INTELLIGENCE: REFLEXES VERSUS DELIBERATION

John W. Krakauer

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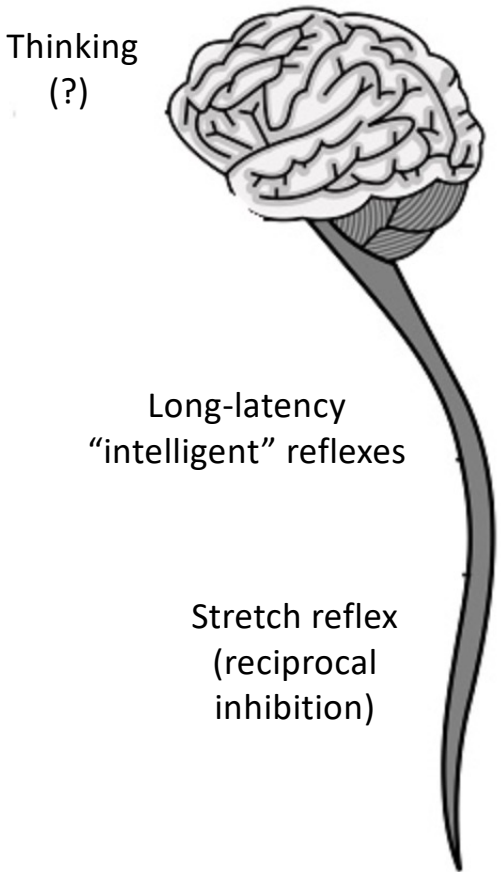
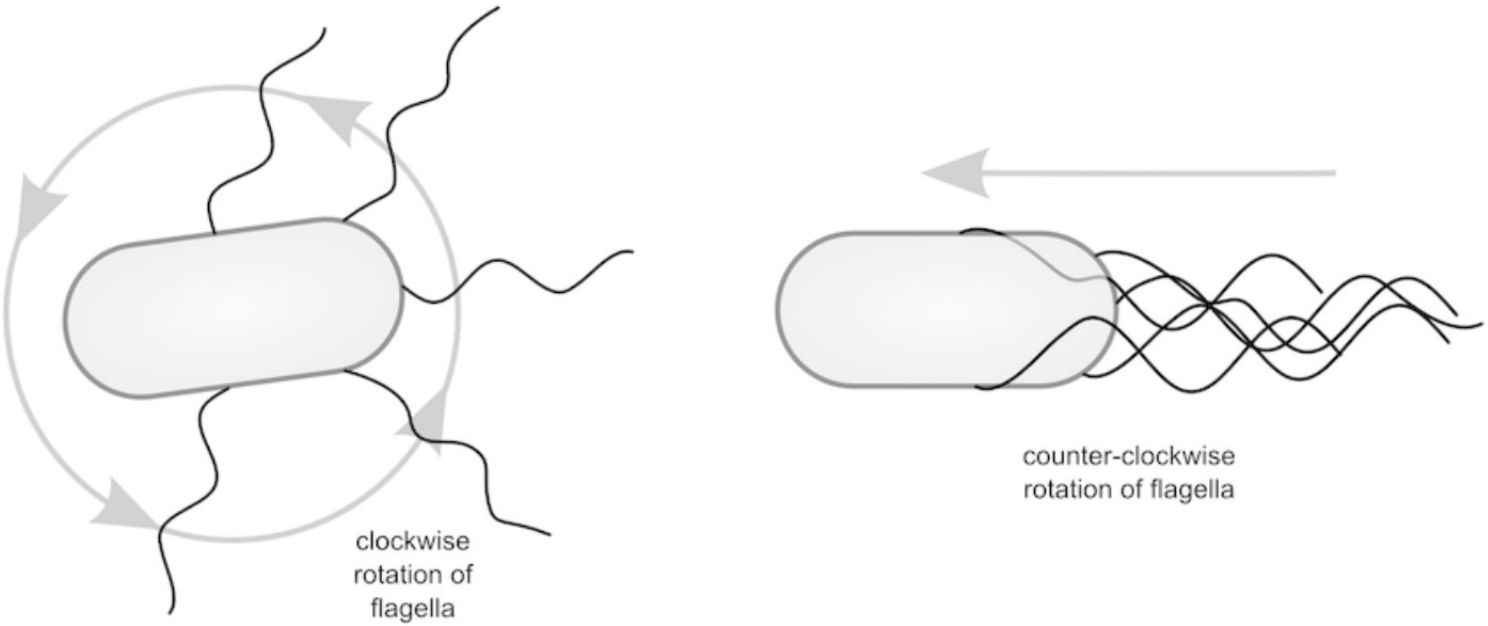
www.BLAM-lab.org

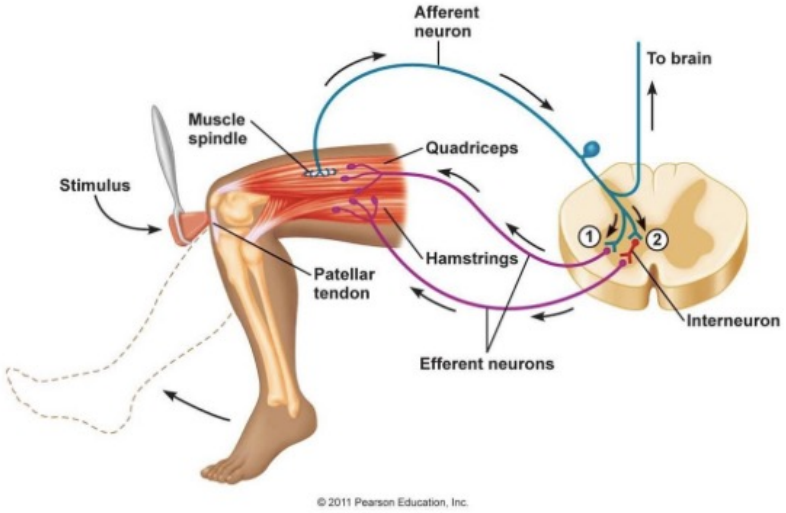
CONTENT VERSUS FORMAT




clockwise
rotation of
flagella
counter-clockwise
rotation of flagella

Animal as sensorimotor movement machines: Descartes proposed that sensory stimulation was transmitted to the pineal gland, which selected and opened neural tubes conveying spiritus animus to muscles, causing them to contract.

"If all human behaviour is simply the result of chains of reflexes, as first clearly proposed by Sechenov (1863), then there is no free will, from which it is a short step to a denial of the soul and responsibility for one's actions." What do reflex and voluntary mean? Modern views on an ancient debate *Exp Brain Res* (2000) 130:417–432



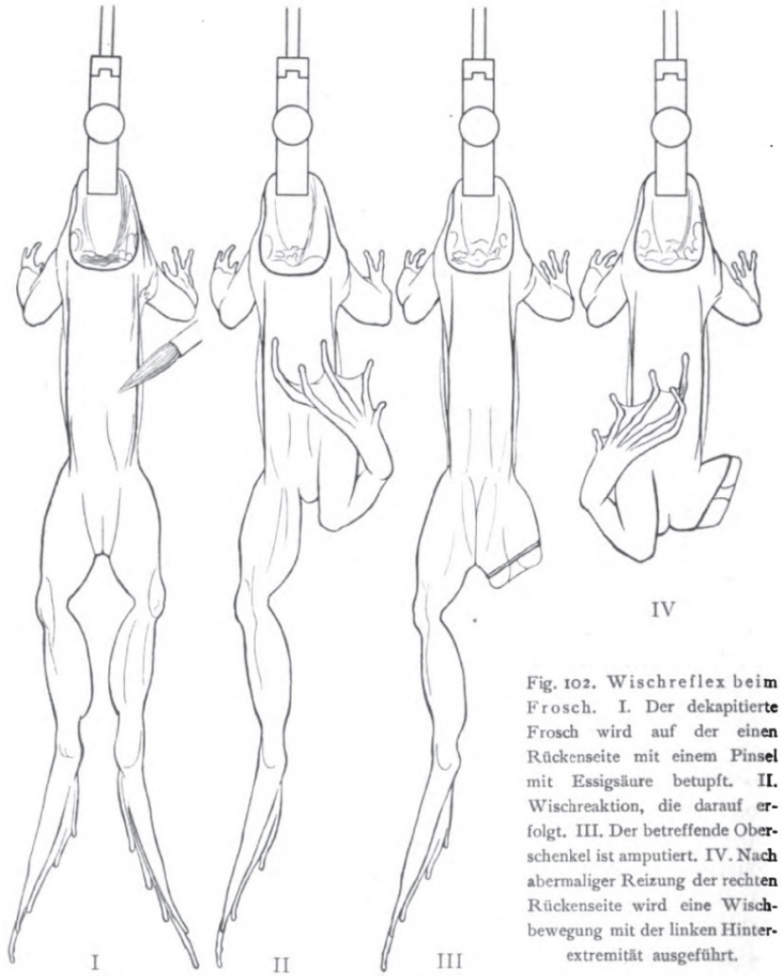


Fig. 102. Wischreflex beim Frosch. I. Der dekapitierte Frosch wird auf der einen Rückenseite mit einem Pinsel mit Essigsäure betupft. II. Wischreaktion, die darauf erfolgt. III. Der betreffende Oberschenkel ist amputiert. IV. Nach abermaliger Reizung der rechten Rückenseite wird eine Wischbewegung mit der linken Hinterextremität ausgeführt.

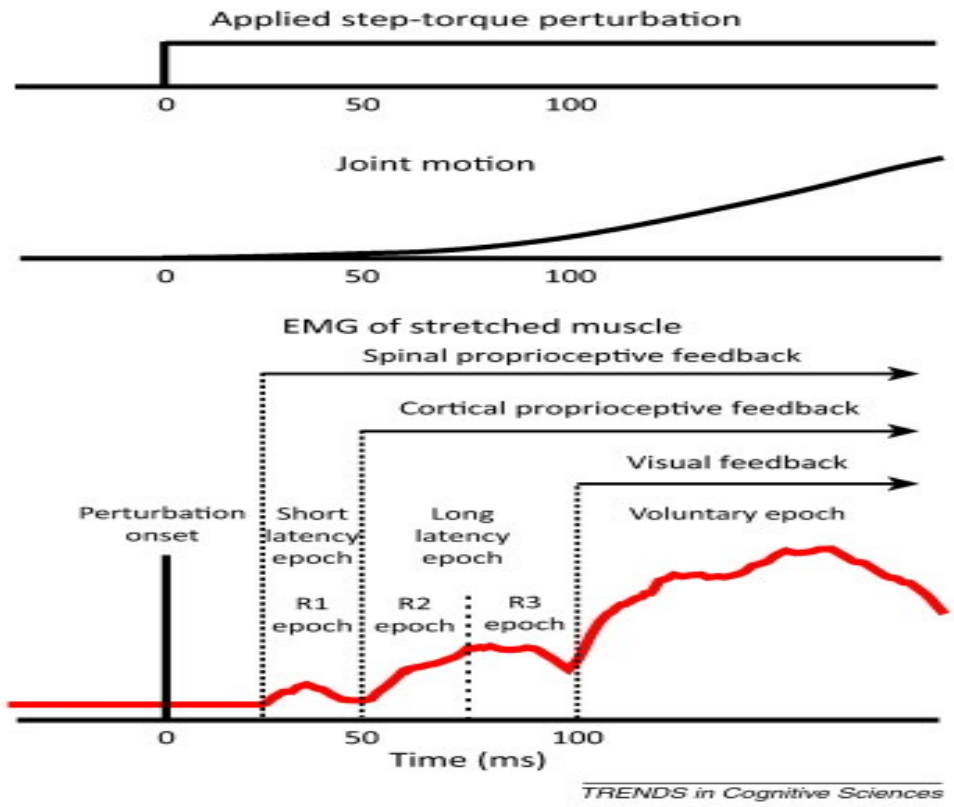


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Figure 1 Optimal Feedback Control and neural implementation. (a) Optimal Feedback Control Policy converts state variables to motor commands. Optimal State Estimation uses efference copy of motor commands and sensory feedback to estimate state variables. ...

Trends in Cognitive Sciences Volume 16, Issue 11 2012 541 - 549

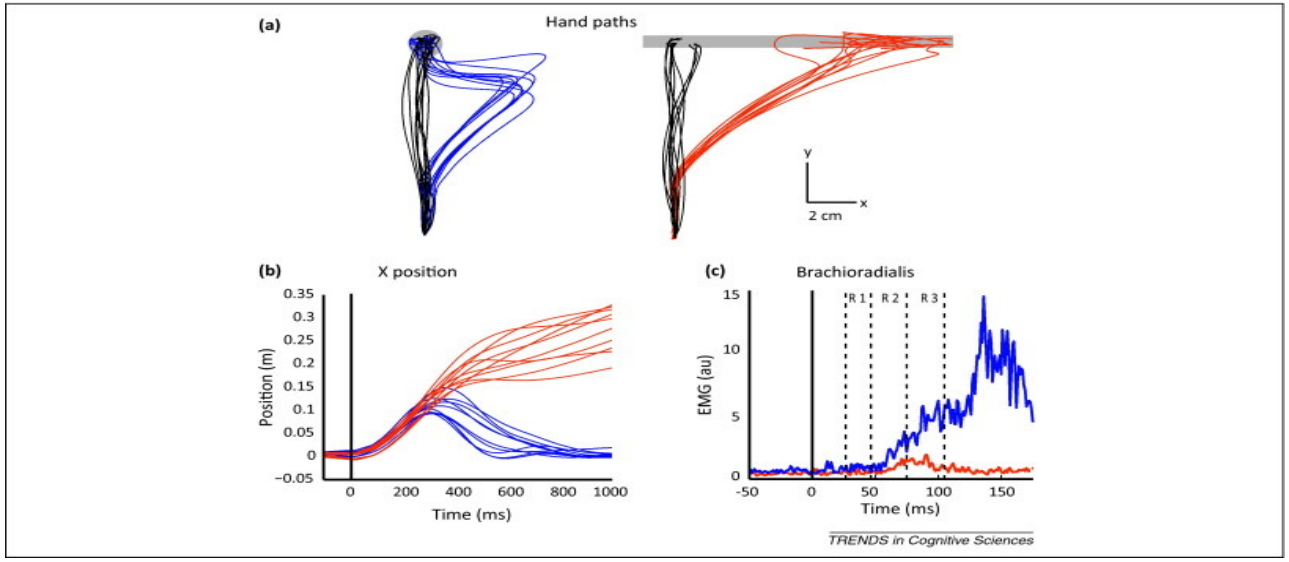


Figure 2 Corrective responses to mechanical perturbations applied when reaching to a circle or rectangular bar. (a) Black lines are unperturbed reaching movements to each target. Display of rectangular bar in diagram is clipped on the left, because unper...

Stephen H. Scott

The computational and neural basis of voluntary motor control and planning

Trends in Cognitive Sciences Volume 16, Issue 11 2012 541 - 549

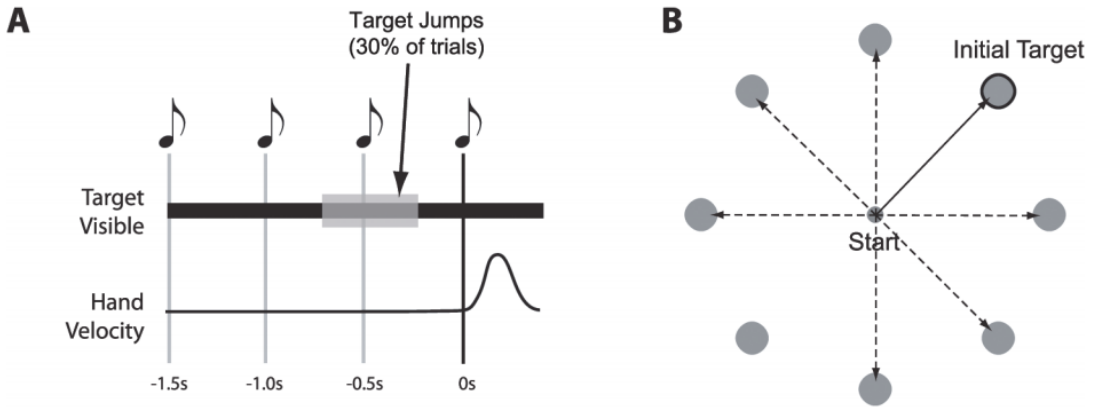
http://dx.doi.org/10.1016/j.tics.2012.09.008

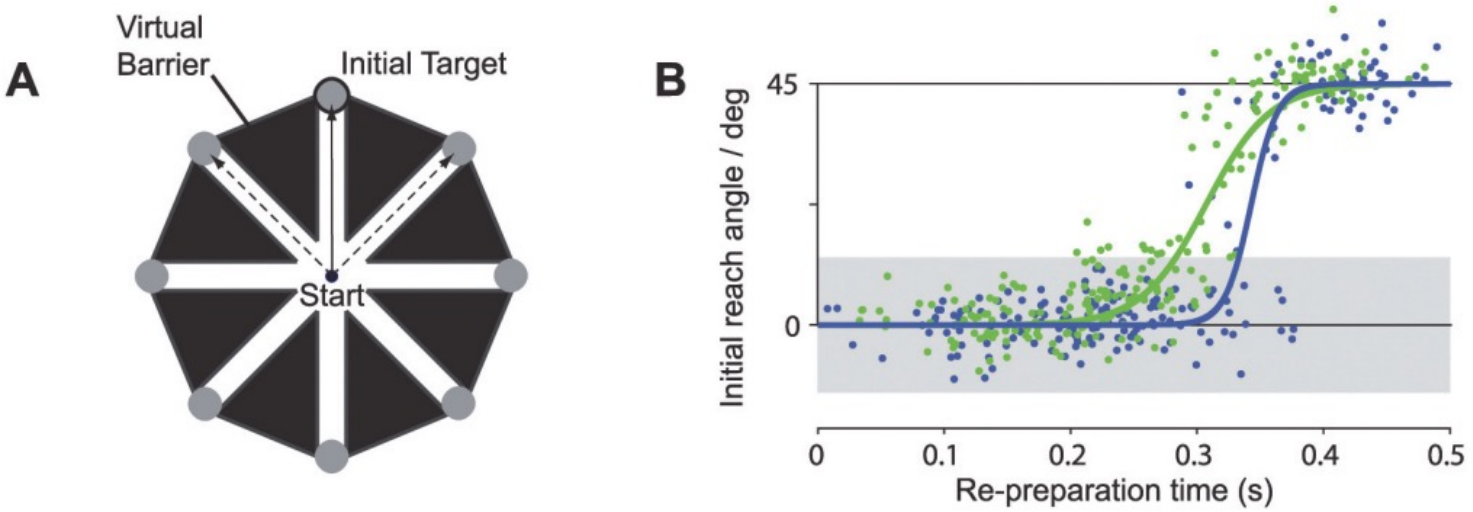
PLOS | COMPUTATIONAL BIOLOGY

RESEARCH ARTICLE

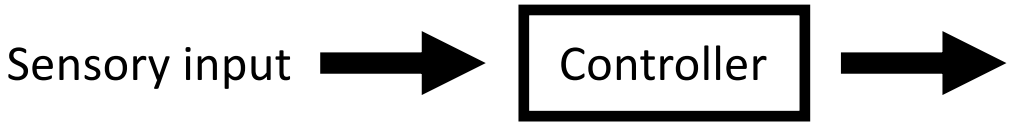
Hedging Your Bets: Intermediate Movements as Optimal Behavior in the Context of an Incomplete Decision

Adrian M. Haith[1]*, David M. Huberdeau[2], John W. Krakauer[1,3]





Haith et al (2015) PLOS CB



$$u = f(x, t, g)$$

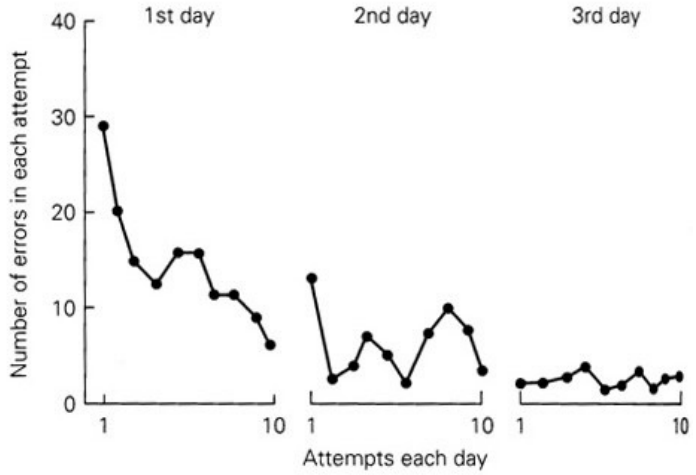
f: controller
x: current state
t: time
g: movement goal
u: motor commands

HYPERCOGNITIVE SEIZURES

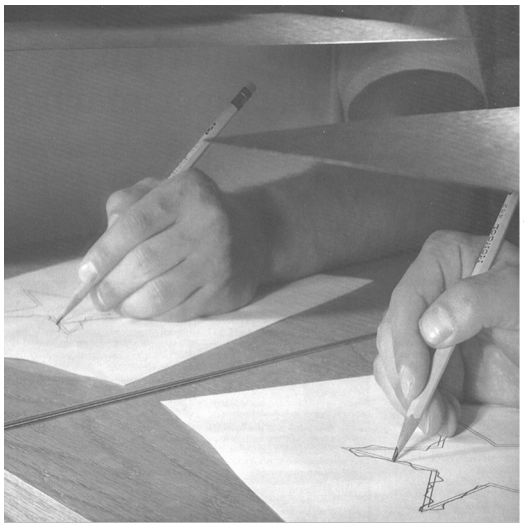
The phrases were either “why don’t you tell them how you feel,“ “why can’t you have a seizure,” or “why don’t you have a seizure.” These phrases kept coming to his mind like a “broken record,” ….

His seizure pattern was a sensation in his head accompanied by a voice which spoke in Afrikaans, commanding or threatening him. He had a feeling of intense fear and finally lost consciousness. Asked where the voice came from, he said, “It was just in my head.” The patient was aware that he could not speak while hearing this voice and felt that his tongue was stiff [a finding common among others who heard voices within the head]. He said, “If I heard the voice I used to point to my head so that my parents would know I was going to have an attack.” The voice spoke in short sentences which were accusatory or threatening, telling him “You do this “ or ” You do that,” “You did something wrong.¨‘‘Things, the¨ patient added, “that I did not do wrong.””

Milner 1962: mirror drawing could be learned over a period of days by the severely amnesic patient H.M. in the absence of any conscious memory of having practiced the task before

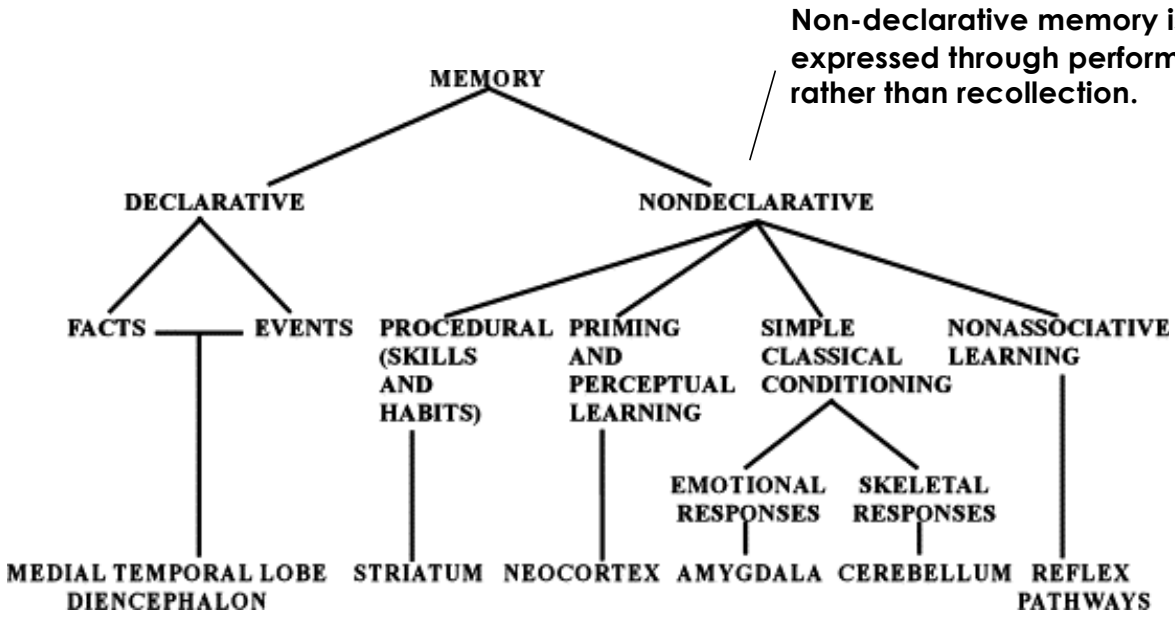


Milner (1962) Physiologie de l'hippocampe.



Kandel et al. Principles of Neural Science 2000 (62-2)

Memory systems of the brain

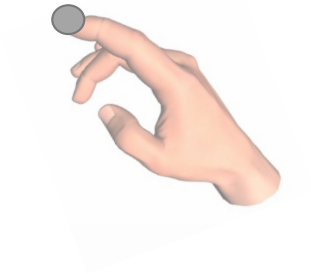


Squire (2004) Neurobiology of Learning and Memory

Motor learning in the laboratory

- Typically studied through adaptation paradigms

- Systematic perturbation applied
  e.g. visuomotor rotation



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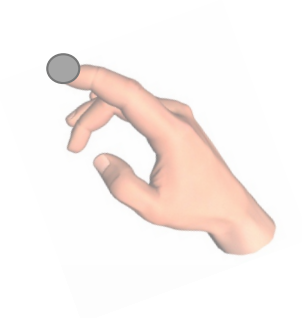
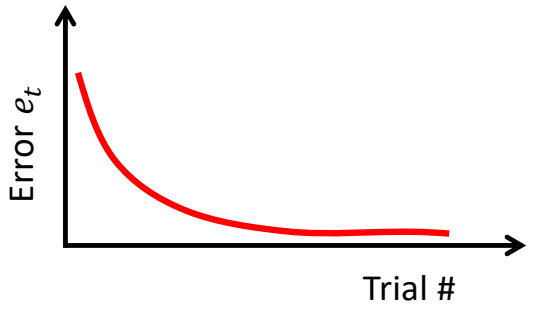


- Similar behavior with force fields, prism goggles etc.

- Systematic perturbation applied
  e.g. visuomotor rotation

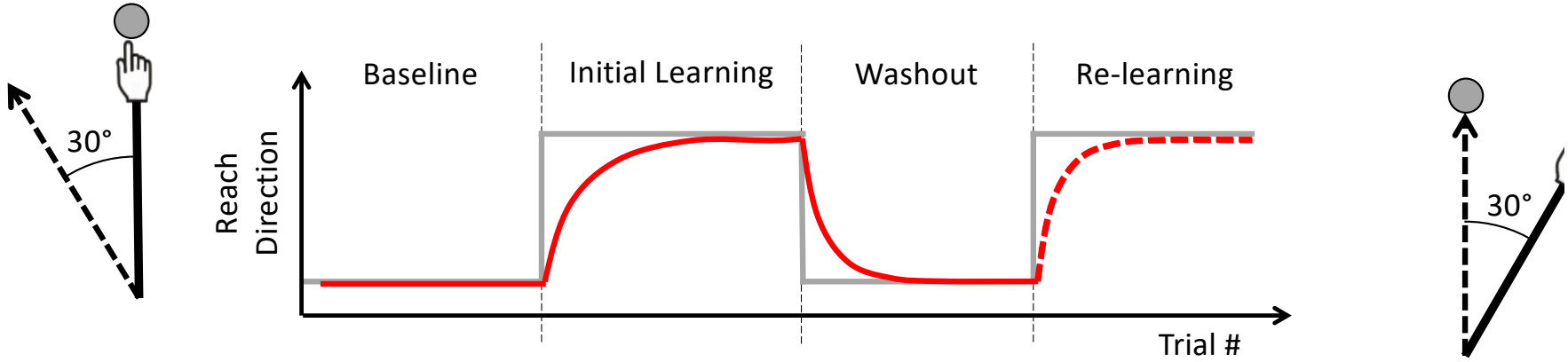
- Incremental trial-by-trial error reduction



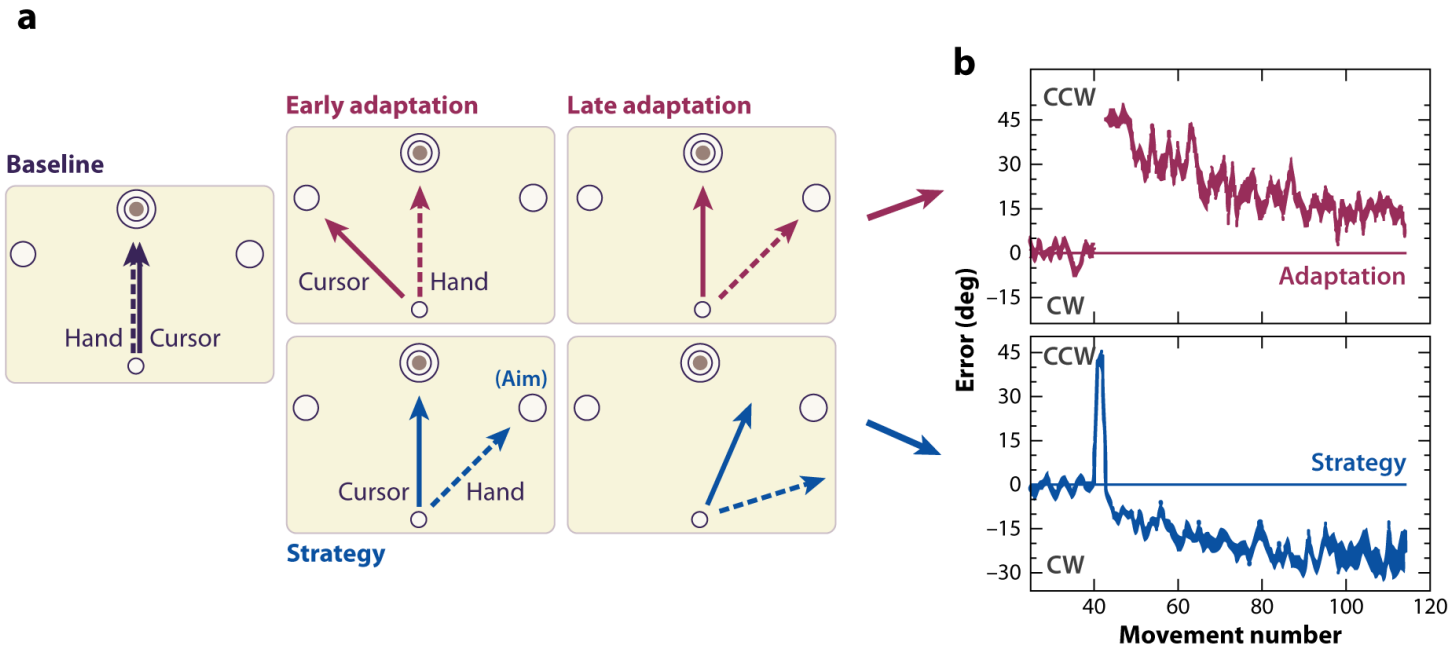
$X_{t+1} = Ax_t + Be_t$

Adaptation

Memory as savings

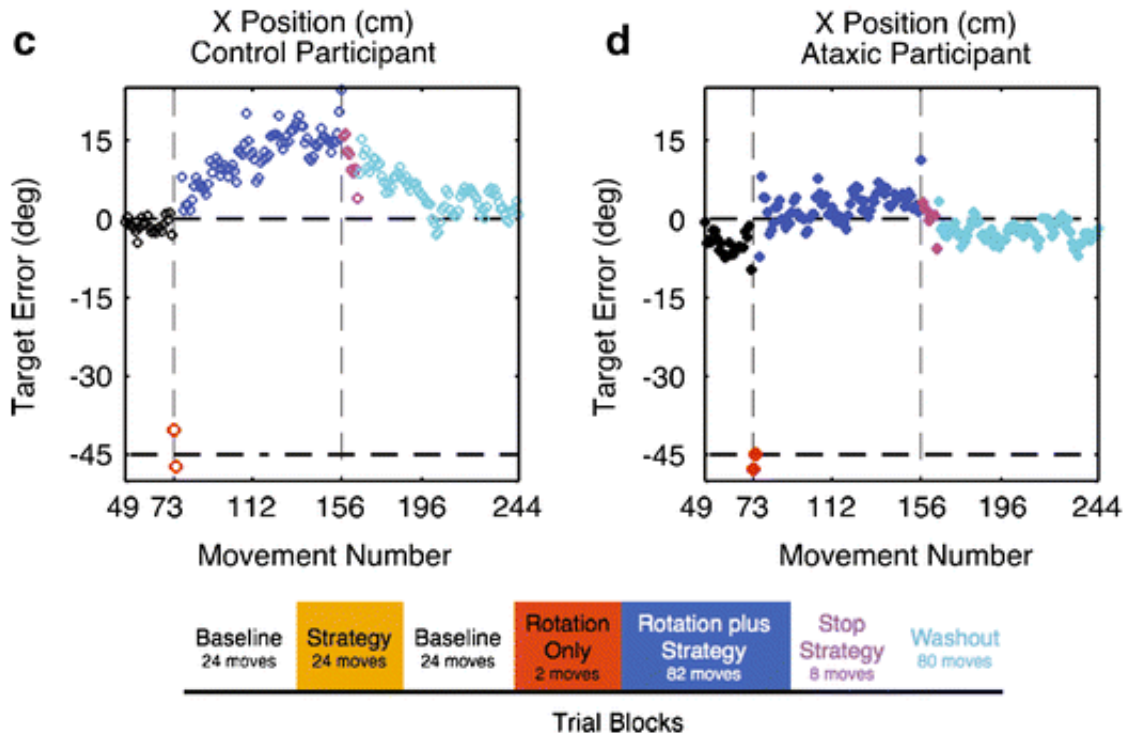


Adaptation is initially driven by prediction errors not target errors



Mazzoni & Krakauer *J.Neurosci* (2006)
Shadmehr, Smith & Krakauer *Ann Rev Neurosci* (*2011*)

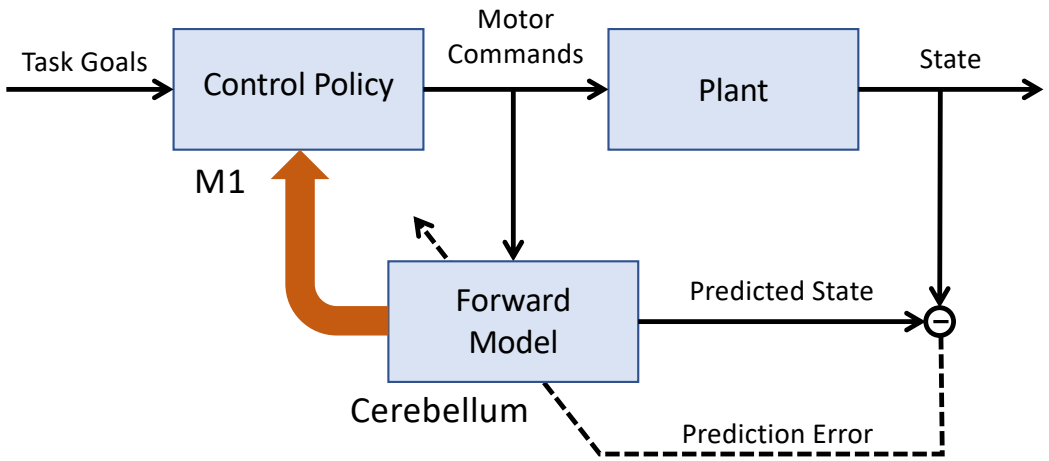
Patients with cerebellar damage do not learn from prediction errors



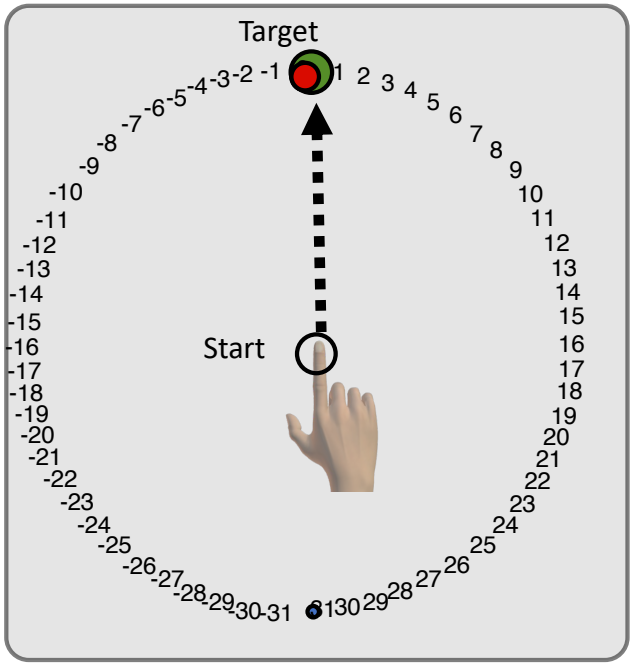
Taylor and Ivry *Cerebellum* (2011)

Motor Learning as Systems Identification

- Perturbation is estimated and countered (Shadmehr and Krakauer, 2009)
- Driven by sensory prediction errors
  - Tseng et al. J Neurophys 2007, Mazzoni and Krakauer, J Neurosci 2006
- Bayesian / Kalman filter interpretation (Korenberg 2002, Burge et al. 2008)

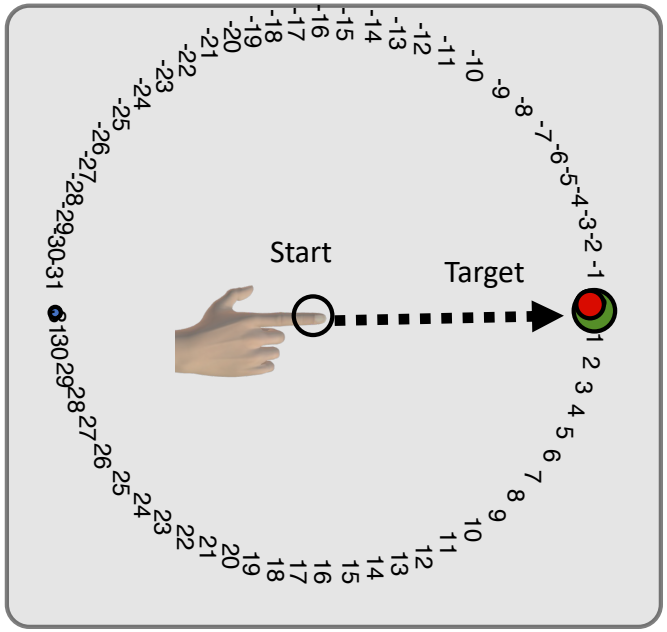


Assessing the strategy



Jordan et al., *J. Neurosci* (2014)

Assessing the strategy



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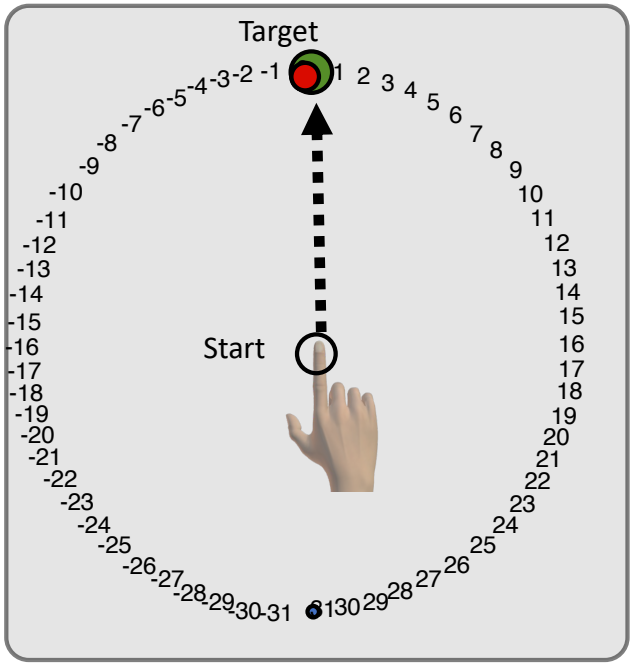
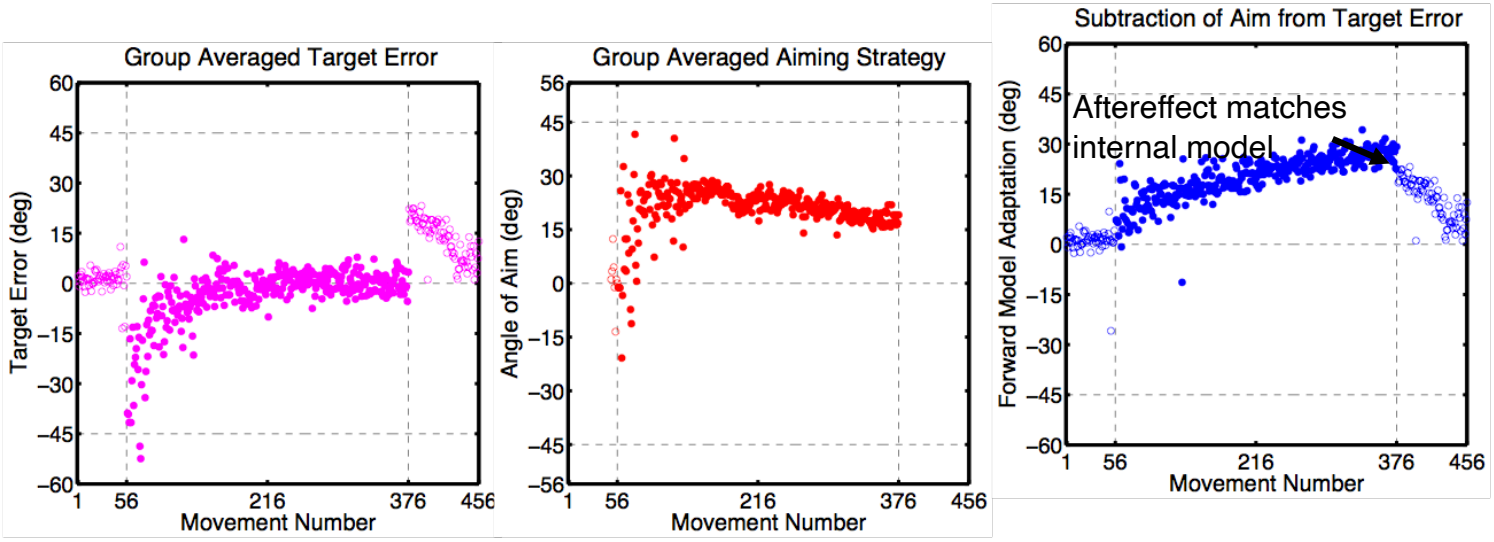


"Before moving tell me where you think you should aim to get your cursor on the target"

Jordan et al., *J. Neurosci* (2014)

Explicit aiming and implicit recalibration processes cooperate and combine to solve an adaptation task



Target Error = Aiming Strategy + IM Adaptation - Rotation

Jordan et al., *J. Neurosci* (2014)

... but what was not forgotten by HM? Does not have explicit and implicit does not have memory

RESEARCH ARTICLE | *Control of Movement*

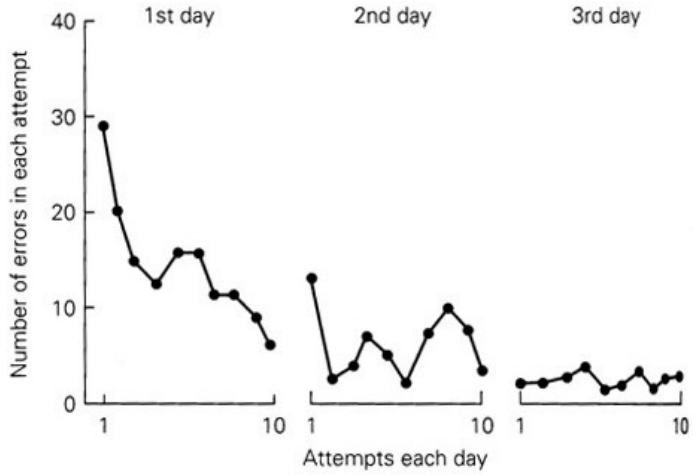
Practice induces a qualitative change in the memory representation for visuomotor learning

David M. Huberdeau,[1] John W. Krakauer,[2,3]* and Adrian M. Haith[2]*

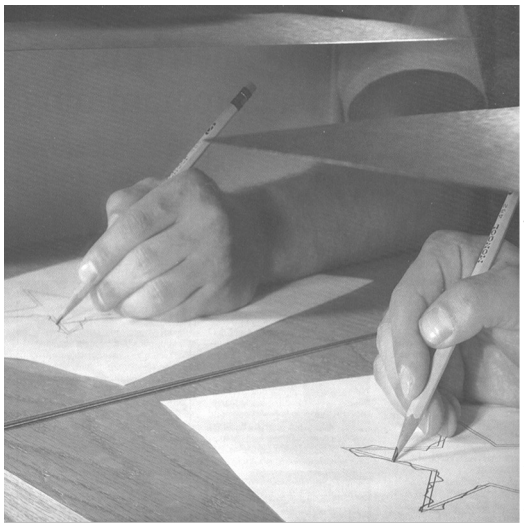
[1]*Department of Biomedical Engineering, Johns Hopkins University School of Medicine, Baltimore, Maryland;* [2]*Department of Neurology, Johns Hopkins University School of Medicine, Baltimore, Maryland; and* [3]*Department of Neuroscience, Johns Hopkins University School of Medicine, Baltimore, Maryland*

Submitted 12 December 2018; accepted in final form 11 July 2019

Milner 1962: mirror drawing could be learned over a period of days by the severely amnesic patient H.M. in the absence of any conscious memory of having practiced the task before

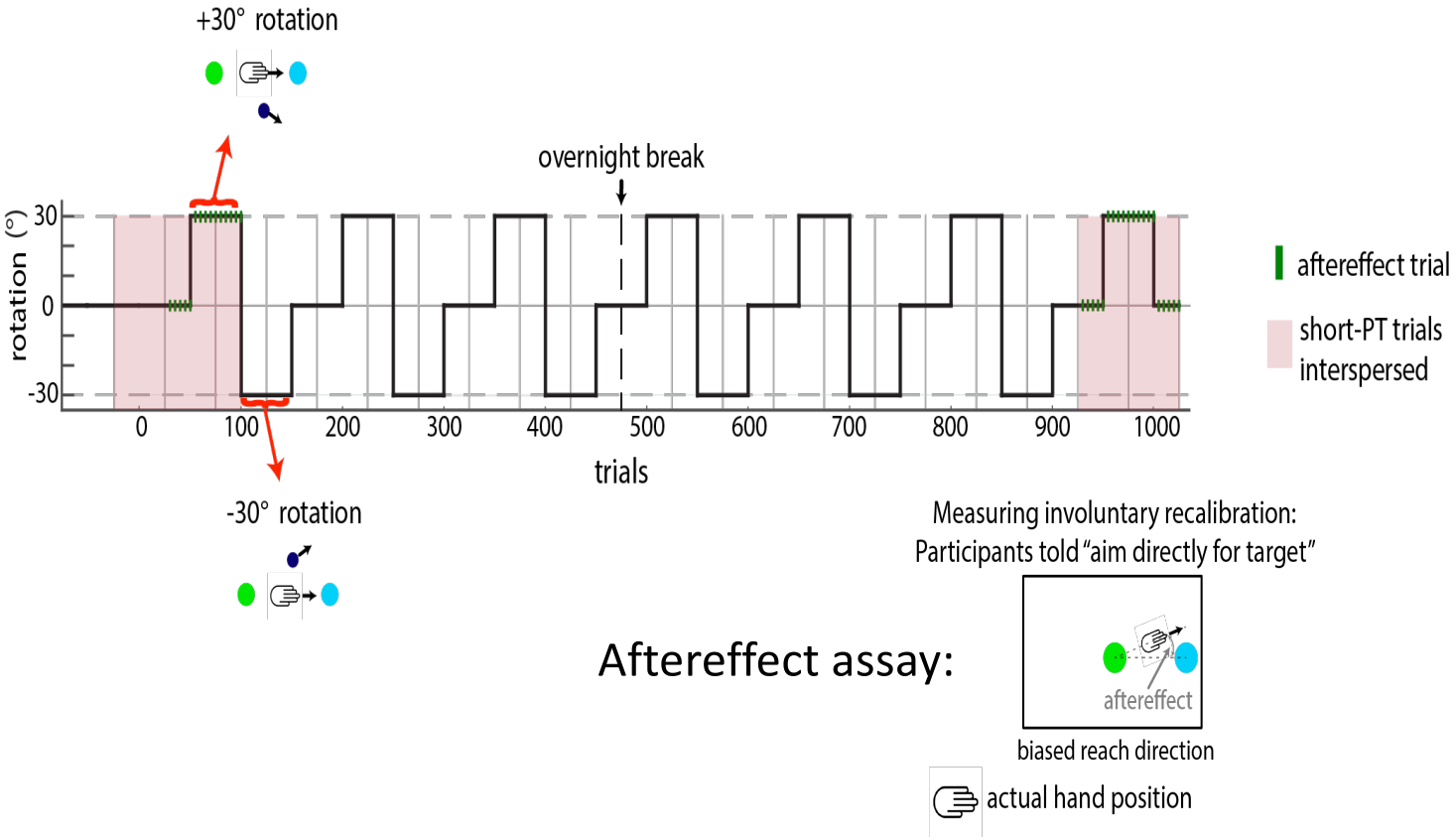


Milner (1962) Physiologie de l'hippocampe.



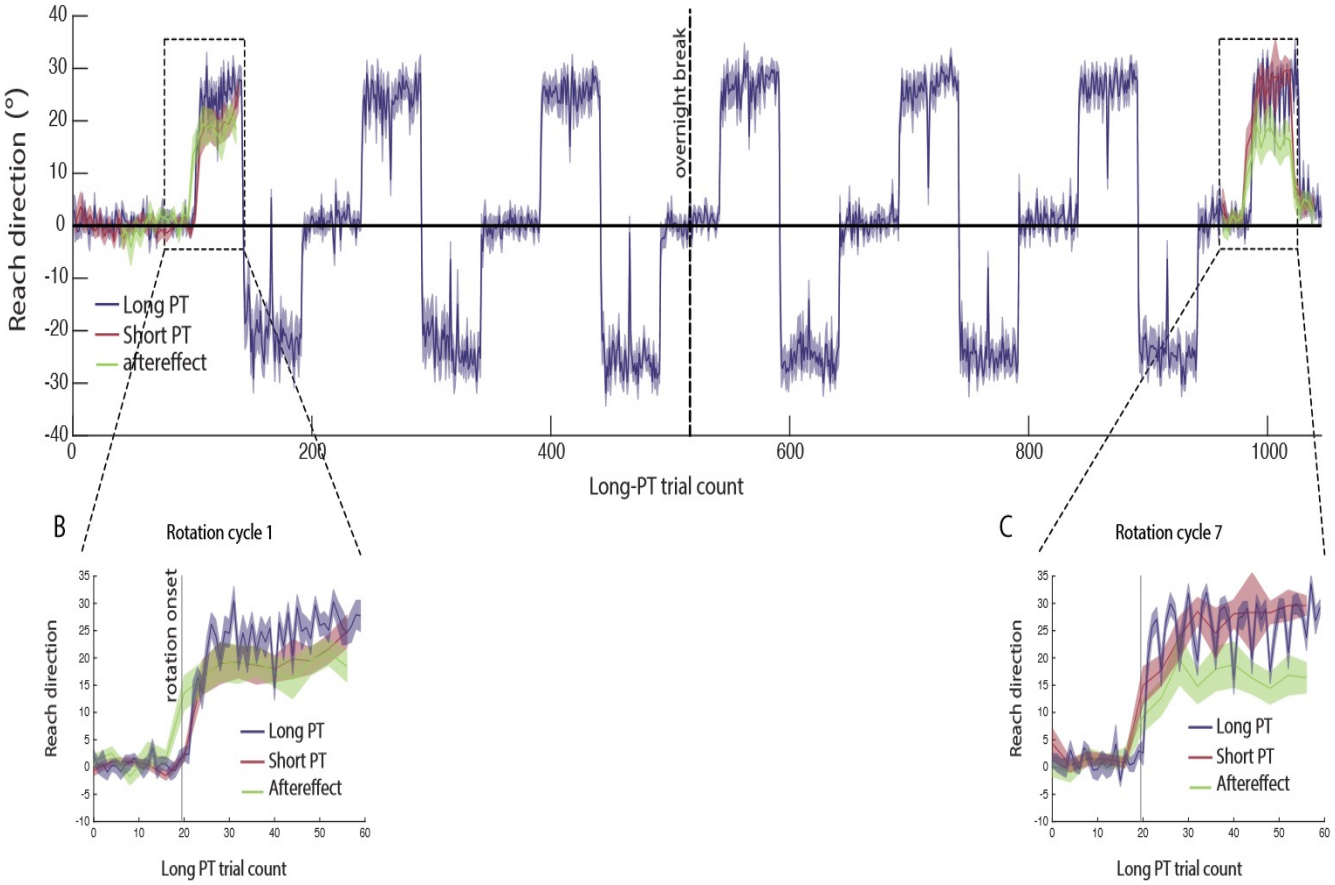
Kandel et al. Principles of Neural Science 2000 (62-2)

Will more practice induce Short-PT time savings?



Prediction: increase in short-PT assay, no change in aftereffect assay

Savings under short PT emerges following practice



PHILOSOPHICAL PSYCHOLOGY
2019, VOL. 32, NO. 5, 823–831
https://doi.org/10.1080/09515089.2019.1607281

Routledge
Taylor & Francis Group

ARTICLE

The intelligent reflex

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The core idea that will be introduced here, backed up by empirical evidence, is that propositional knowledge can, as suggested by Dreyfus, be transformed into goal-directed, automatized responses – intelligent reflexes.

Overt deliberations which, through practice, are transformed into control policies that are then cached for subsequent fast retrieval without there being a need to rethink them again. What do we mean here by intelligence? For the purposes of this article, we mean actions that are flexible and goal directed. A control policy is a goal-dependent mapping or a set of rules between the state of the body and its motor commands.

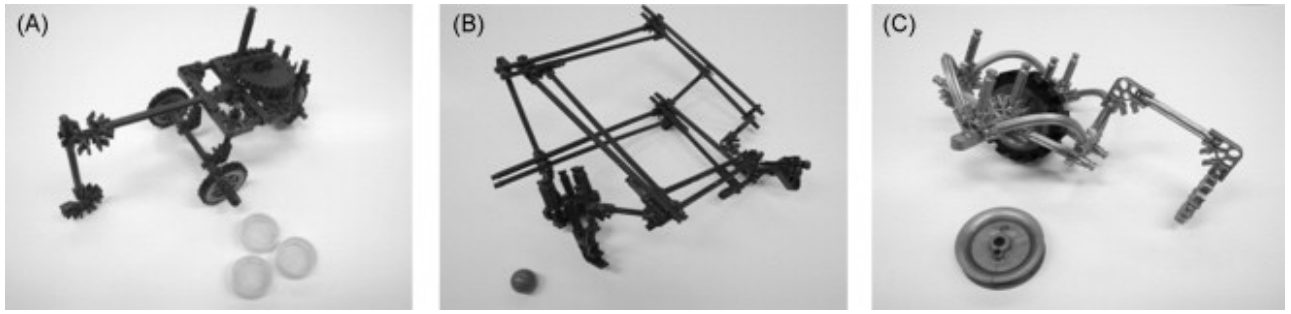


Fig. 2. Examples of novel complex tools and their associated recipients. Fifteen tools were constructed for this study. Ten tools served as target tools for which participants received six trials of functional training along with memory tests of tool attribute...

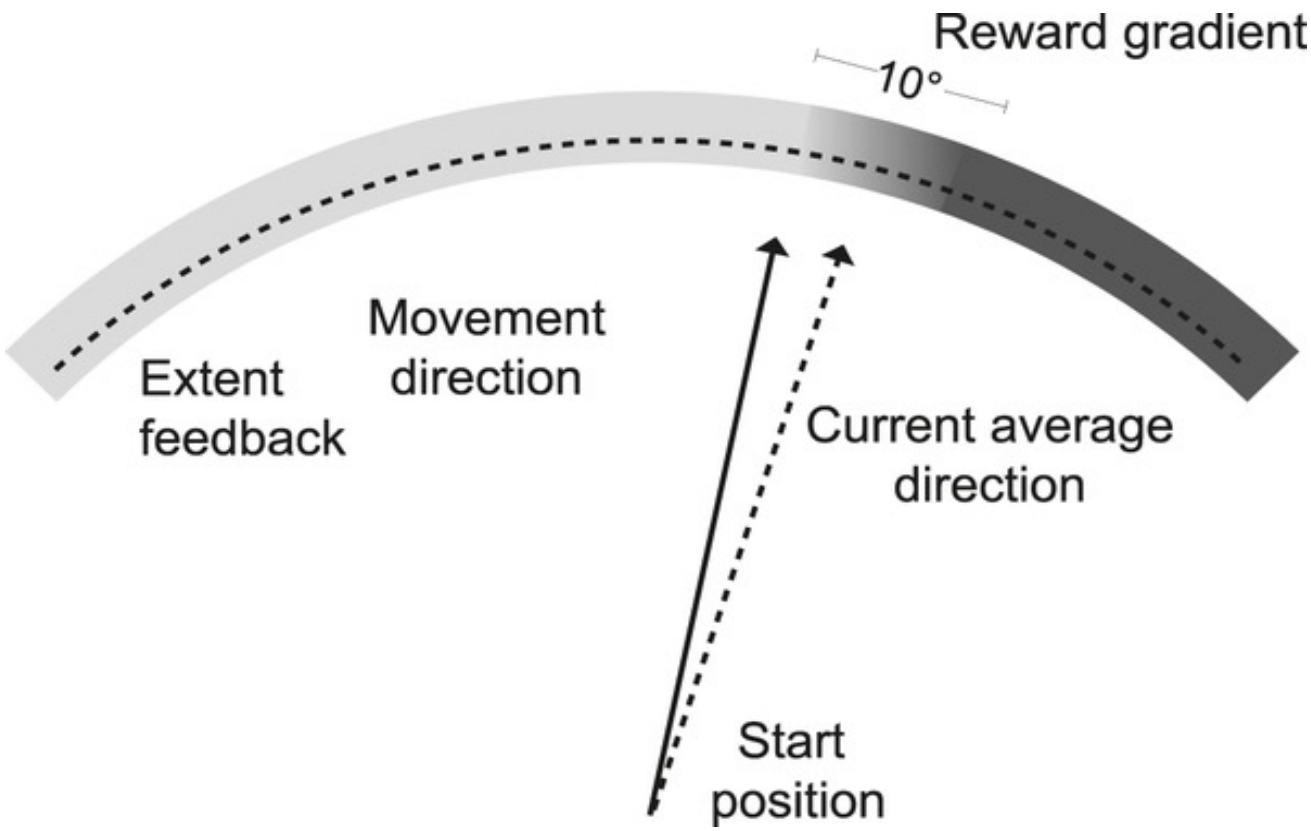
Shumita Roy, Norman W. Park

Dissociating the memory systems mediating complex tool knowledge and skills

Neuropsychologia, Volume 48, Issue 10, 2010, 3026–3036

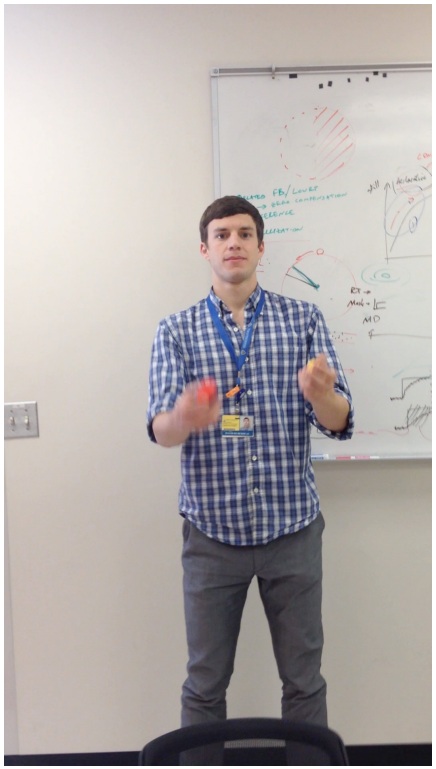
http://dx.doi.org/10.1016/j.neuropsychologia.2010.06.012

Figure 2. Task design.



Manley H, Dayan P, Diedrichsen J (2014) When Money Is Not Enough: Awareness, Success, and Variability in Motor Learning. PLoS ONE 9(1): e86580. doi:10.1371/journal.pone.0086580
http://www.plosone.org/article/info:doi/10.1371/journal.pone.0086580

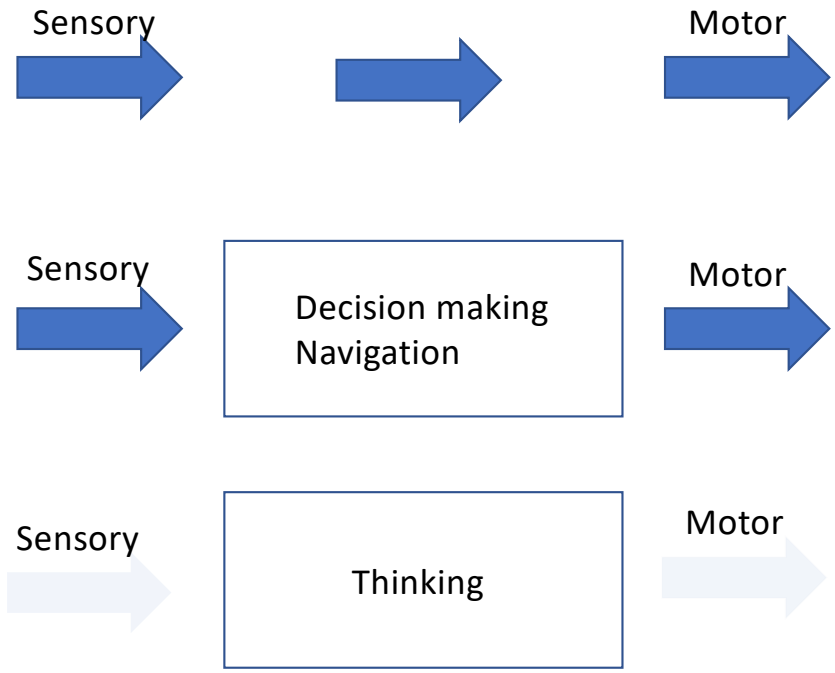

CONSOLIDATION
Fitts 1966
ADAPT
AIM 2:

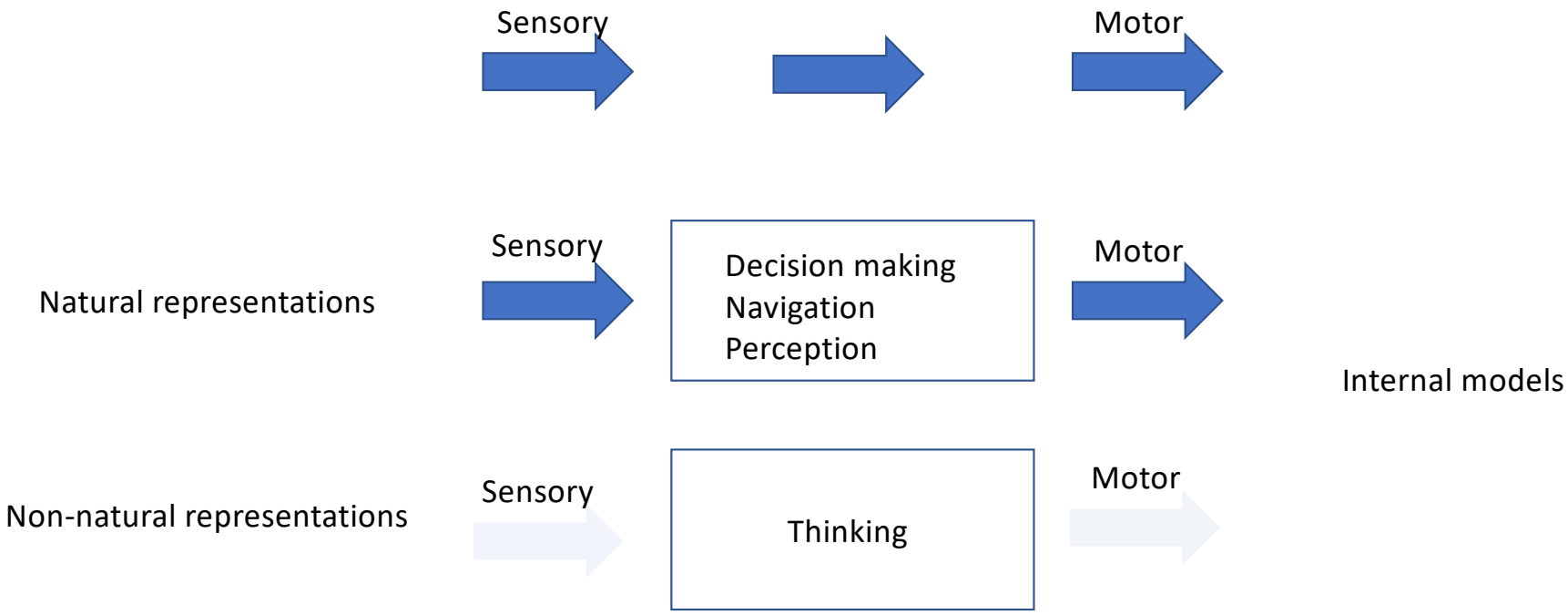


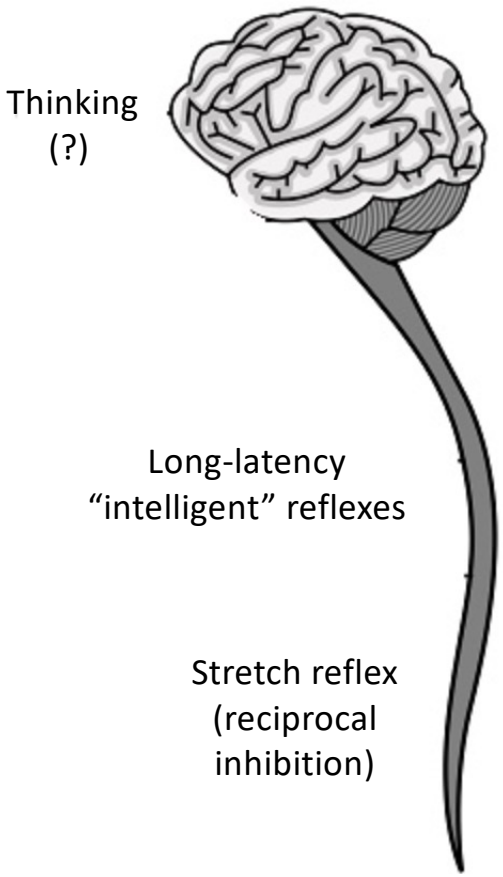
Start by throwing the ball in the front of your right hand in an arc to your left hand. When ball (1) reaches its highest point, throw the ball in your left hand (2) in an arc to your right hand. Catch (1) in your left hand. This is like the two ball exercise.

TWO KINDS OF INTELLIGENCE

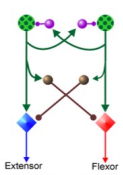
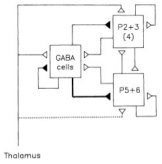
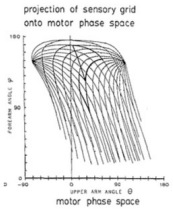
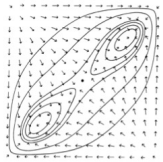
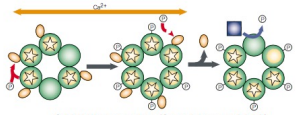
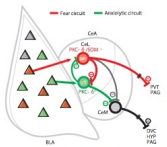
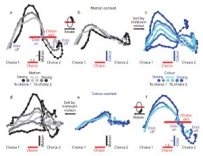
“Assuming then the existence of the external world, I have outlined a symbolic theory of thought,
In which the nervous system is viewed as a calculating machine capable of modeling or paralleling external events
, and have suggested that the process of paralleling is the basic feature of thought and of explanation”.
THE NATURE OF EXPLANATION – Kenneth Craik (1943)



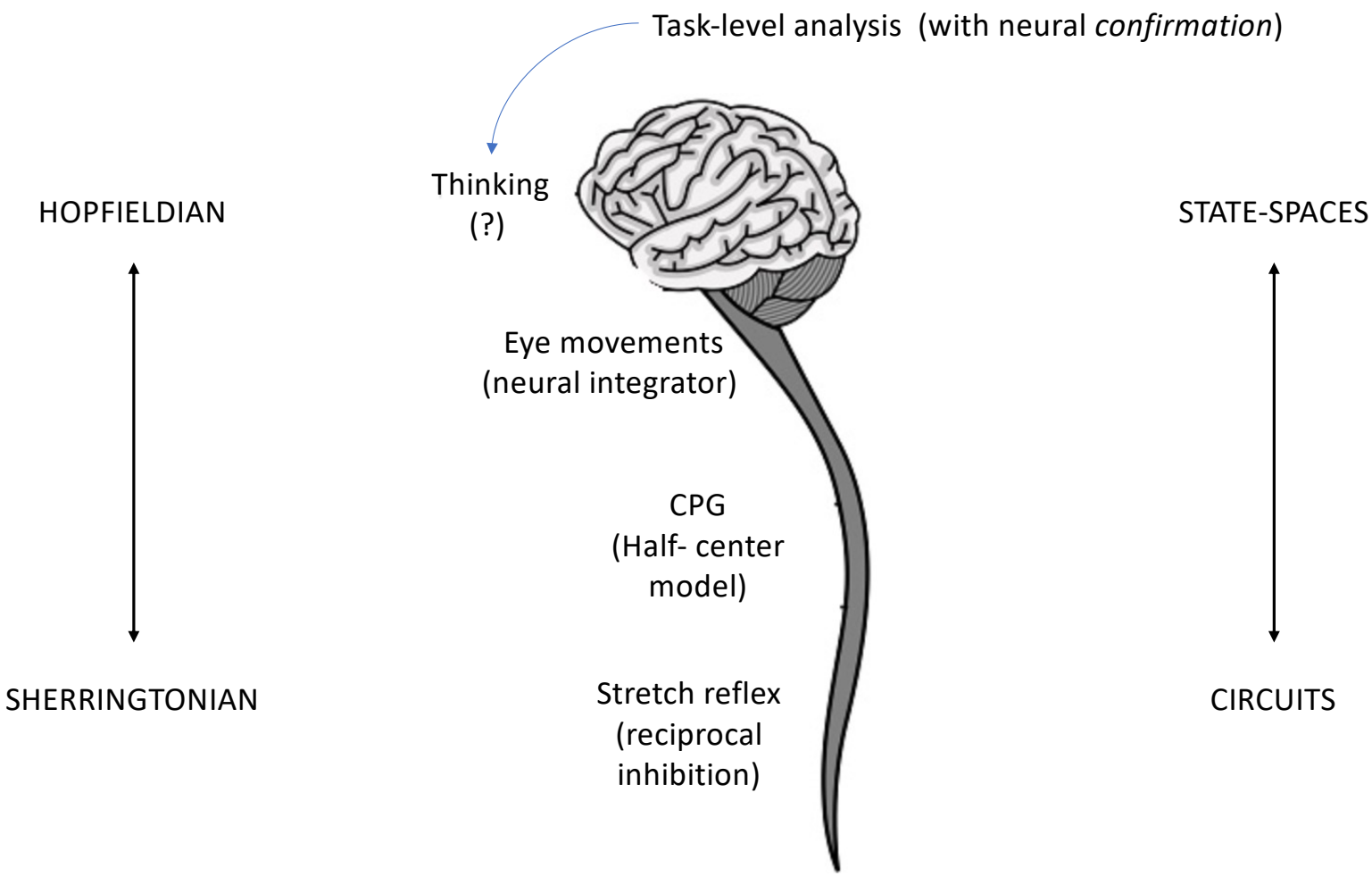

Sensory
Motor
Natural representations
Sensory
Decision making
Navigation
Perception
Motor
Internal models
Non-natural representations
Sensory
Thinking
Motor


Thinking
(?)
Long-latency
“intelligent” reflexes
Stretch reflex
(reciprocal
inhibition)

Can neural data be a first level explainer of cognition?

VIEW	Sherringtonian	Hopfieldian
Algorithmic / Computational	- Node-to-node connections - Activation or transfer functions - Representations necessarily carried by individual neurons  Half-center model  Canonical cortical microcircuit (from Nelson 2002)	- Representational spaces - Movement through or transformations between spaces  Metric deformation (from Churchland 1986)  Attractor basins (from Hopfield 1982)
Implementational	- Neurons - Circuits - Pathways (intra- and extra-cellular)  CAMKII cascades (from Lisman 2012)  Amygdala circuits for fear and anxiety (from Janak and Tye 2015)	- Neural spaces - Mass measures of neural activity  Neural task parameter space (from Mante et al. 2013)  Trajectories in neural space in PMd recovered from Gaussian Process Factor Analysis during a reaching task in monkeys (from Churchland et al. 2010)

Barack and Krakauer (2021) *Nature Reviews Neuroscience*


Task-level analysis (with neural *confirmation*)
Thinking
(?)
HOPFIELDIAN
STATE-SPACES
Eye movements
(neural integrator)
CPG
(Half- center
model)
Stretch reflex
(reciprocal
inhibition)
SHERRINGTONIAN
CIRCUITS

SYSTEM II
COGNITION

- Computation over non-natural semantic representations
- These non-natural representations are:
  - first-level explainers for psychology
  - have content that substitutes for and is detached from stimuli.
- This kind of deliberative cognition allows the construction, within one lifetime, of a huge repertoire of intelligent reflexes. This is much faster than evolution or deep learning because understanding provides a short-cut and a scaffolding.
- This kind of intelligence *spandrelized* into culture and thereby self-reinforced and magnified itself.

DEEP LEARNING NEEDS A PREFRONTAL CORTEX

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We have argued that there is a striking correspondence between the tasks on which humans outperform current AI systems and the executive functions associated with the PFC.