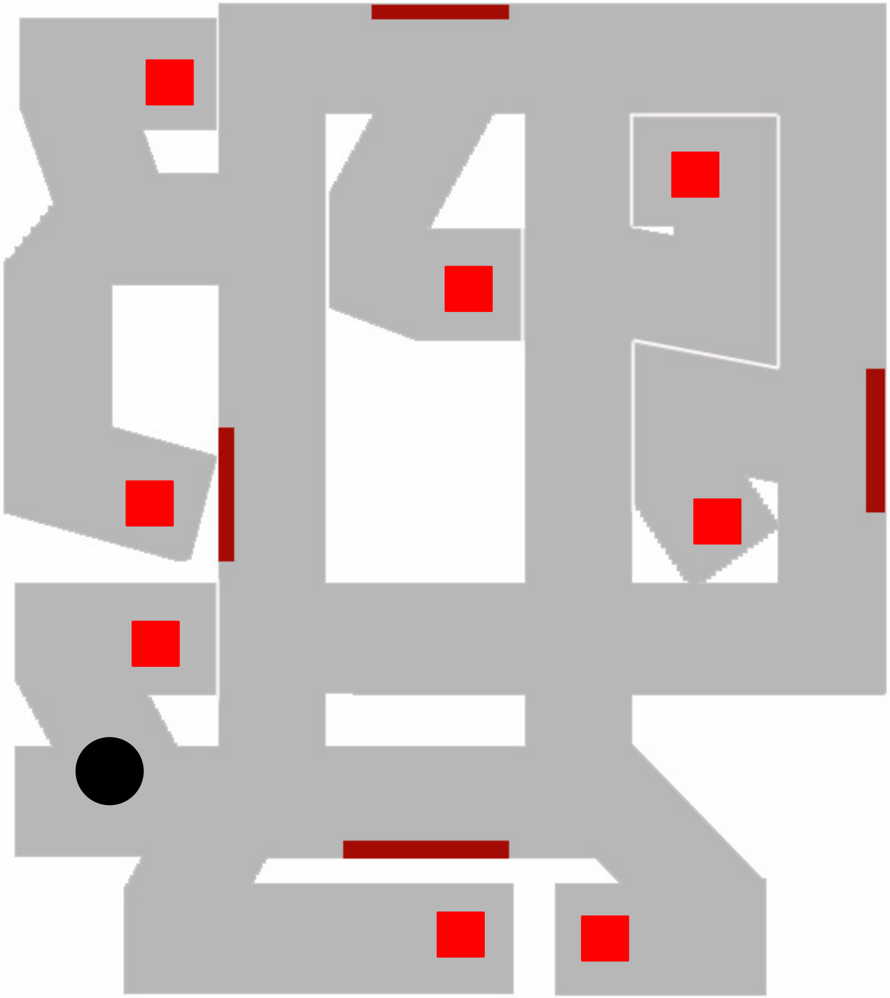


Chrastil & Warren,
Psychonomic Bulletin & Review, 2012

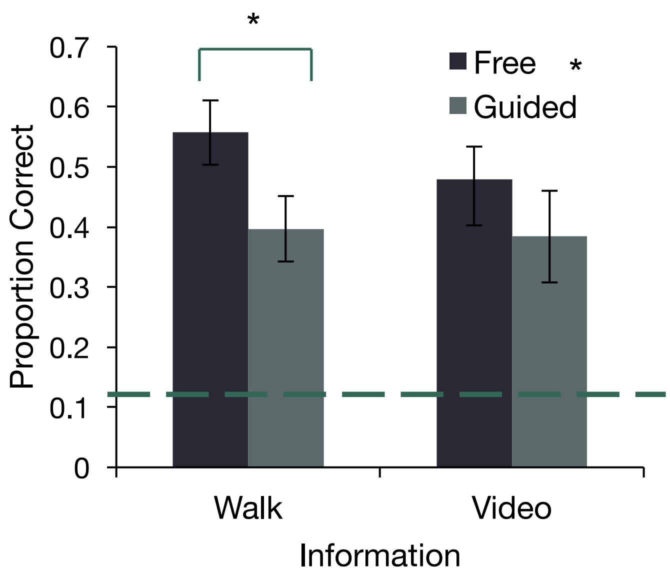
Maze Learning

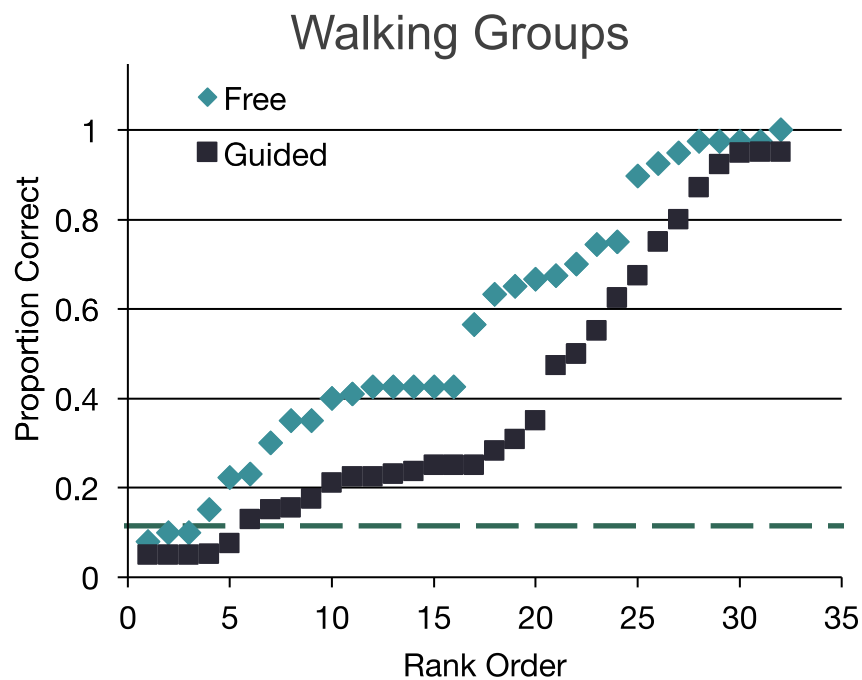


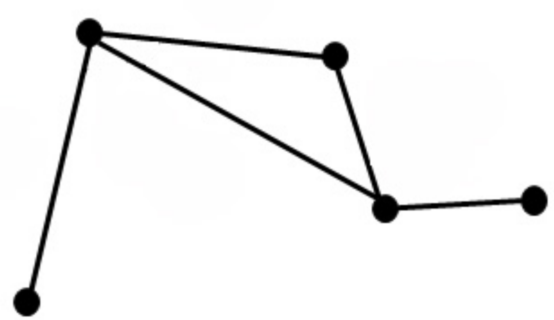
Shortest Route Task



Decision Making and Individual Differences



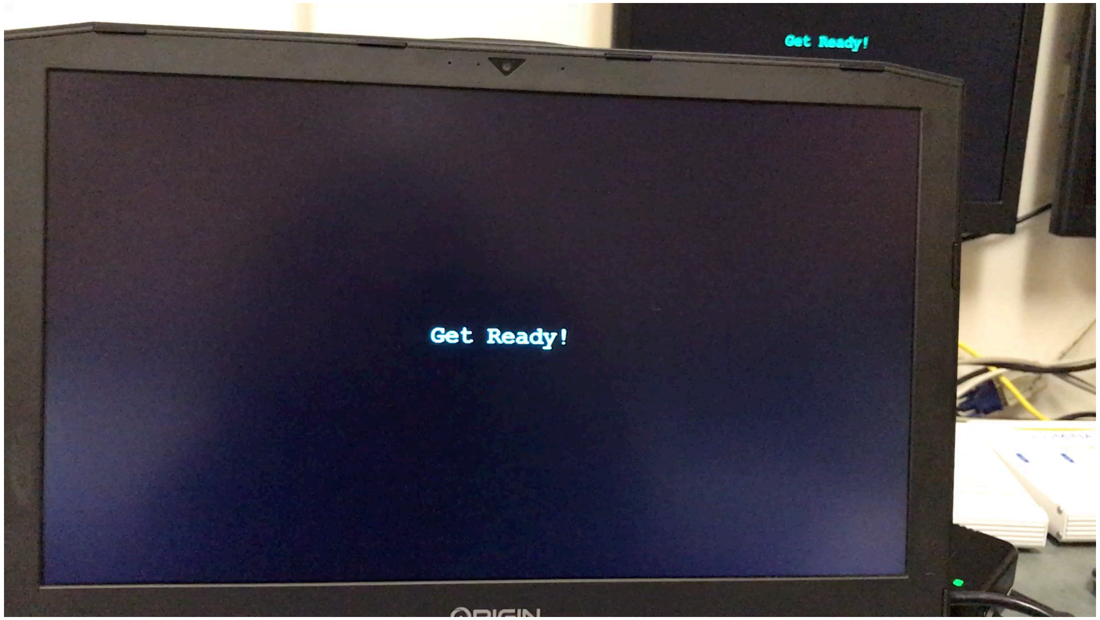




Chrastil & Warren, *JEP:LMC*, 2015

Active Navigation – Next Experiments

- Does active decision making increase synchronous communication in the brain? – EEG
- Do better navigators have greater connectivity between different regions in the brain? – fMRI



How can we learn new environments?

- Specific components of active learning differentially contribute to particular forms of spatial knowledge
  - Active walking contributes to survey knowledge
  - Active decision making contributes to graph knowledge
- Individual differences in learning

SPATIAL LEARNING THROUGH SELF-MOTION

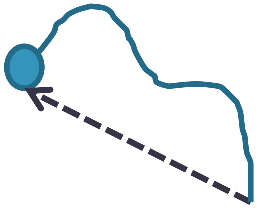
How does the brain track locations during human path integration?

What sources of visual and body-based information contribute to human path integration?

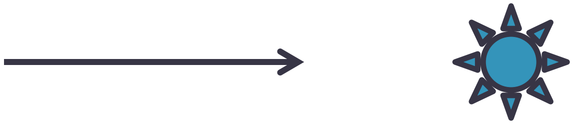
Path Integration

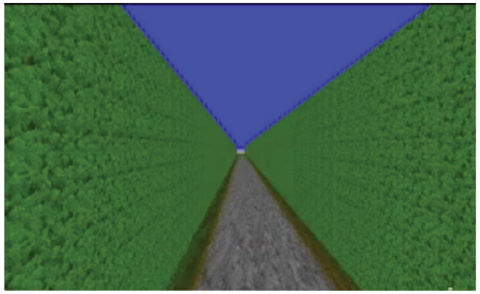
Continuous updating of position and orientation during movement in an environment

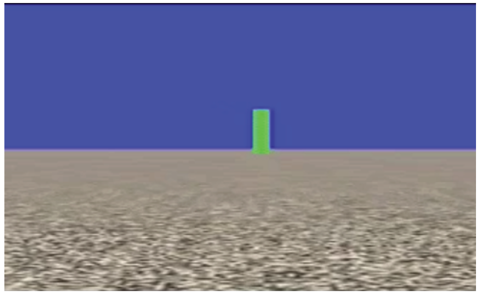
- Tracking a location



- Tracking translation and rotation

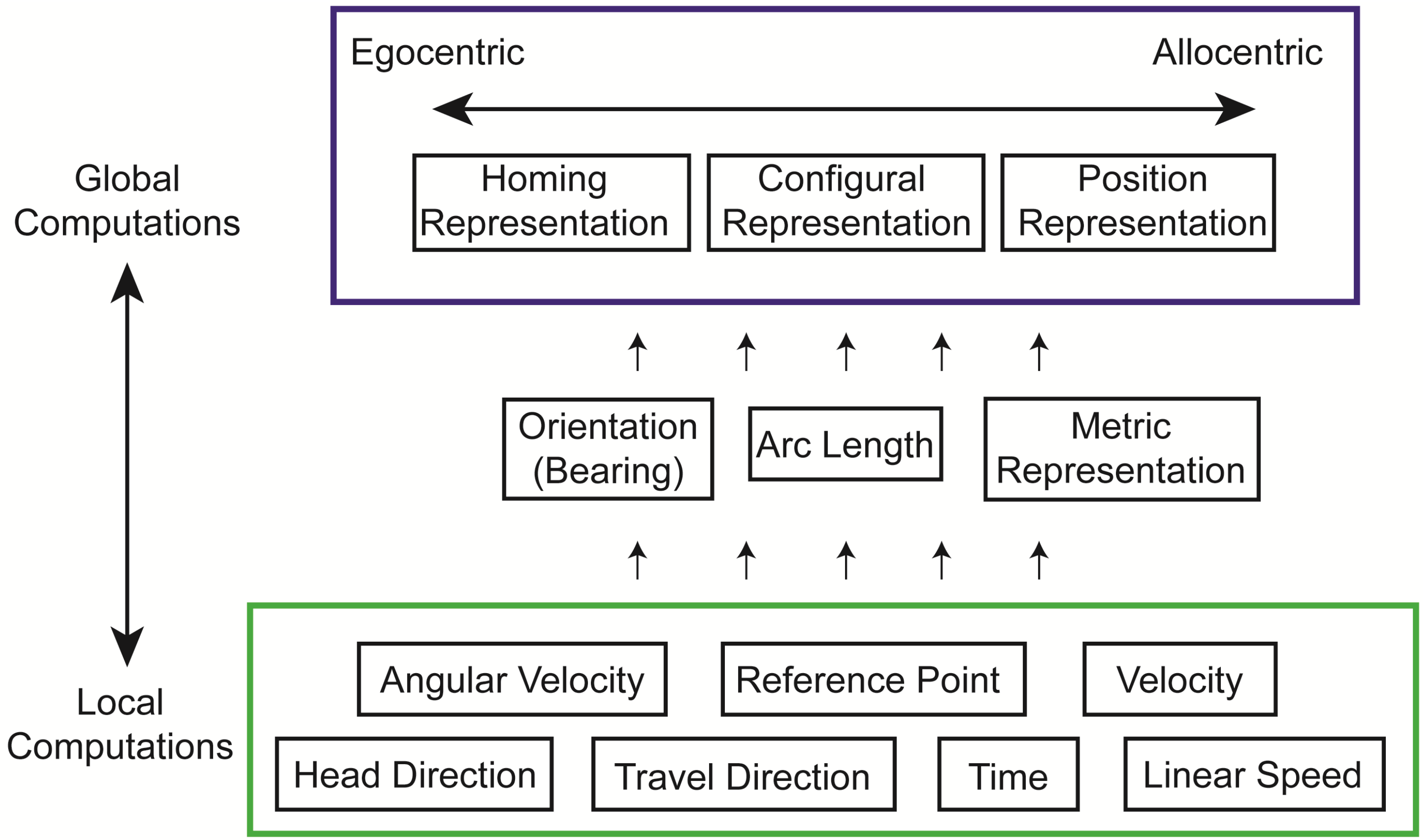




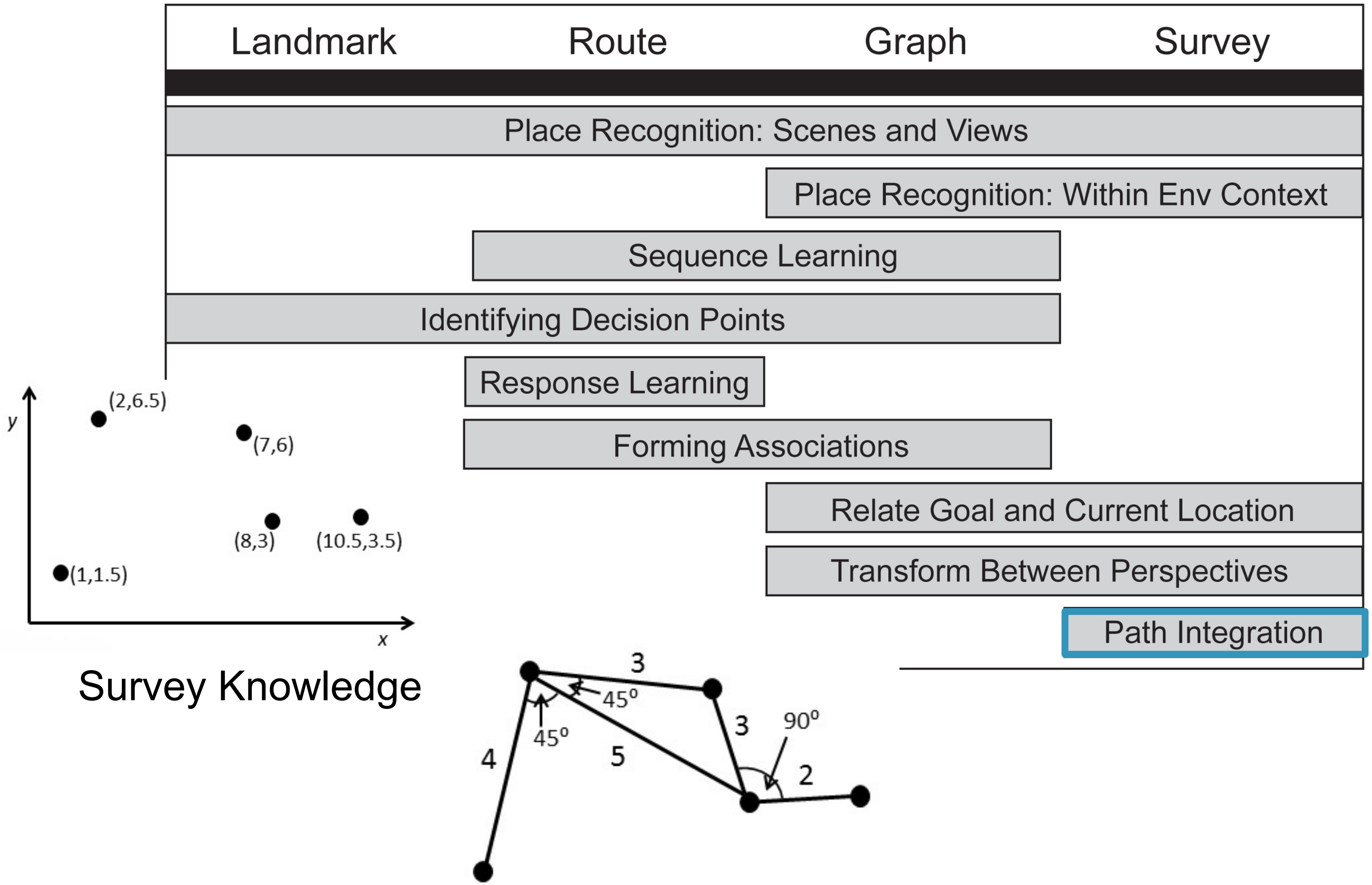


Chrastil & Warren, *Exp Brain Res,* 2017
Chrastil & Warren, *in preparation*
Chrastil et al., *in preparation*

Vision and Path Integration



Path Integration – Cognition

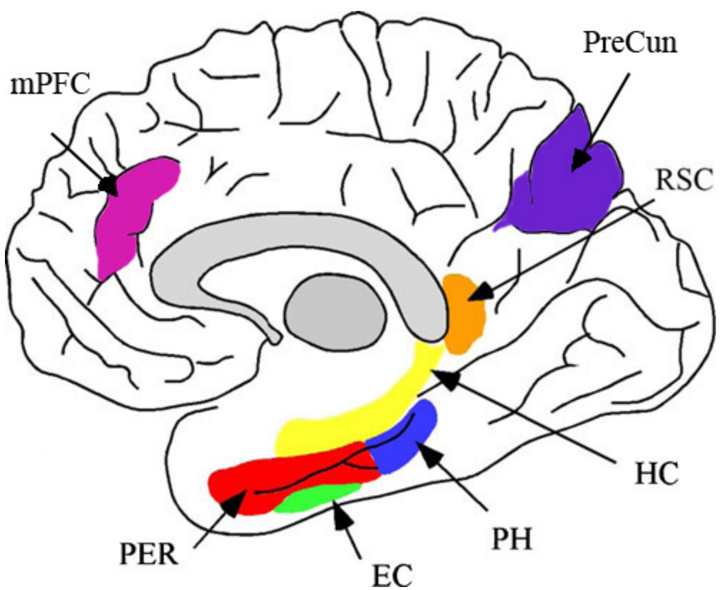


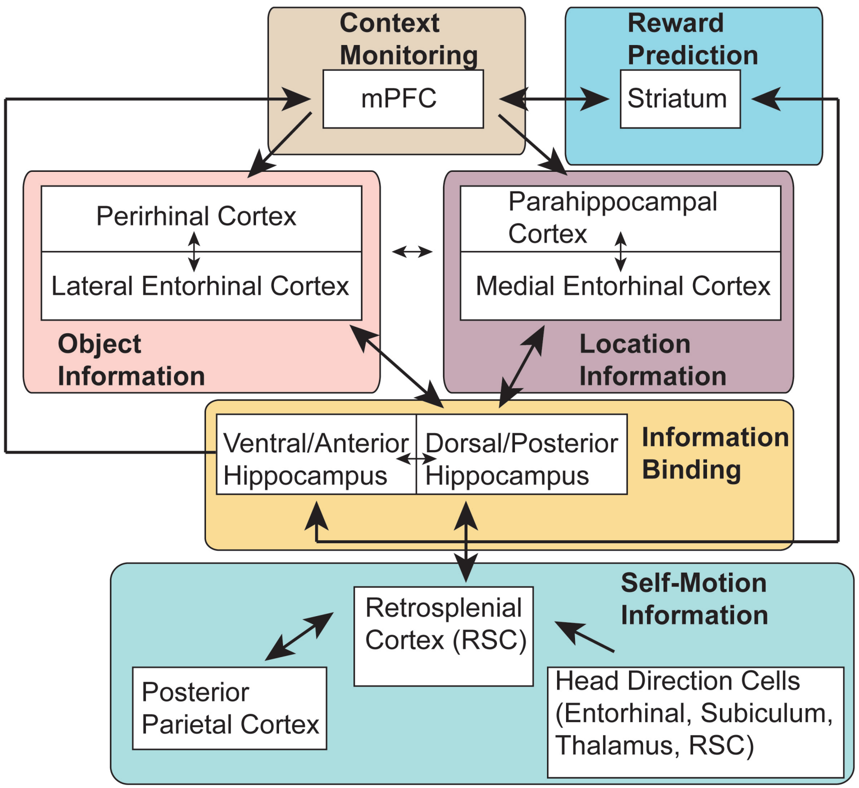
Survey Knowledge

Labeled Graph Knowledge

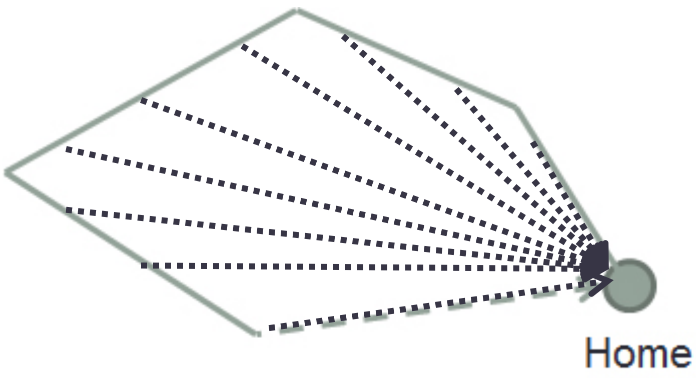
Path Integration - Neuroscience

- Hippocampus, retrosplenial cortex, parahippocampal cortex, entorhinal cortex, precuneus, medial prefrontal cortex





Two Models of Path Integration



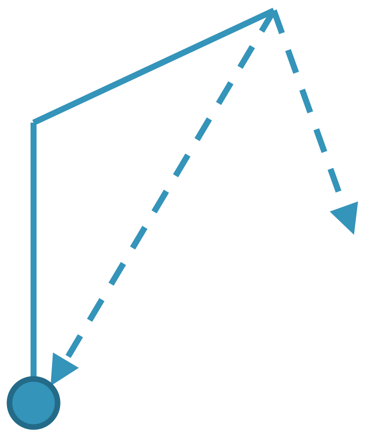
- Configural/Accumulator Model: Encode entire outbound path, then compute return trajectory (Fujita et al., 1993; Klatzky et al., 1999; Loomis et al., 1993)

- Homing Vector Model: Track the trajectory back to the home location during the entire outbound path (Fujita et al., 1990; Philbeck et al., 2001)

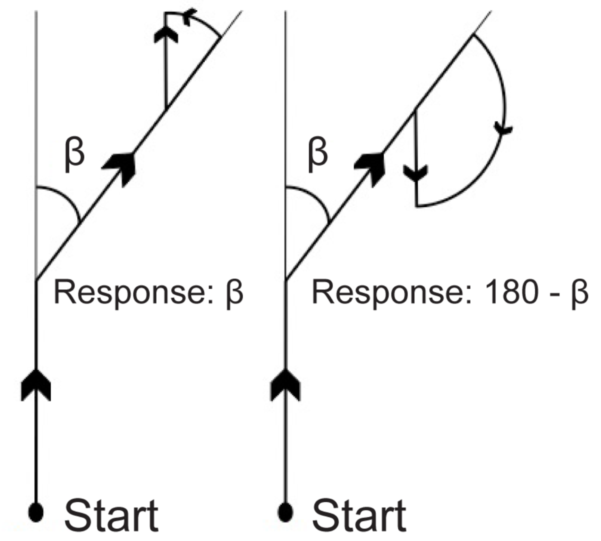
- Recent evidence suggests that humans can use either strategy when necessary (Wiener et al., 2011)

Loop Closure

- Difficult problem in robotics
- Eliminates execution step in triangle completion



Substantial execution errors have been found

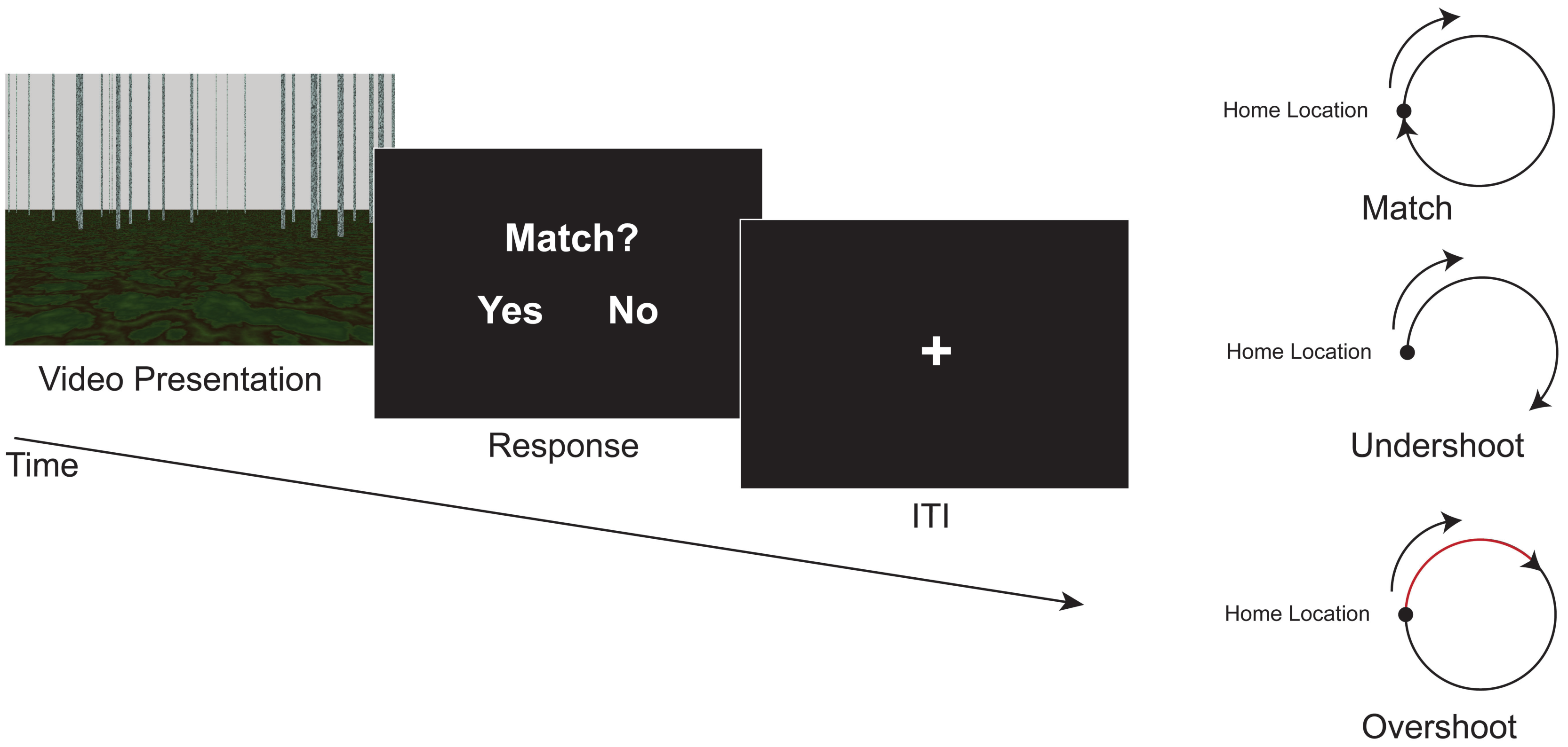


Parallel Same

Parallel Opposite

Chrastil & Warren, *Exp Brain Res,* 2017

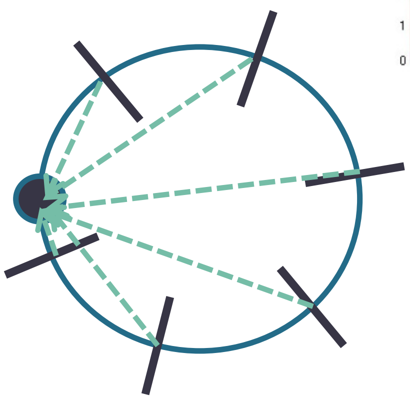
Loop Closure

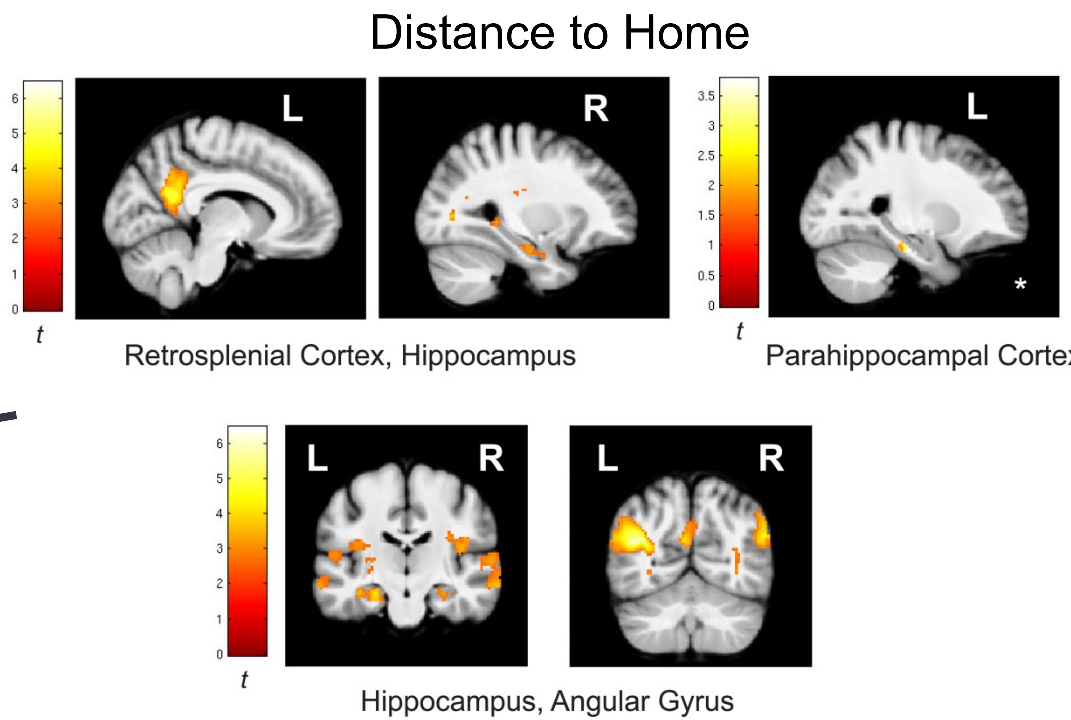


Chrastil et al., *J Neurosci*, 2015

Loop Closure

Spatial Coding – Homing Vector



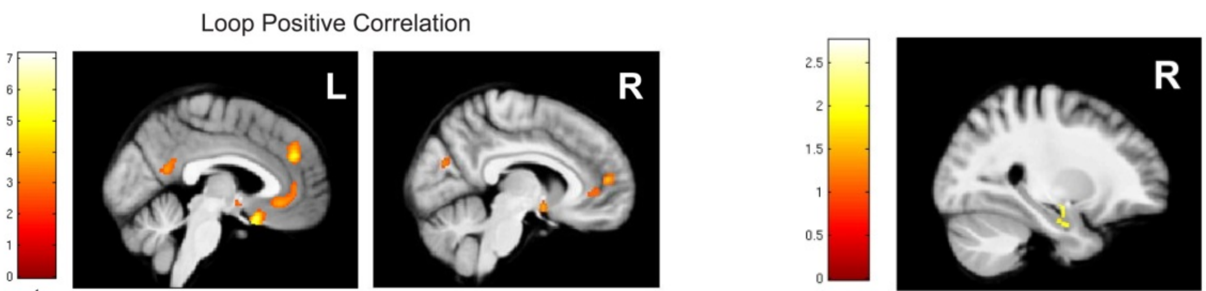


- Hippocampus, RSC, and PHC track Euclidean distance from the home location
- Consistent with a homing vector system
- New directions for computational and animal models

Chrastil et al., *J Neurosci*, 2015

Homing Vector – Individual Differences

Larger gray matter volume in better navigators

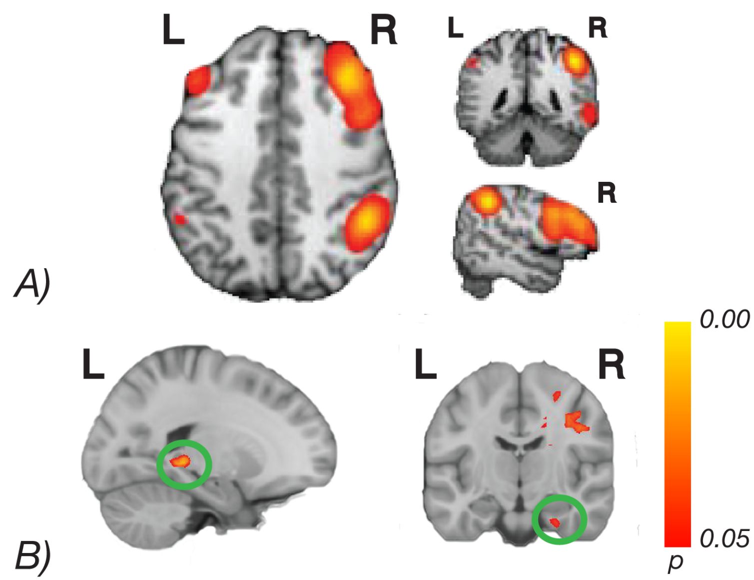


Retrosplential Cortex, mPFC, Anterior Cingulate

Hippocampus

Resting state connectivity

- Hippocampus and entorhinal cortex with Central Executive Network

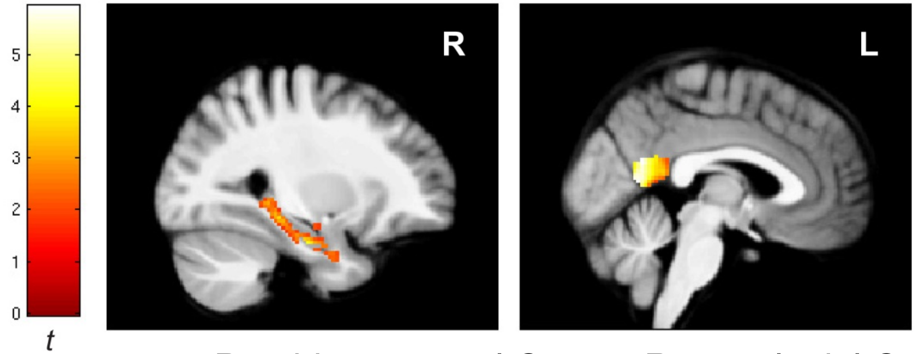


Chrastil et al., *eNeuro,* 2017

Izen, Chrastil et al., *in revision*

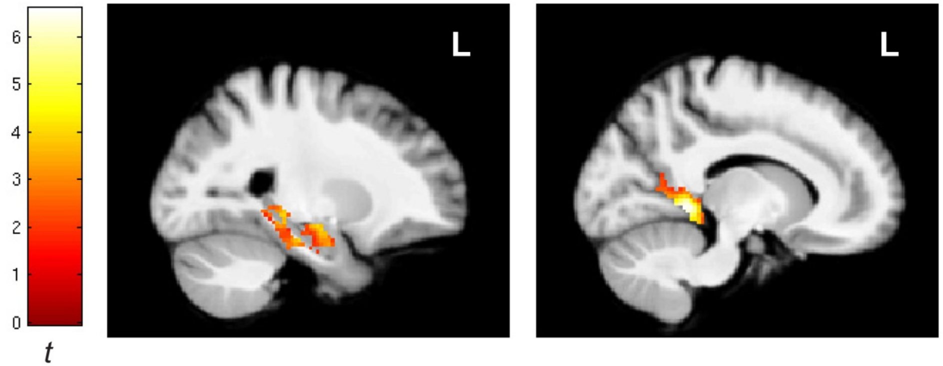
Spatial Coding – Translation and Rotation

Translation



Hippocampus, Parahippocampal Cortex, Retrosplenial Cortex

Rotation



Hippocampus, Parahippocampal Cortex, Retrosplenial Cortex

Correct trials only
Encoding phase (1^{st} video)

Chrastil et al., *Human Brain Mapping*, 2016

How does the brain track locations during human path integration?

- Path integration – the constant updating of position and orientation during movement through an environment
- Neural evidence for a homing vector system of path integration
- Neural evidence for encoding translation and rotation

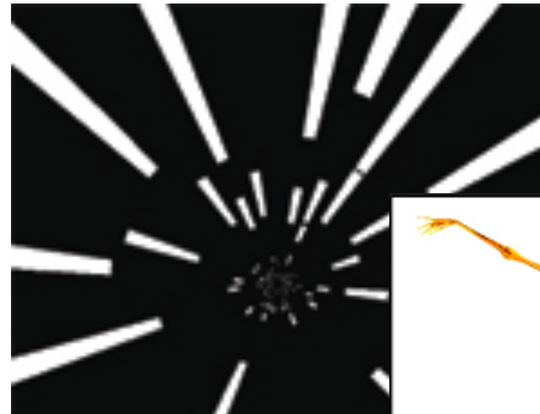
Cues to Self-Motion

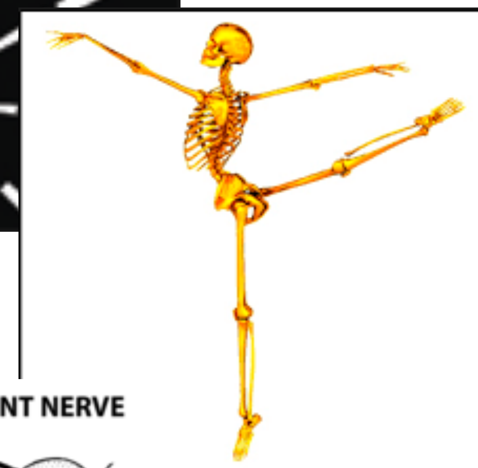
i. *Optic Flow*
   - Information from vision about how fast you are moving

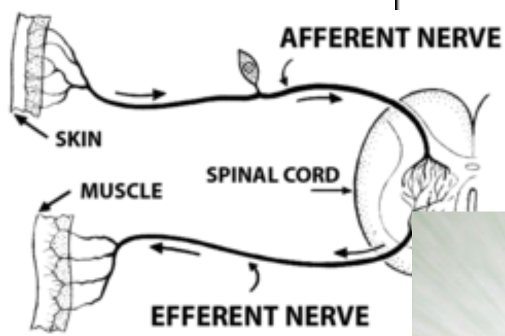
ii. *Proprioception*
   - Information from muscles and joints about the location of the limbs

iii. *Motor Efference*
   - Commands coming from the brain used to predict the locations of the limbs

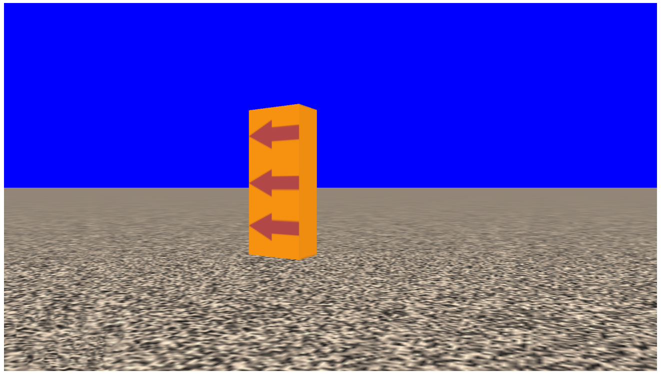
iv. *Vestibular Information*
   - Information from inner ear about balance and rotation

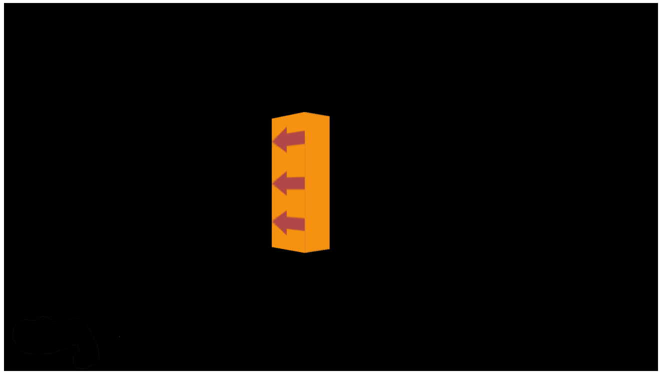






		Proprioception	
		Yes	No
Vision	Yes	*Walk Vision*	*Wheelchair Vision*
	No	*Walk No Vision*	*Wheelchair No Vision*



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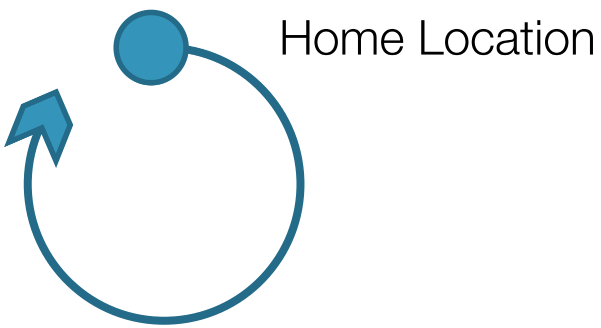
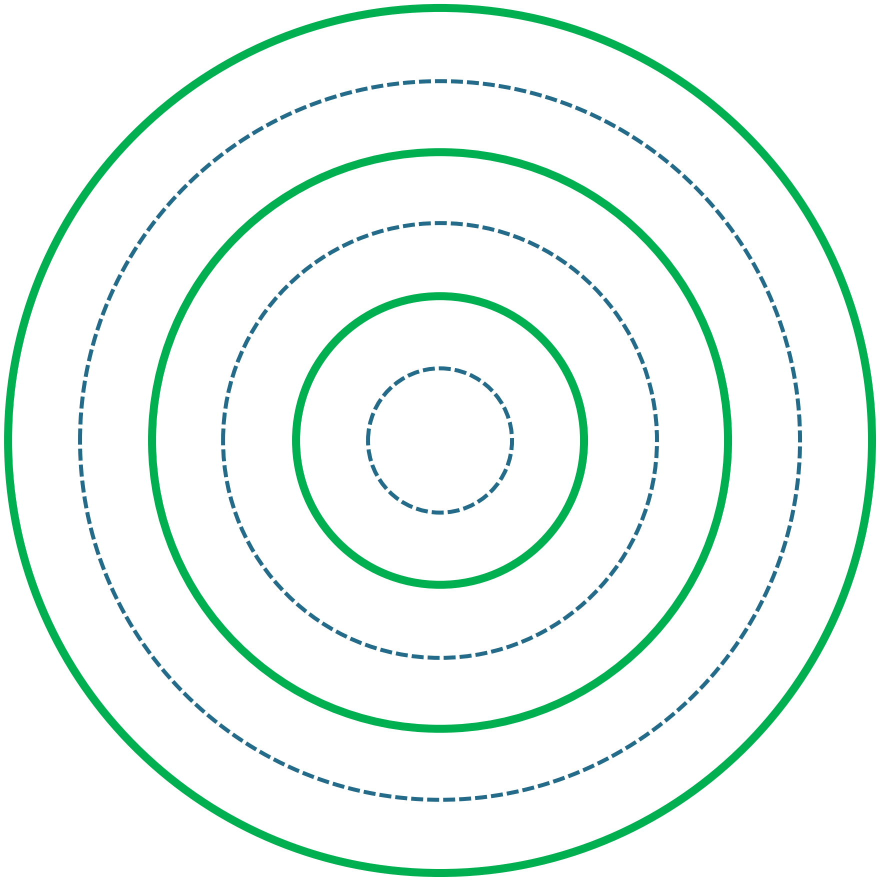
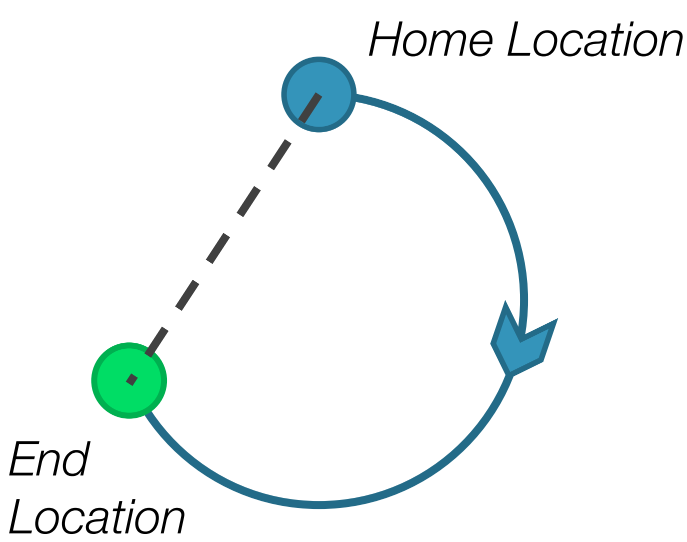
Loop Closure

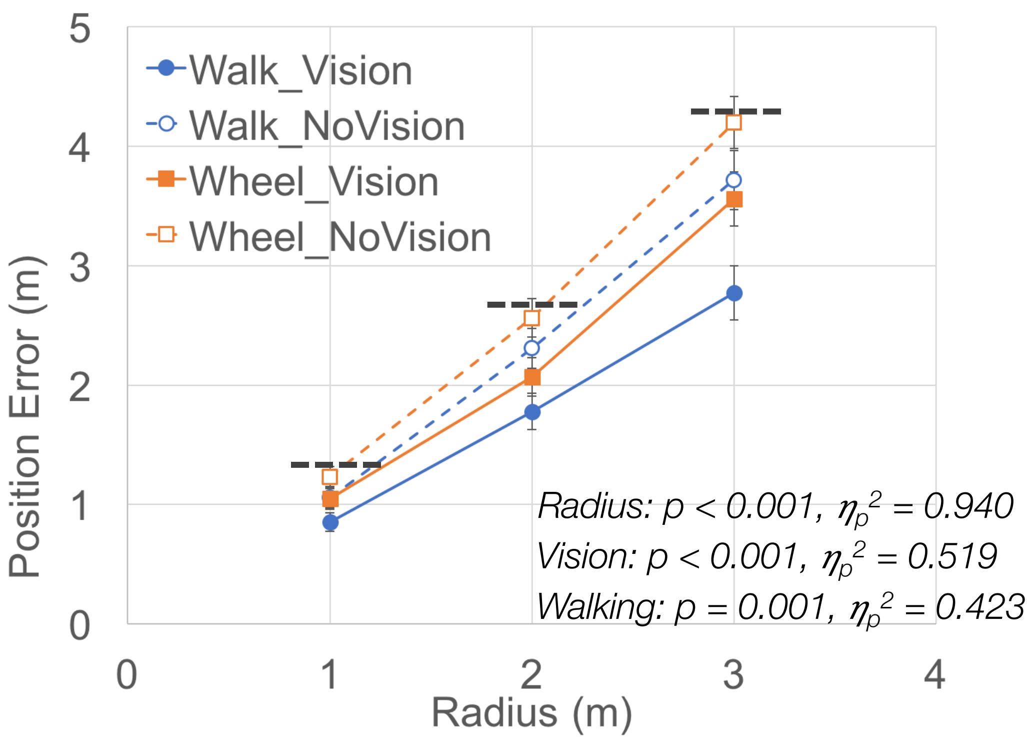


1,2,3 meter radii
3 additional radii as fillers
12 of trials at each radius per condition
4 start quadrants in room
Alternating right and left turns
N = 23 healthy young adults (10 women)



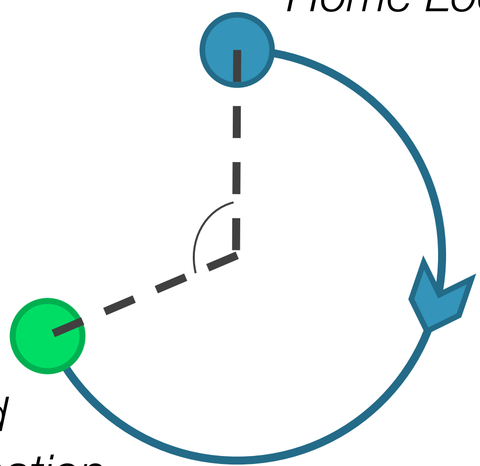
Position Error

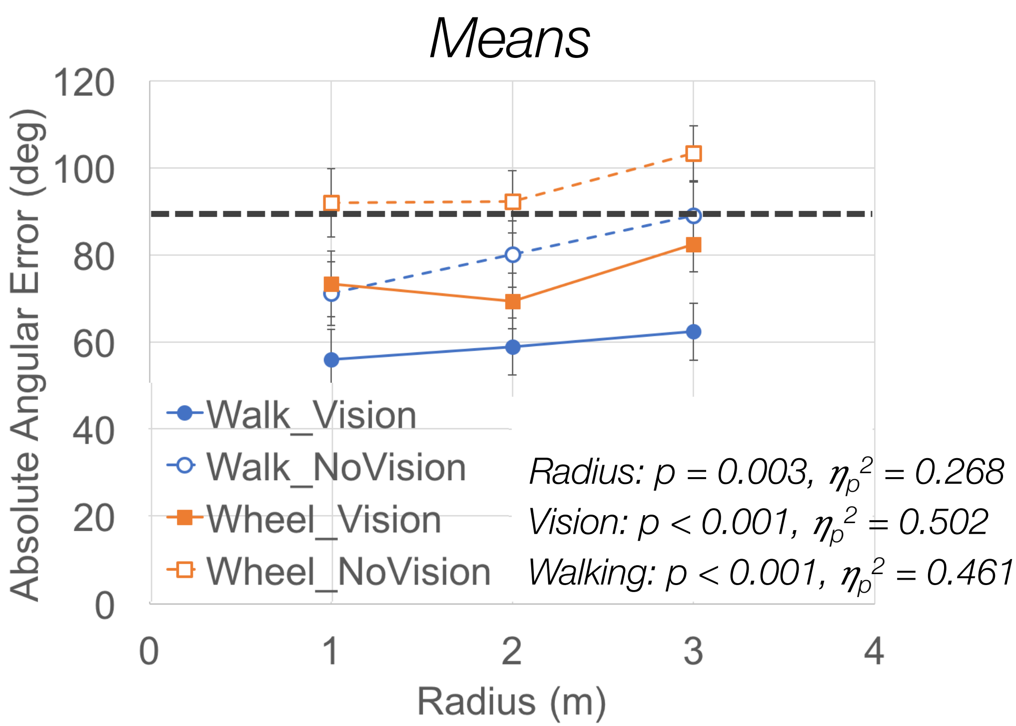




Chrastil et al., *in preparation*

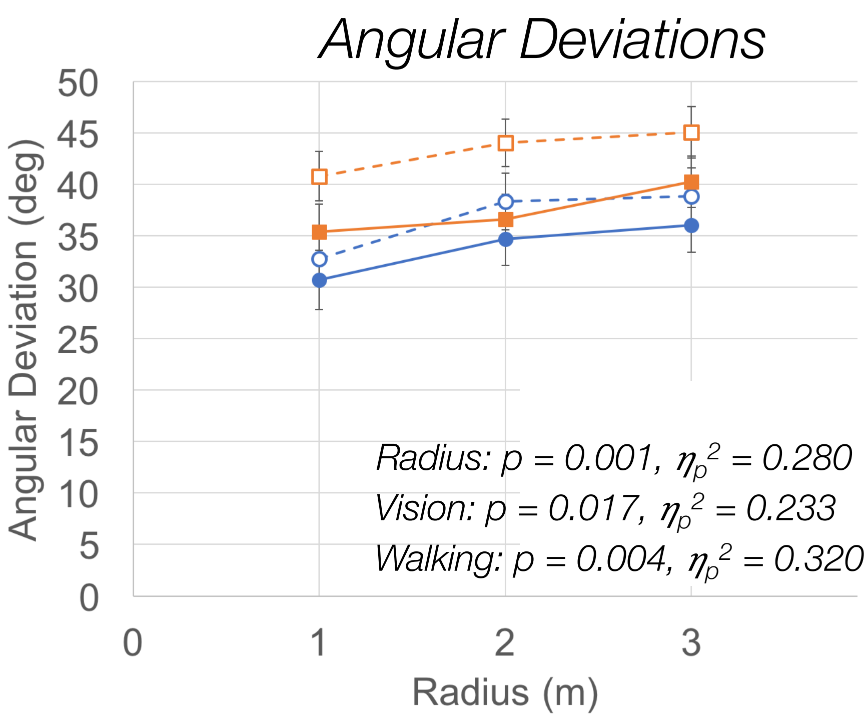
Absolute Angular Error

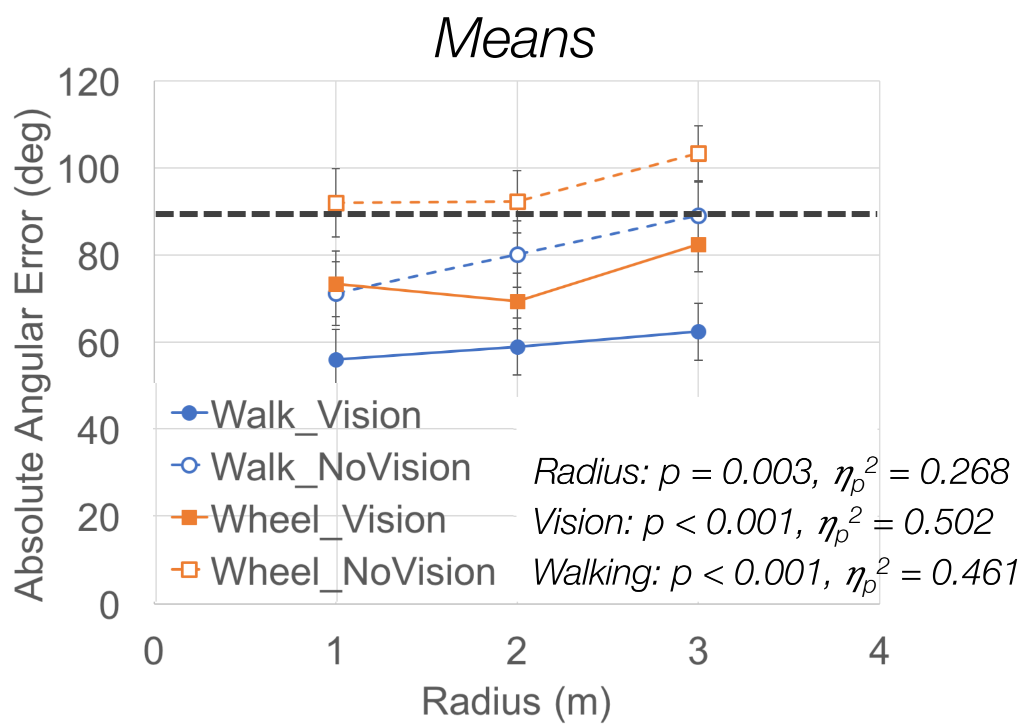




Chrastil et al., *in preparation*

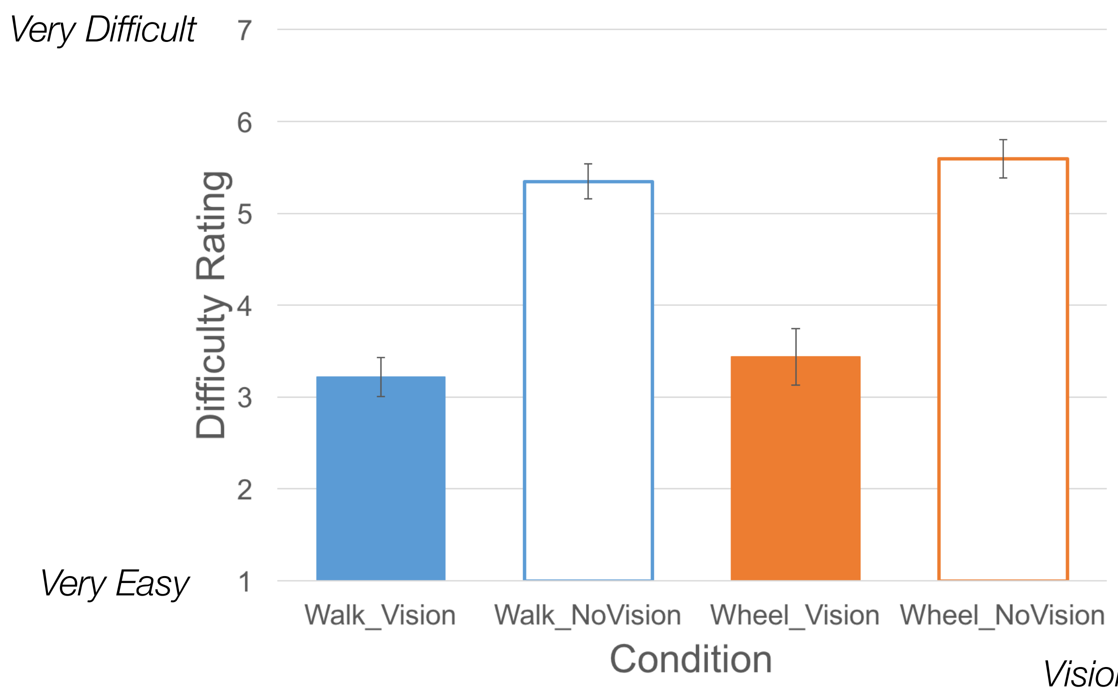
Absolute Angular Error





Chrastil et al., *in preparation*

Difficulty Ratings



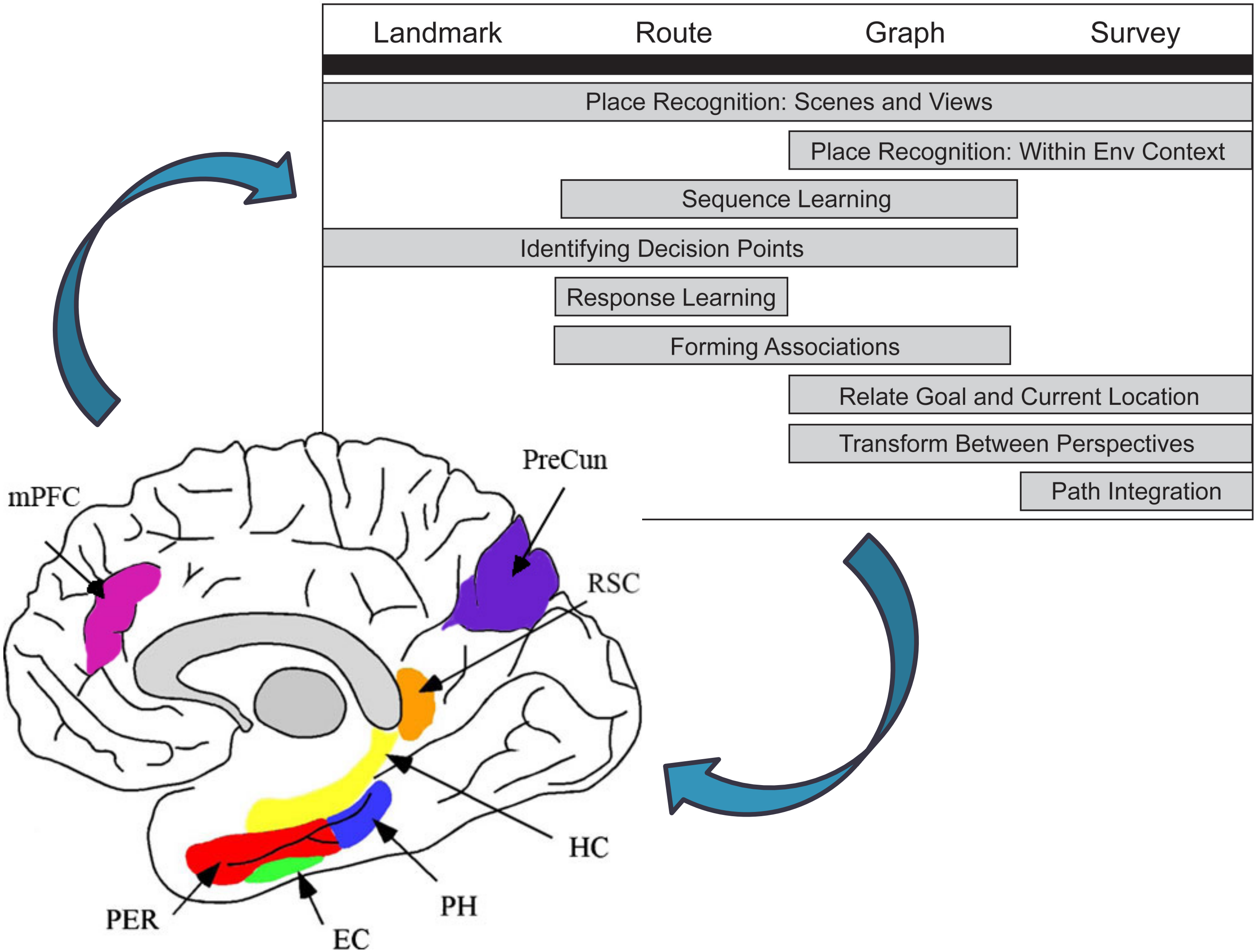
Vision: $p < 0.001$, $\eta_p^2 = 0.728$

Chrastil et al., *in preparation*

What sources of visual and body-based information contribute to human path integration?

- Visual information and proprioceptive information contribute equally to location tracking during path integration
- Pure vestibular (Wheelchair No Vision) was no better than chance and was less accurate and precise than all other conditions
- Results differ from previous work showing primary contribution from proprioception
- Loop closure might differ from triangle completion in the contributions of different sources of information

Conclusions



Summary

- What is the structure of spatial knowledge?
  - Cognitive graphs
- How can we learn new environments?
  - Active learning
- How does the human brain track locations during self-motion?
  - Path integration – homing vector in hippocampus, retrosplenial cortex
- What sources of visual and body-based information contributes to human path integration?
  - Vision and proprioception make equal contributions
- How do individuals differ in their spatial abilities?
  - Large range of individual abilities, gray matter volume differences, functional connectivity differences

Thank you!

<u>UCSB</u>

Dr. Mary Hegarty
Dr. Dan Montello
Dr. Emily Jacobs
Lily Cheng
Rie Davis
Justin Smith
Grace Nicora
Courtney Shafer

<u>Brown University</u>

Dr. William Warren
Dr. Mintao Zhao

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Dr. Chantal Stern
Dr. Michael Hasselmo
Dr. Sam Ling
Dr. Katherine Sherrill
Rachel Nauer
Allen Chang
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Dr. Erika Nyhus

<u>Bentley University</u>

Dr. Jon Ericson

<u>Army Collaboration</u>

Dr. Tad T. Brunyé, U.S. Army NSRDEC, Center for Applied Brain & Cognitive Sciences
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Dr. Jay Goodwin, U.S. Army Research Institute

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