UNIVERSITY OF BIRMINGHAM | CHBH CENTRE FOR HUMAN BRAIN HEALTH

# The basics of human motor control

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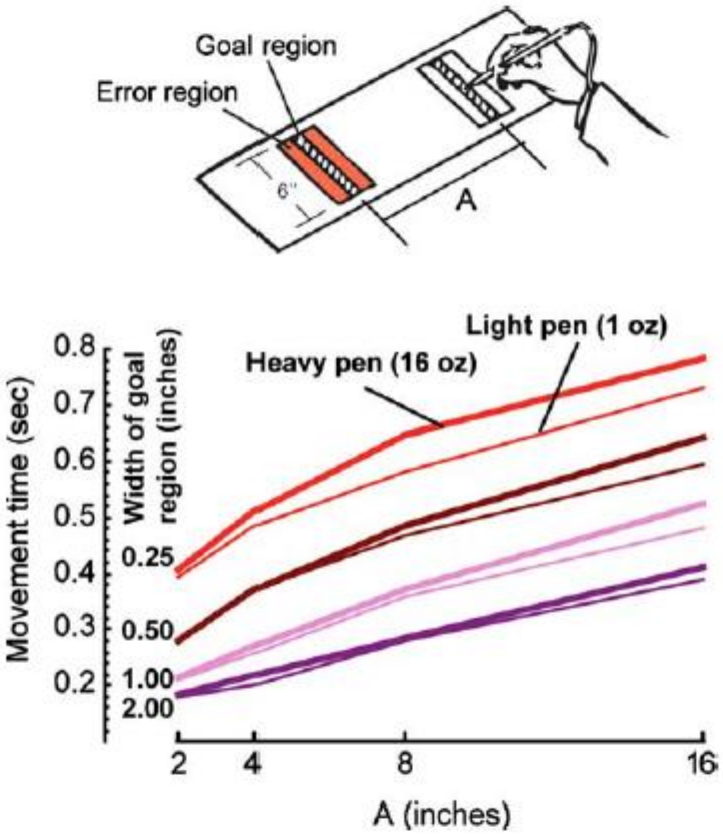
# Motor behaviour can be amazingly consistent across individuals…



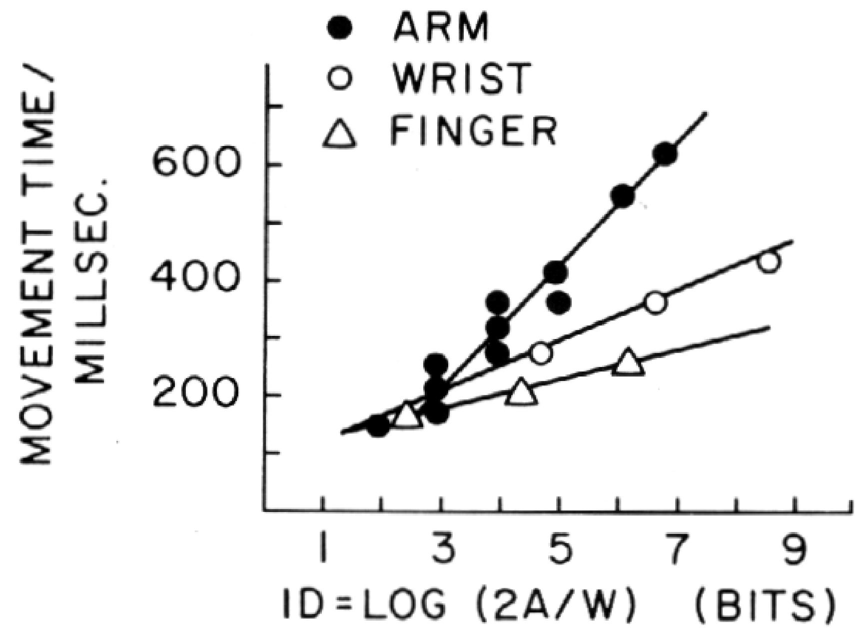
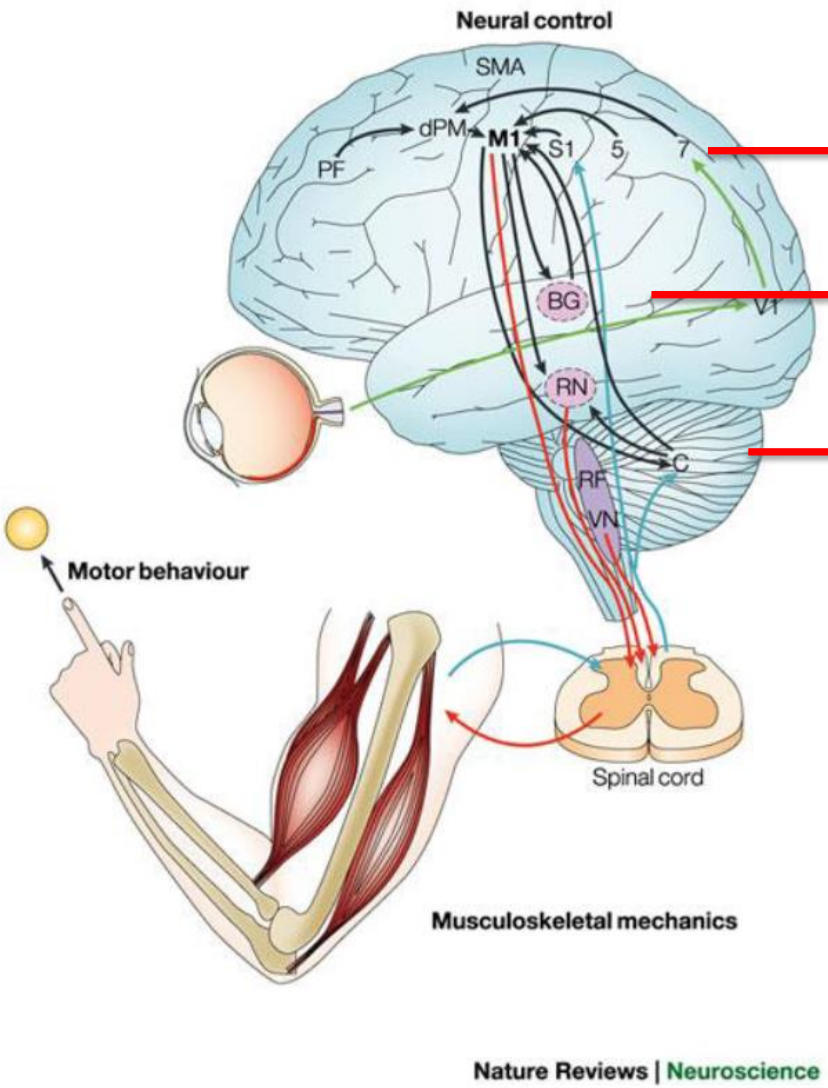




FIG. 6.5. Movement time as a function of the index of difficulty of the movement for movements made under a microscope by finger, or by wrist, or by normal movements of the arm (from Langolf, Chaffin, & Foulke, 1976).



Fitts, 1954

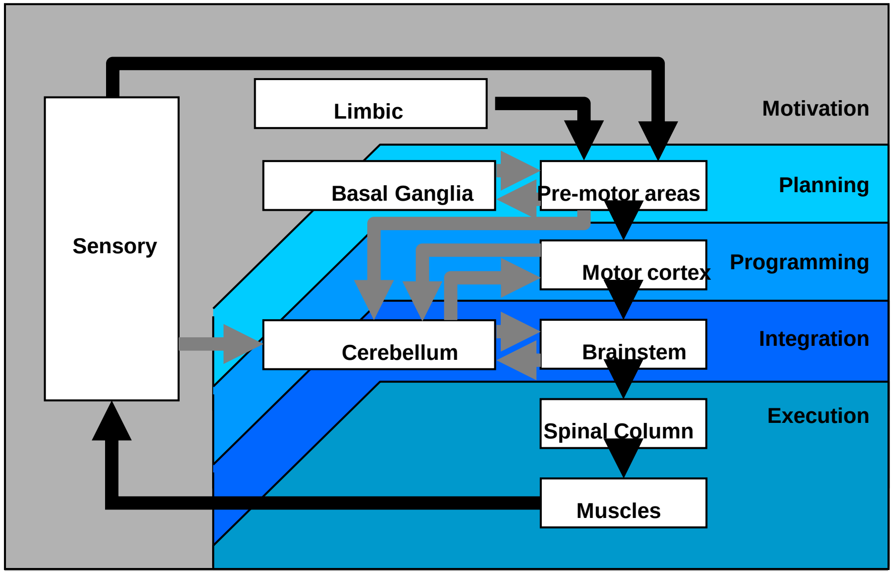
# But goal-directed movements involve a complex neural network




Parietal cortex

Basal Ganglia

Cerebellum



# What are the key principles of this feedback driven process?

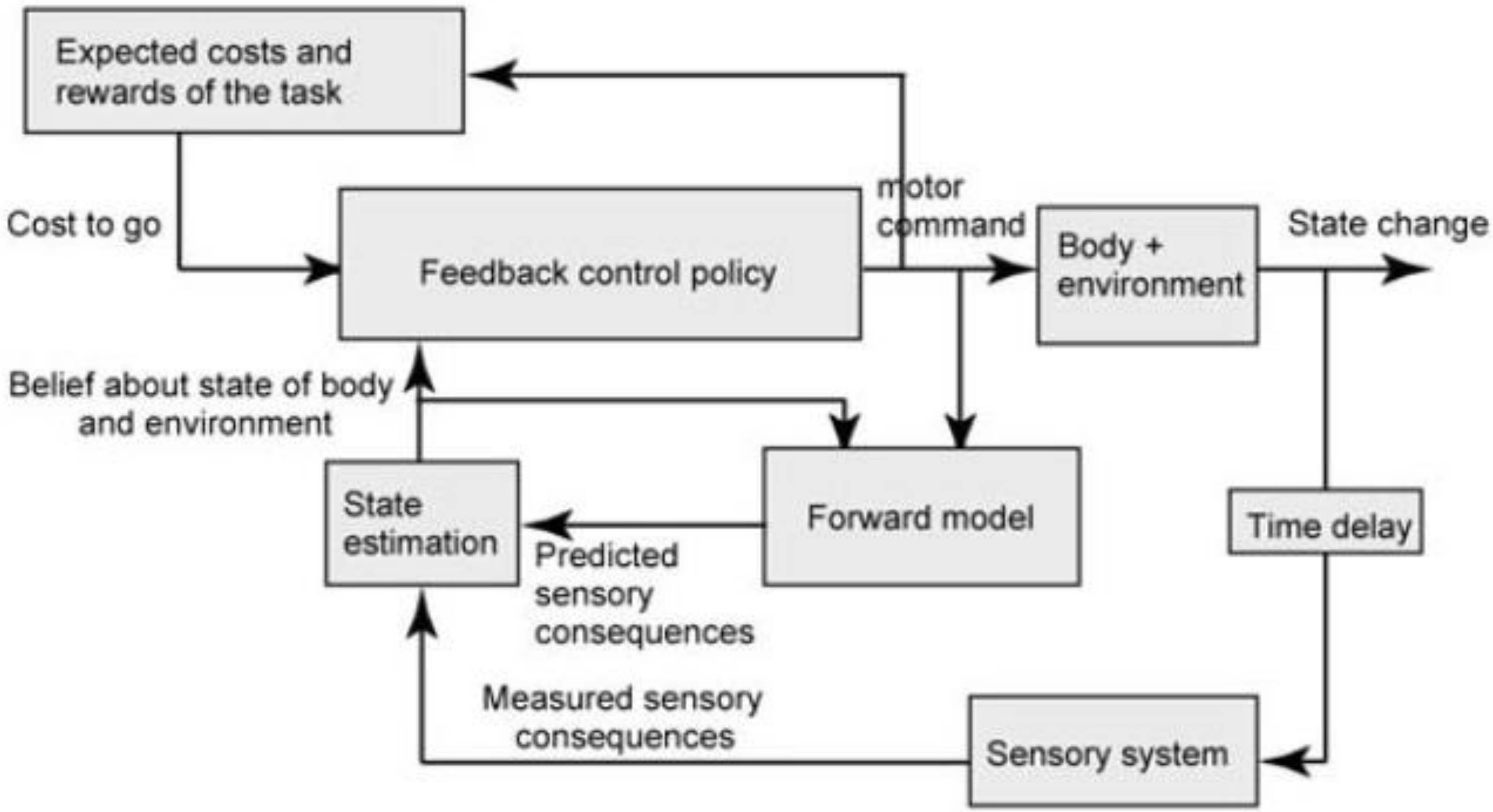
- In order to make a movement, our brain needs to solve three kinds of problems:

1) Accurately predict the sensory consequences of our motor commands: **system identification.**
2) Combine these predictions with actual sensory feedback to form a belief about the state of our body and the world: **state estimation**.
3) Given this belief about the state of our body and the world, the gains of the sensorimotor feedback loops need to be adjusted so that movements maximize some measure of performance: **optimal control**.

- **Key idea**: the rewards we expect to get and the costs we expect to pay determine how quickly we move, what trajectory we choose to execute, and how we will respond to sensory feedback (i.e. nothing is fixed and is constantly being updated).

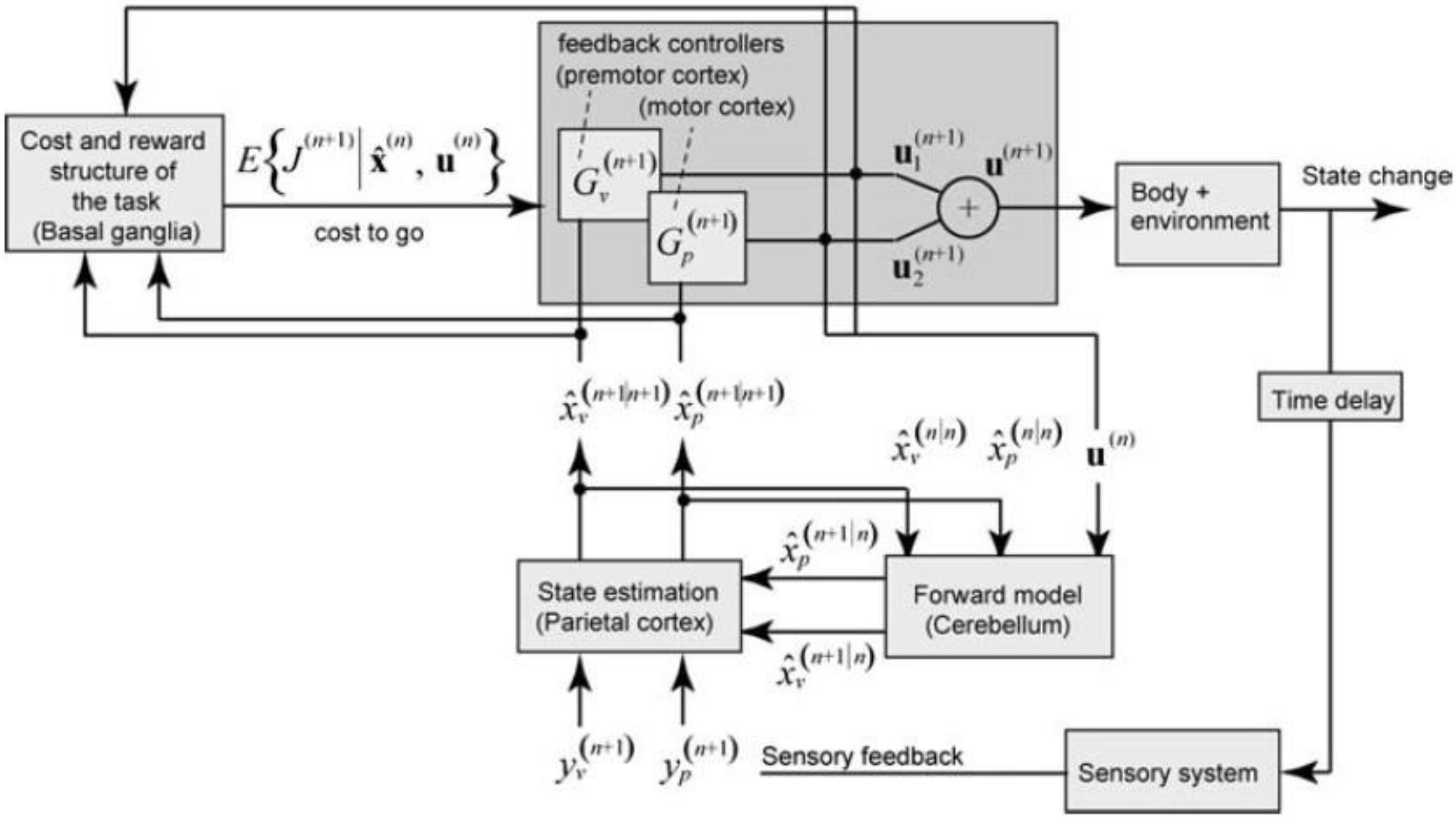


Todorov & Jordan (2002) Shadmehr & Krakauer (2008)





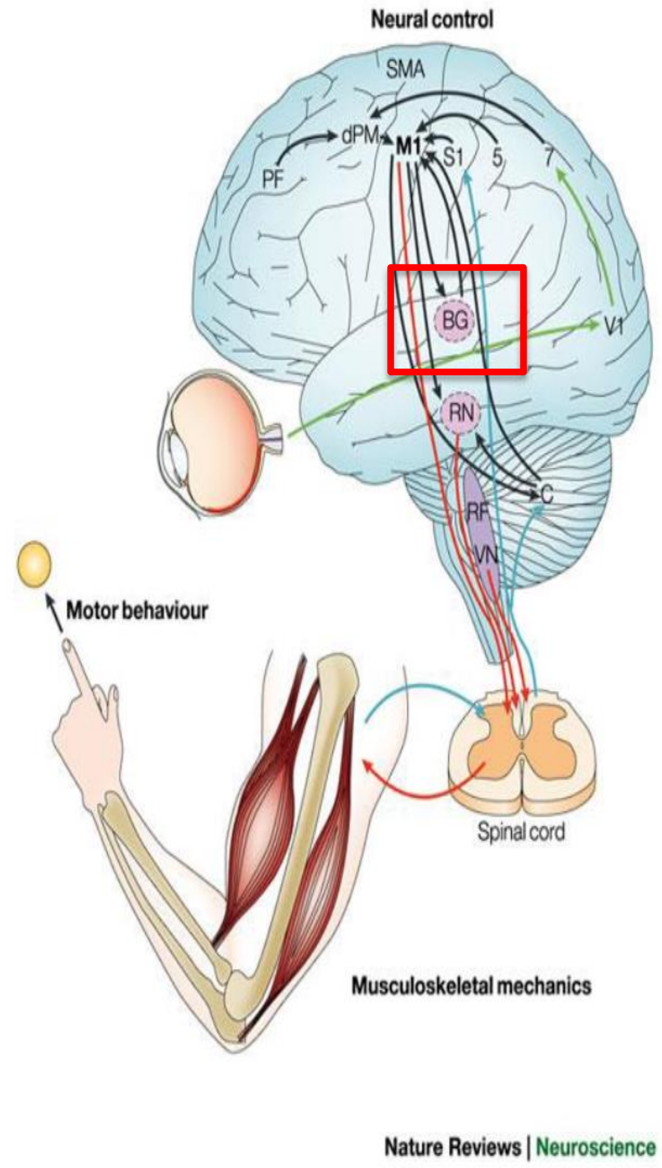

Shadmehr & Krakauer (2008)






Shadmehr & Krakauer (2008)

- **Basal ganglia:** forms the expected costs of the motor commands and the expected rewards of the predicted sensory states.
- **Cerebellum:** predicts the sensory consequences of motor commands.
- **Parietal cortex:** combines the expected sensory feedback with the actual sensory feedback, computing a belief about the state.
- **Premotor/primary motor cortex:** assigns feedback gains to states, resulting in sensorimotor maps that transform the internal belief about states into motor commands.



# Basal ganglia, dopamine and effort cost

- Movement characteristics are the result of a cost minimization.
- The cost depends on two quantities: spatial accuracy and required effort (energy cost).
- Parkinson's disease patients (low dopamine levels) suffer from micrographia; abnormal choice of speed/amplitude when handwriting.
- But patients show normal accuracy, suggesting they have increased sensitivity to effort.
- Also helps explains Bradykinesia: movement slowing.

# Basal ganglia, dopamine and effort cost



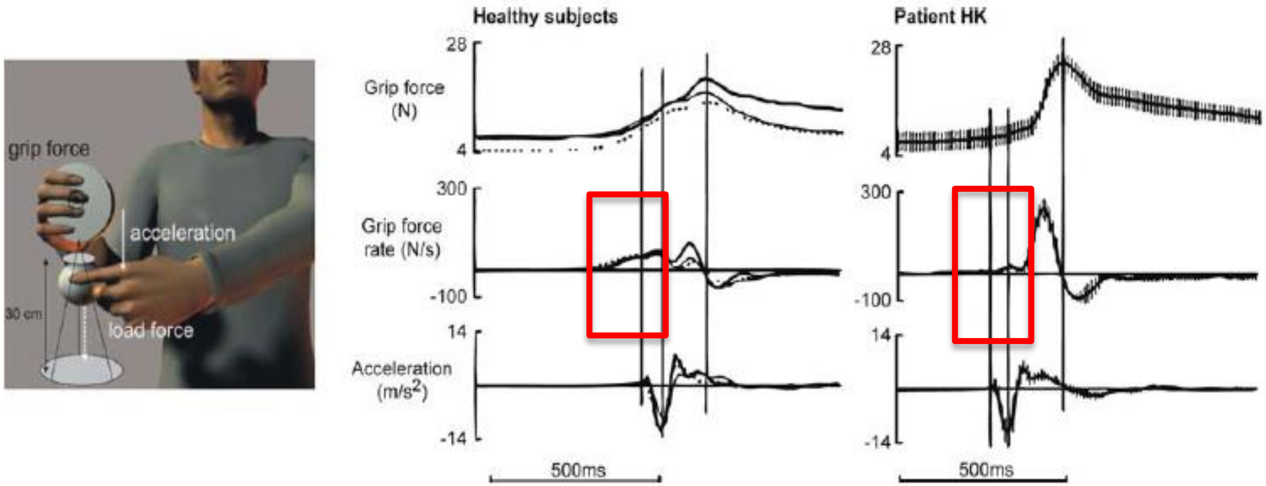
https://www.youtube.com/watch?v=6sTtdcsZkDk

https://www.youtube.com/watch?v=3-t6w2JC0M8

# Cerebellum and prediction

- Control policies generate motor commands based on beliefs about the state of the body and the environment. Beliefs depends on two quantities: a prediction and observation.

- Cerebellar lesion patients are unable to predict the sensory consequences of their own motor commands.




- Patients suffer from ataxia (uncoordinated movement) and specifically impaired end point position.

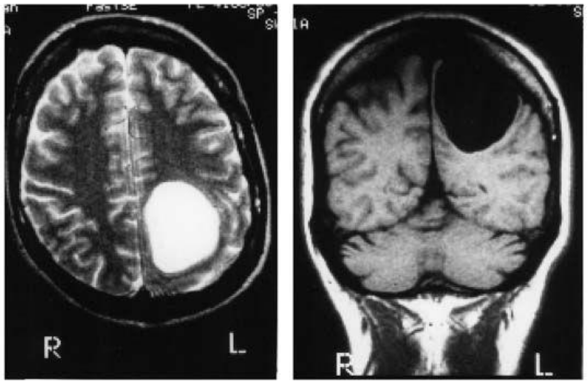
# Cerebellum and prediction

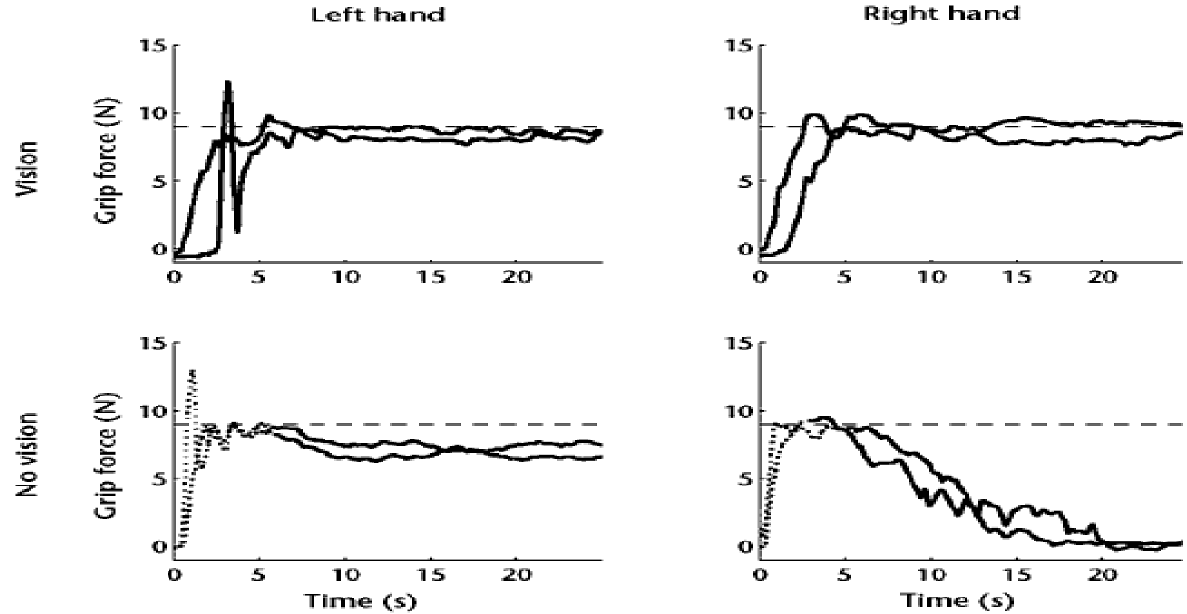


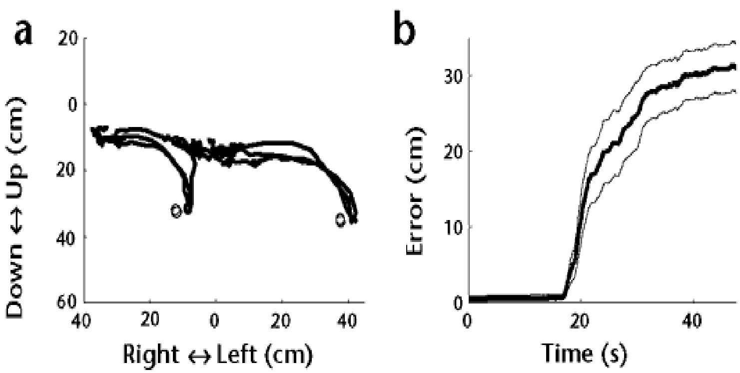
https://www.youtube.com/watch?v=-dFMisBl1aM

https://www.youtube.com/watch?v=Txlvuu2byUY

# Parietal cortex and state estimation




- Parietal lesion patients are unable to maintain an estimate of limb state.
- Arm position becomes increasingly uncertain.



Wolpert et al., (1998)

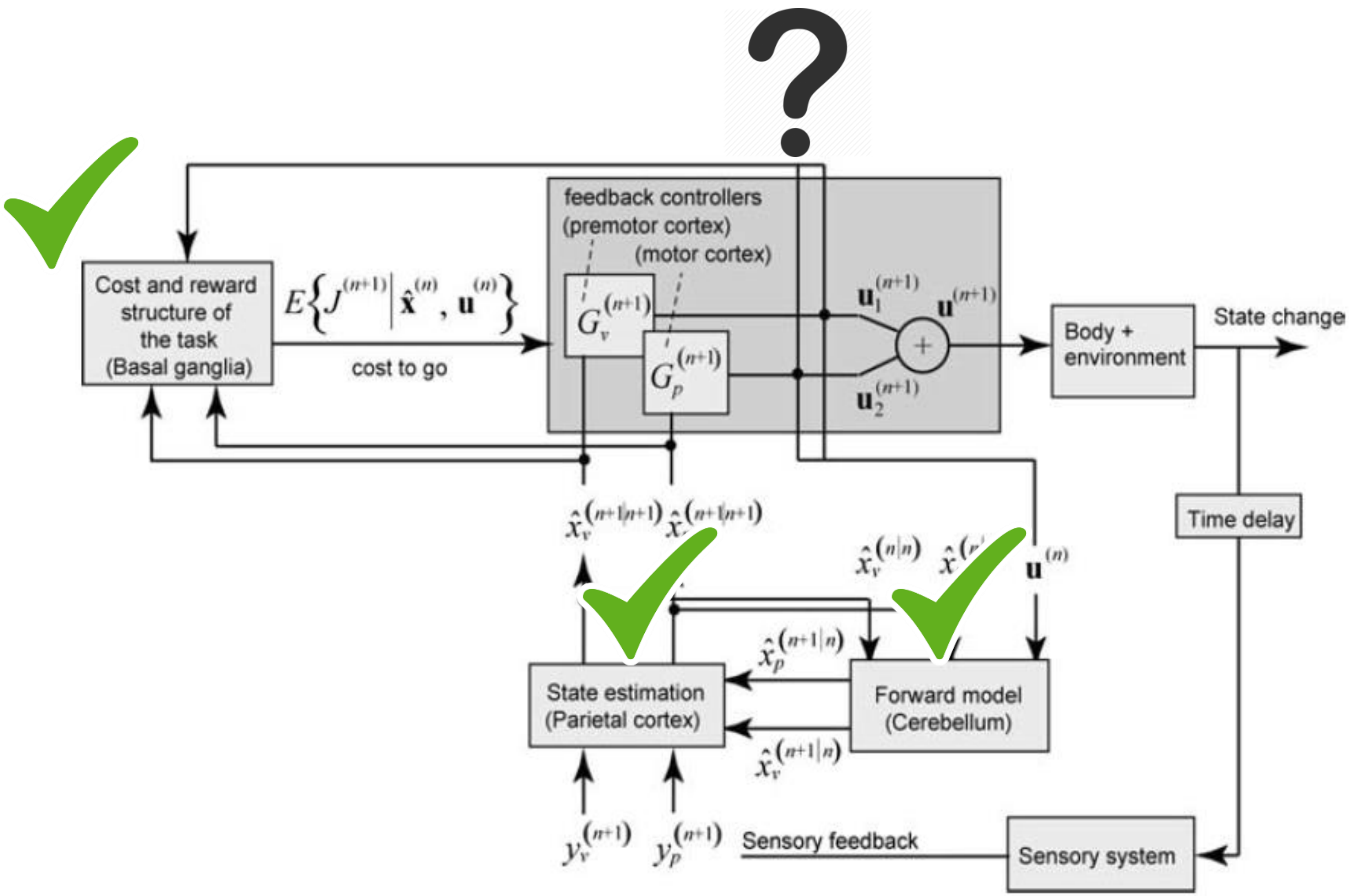
# Motor Cortex: a problem of execution

https://www.youtube.com/watch?v=OB5G0XUpYwE

# Proprioception: we can live without!

Ian Waterman:

https://www.youtube.com/watch?v=FKxyJfE831Q



Cost and reward structure of the task (Basal ganglia)
cost to go
feedback controllers
(premotor cortex)
(motor cortex)
Body + environment
State change
Time delay
State estimation (Parietal cortex)
Forward model (Cerebellum)
Sensory feedback
Sensory system

# Funding

EPSRC

Engineering and Physical Sciences Research Council

erc

European Research Council