

***E cingulus pluram:* Multiple computational roles of anterior cingulate activity**

**William Alexander
Ghent University**

What do we want out of a theory?

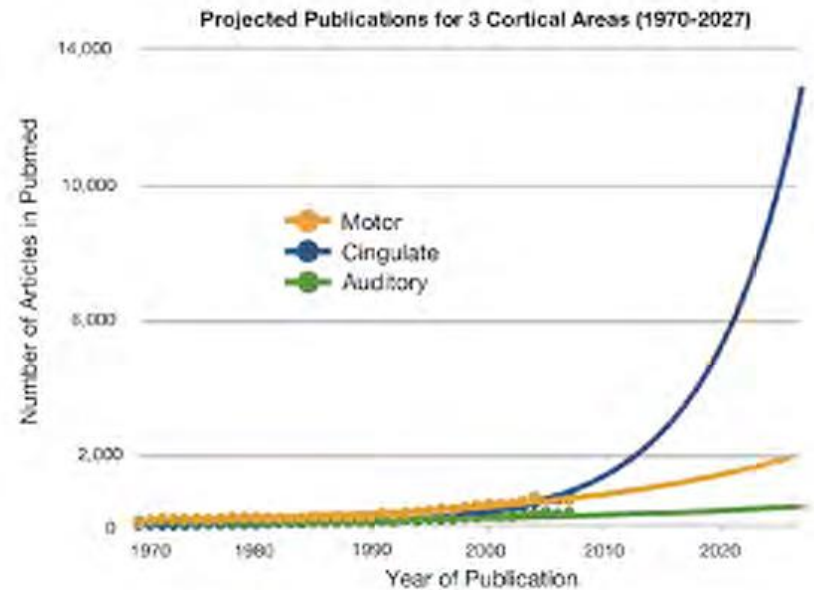
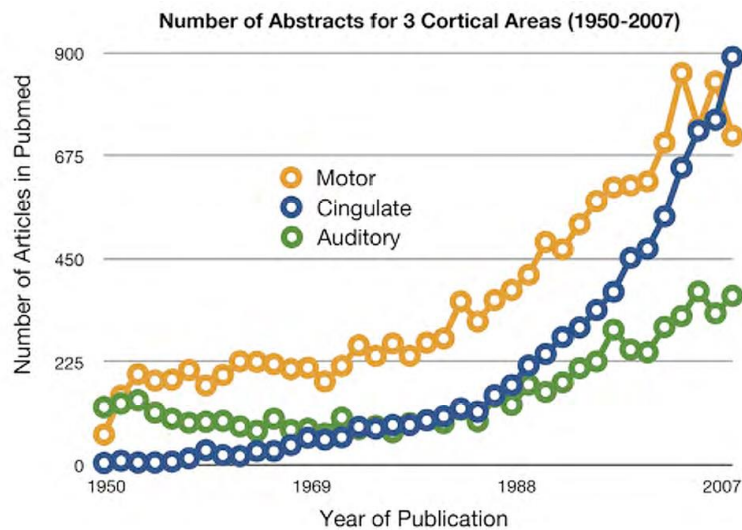
It should:

- Explain some set of data
- Predict future observations

It *might*:

- Generalize to novel contexts
- Inform and constrain the function of additional regions

The Cingularity



Gage, Parikh & Marzullo (2008)

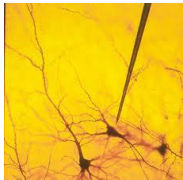
What do we want out of a theory?

It should:

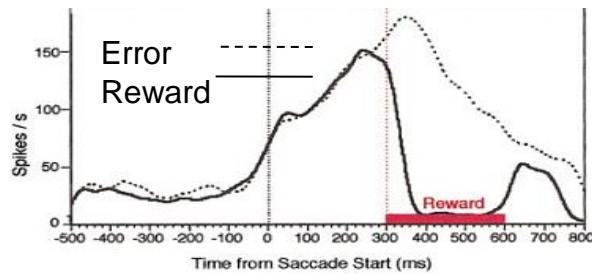
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Single-Unit Neurophysiology

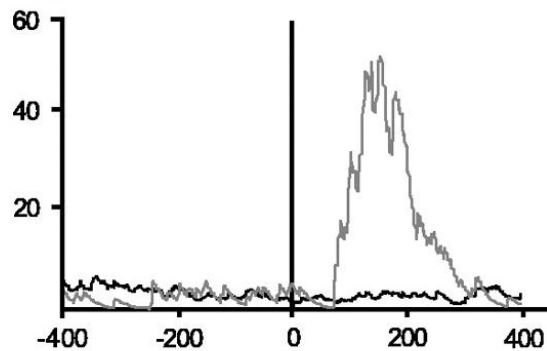


Amador et al, 2000

**Reward
Prediction**

≠

**Reward
Detection**



Ito et al, 2003

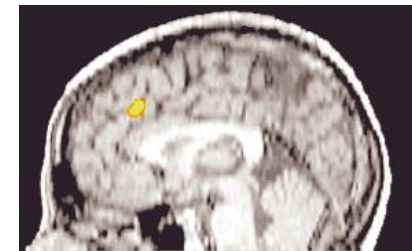
fMRI



EEG

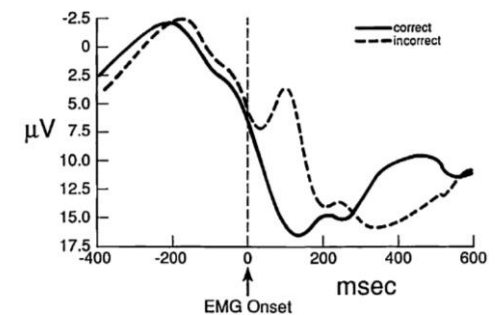


**Conflict
Monitoring**



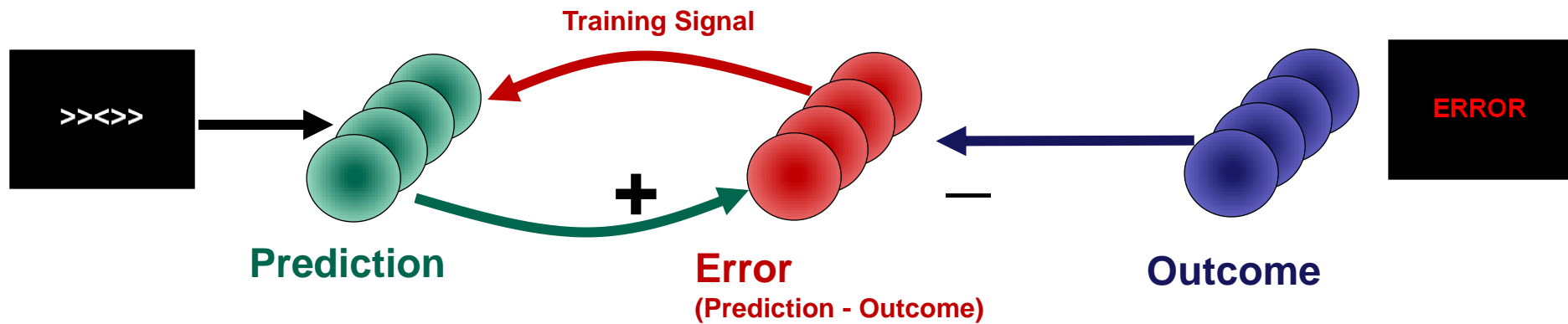
Botvinick et al, 1999

**Error
Detection**

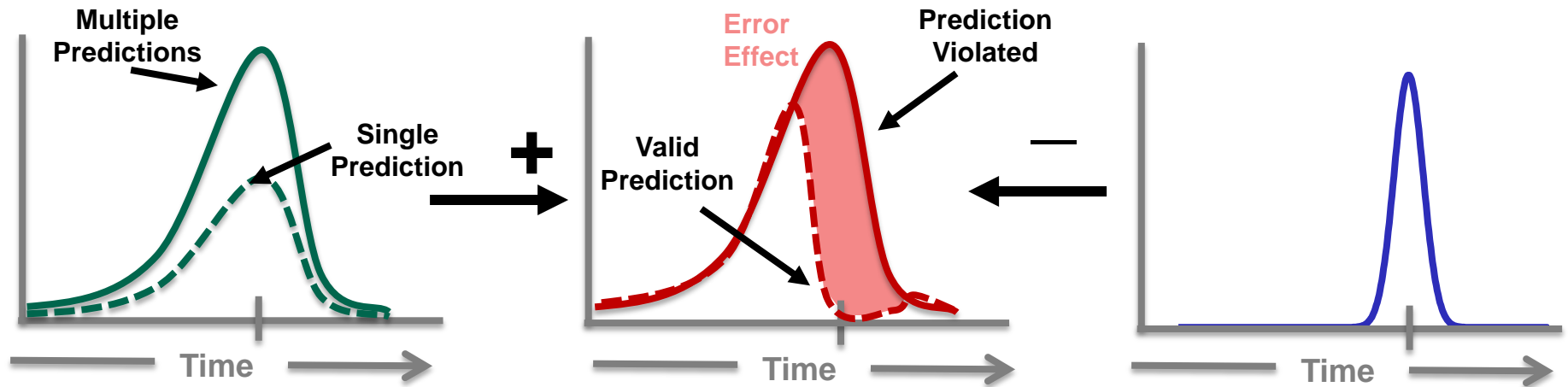
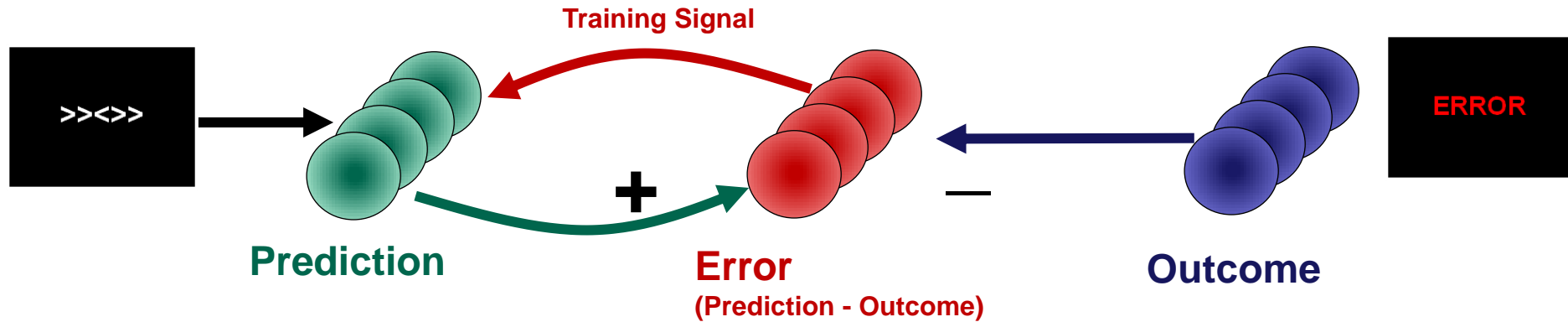


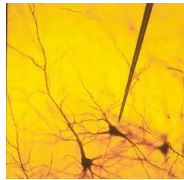
Gehring et al, 1993

Predicted Response-Outcome Model

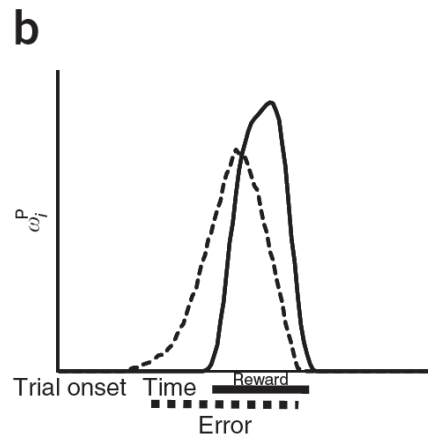
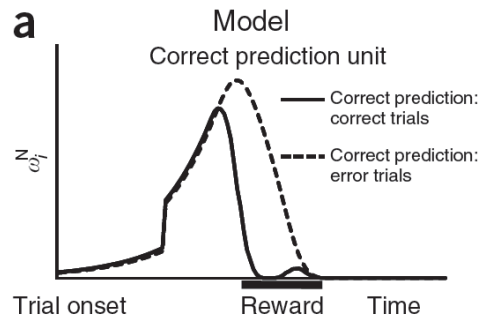


Predicted Response-Outcome Model



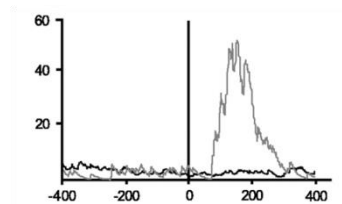
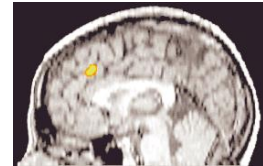
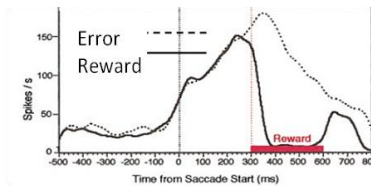


Model Simulations

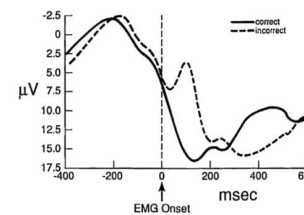


Alexander & Brown, 2011

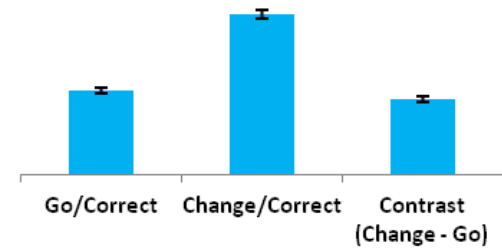
Neural Activity



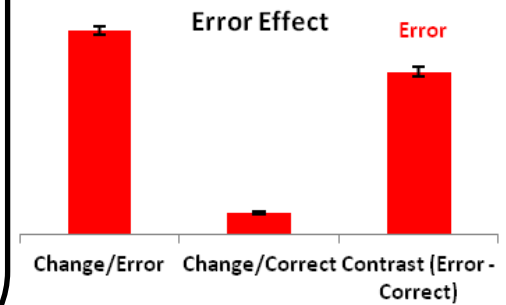
Ito et al, 2003



Conflict Effect

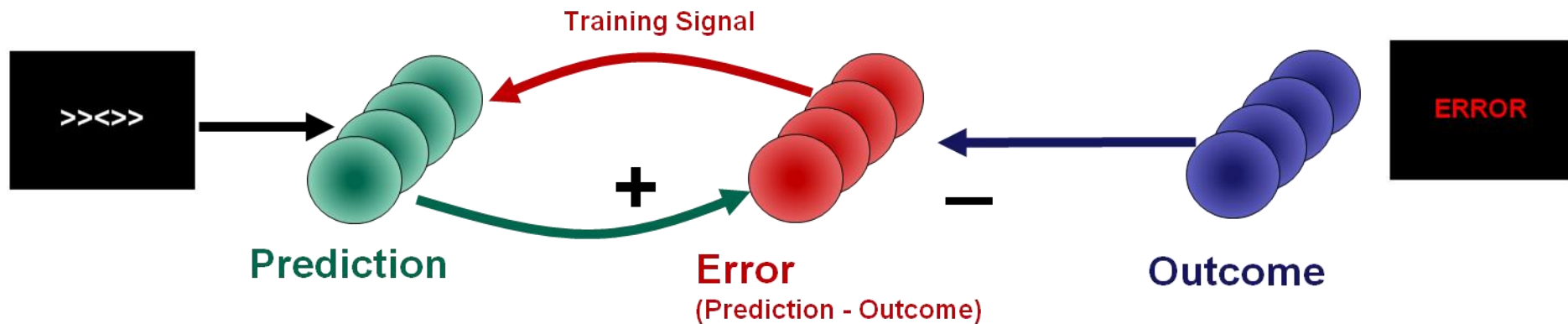


Error Effect



Alexander & Brown, 2011

Predicted Response-Outcome Model



Additional Effects

Error Likelihood
Unexpected Errors
Unexpected Correct Feedback
Environmental Volatility
Multiple Outcome Predictions

Multiple Responses
Time on Task
Delay of Feedback
Speed-Accuracy Tradeoff
And others...

What do we want out of a theory?

It should:

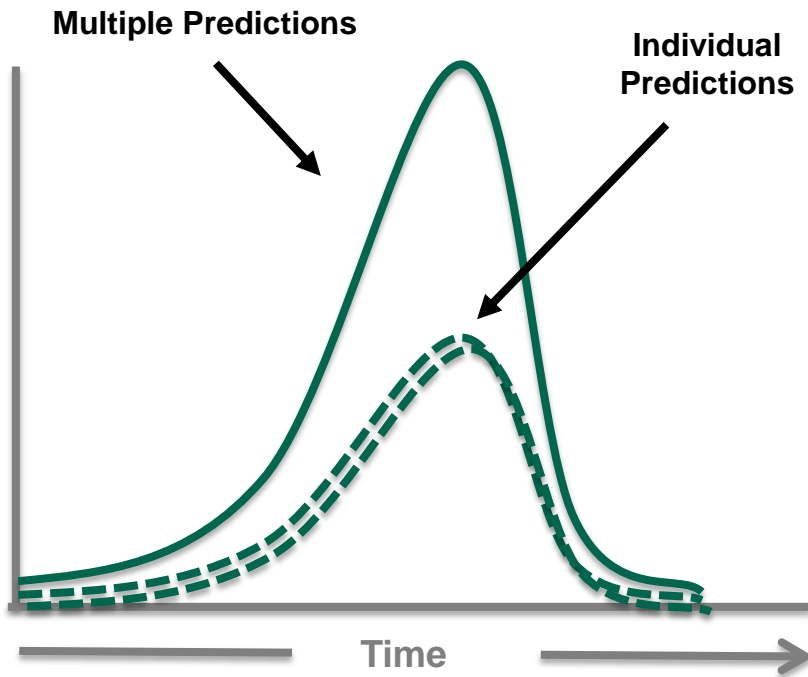
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- **Predict future observations**

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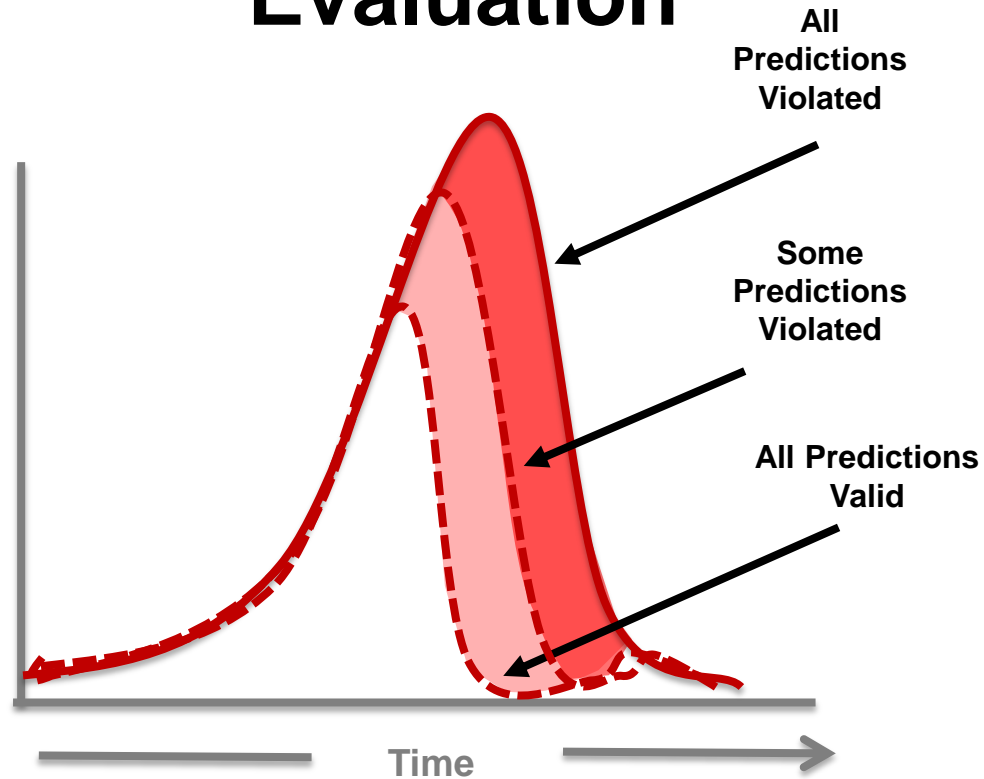
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Monitoring Multiple Outcomes

Prediction

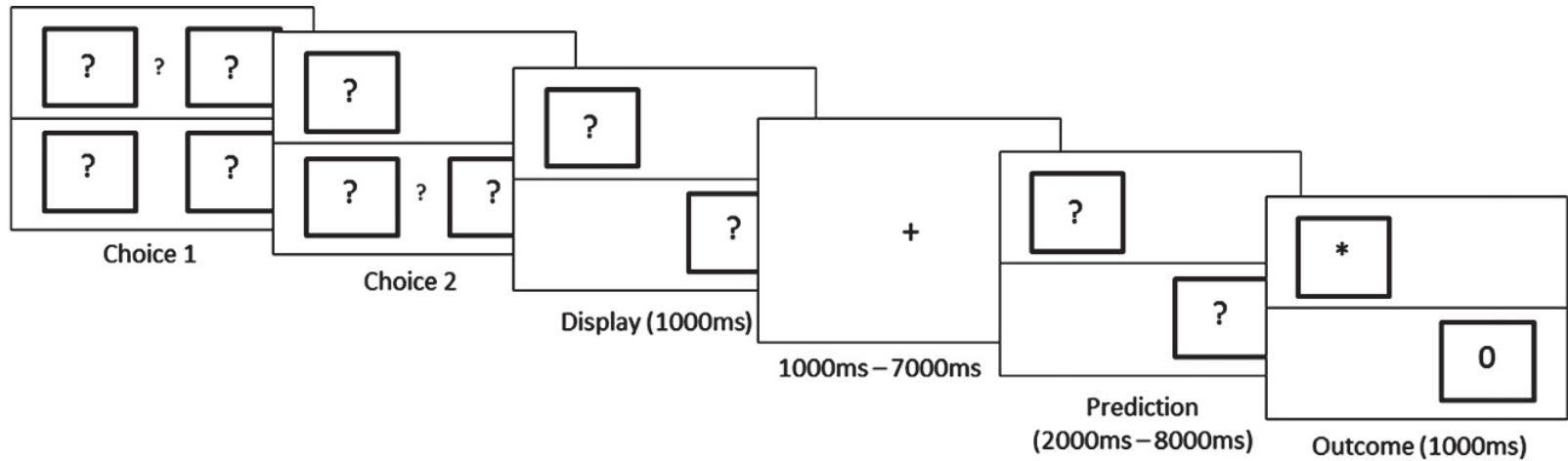


Evaluation



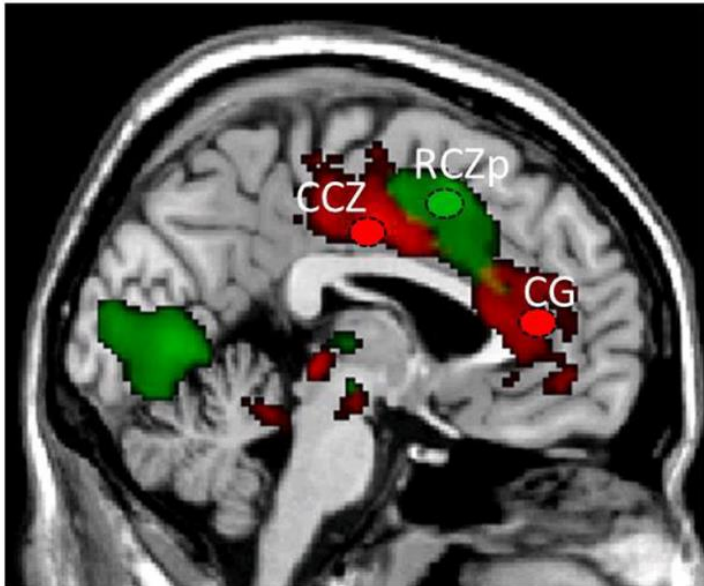
Partial Error Effect
Complete Error Effect

Monitoring Multiple Outcomes

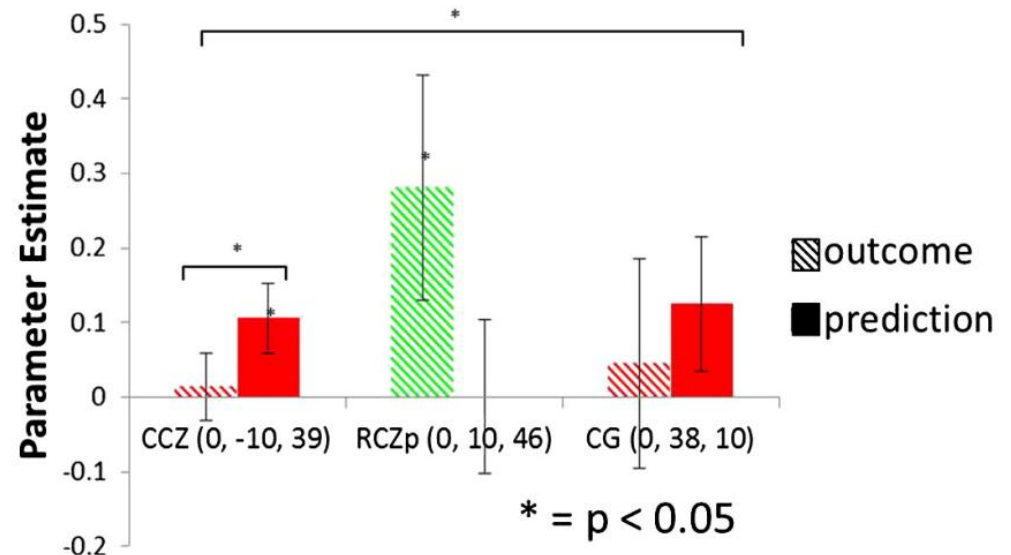


Jahn et al., 2014, Neuroimage

Monitoring Multiple Outcomes



Jahn et al., 2014



What do we want out of a theory?

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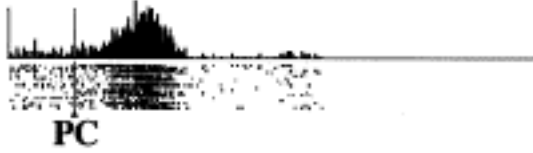
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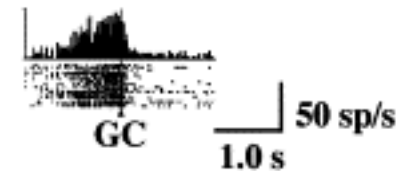
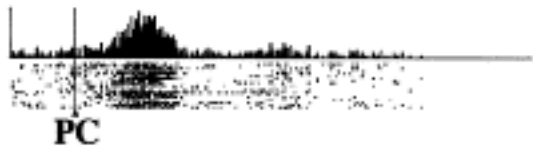
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ACC in stimulus processing

Pain-avoidance trials



Reward trials



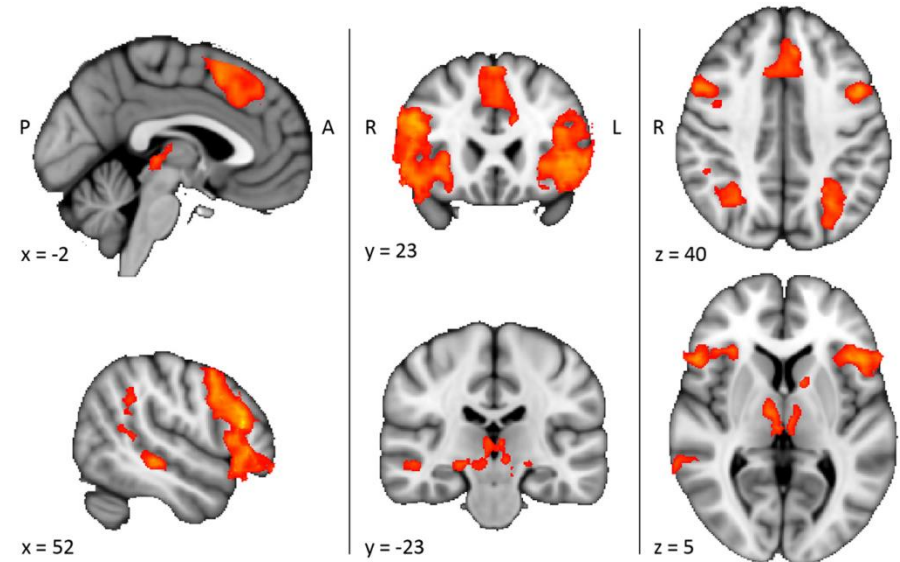
Anticipation of cue presentation

Koyama et al., 2001

Koyama et al., 2001

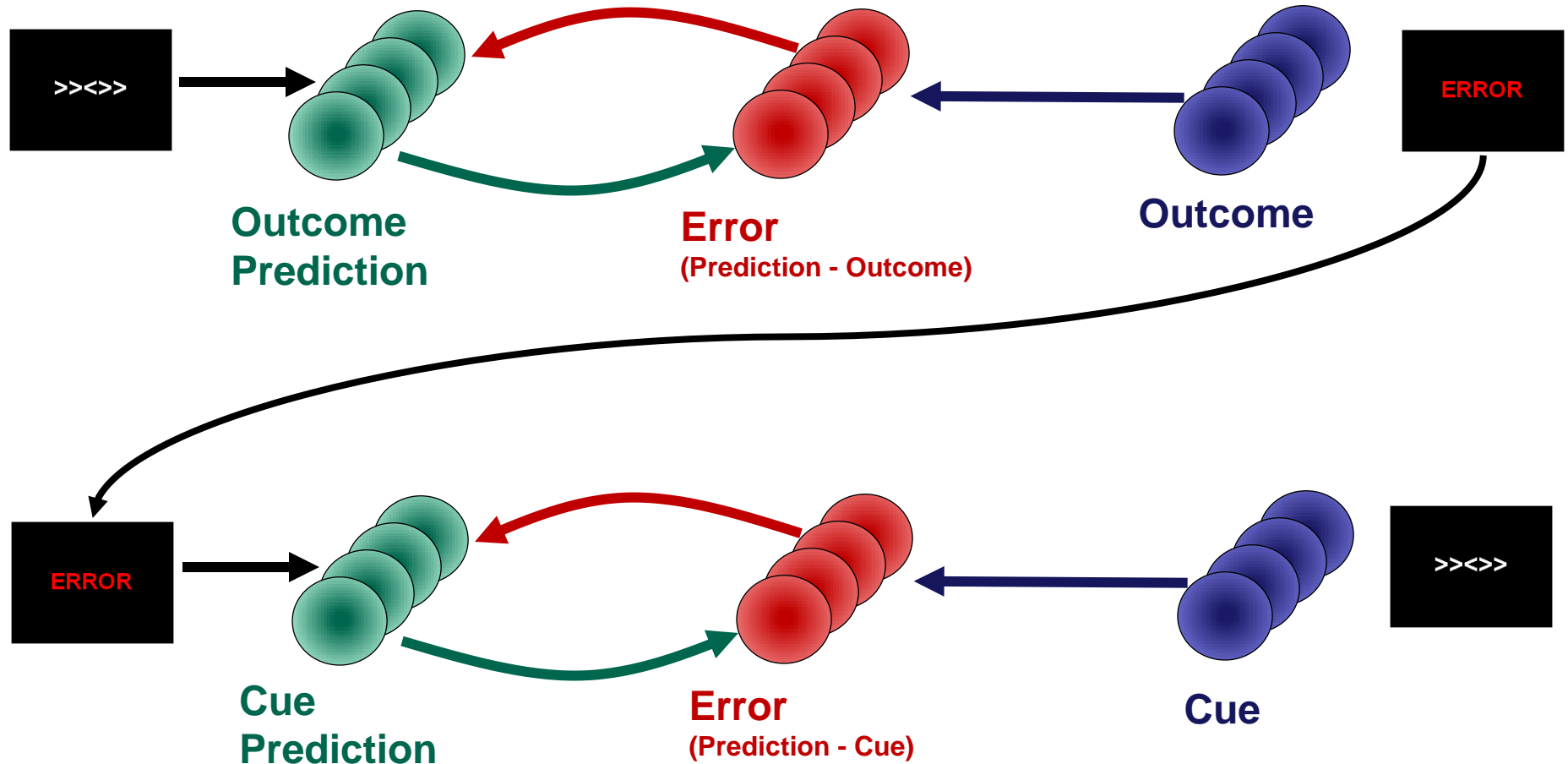
Overlap of error and novelty effects

Wessel et al., 2012

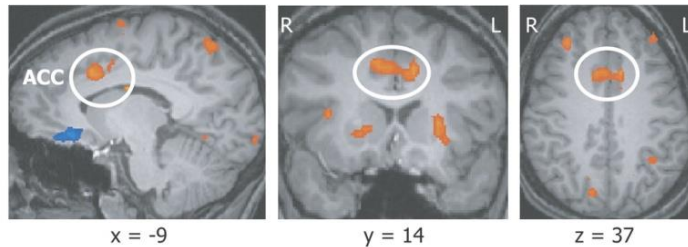


Wessel et al., 2012

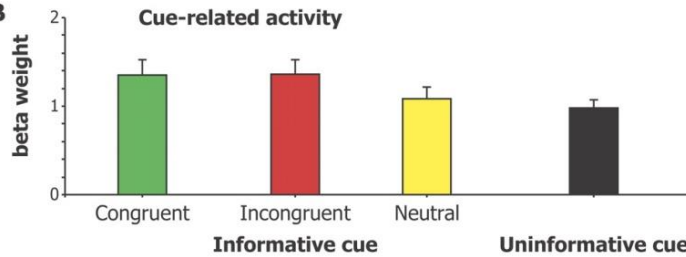
Event Prediction



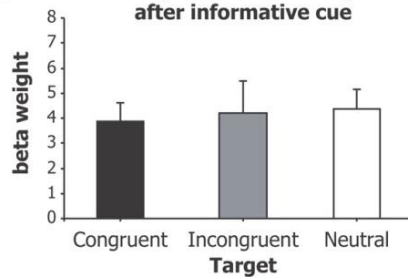
A Informative cues > Uninformative cues



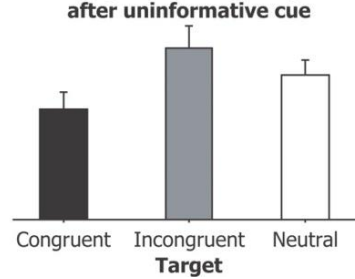
B Cue-related activity



C Target-related activity after informative cue

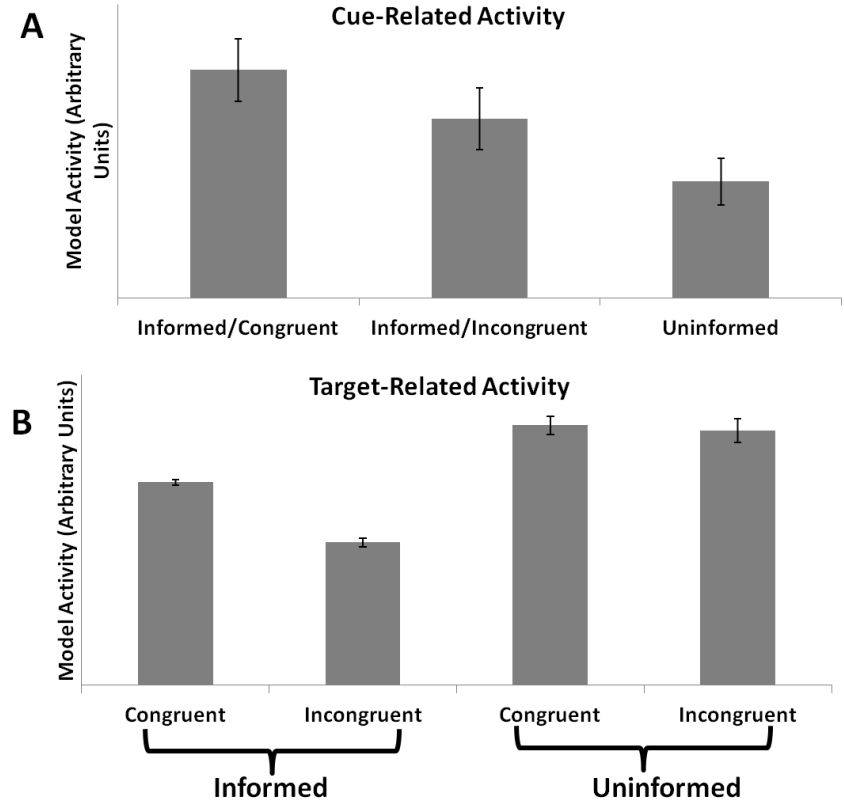


D Target-related activity after uninformative cue



Aarts et al, 2008

Model Activity



Alexander & Brown, 2014

Other Contexts

Stimulus Processing

Global vs. local control – Blais & Bunge, 2010

Mismatch Negativity – Crottaz-Herbette & Menon, 2006

Bayesian Surprise – Ide et al., 2013

Social Neuroscience

Monitoring outcomes for others – Apps et al., 2012

Signaling others' rewards – Change et al., 2013

Detecting errors by others – Yoshida et al., 2012

Clinical Neuroscience

ACC activity in substance dependence – Alexander et al., submitted

Affective Neuroscience

Surprising absence of pain – Jahn et al., in preparation

What do we want out of a theory?

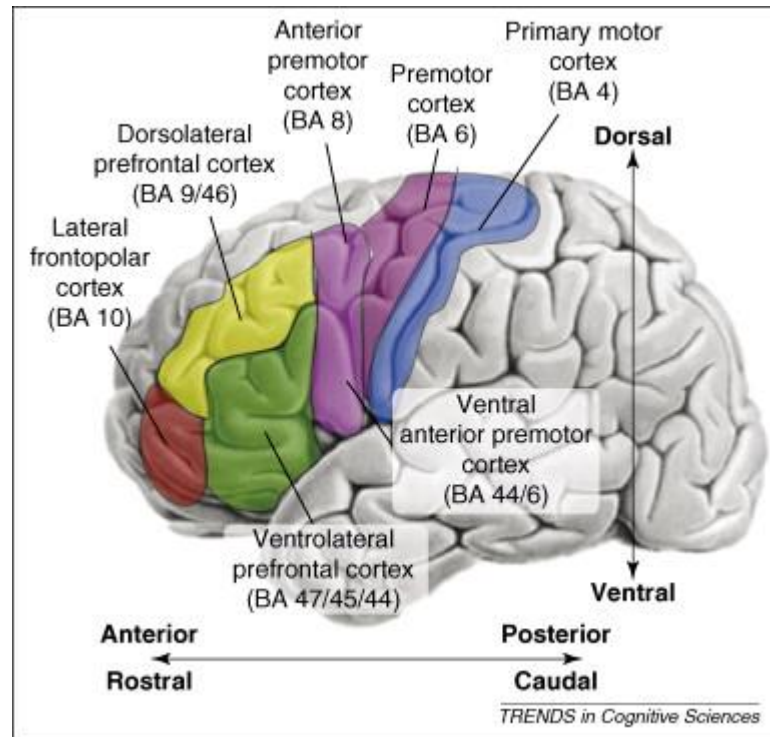
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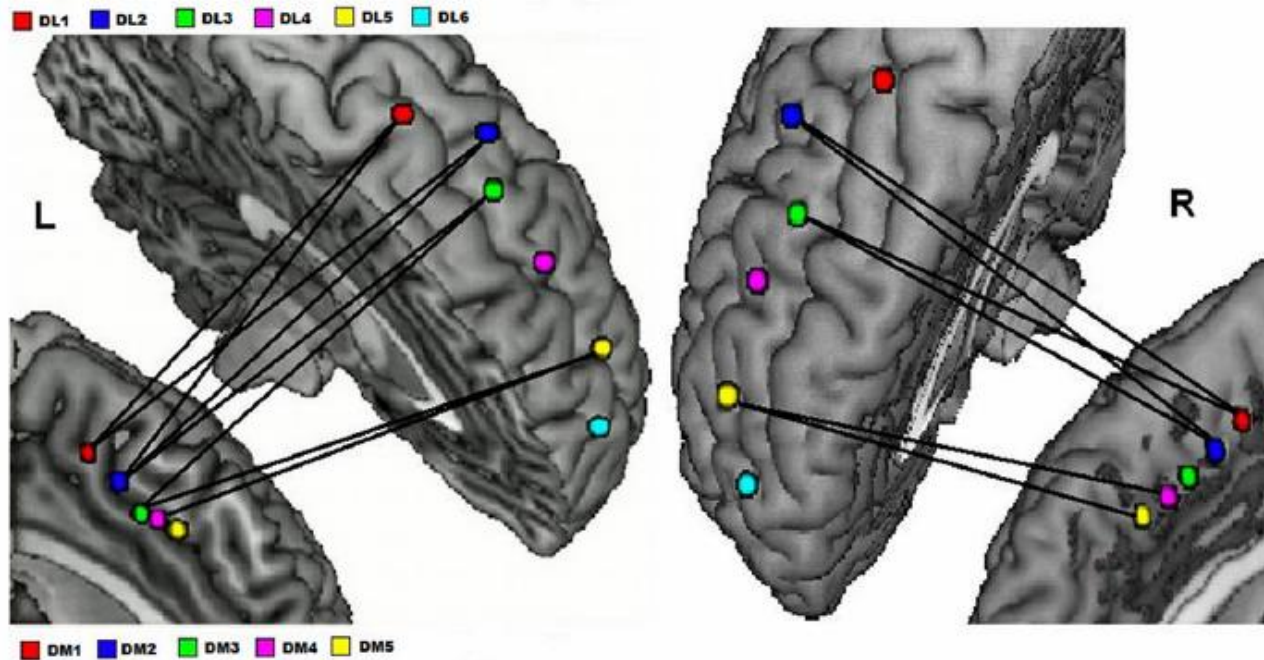
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Interactions with dlPFC



Badre, 2008, Trends in Cognitive Sciences

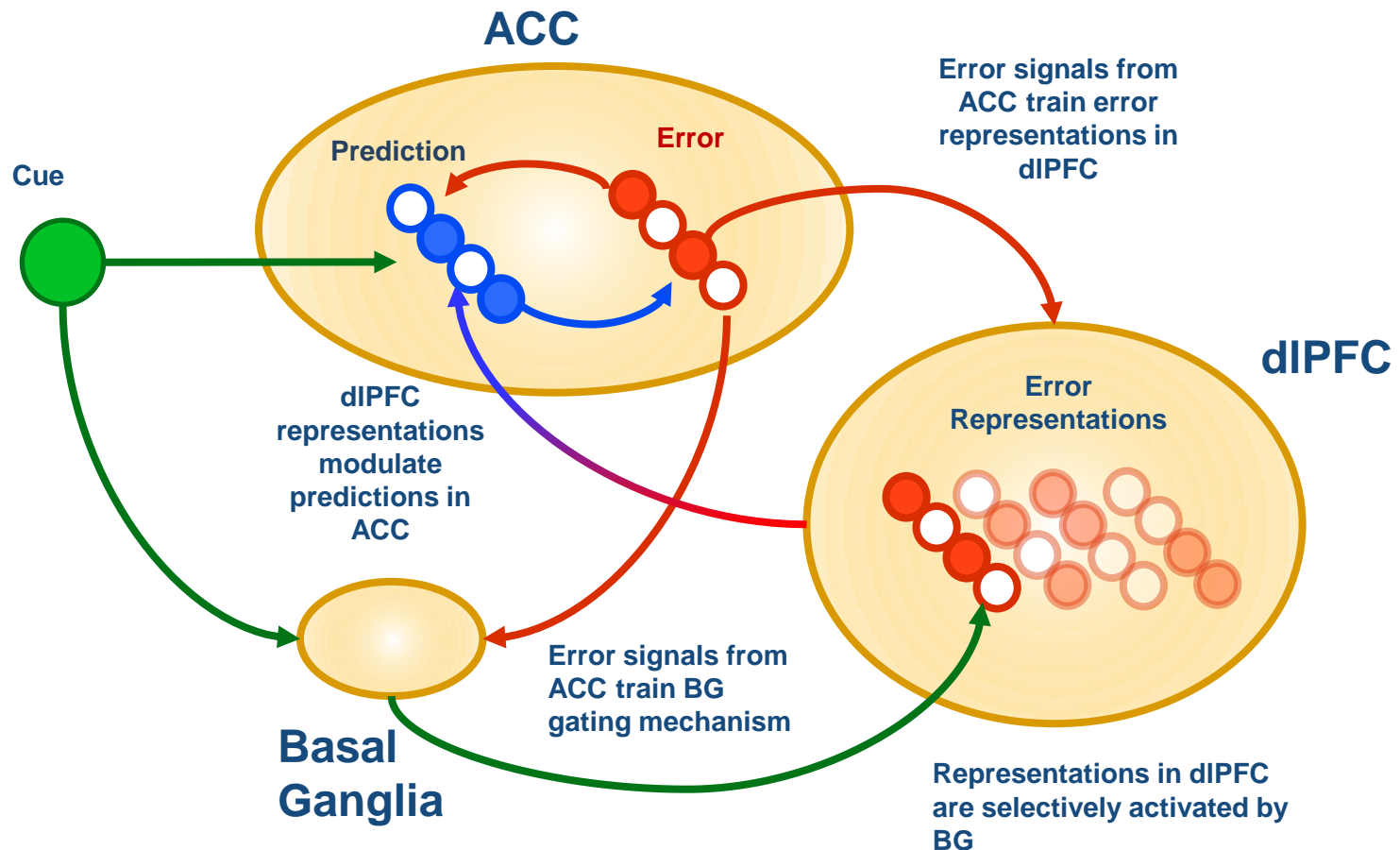
Interactions with dlPFC



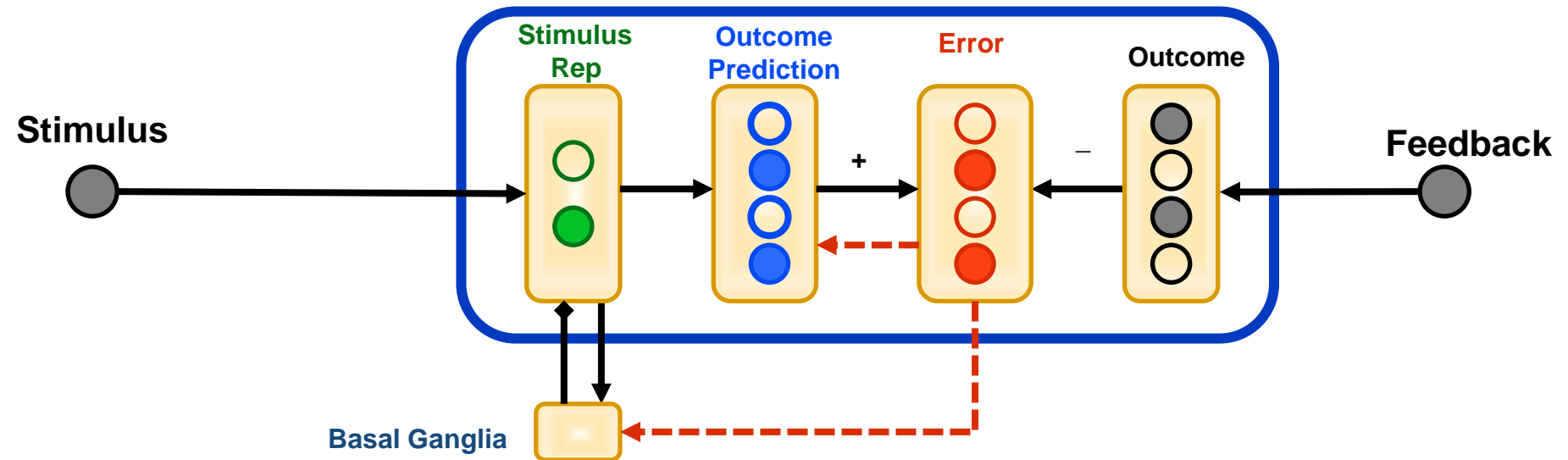
Taren et al., 2011, J Neurosci

Error Representation Hypothesis

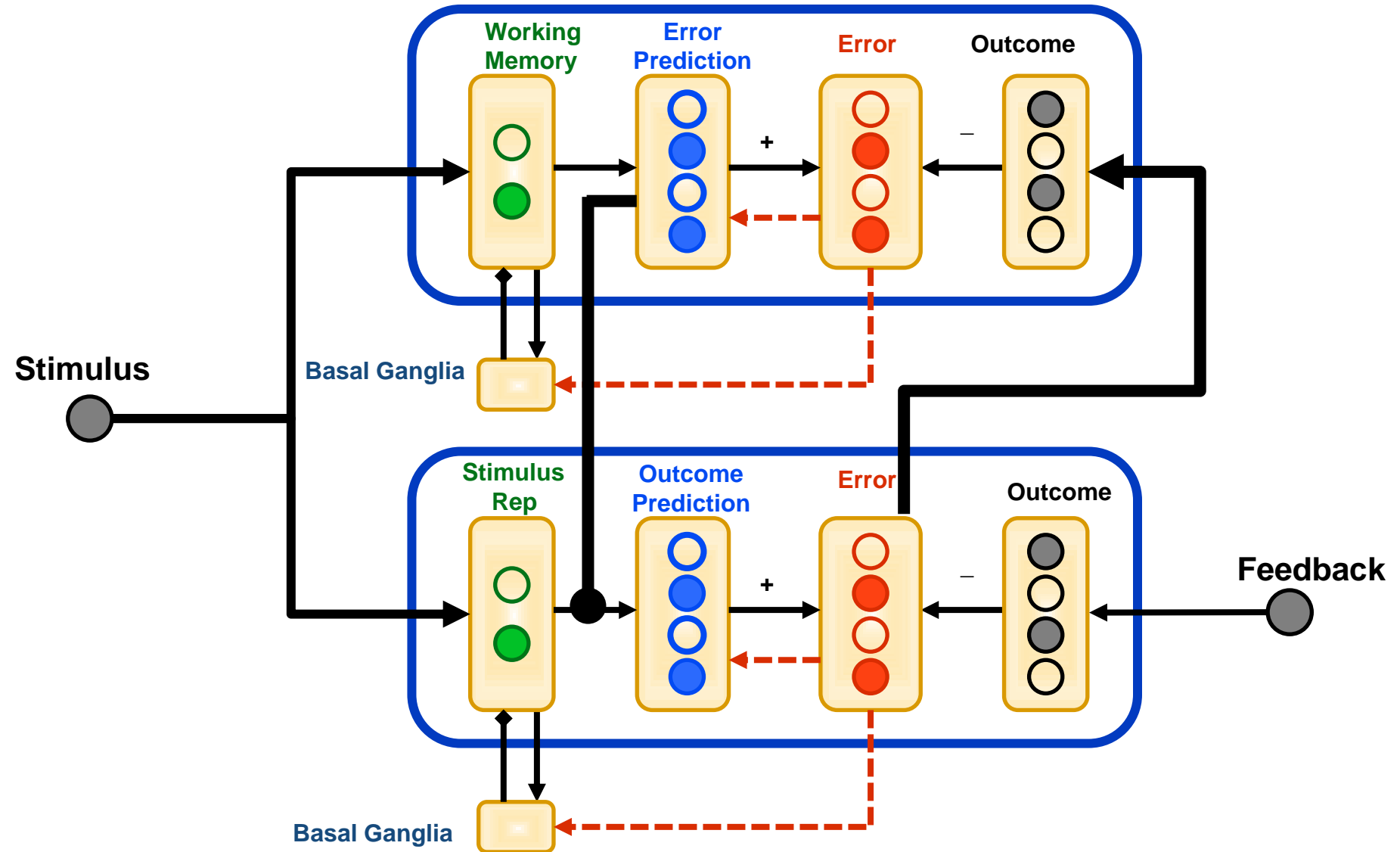
Error signals generated by ACC train **error representations** in dIPFC which are then associated with task-relevant stimuli. Error representations maintained in dIPFC **modulate predictions** in ACC



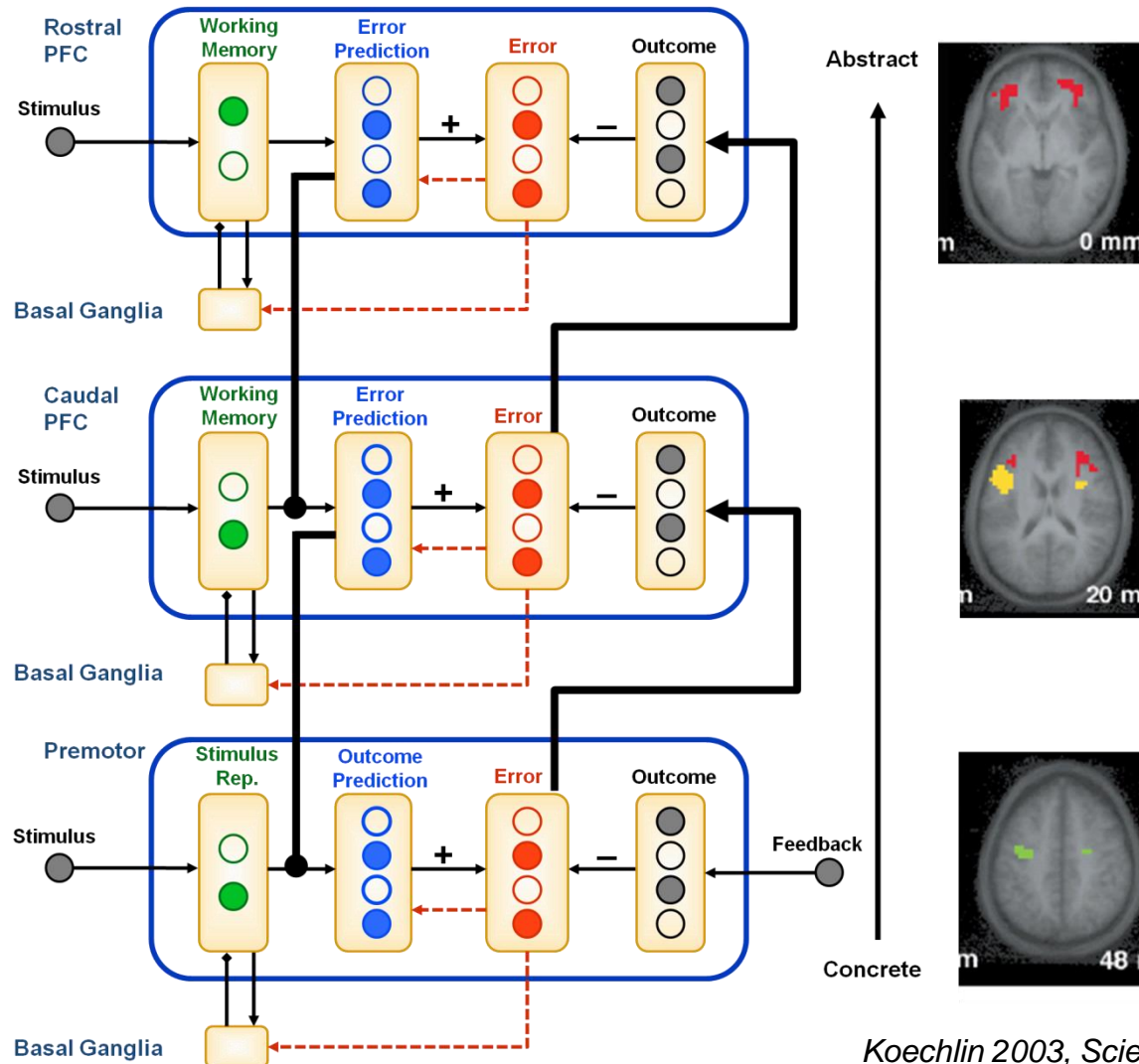
Hierarchical Error Representation Model



Hierarchical Error Representation Model



Hierarchical Organization

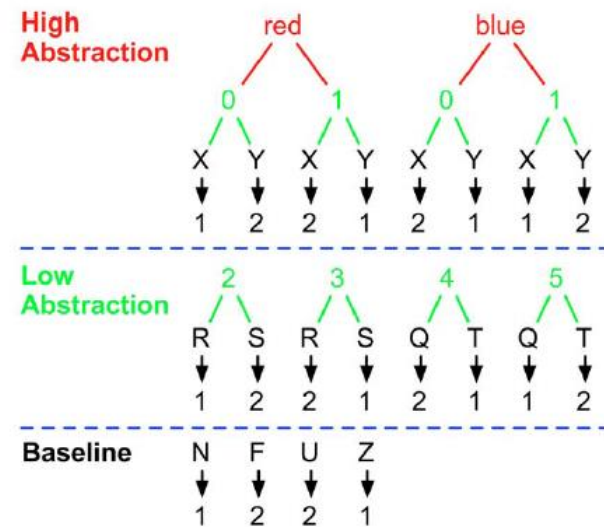
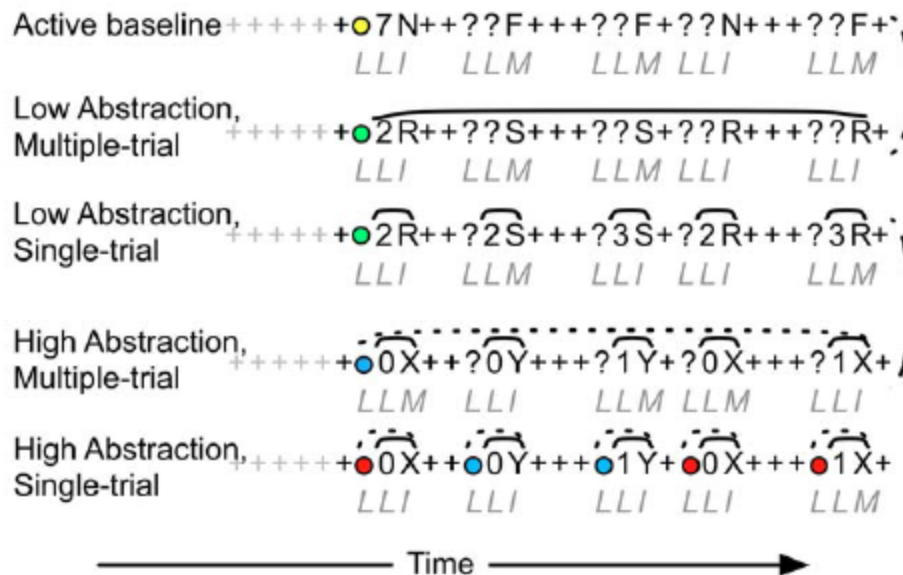


Koechlin 2003, Science

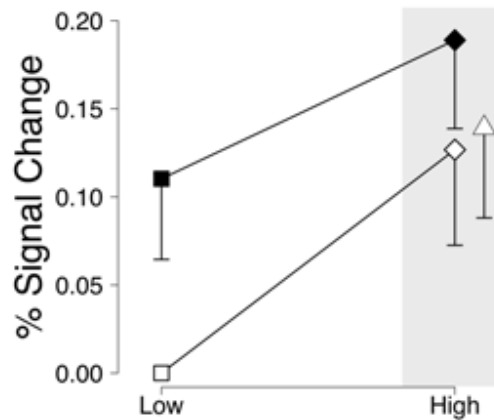
Reynolds et al., 2012

Manipulation of

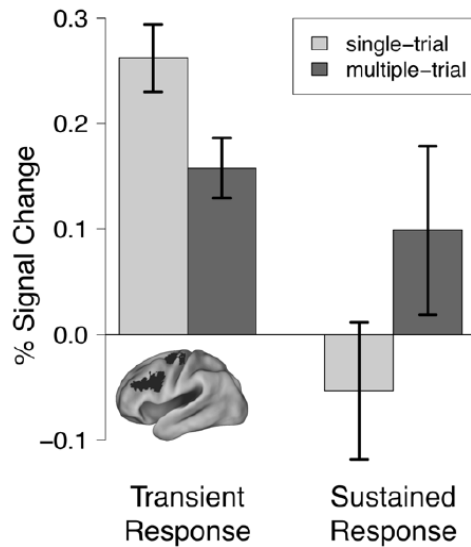
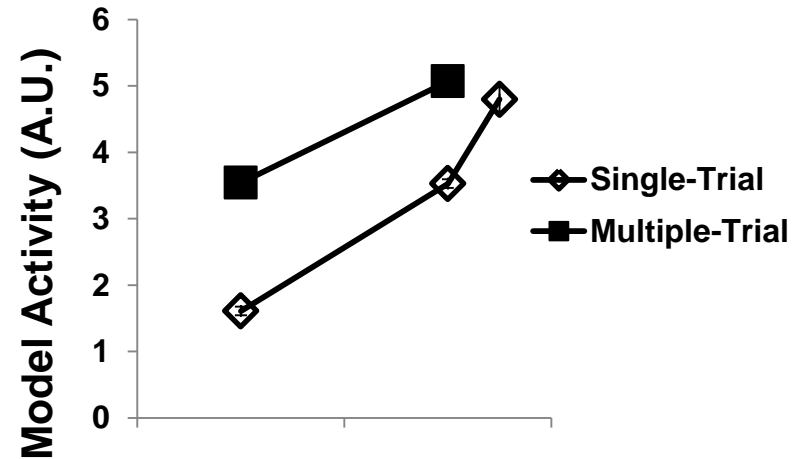
- Maintenance Duration
- Abstraction



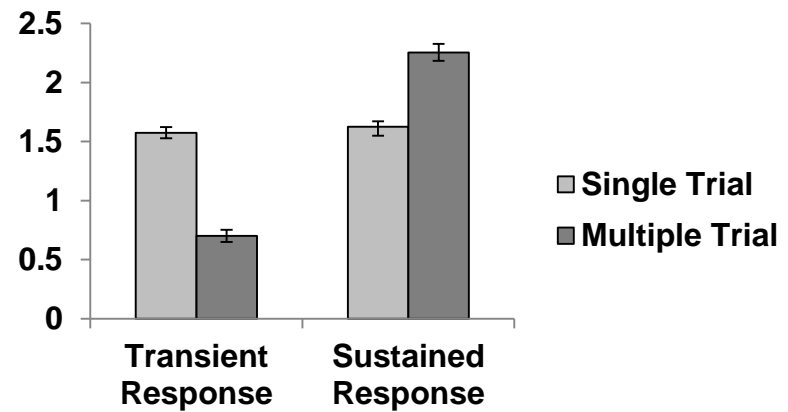
Observed



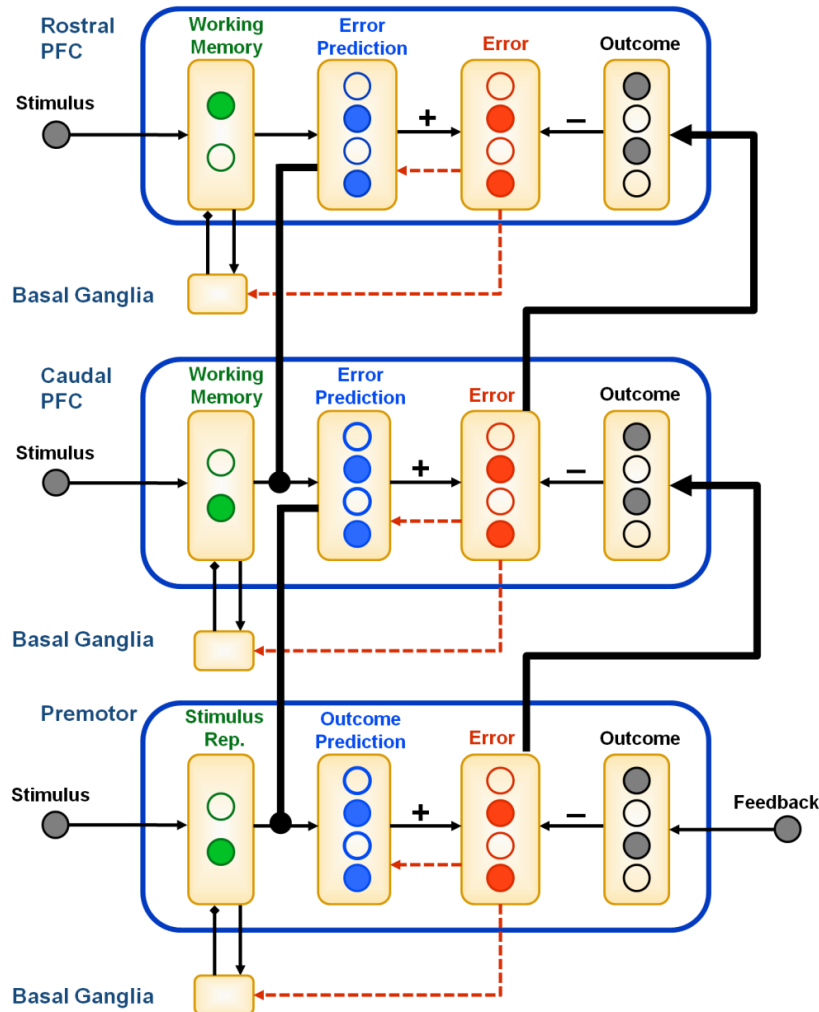
HER Model - Layer 2



Model - Layer 2



Hierarchical Organization



Additional Simulations

1-2-AX CPT

Nee & Brown, 2012

Temporal vs. Relational Abstraction

Nee, Jahn & Brown, 2013

Flat vs. Structured Tasks

Badre, Kayser, & D'Esposito, 2010

Information Cascade

Koechlin, 2003

Single-Unit Match Suppression

Miller et al., 1996

dIPFC Lesion

Gehring & Knight, 2000

Conclusions

Cingulate is primarily involved in predicting future events and signaling deviations from expectations

Across modalities

Across domains

At multiple levels of abstraction

Provides a framework for elucidating the function of additional regions involved in cognitive control, e.g.,

Dorsolateral PFC

Anterior Insula

Acknowledgements

Collaborators

Indiana University, Bloomington

Joshua Brown

Andrew Jahn

Rena Fukunaga

University of California, Berkeley

Derek Nee

Ghent University

Tom Verguts

Massimo Silvetti

Eliana Vassena

Funding



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