Coming to Grips with Motor Control

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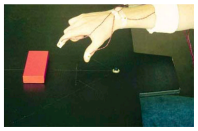
Motor Control Research

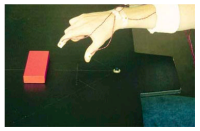
Pointing to targets



Reach to Grasp Objects

Motor Control Research

Pointing to targets



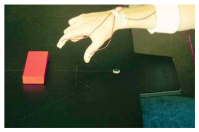
Reach to Grasp Objects

Real-world Action Tasks

Interacting with and re-arranging the world

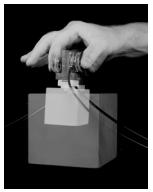
Motor Control Research

Pointing to targets



Reach to Grasp Objects

Real-world Action Tasks

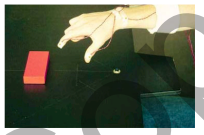


Object Lifting

Interacting with and re-arranging the world

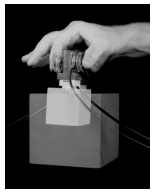
Motor Control Research

Pointing to targets



Reach to Grasp Objects

Real-world Action Tasks

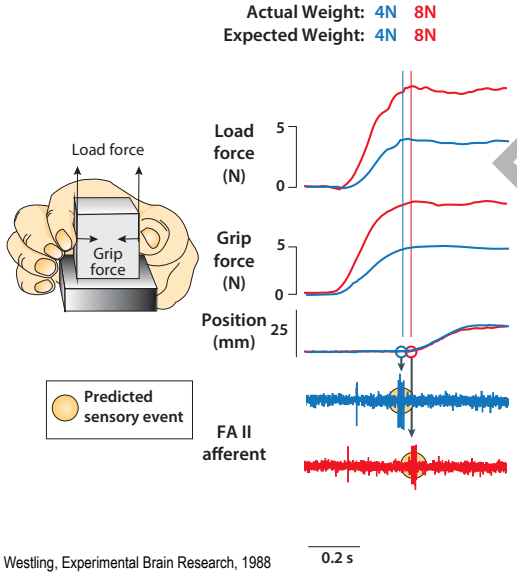


Object Lifting

Interacting with and re-arranging the world

Prediction of object weights based on memory

Prediction is critical in dexterous object manipulation



Johansson & Westling, Experimental Brain Research, 1988
Gordon et al., Experimental Brain Research, 1991

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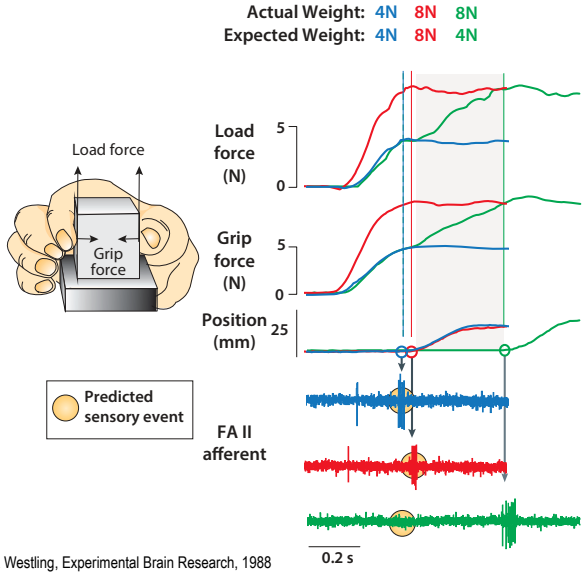

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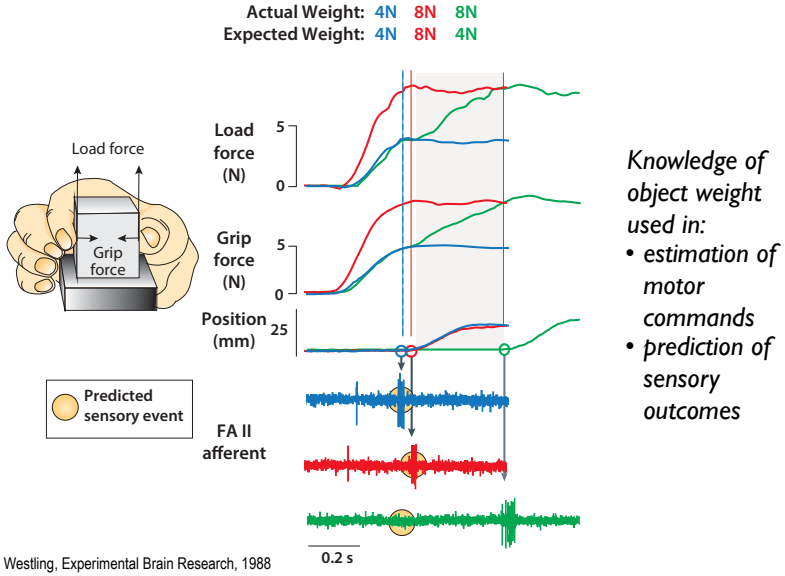


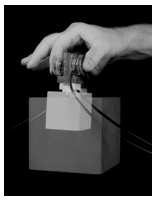
Knowledge of object weight used in:

- *estimation of motor commands*
- *prediction of sensory outcomes*

Johansson & Westling, Experimental Brain Research, 1988
Gordon et al., Experimental Brain Research, 1991

Memory systems underlying prediction

Size-weight illusion



Flanagan and Beltzner, *Nature Neuroscience*, 2000

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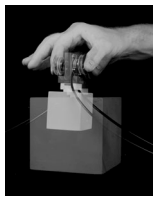

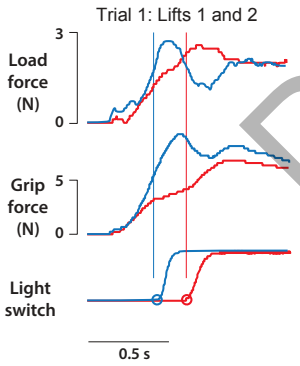

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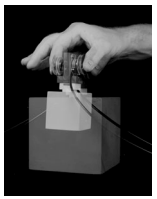
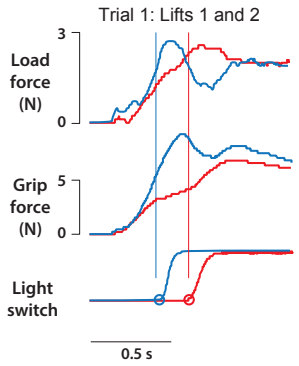


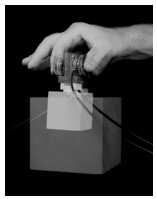


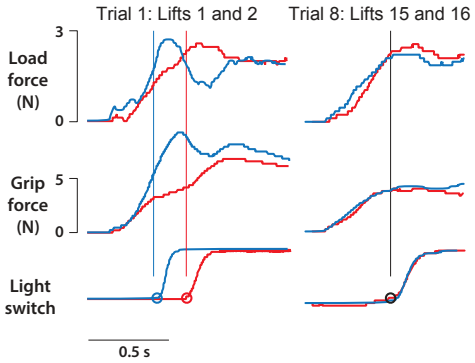
Associative Memory (priors)

Flanagan and Beltzner, *Nature Neuroscience*, 2000

Memory systems underlying prediction

Size-weight illusion





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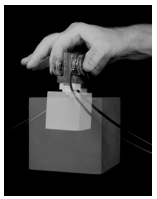

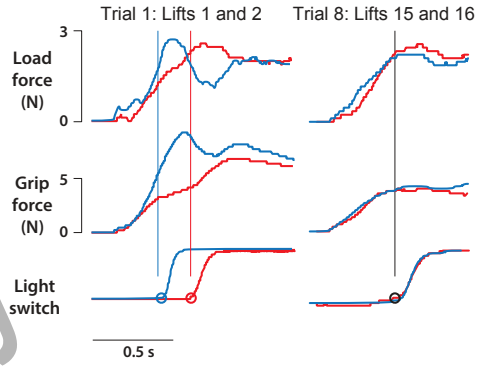

Associative Memory (priors)

Object-Specific Memory

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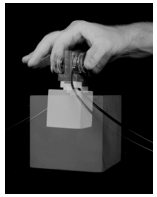
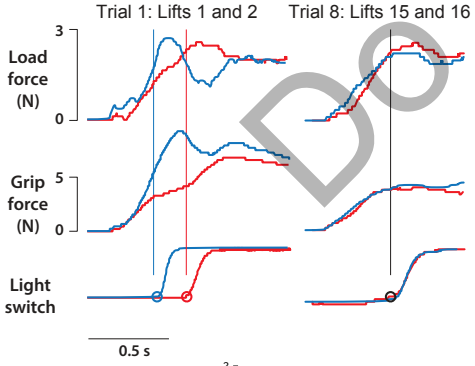
Memory systems underlying prediction

Size-weight illusion





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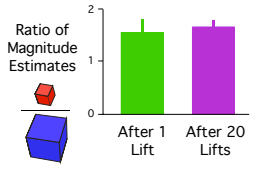

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Memory systems underlying prediction

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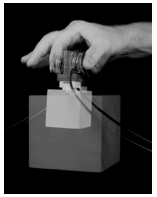
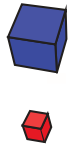
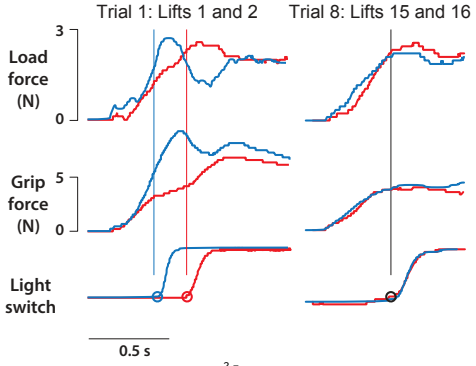
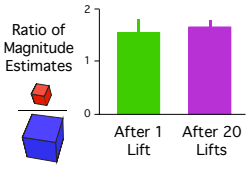






Associative Memory (priors) > Perception & Action

Object-Specific Memory > Action

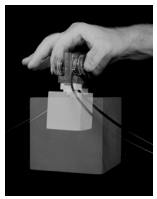


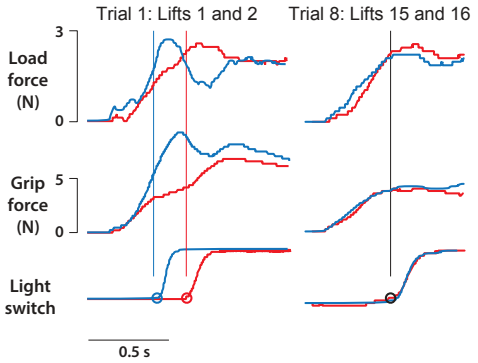
Flanagan and Beltzner, *Nature Neuroscience*, 2000

Memory systems underlying prediction

What about the underlying neural representations?

Size-weight illusion





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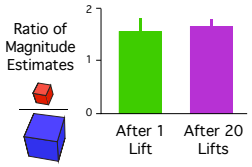

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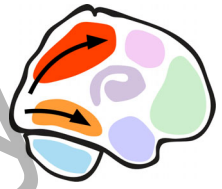
Two Visual Streams Model

Goodale & Milner

Dorsal Stream:
Vision for action



Ventral Stream:
Vision for perception

Two Visual Streams Model

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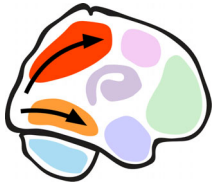
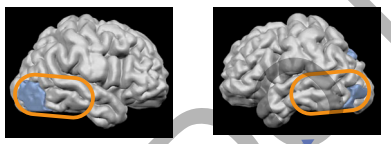


Ventral Stream:
Vision for perception

Patient DF



Area LO lesion

Two Visual Streams Model

Goodale & Milner

Dorsal Stream:
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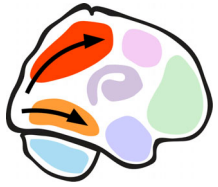

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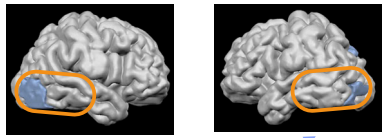


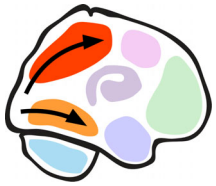
Area LO lesion

Verbally report orientation

Two Visual Streams Model

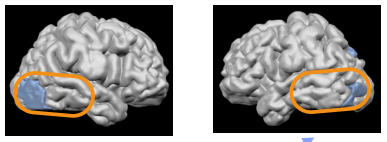
Goodale & Milner

Dorsal Stream:
Vision for action



Ventral Stream:
Vision for perception

Patient DF



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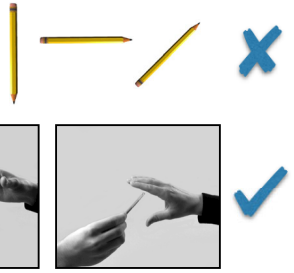

Two Visual Streams Model

Goodale & Milner

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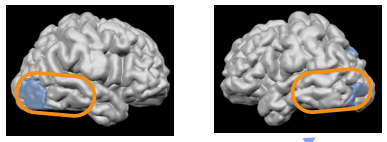

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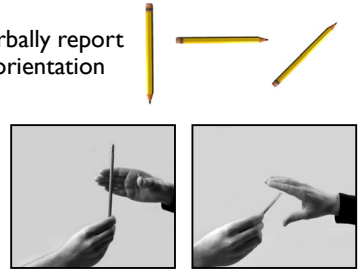
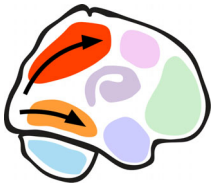


Dissociation between
Action and ***Perception***
but …

Two Visual Streams Model

Goodale & Milner

Dorsal Stream:
Vision for action



Ventral Stream:
Vision for perception

What about **object manipulation** and **memory for weight**?

Two Visual Streams Model

Goodale & Milner

Dorsal Stream:
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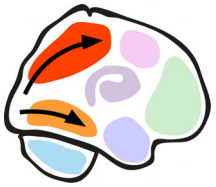

Ventral Stream:
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What about **object manipulation** and **memory for weight**?

Learned associations

Object-specific memory

light *heavy*

Two Visual Streams Model

Goodale & Milner

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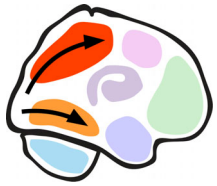

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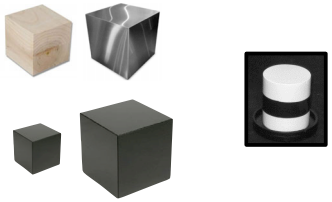

Ventral stream engaged in object recognition, processing texture, memory associations

Two Visual Streams Model

Goodale & Milner

Dorsal Stream:
Vision for action

Ventral Stream:
Vision for perception

and for real-world action

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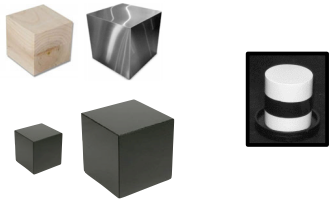
Object-specific memory



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Goodale & Milner

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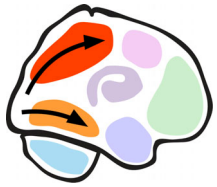

Ventral Stream:
Vision for perception

and for real-world action

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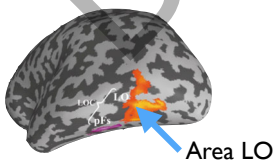
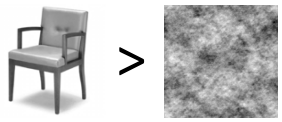


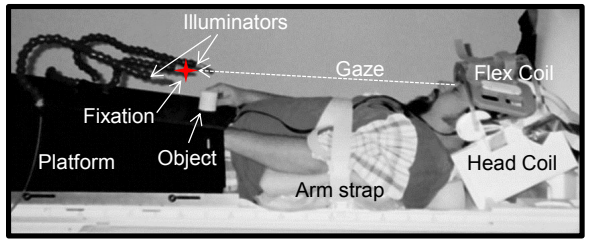
Contrast:



Gallivan, Cant, Goodale, Flanagan, *Current Biology*, 2014

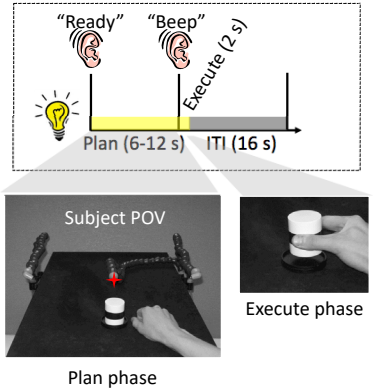
Memory Representations of Object Weight

Apparatus



Gallivan, Cant, Goodale, Flanagan, *Current Biology*, 2014

Experiment 1: Object-Specific Memory



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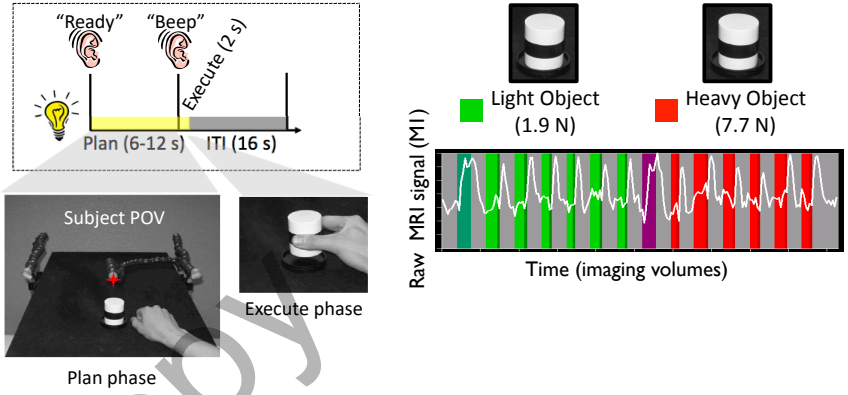

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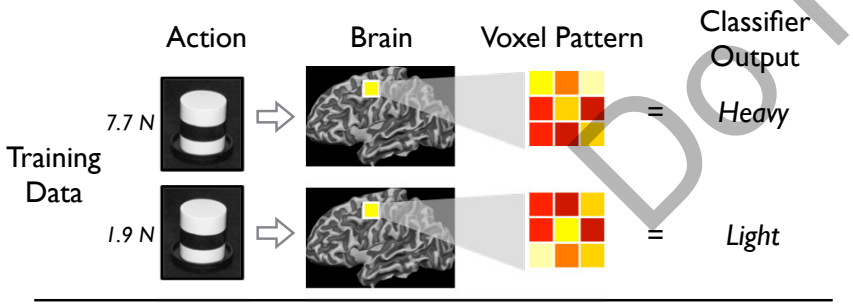
Multi-Voxel Pattern Analysis (MVPA)



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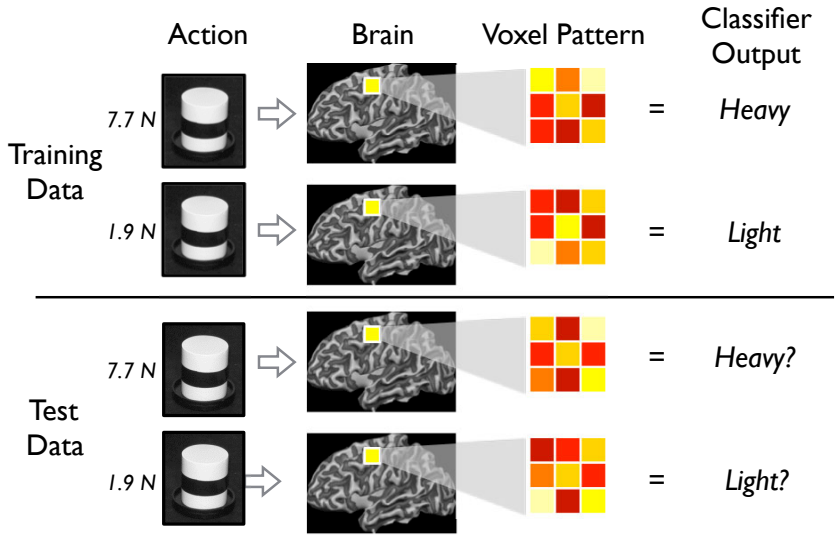

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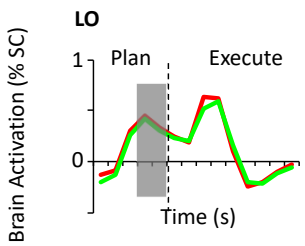
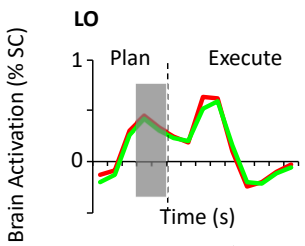
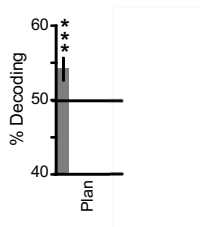


Timecourse Legend
- Light Object
- Heavy Object

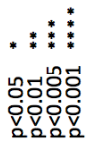
Gallivan, Cant, Goodale, Flanagan, *Current Biology*, 2014

Experiment 1: Object-Specific Memory





Significance levels (vs. chance)



Timecourse Legend
- Light Object
- Heavy Object

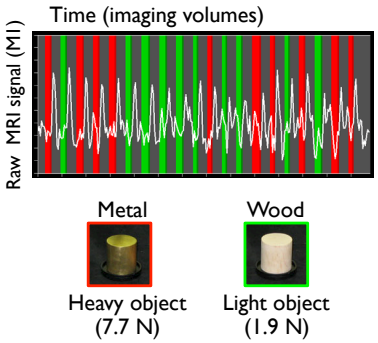
Decoding Legend
- **Weight**: Heavy vs. Light

Gallivan, Cant, Goodale, Flanagan, *Current Biology*, 2014

Experiment 2: Associative Memory

First half of experiment

Normal object mapping



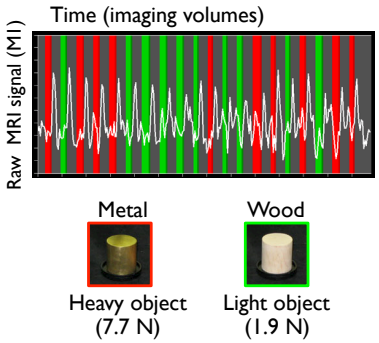
**Same group of participants as in Experiment 1*

Gallivan, Cant, Goodale, Flanagan, *Current Biology*, 2014

Experiment 2: Associative Memory

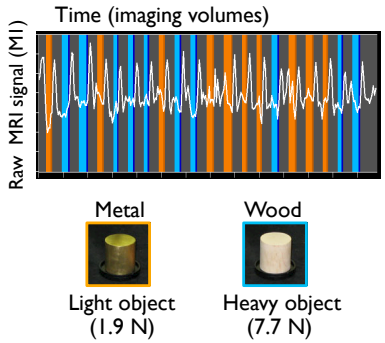
First half of experiment

Normal object mapping



Second half of experiment

Inverse object mapping



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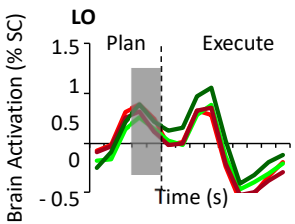
Gallivan, Cant, Goodale, Flanagan, *Current Biology*, 2014

Experiment 2: Associative Memory

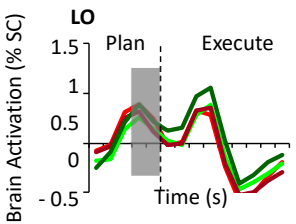


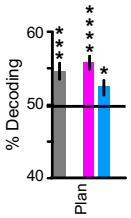
Timecourse Legend

- Light Wood Object
- Light Metal Object
- Heavy Metal Object
- Heavy Wood Object

Gallivan, Cant, Goodale, Flanagan, *Current Biology*, 2014

Experiment 2: Associative Memory





Significance levels (vs. chance)

p<0.05
p<0.01
p<0.005
p<0.001

Timecourse Legend

- Light Wood Object
- Light Metal Object
- Heavy Metal Object
- Heavy Wood Object

Expt. 1 Decoding Legend

- **Object Weight**: Heavy vs. Light

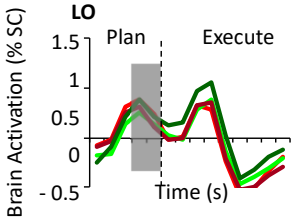
Expt. 2 Decoding Legend

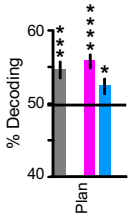
- **Object Weight**: Heavy vs. Light
- **Object Material**: Metal vs. Wood

Gallivan, Cant, Goodale, Flanagan, *Current Biology*, 2014

Experiment 2: Associative Memory

What about Material?





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Timecourse Legend

- Light Wood Object
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- Heavy Metal Object
- Heavy Wood Object

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Expt. 2 Decoding Legend

- **Object Weight**: Heavy vs. Light
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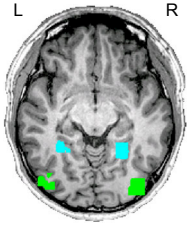
Gallivan, Cant, Goodale, Flanagan, *Current Biology*, 2014

Material Processing Regions

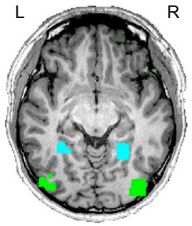


Contrast:

Cant and Xu, 2012, *J. Neuroscience*

Gallivan, Cant, Goodale, Flanagan, *Current Biology*, 2014

Material Processing Regions



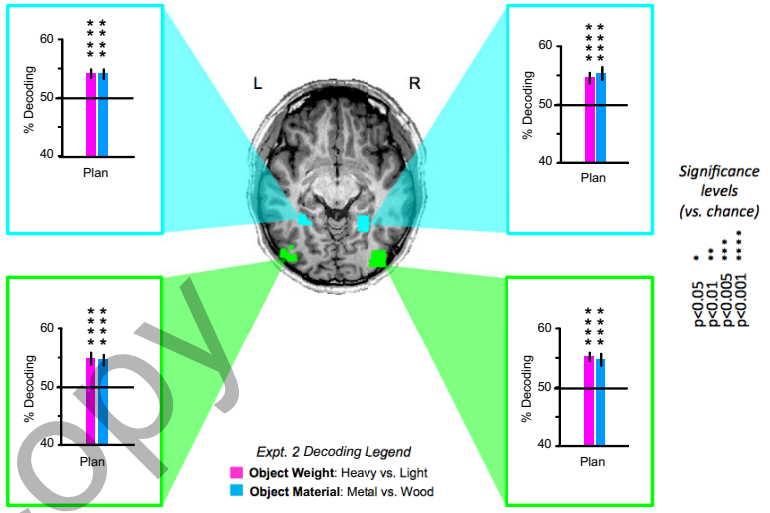
Contrast:

Cant and Xu, 2012, *J. Neuroscience*

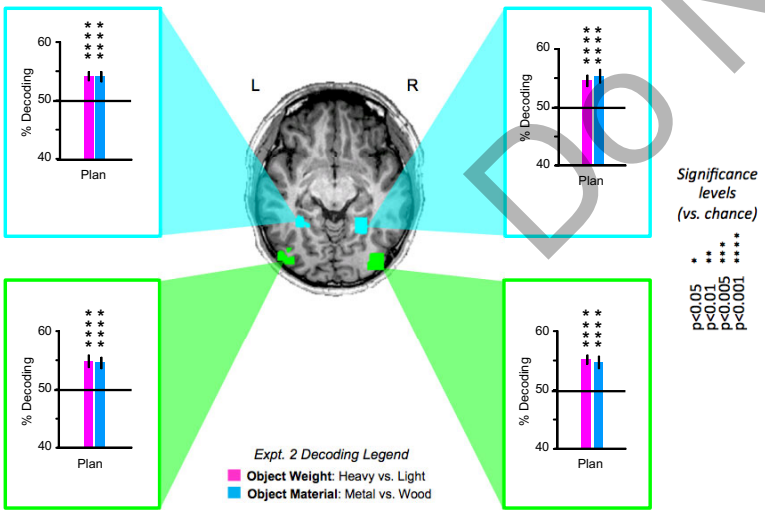
Do these regions represent object weight when it can be predicted based on object material?

Gallivan, Cant, Goodale, Flanagan, *Current Biology*, 2014

Material Processing Regions

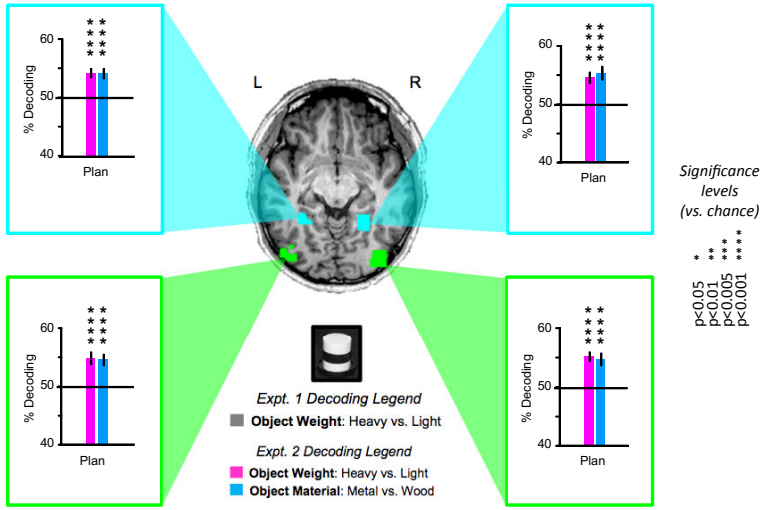


Material Processing Regions



Do these regions ONLY represent weight when predicted by object material?

Material Processing Regions



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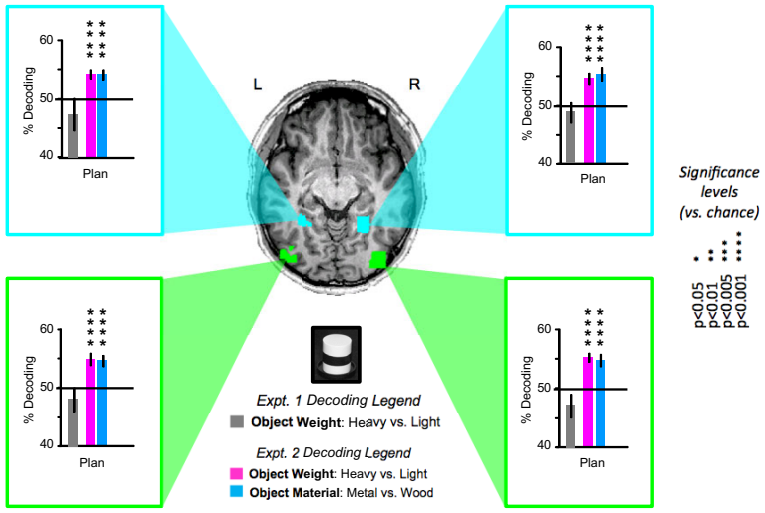


Do these regions ONLY represent weight when predicted by object material?

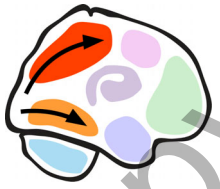
Two Visual Streams Model

Goodale & Milner

Dorsal Stream:
Vision for action

Real-time visuomotor processing

Processing of spatial features



Ventral Stream:
Vision for perception

and for real-world action

Ventral visual stream represents intrinsic, non-visual object properties (i.e., weight)

Coding of associations, lasting properties

Gallivan, Cant, Goodale, Flanagan, *Current Biology*, 2014

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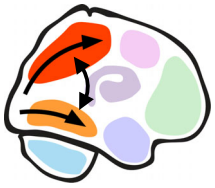

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Medial Temporal Lobe Structures in Action

Interacting with and re-arranging the world

Medial Temporal Lobe Structures in Action

Interacting with and re-arranging the world

Declarative Memory: ***Object weights***

Medial Temporal Lobe Structures in Action

Interacting with and re-arranging the world

Declarative Memory: ***Object weights***
Spatial Memory: ***Object locations***

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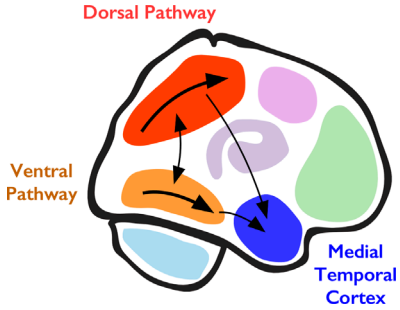

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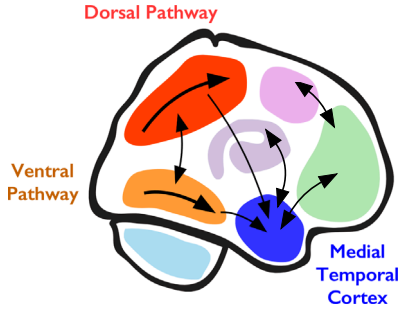

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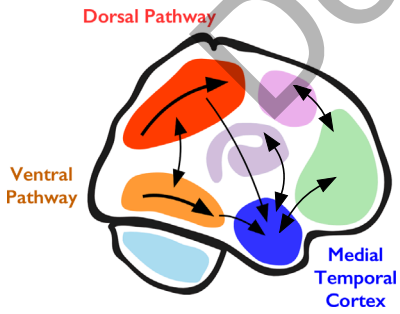

Patient H.M. exhibited learning of a mirror drawing tasks …

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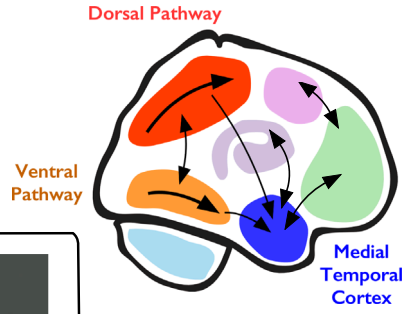

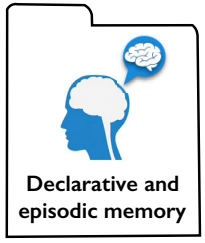

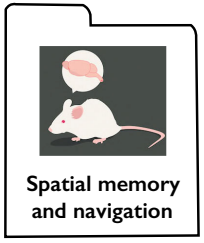

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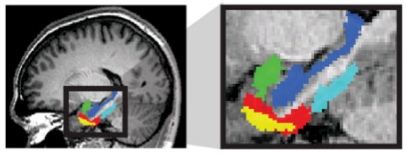
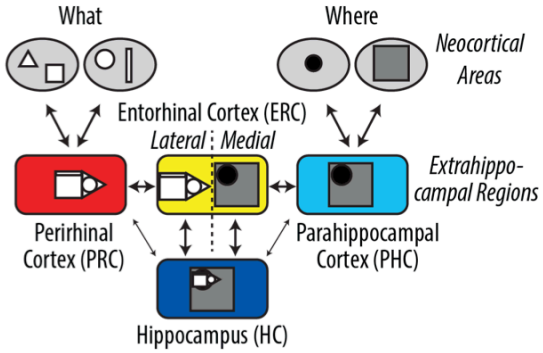
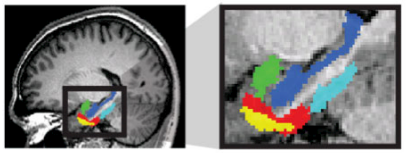
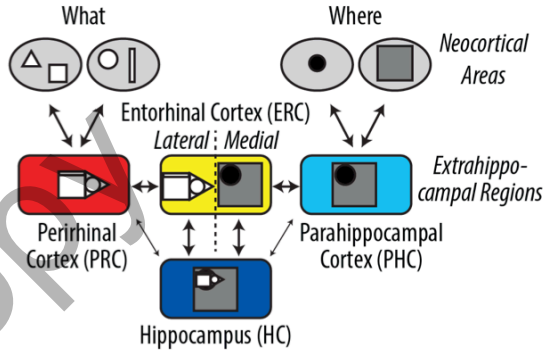




Modified from Eichenbaum & Ranganath, 2007, *Ann. Rev. Neurosci.*



Object Properties (weight) **Object Locations**



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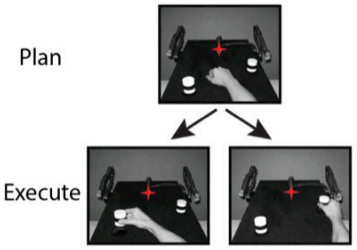
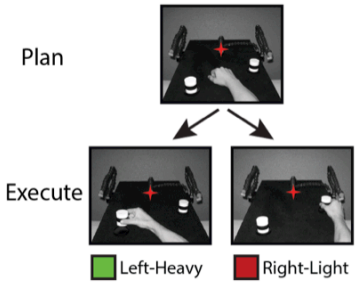
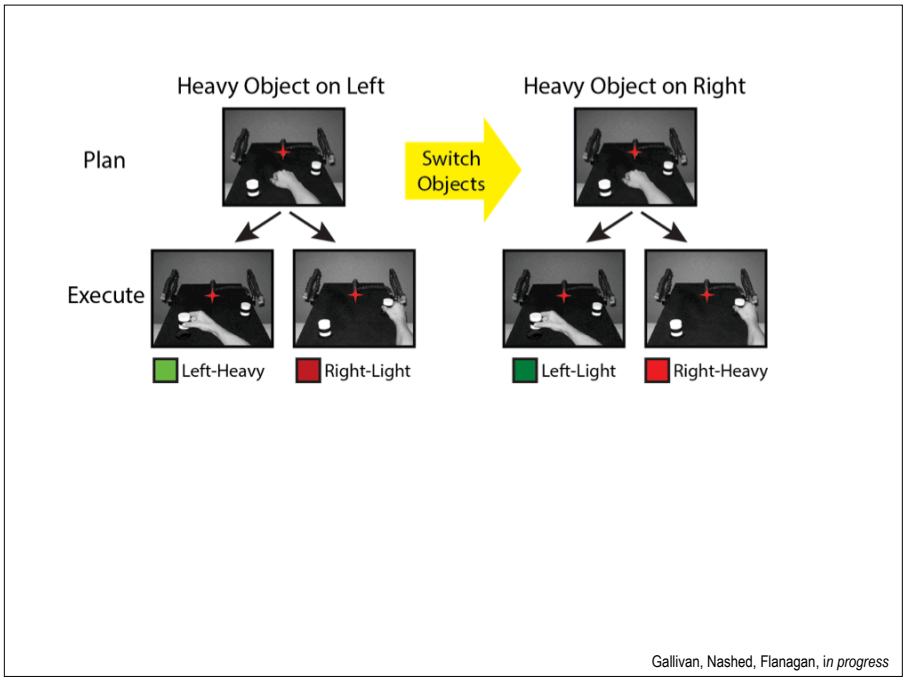
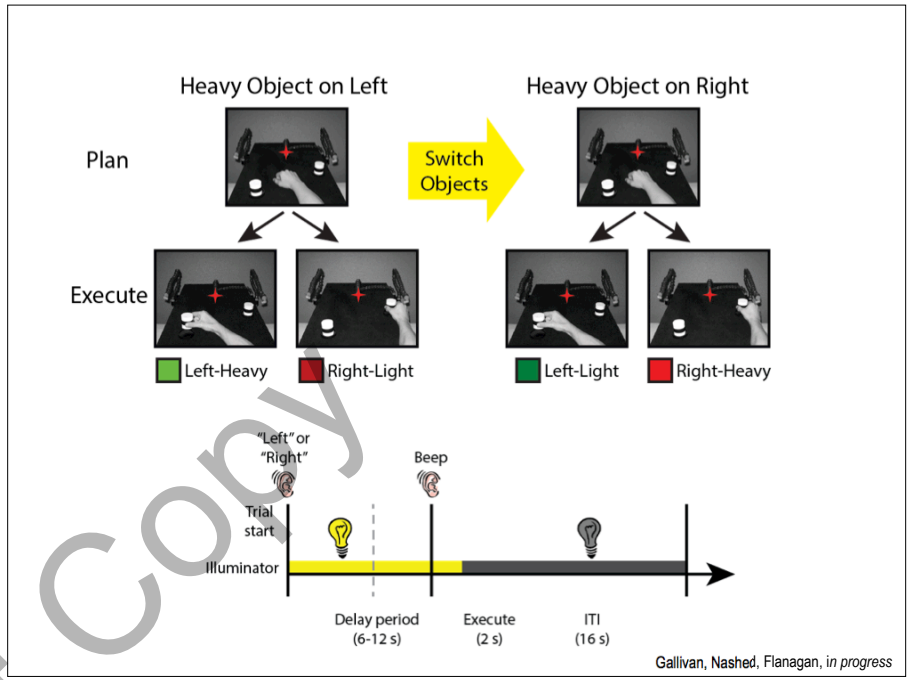


Heavy Object on Left





Gallivan, Nashed, Flanagan, *in progress*



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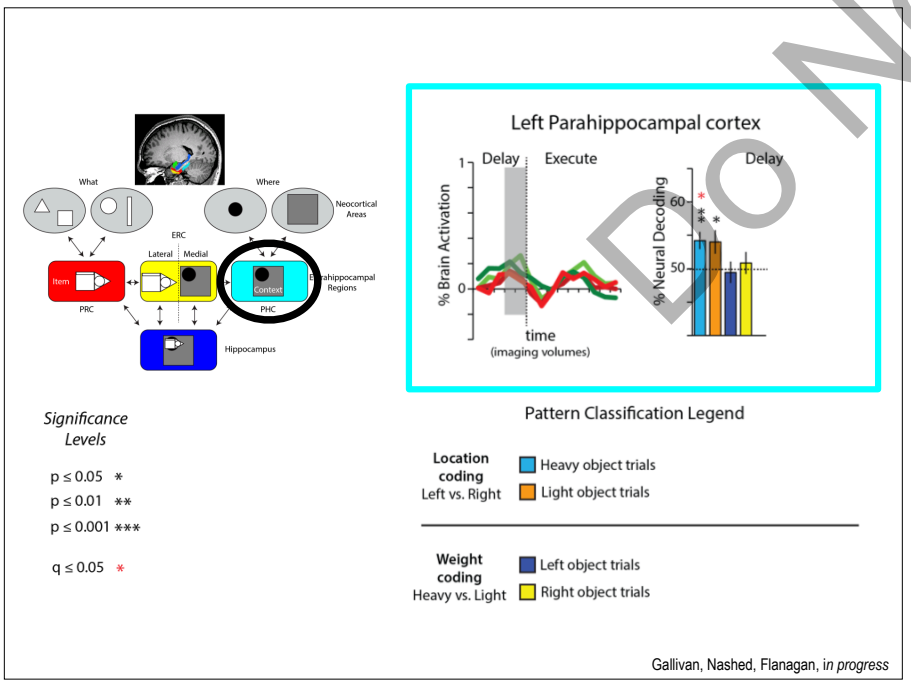

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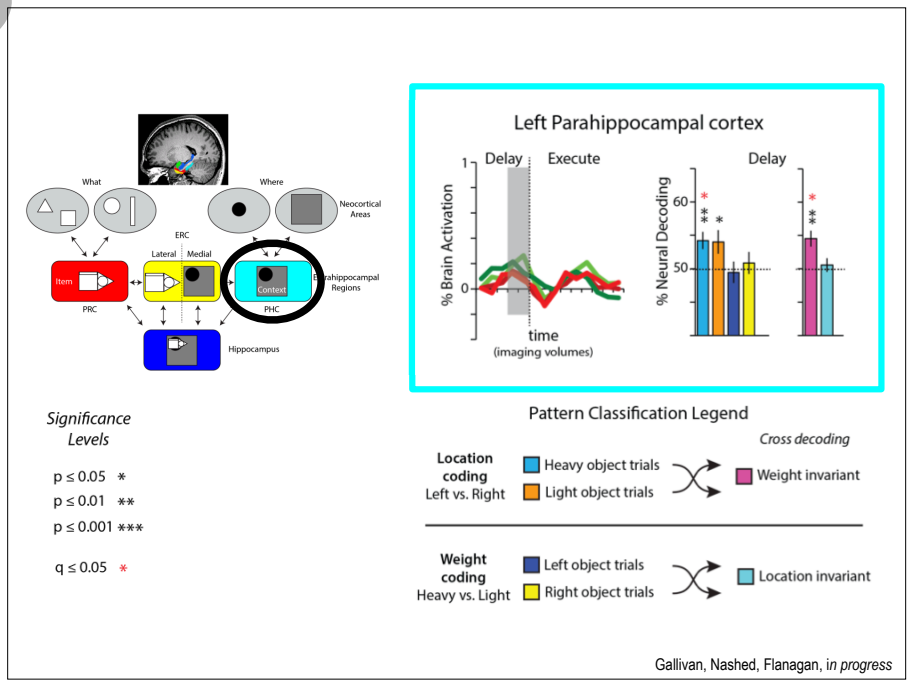

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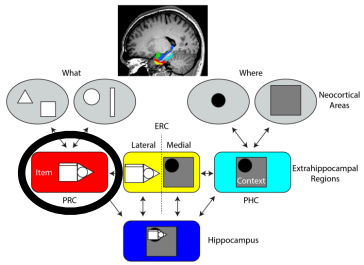
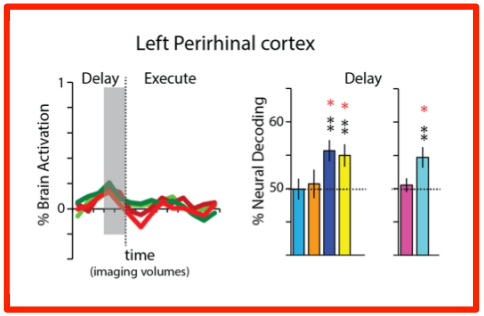




Significance Levels

p ≤ 0.05 *
p ≤ 0.01 **
p ≤ 0.001 ***

q ≤ 0.05 *

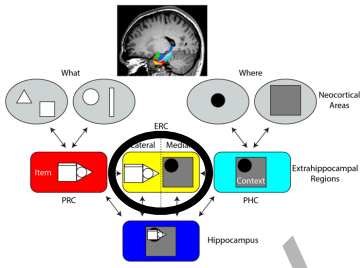
Pattern Classification Legend

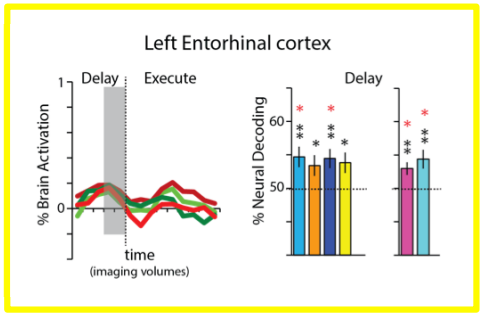
Cross decoding

Location coding Left vs. Right: Heavy object trials, Light object trials → Weight invariant

Weight coding Heavy vs. Light: Left object trials, Right object trials → Location invariant

Gallivan, Nashed, Flanagan, *in progress*





Significance Levels

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p ≤ 0.01 **
p ≤ 0.001 ***

q ≤ 0.05 *

Pattern Classification Legend

Cross decoding

Location coding Left vs. Right: Heavy object trials, Light object trials → Weight invariant

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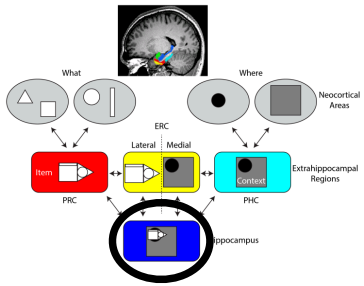

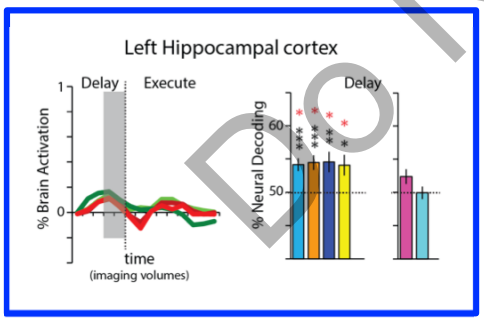

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Cross decoding

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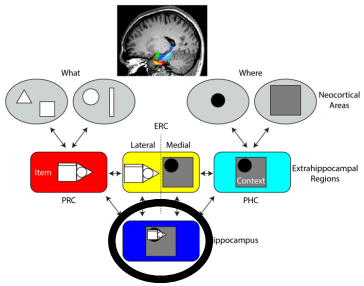
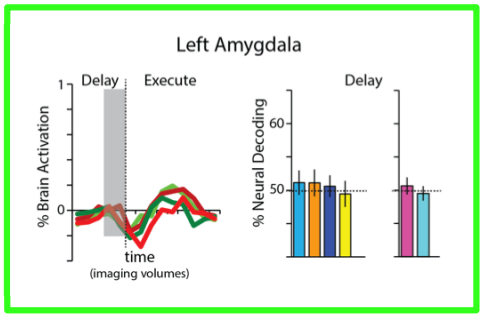
Gallivan, Nashed, Flanagan, *in progress*





Significance Levels

p ≤ 0.05 *
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p ≤ 0.001 ***

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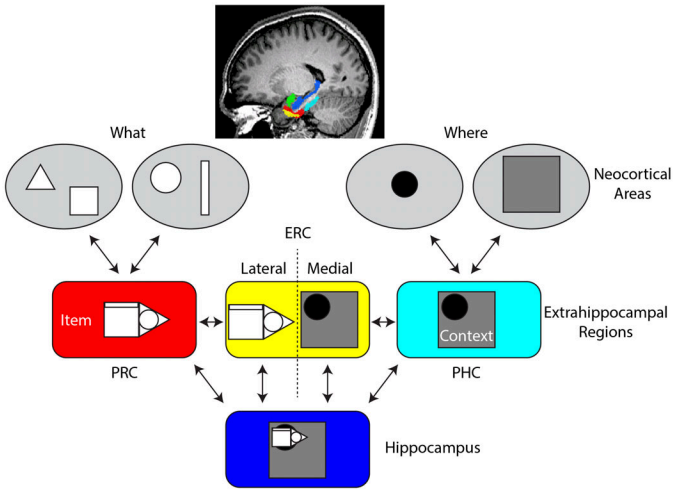

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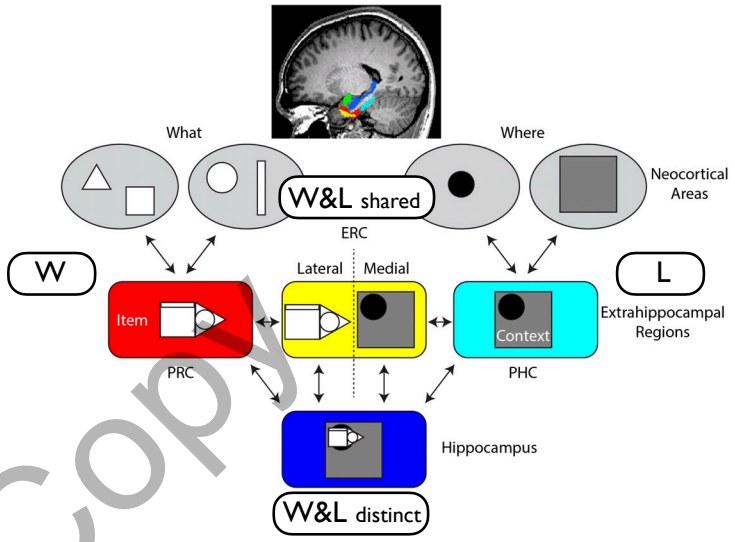

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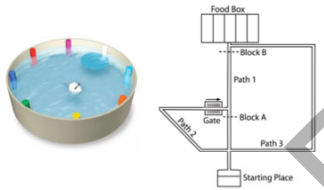
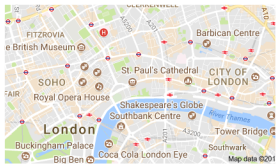
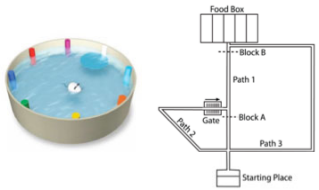
Classic Spatial Memory Tasks





Learning 'fixed' environments

Classic Spatial Memory Tasks

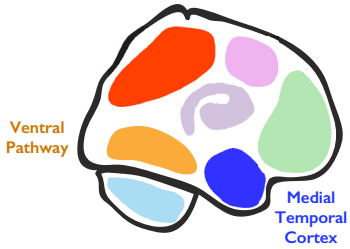


Learning 'fixed' environments

Object Manipulation Tasks

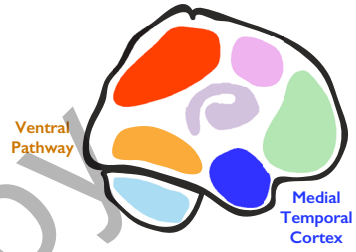
Actively changing the world

Summary



Summary

Ventral visual stream areas are engaged in object manipulation and represent weight, a non-visual object property.



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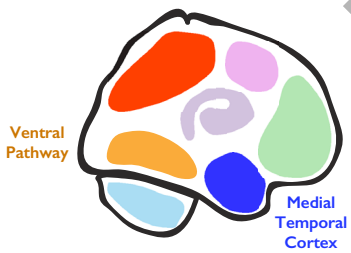

MTL structures may support real-world action tasks involving manipulating and re-arranging objects

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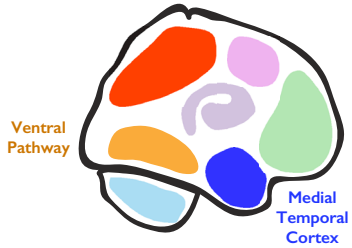
Impairments in real-world tasks involving manipulation may reflect sensory, motor, or cognitive deficits



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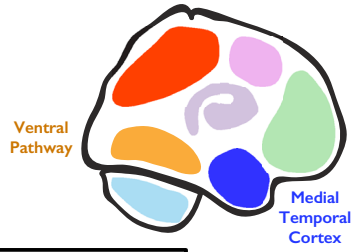

Manipulation tasks might provide a novel window onto understanding how declarative, spatial, and episodic memory systems interact.

MTL structures may support real-world action tasks involving manipulating and re-arranging objects

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