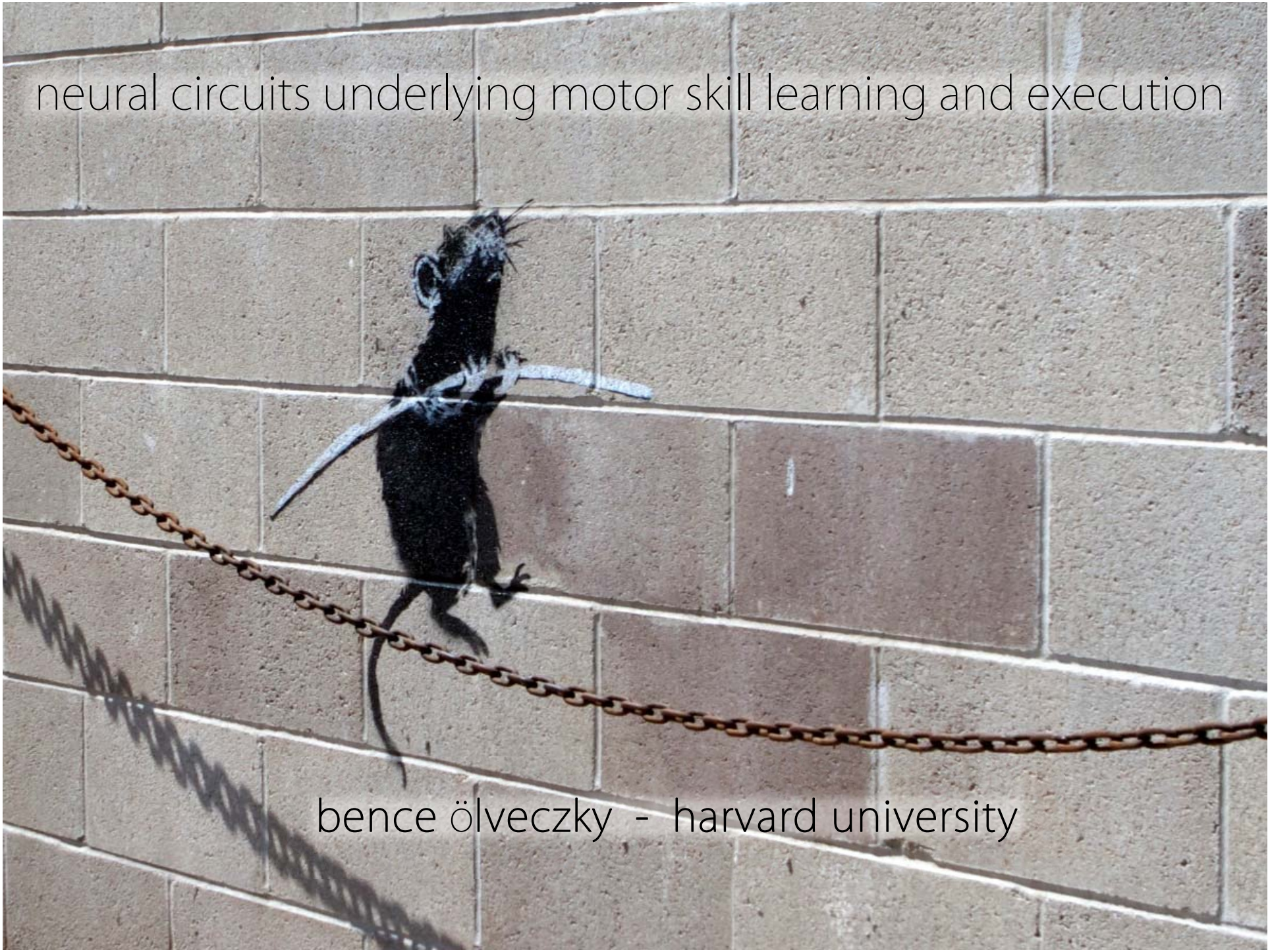
neural circuits underlying motor skill learning and execution



bence ölveczky - harvard university

learning to eat spaghetti – an essential motor skill

learning to eat spaghetti

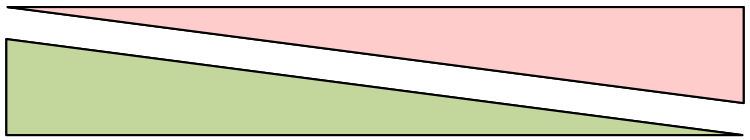
motor exploration

↓

evaluate performance

↓

reinforce 'good' motor programs



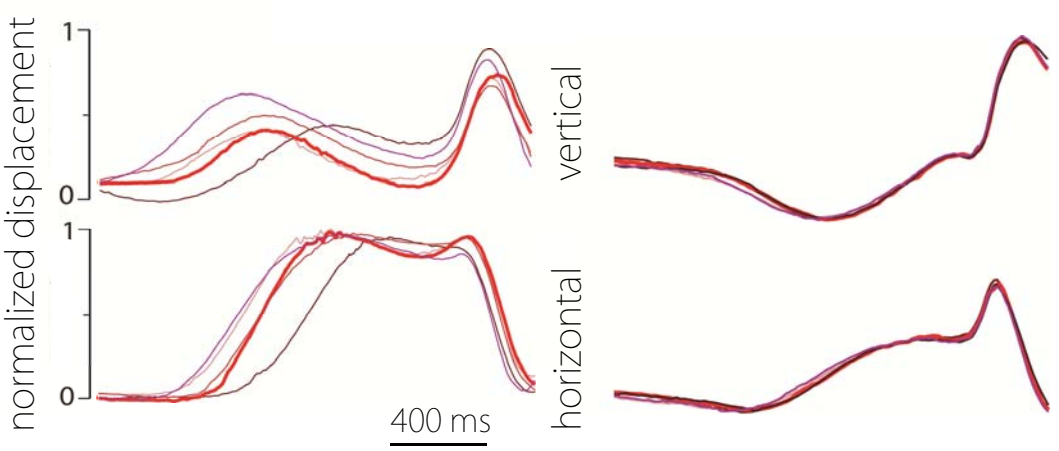
improved performance

decreased variability

motor skill learning

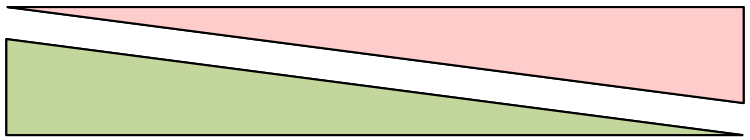
beginner

hand trajectory of tennis player



expert

performance

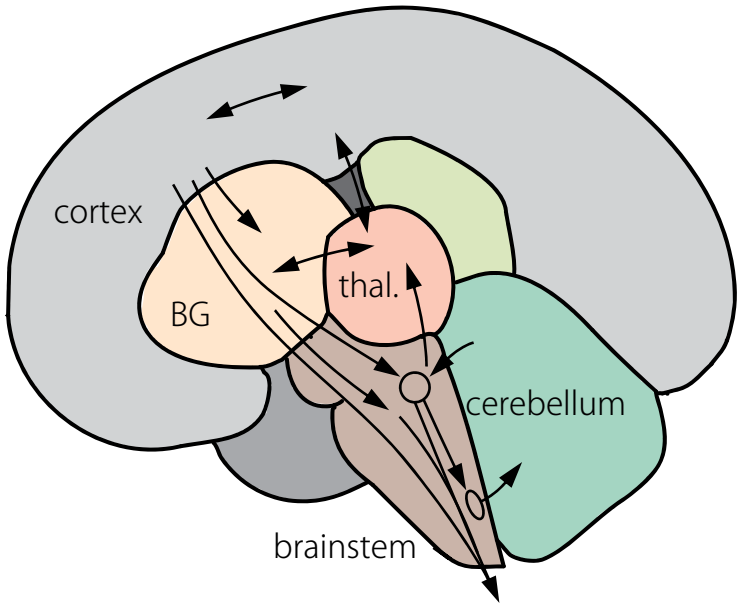


variability

wu et al, nature neuroscience, 2014

how does the brain underlie motor skill learning and execution?

beginner



expert

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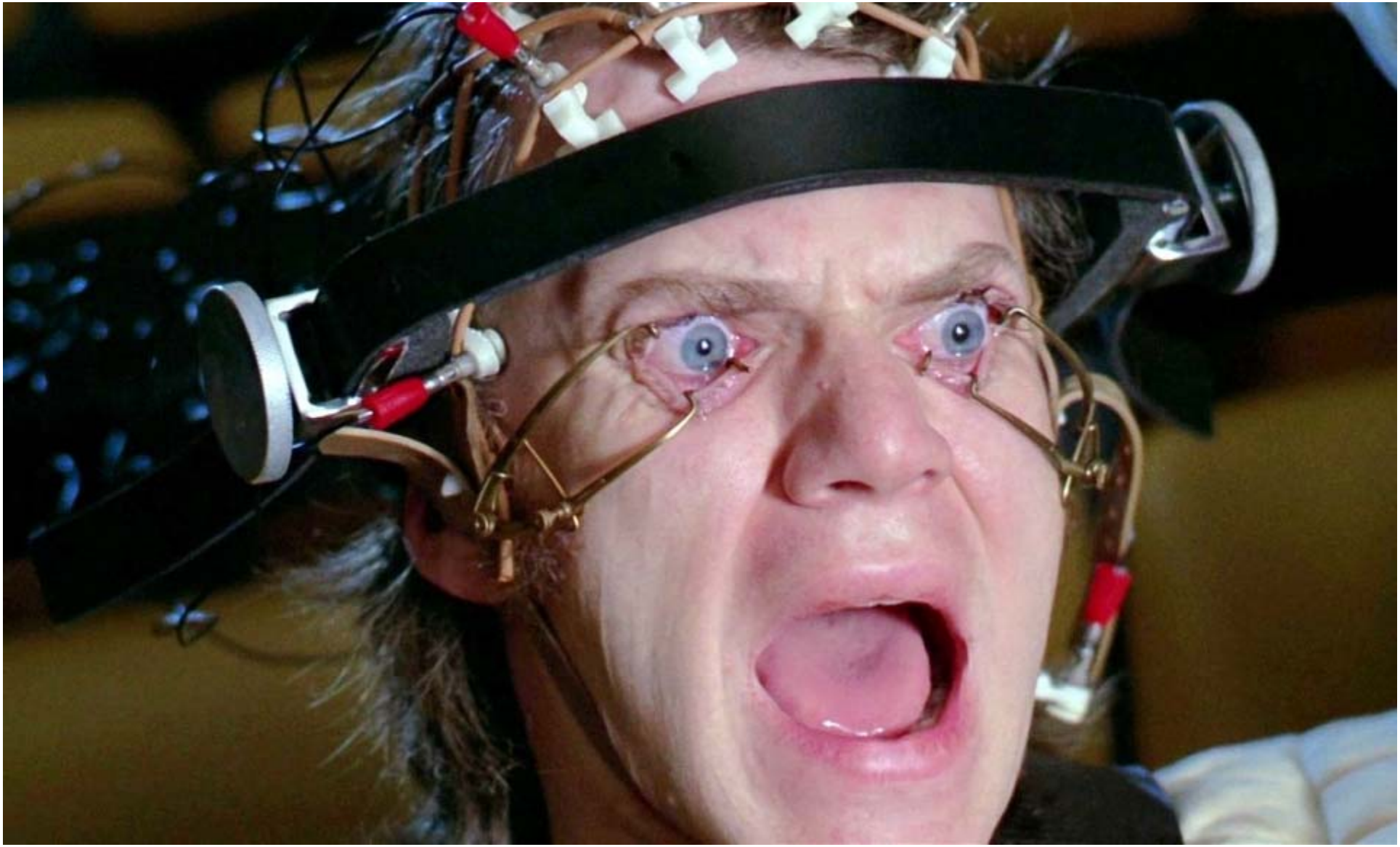


how does the brain underlie motor skill learning and execution?

the expert

the generalist
(and mammal)

using songbirds to probe motor sequence learning

learning timeline

sound generation in songbirds

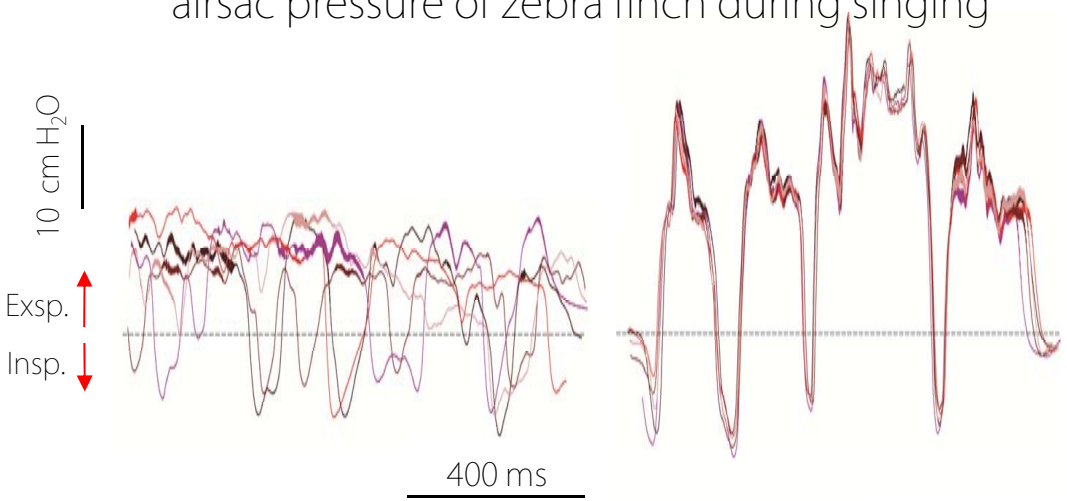
syringeal muscles

respiratory muscles

learning to control the sound-producing organ

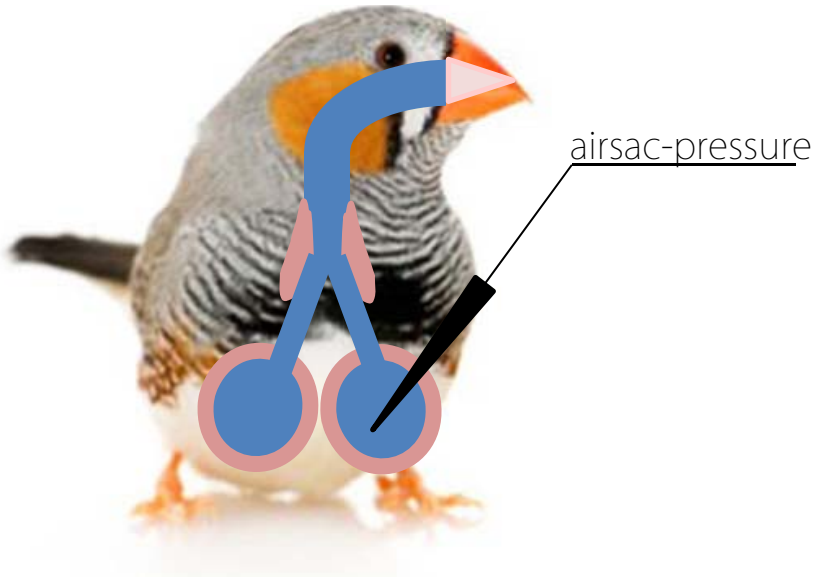
beginner
(45 days)

airsac pressure of zebra finch during singing



expert
(90 days)

sound generation in songbirds

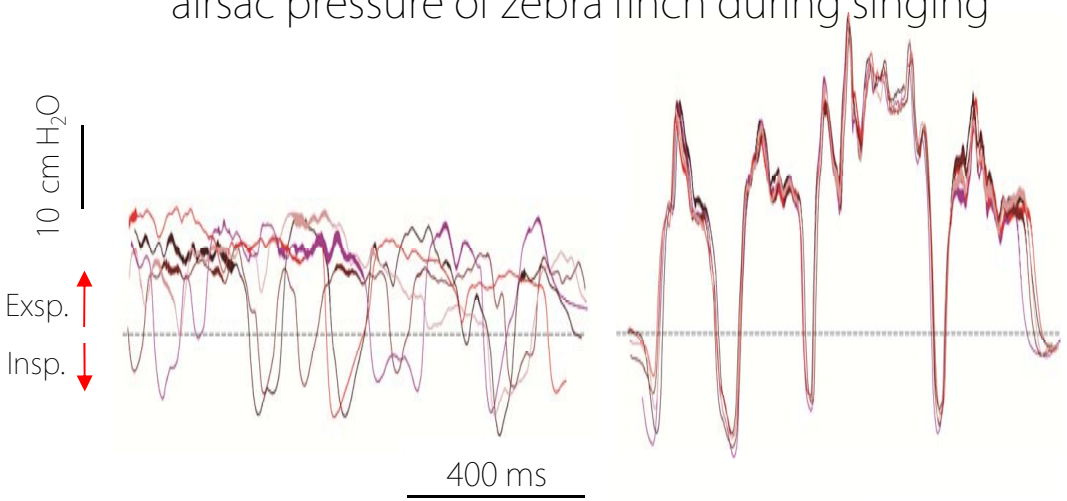


Lena Veit (Fee lab)

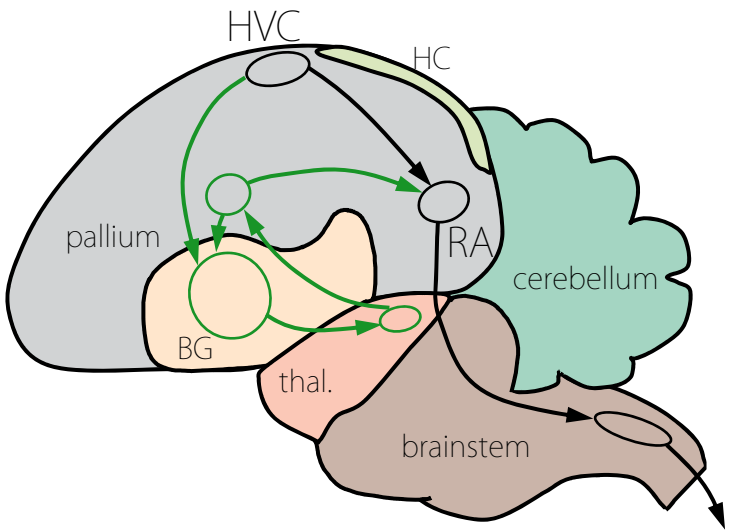
neural control of song

beginner
(45 days)

airsac pressure of zebra finch during singing



expert
(90 days)



motor pathway

learning pathway
(AFP)

vocal muscles - song

how does the brain underlie motor skill learning and execution?

the expert

the generalist
(and mammal)

how does the mammalian brain underlie motor skills?

primate

oscar, 2011

rodent

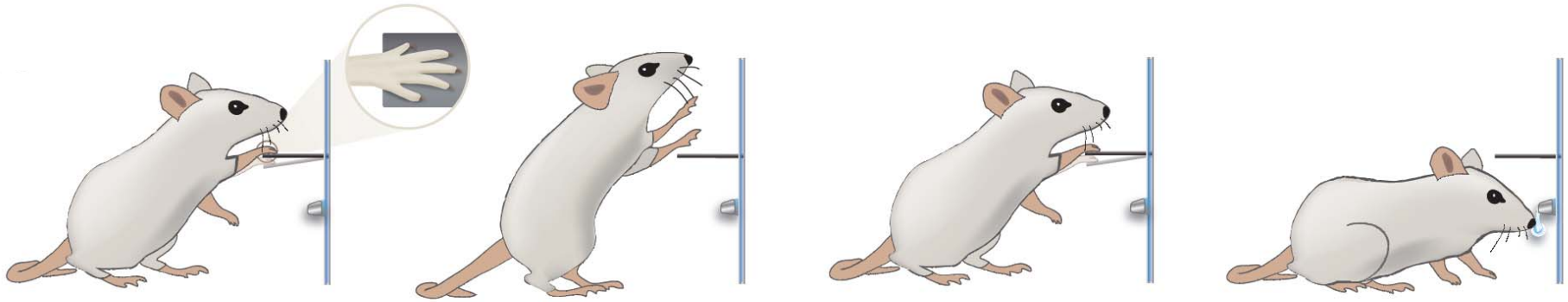
tennant et al, 2010, jove

how does the brain underlie motor skill learning and execution?

high-throughput automated animal training of rodents

poddar et al. (2013)

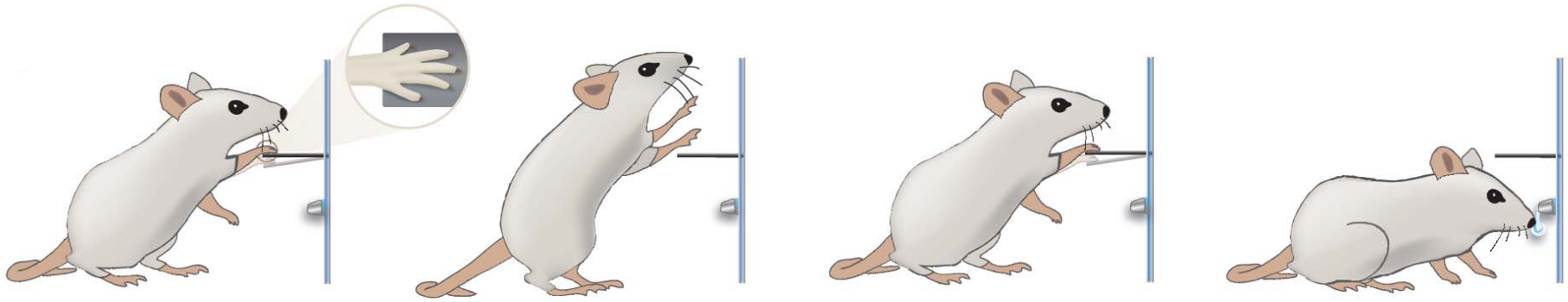
a new motor skill learning paradigm in rodents



press 1 delay (700 ms) press 2 reward

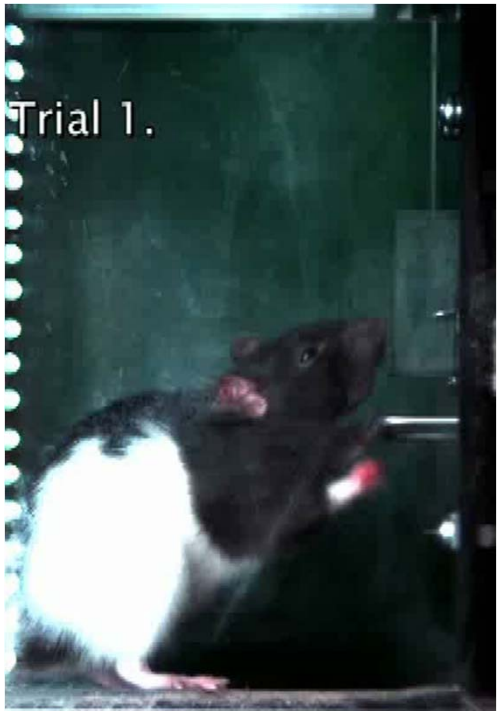
kawai et al, neuron

a new motor skill learning paradigm in rodents

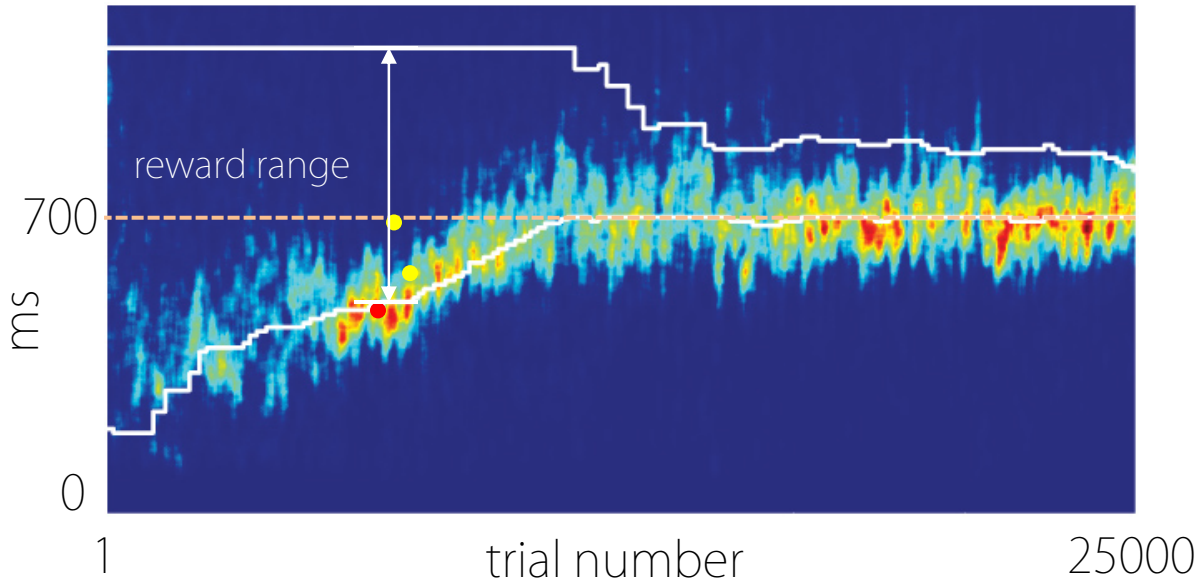


press 1 | delay (700 ms) | press 2 | reward

slowed down 1.5x

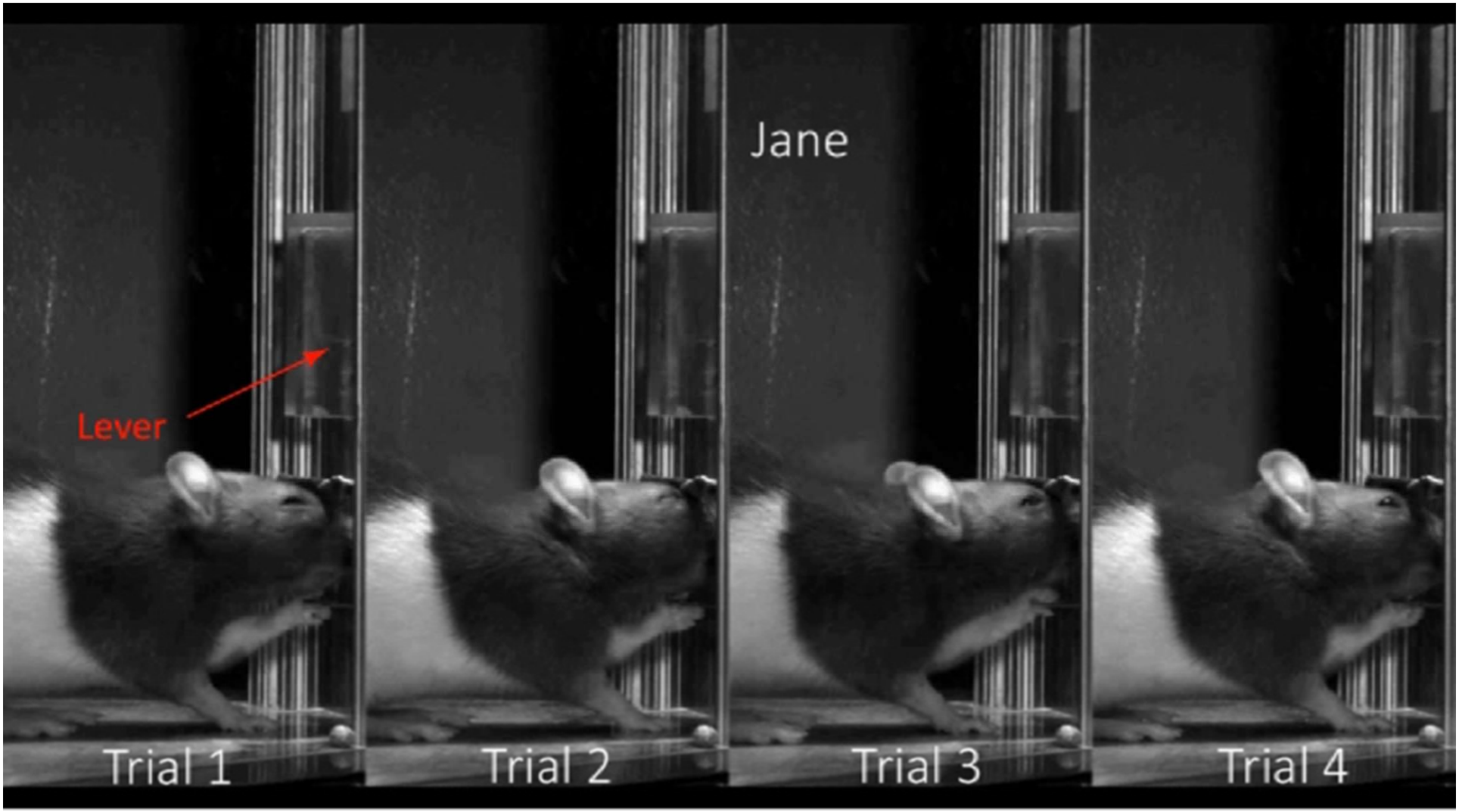


learning 700 ms inter-press interval



kawai et al, neuron

learned motor sequences are highly stereotyped and idiosyncratic



kawai et al, neuron

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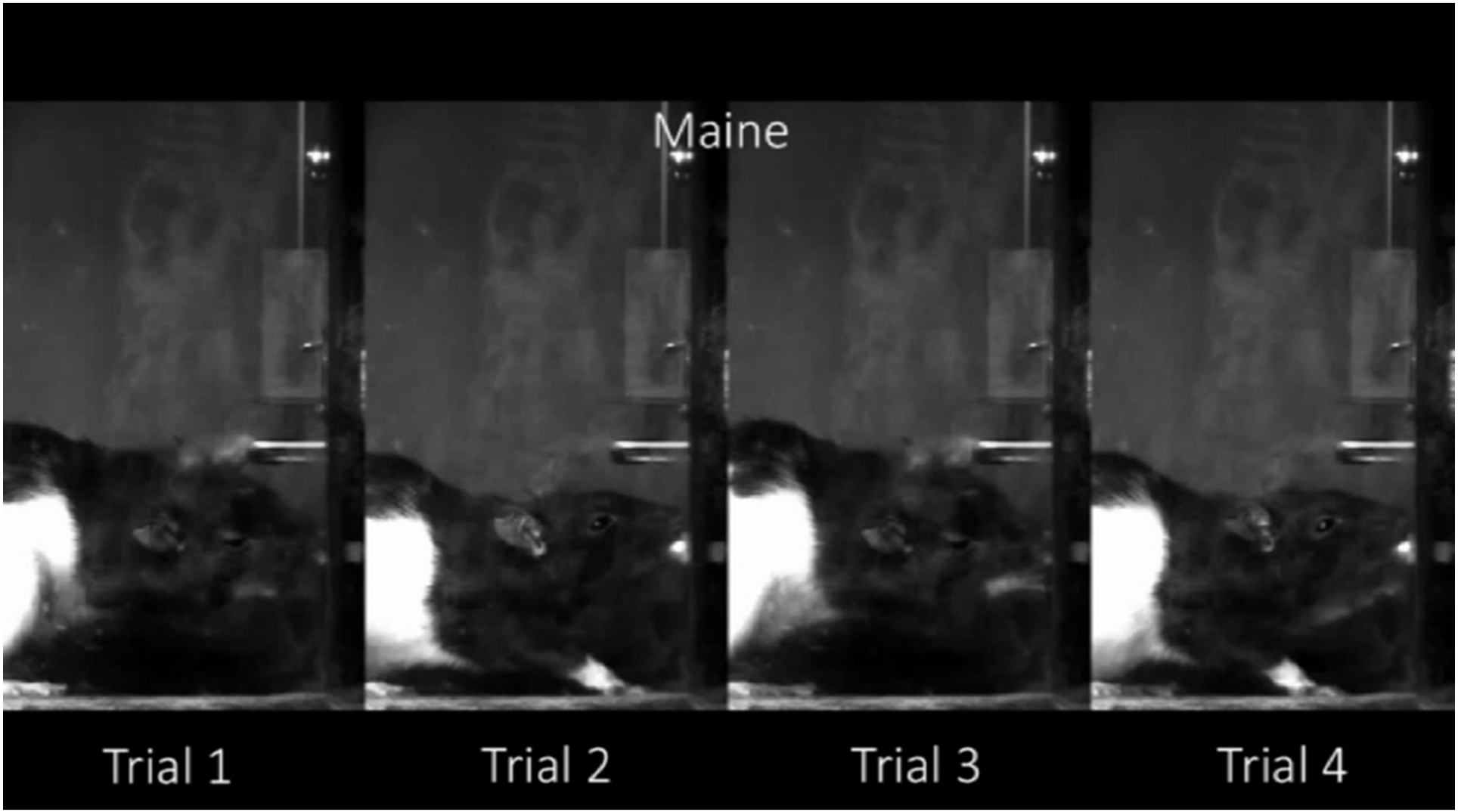

kawai et al, neuron

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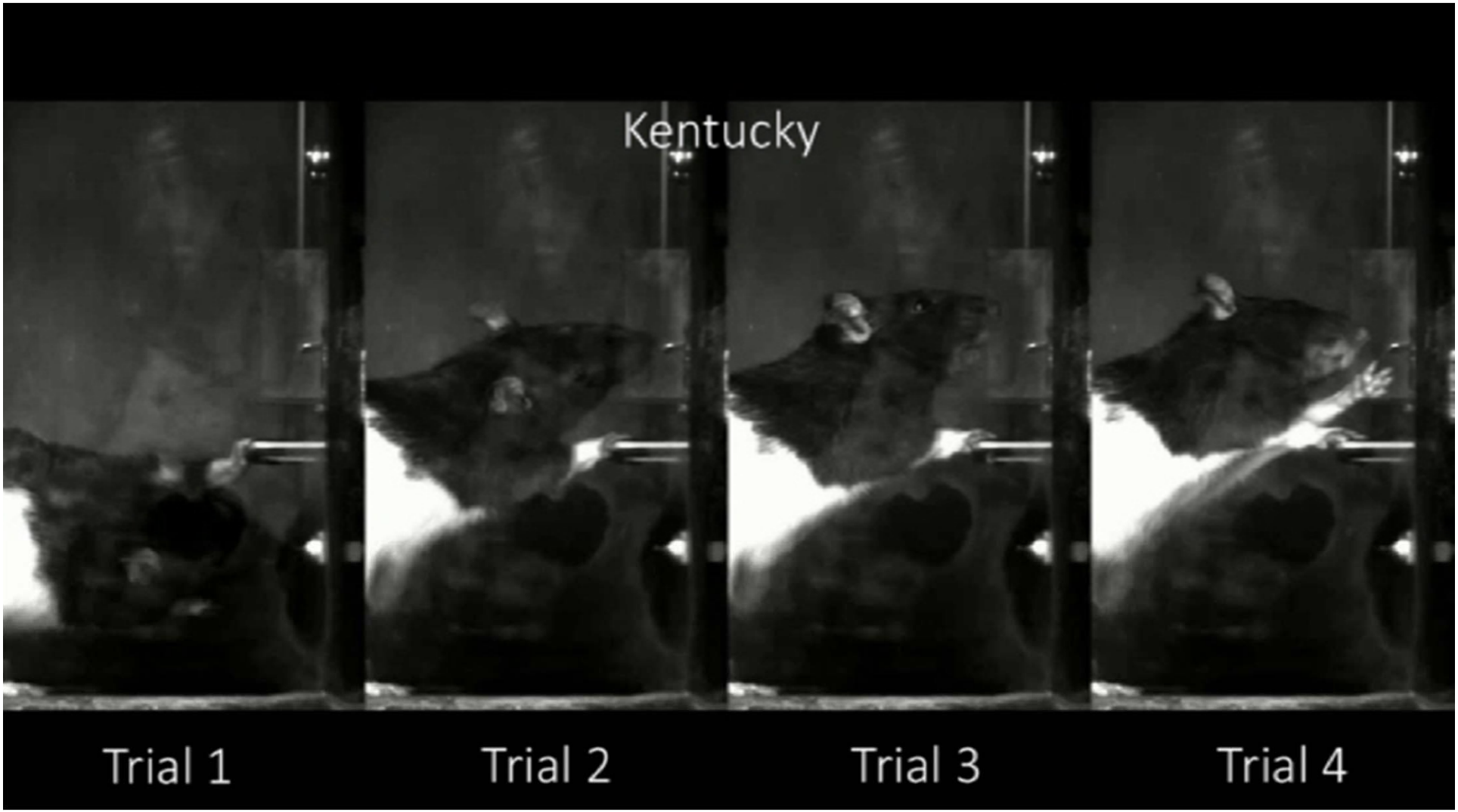
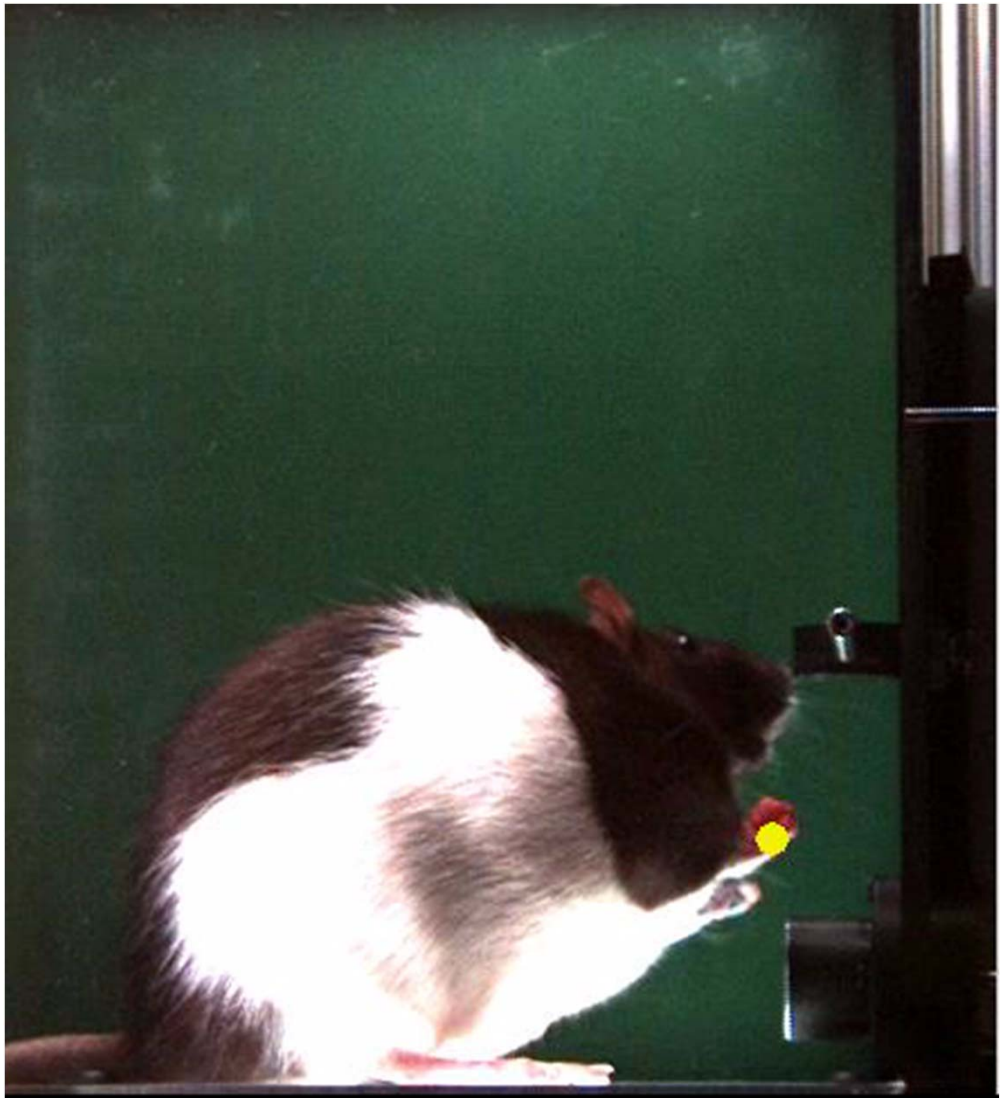


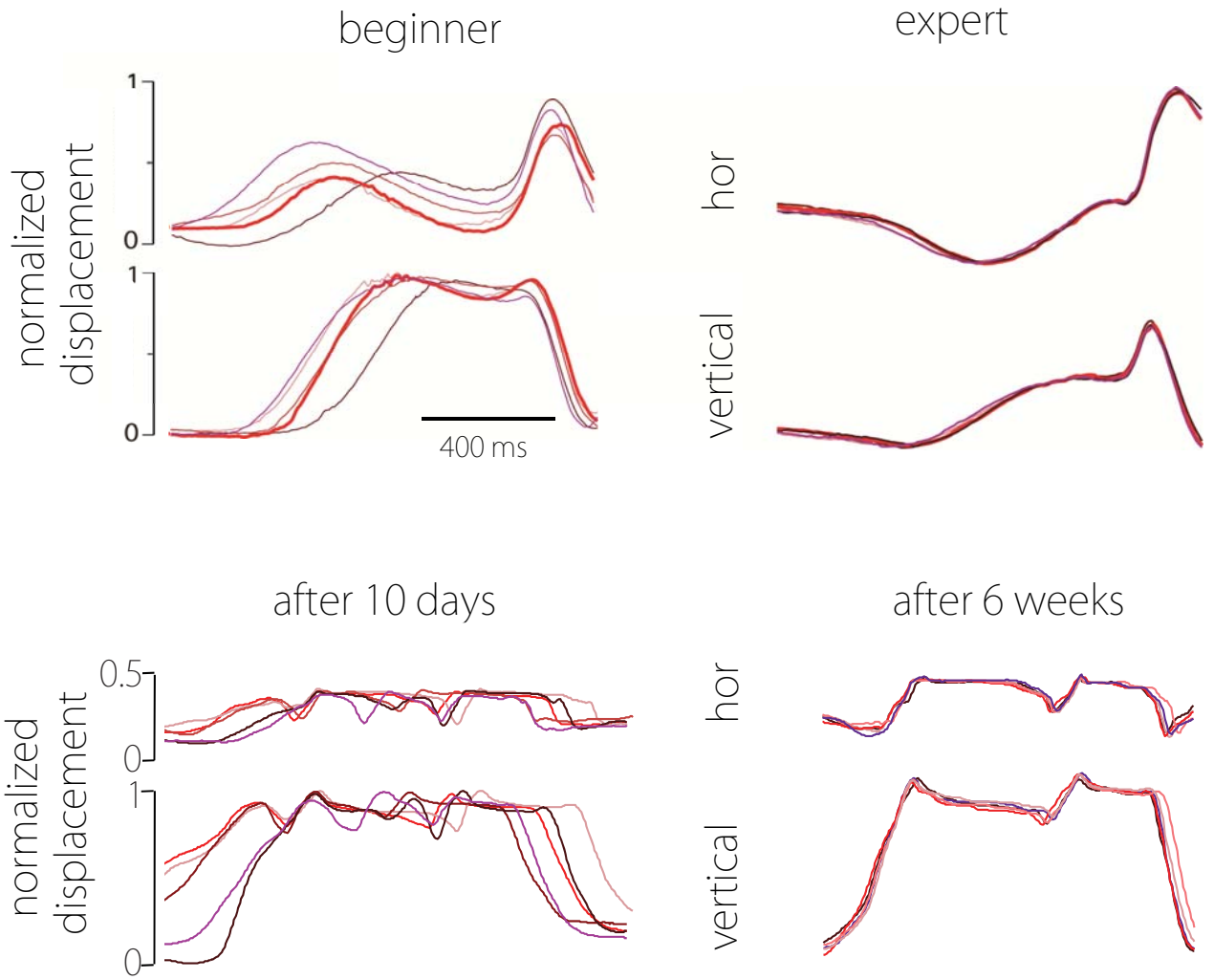
kawai et al, neuron

continuous kinematic tracking

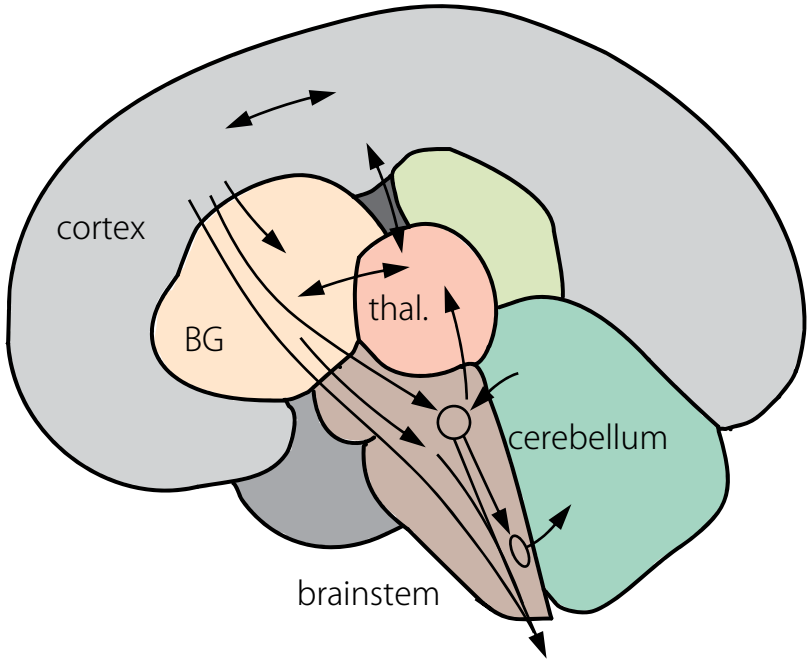


kawai et al, neuron

practice makes perfect



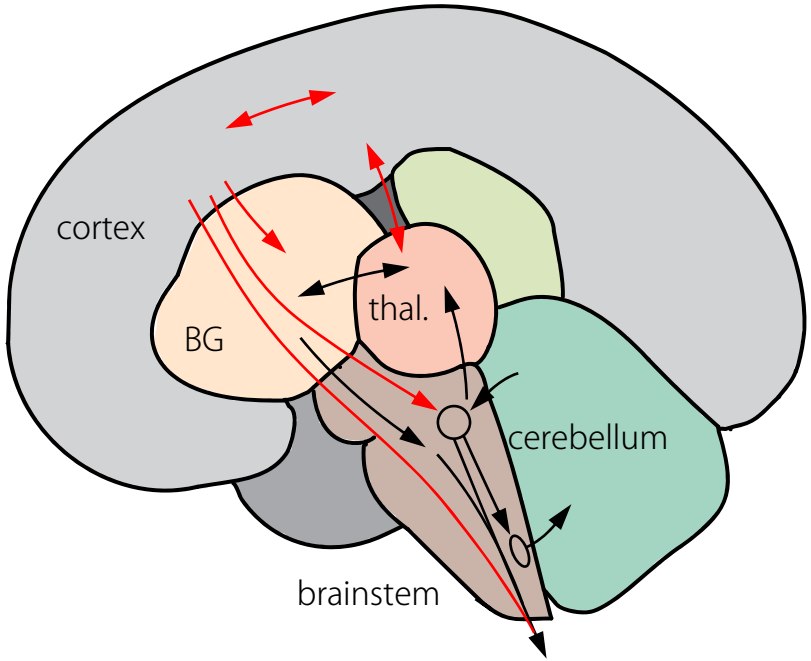
neural circuits underlying motor skill execution



from wikipedia (2014):

"…the development of motor skill occurs in the motor cortex."

neural circuits underlying motor skill execution



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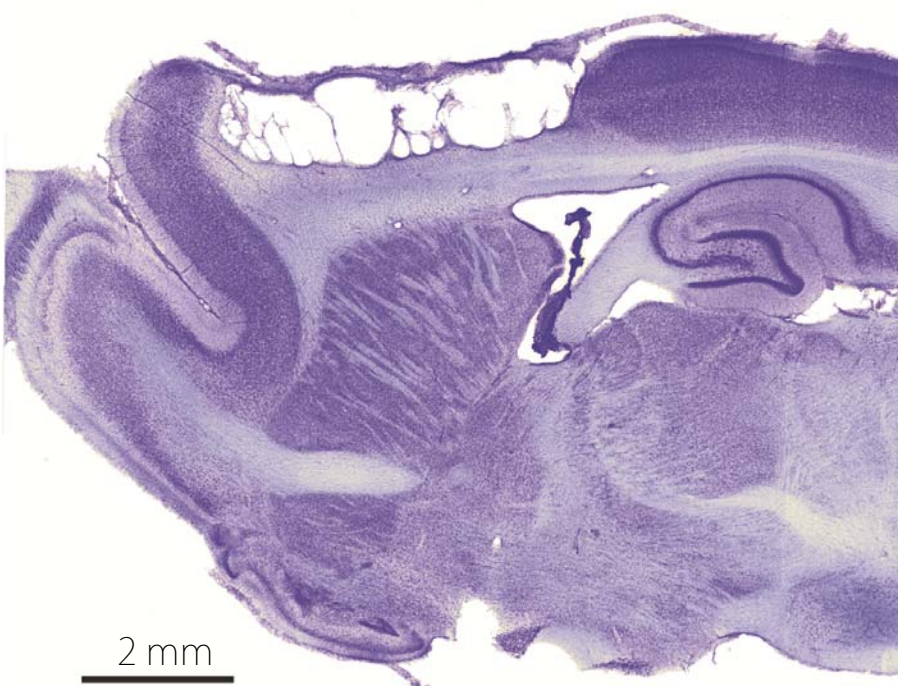
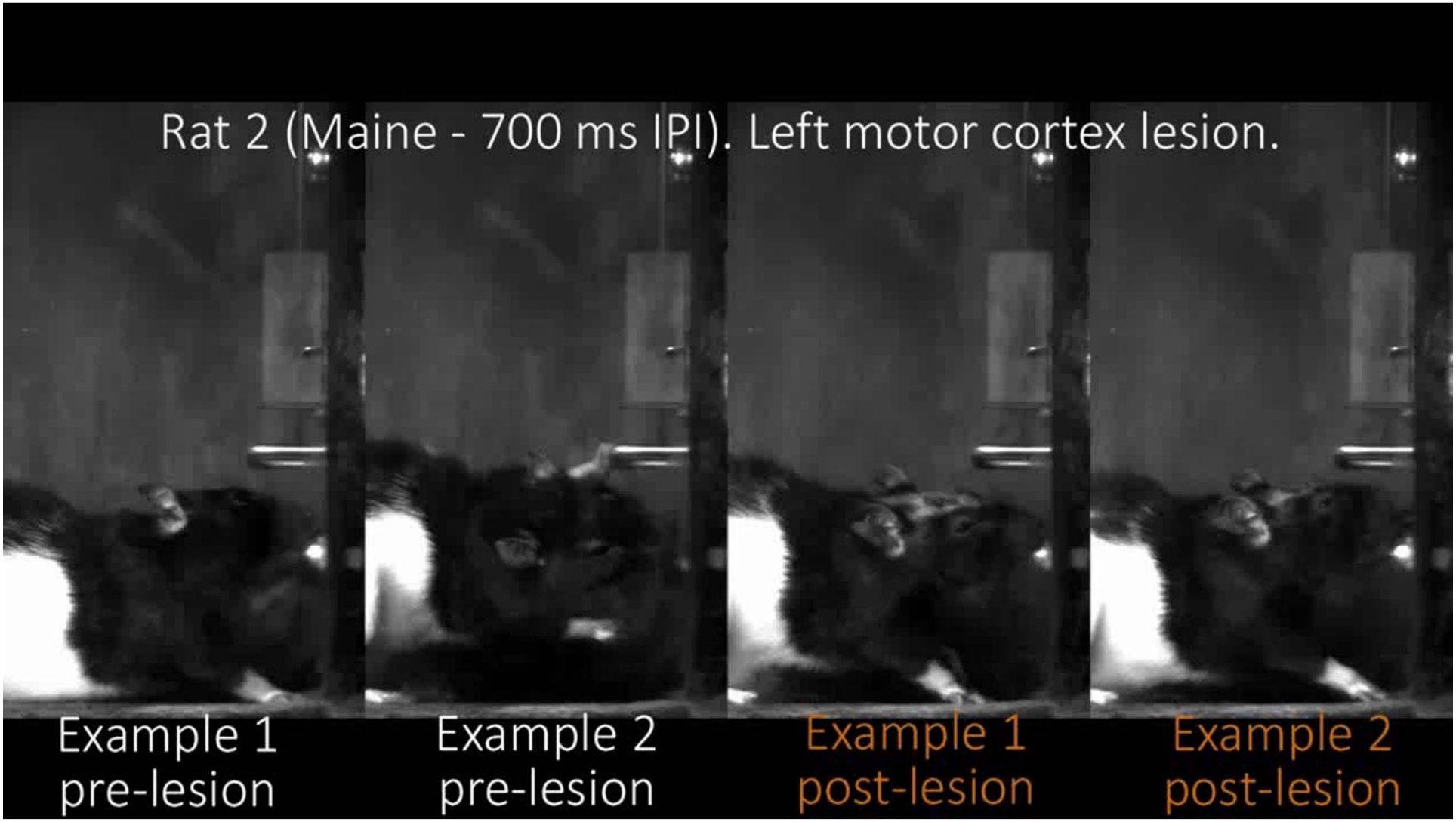
lesioning M1+M2



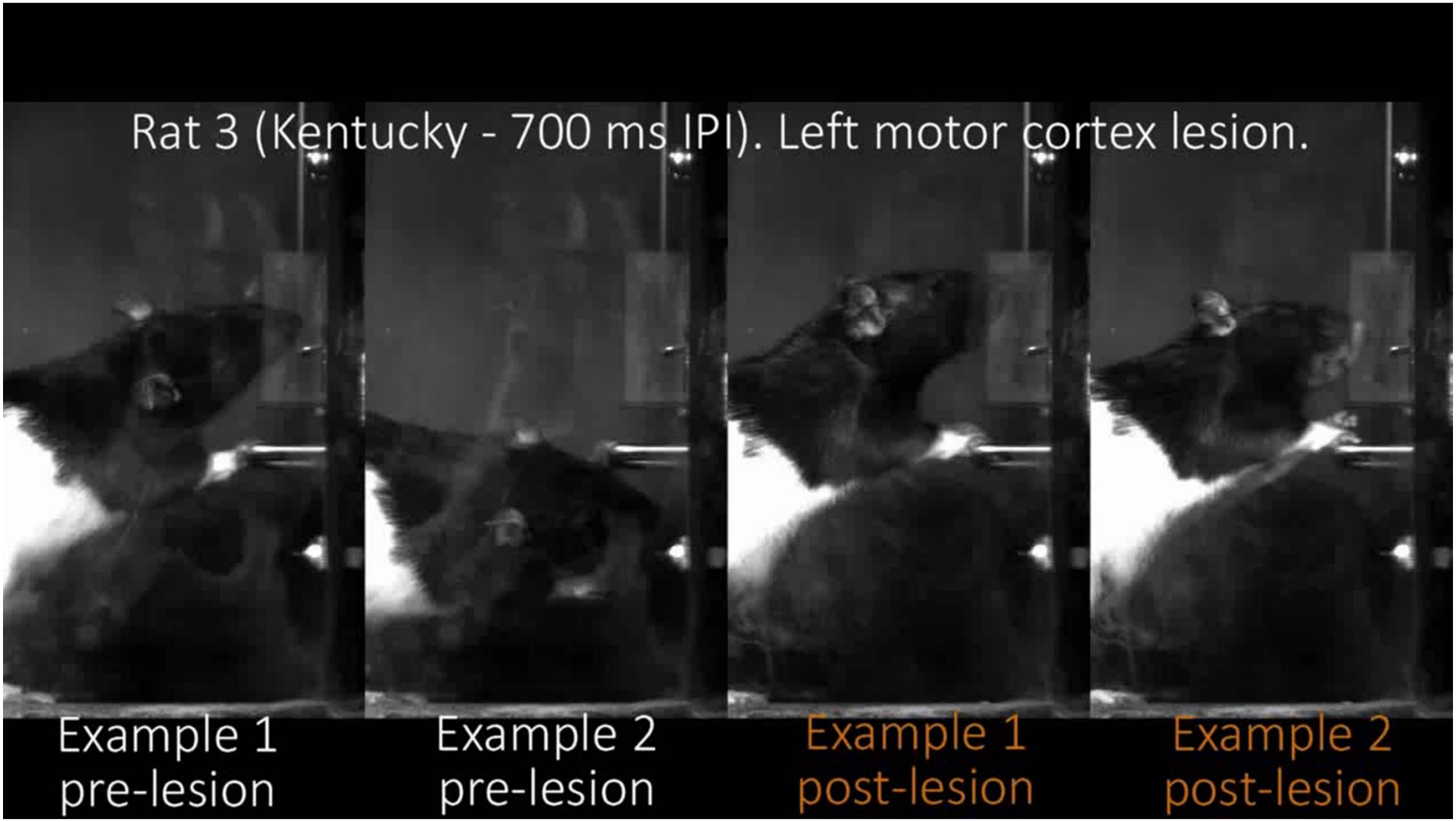
kawai et al, neuron

lesioning M1+M2



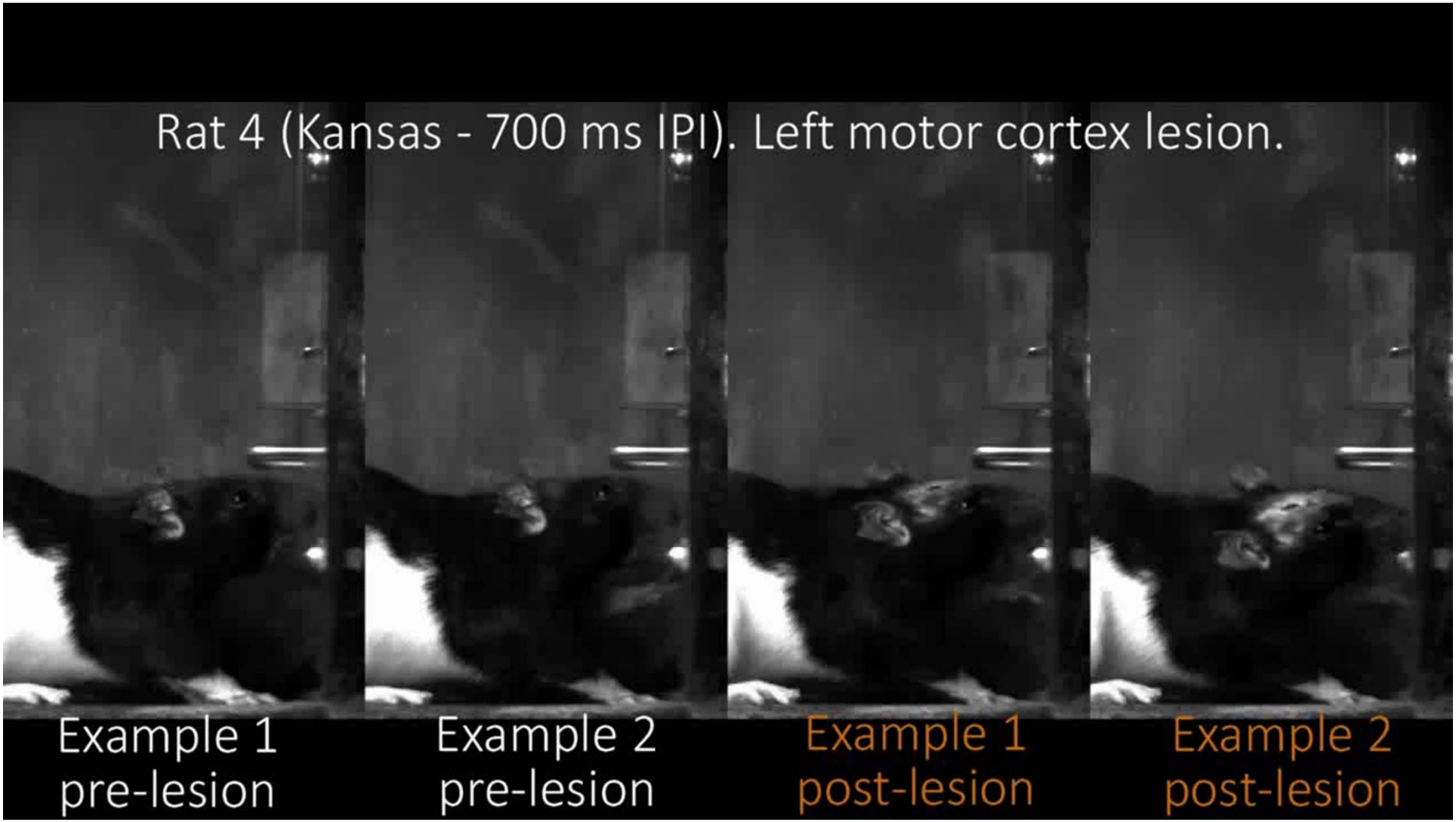
kawai et al, neuron

lesioning M1+M2



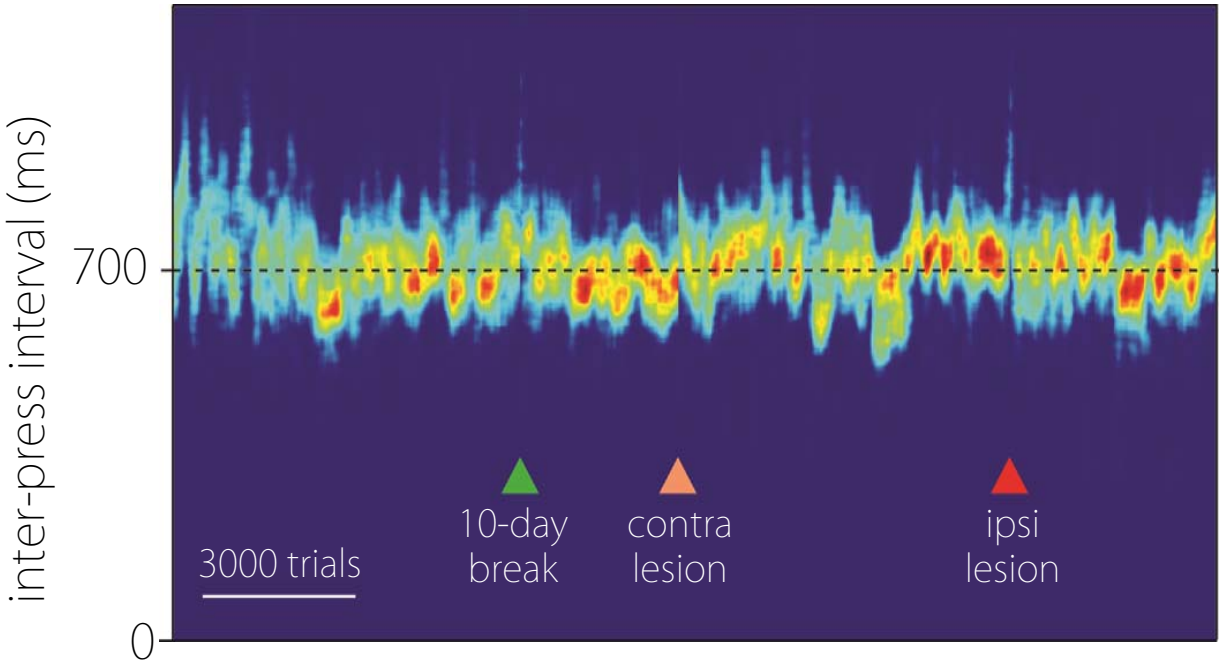
kawai et al, neuron

lesioning M1+M2



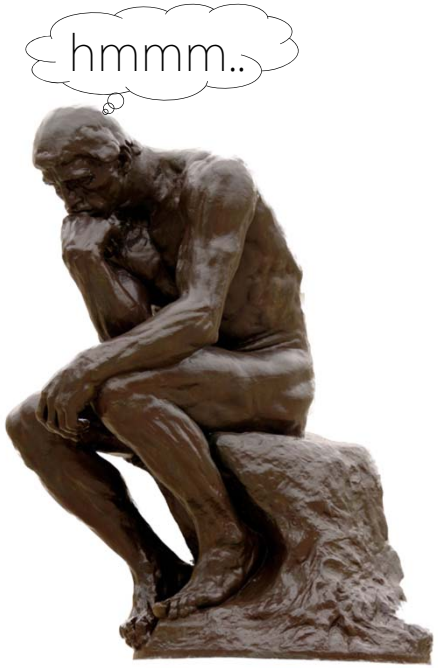
kawai et al, neuron

motor cortex lesions do not interfere with the learned skills



only 1 of 11 rats showed a significant effect of the lesions

kawai et al, neuron



⋯the development of motor skill occurs in the motor cortex?

most motor skill learning paradigms probe dexterity

primate

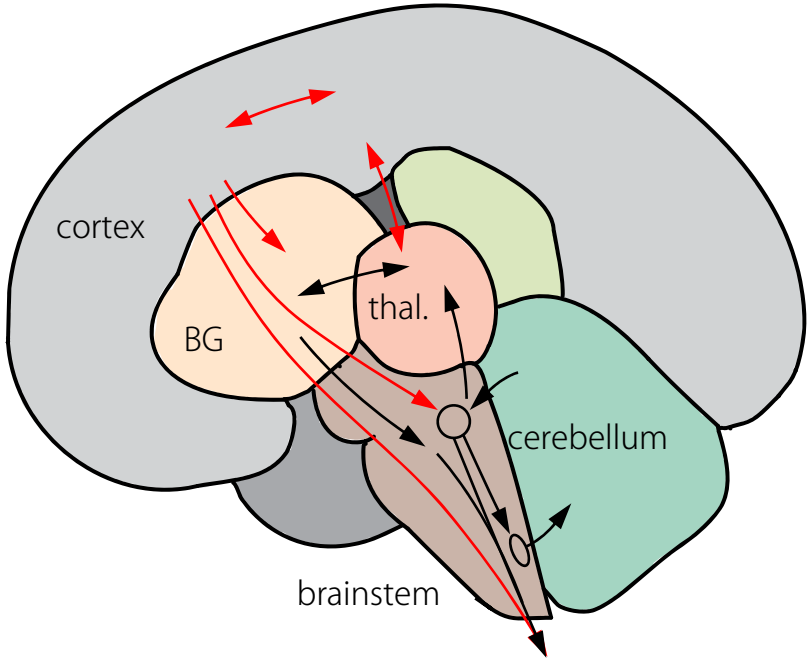
kinoshita et al, 2012, nature

rodent

whishaw (youtube)

motor cortex is essential for executing dexterous skills

not all movements require cortical 'control'



corticospinal system necessary for individuated joint and digit movements (dexterity)

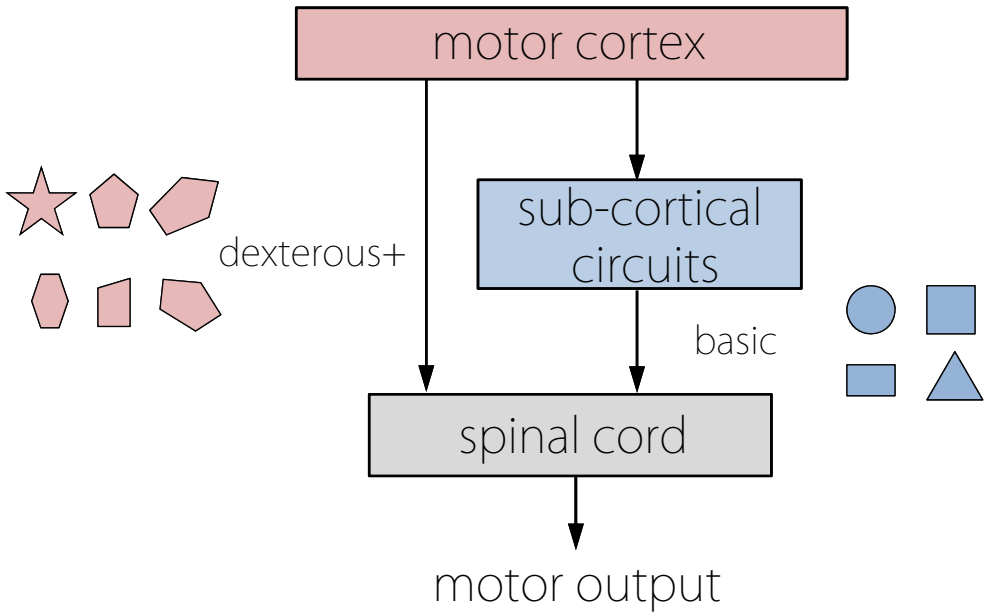
not all movements require cortical 'control'

monkey with complete, bilateral lesion of the corticospinal system

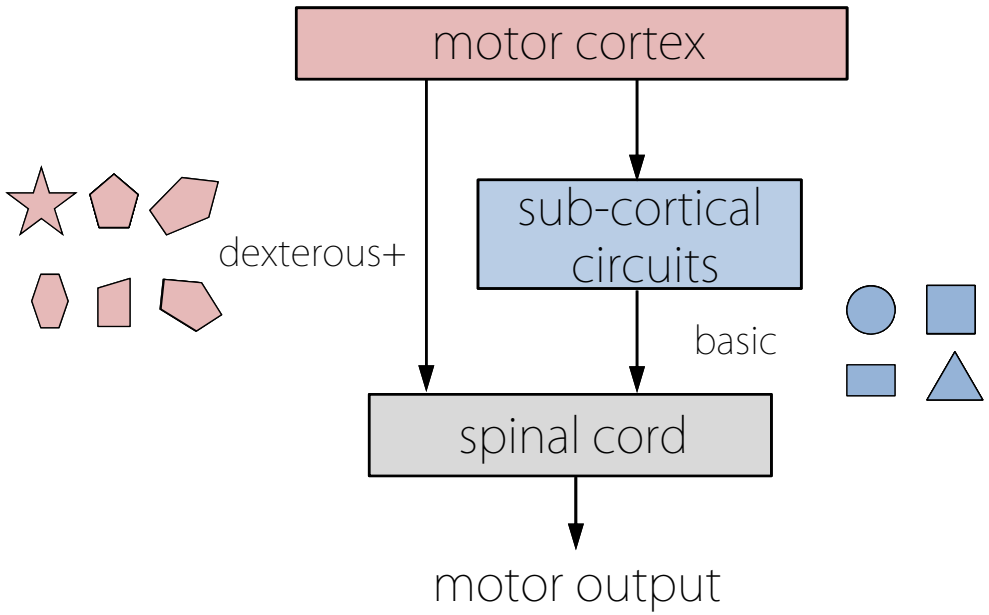
Lawrence and Kuypers, 1968, Brain

while motor cortex is required for dexterity....
....subcortical controllers can generate 'basic' movements

motor skills rely on different control challenges

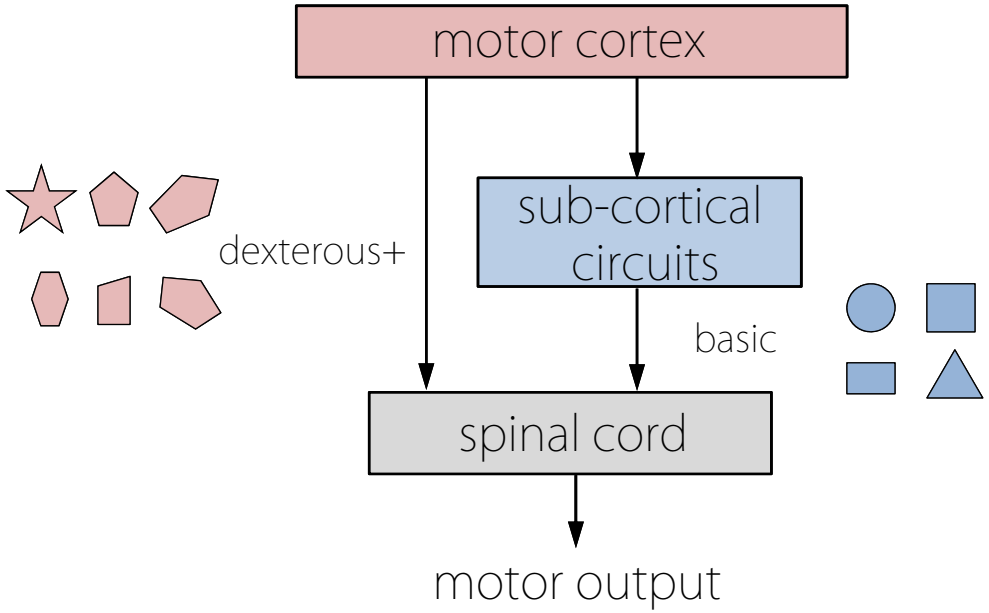


skill learning - acquiring and executing task-specific motor sequences



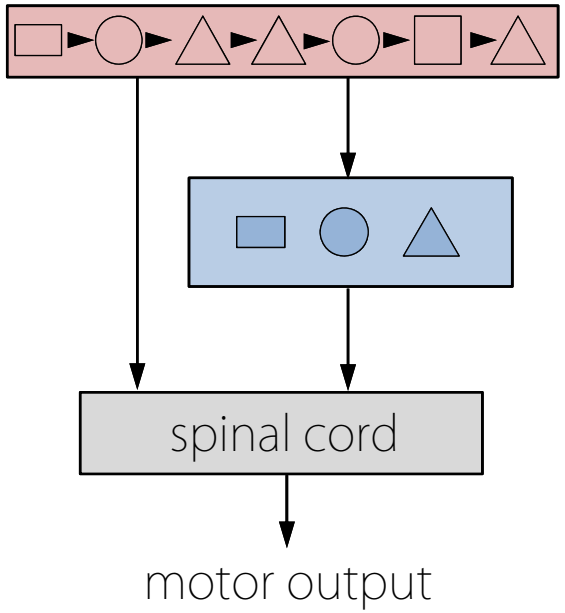
task 1 ► ► ► ► ► ►

skill learning - acquiring and executing task-specific motor sequences



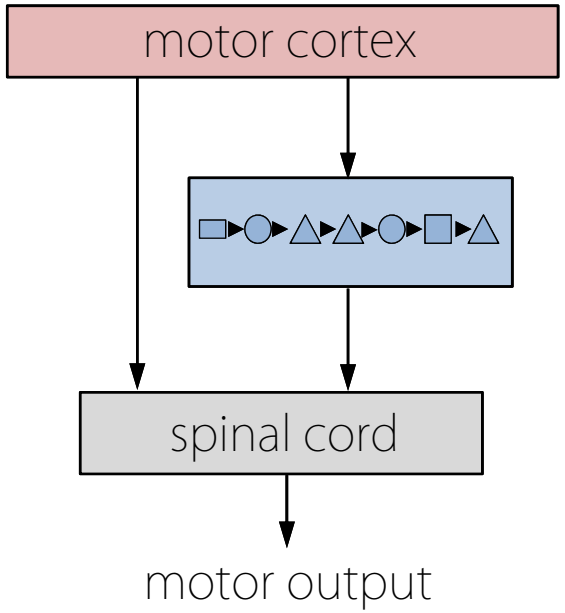
task 2

skill learning - acquiring and executing task-specific motor sequences



task 3

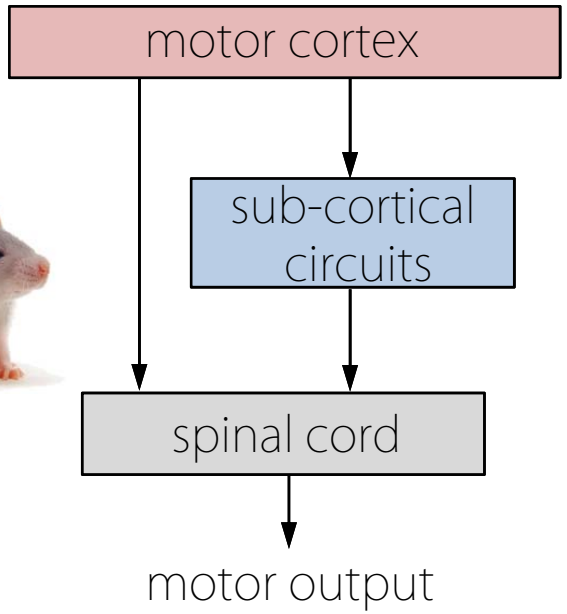
skill learning - acquiring and executing task-specific motor sequences



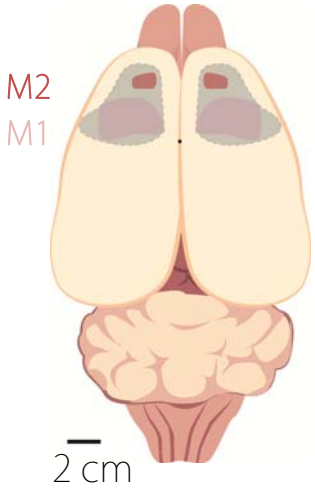
task 3

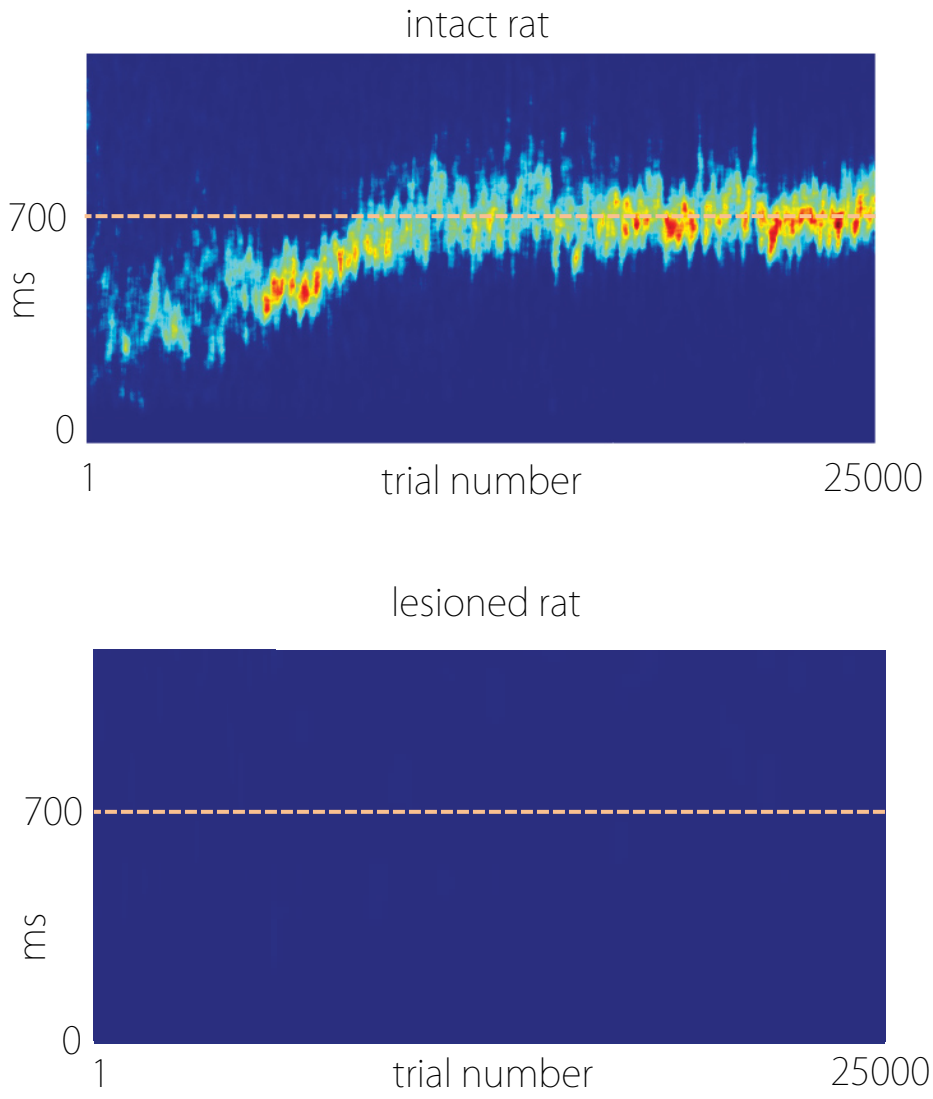
but what does motor cortex do?

does motor cortex contribute to learning?



lesioning motor cortex prior to training

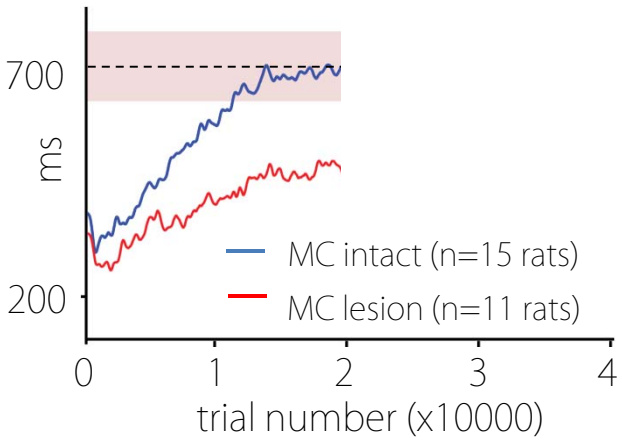




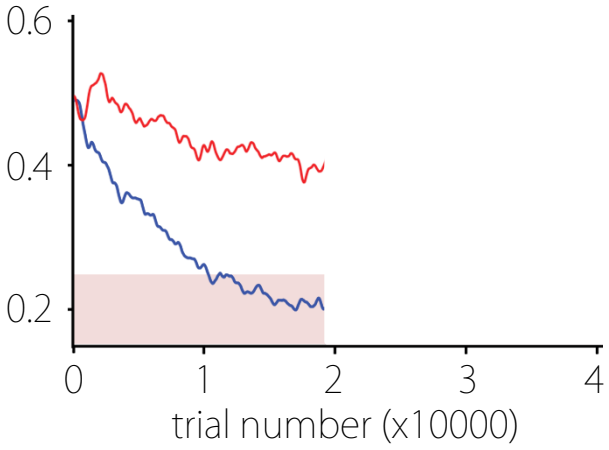
kawai et al., neuron

motor cortex lesioned animals can not learn the task

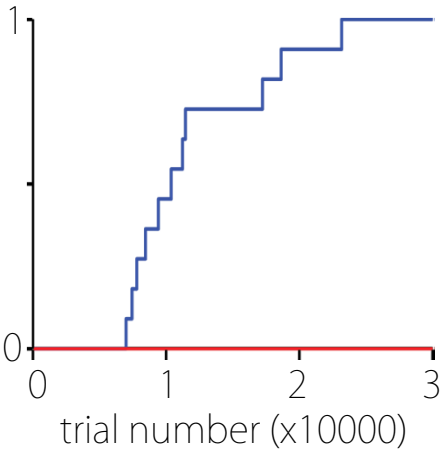
mean inter press interval



IPI variability (CV)



fraction of animals
that 'learned' the task

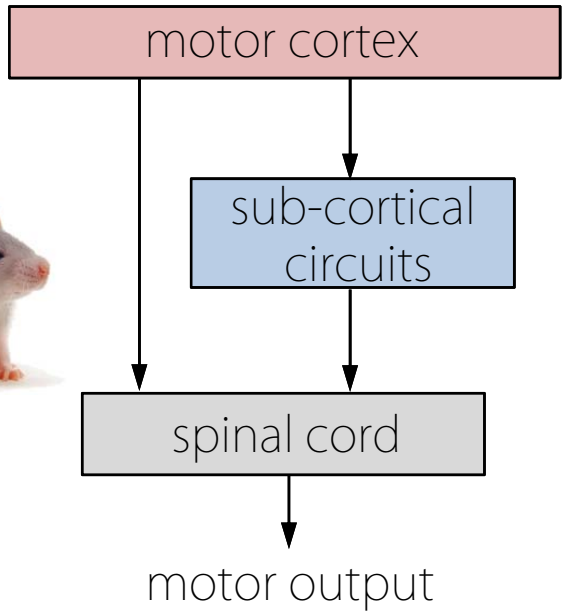


kawai et al (neuron 2015)

asymptotic behavior of a rat trained on the task
for 2 months after bilateral motor cortex lesions

conclusions

- rats can be trained to produce stereotyped complex task-specific motor sequences



conclusions

- rats can be trained to produce stereotyped complex task-specific motor sequences
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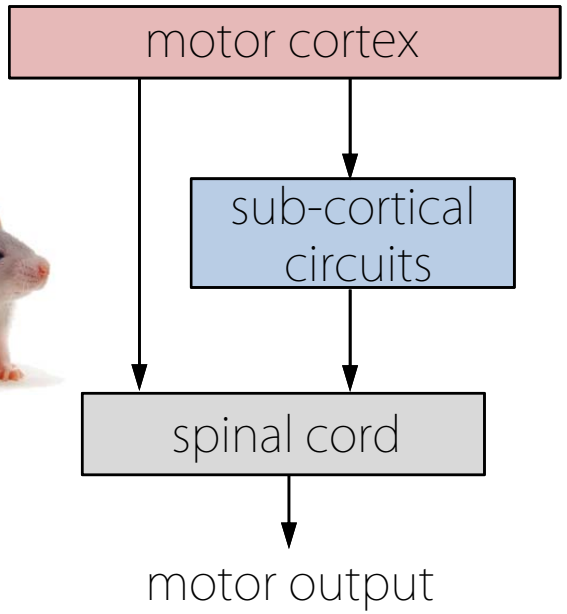

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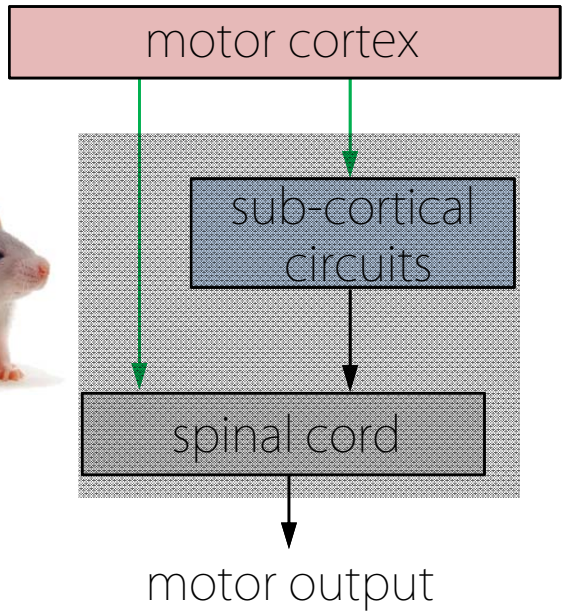


conclusions

- rats can be trained to produce stereotyped complex task-specific motor sequences
- motor cortex is not required for executing the learned skills we train
- motor cortex is required for learning

motor cortex

motor output

reprogrammed microprocessor

serving only *many of the* needs of animal

Gary Neal low-fiving imaginary teammates

be automatic - don't think!


Yips

the centipede's dilemma

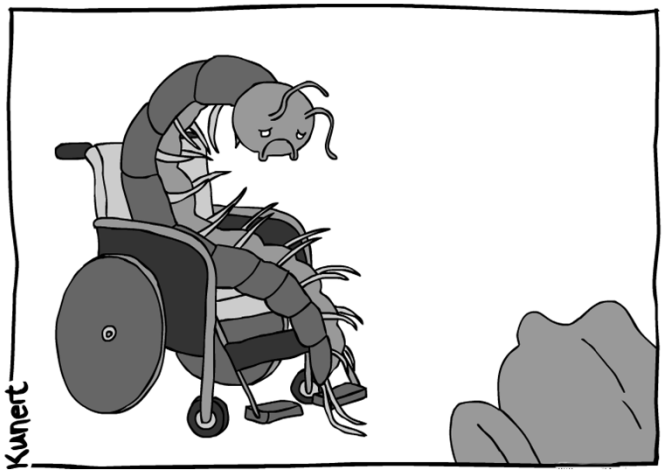
A centipede was happy – quite!

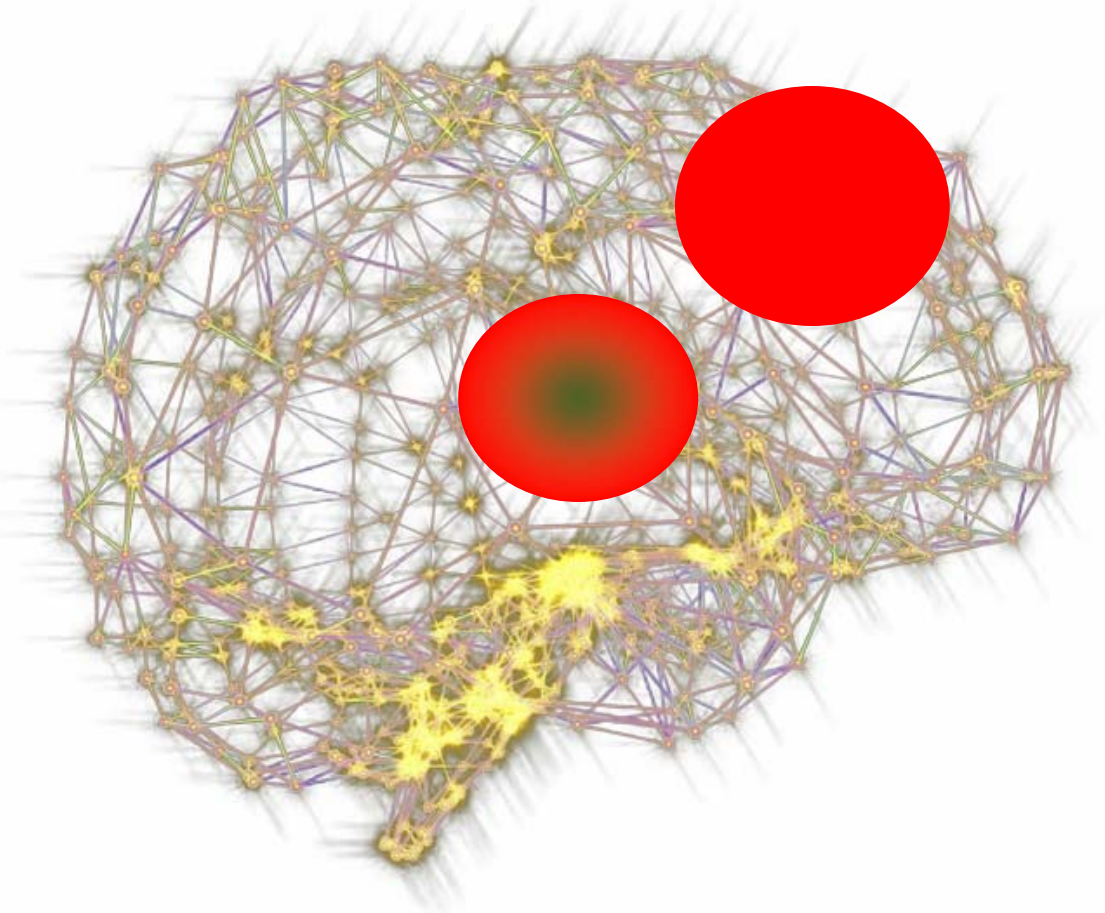
Until a toad in fun said, "Pray, which leg moves after which?"

This raised her doubts to such a pitch, she fell exhausted in the ditch.

Not knowing how to run.

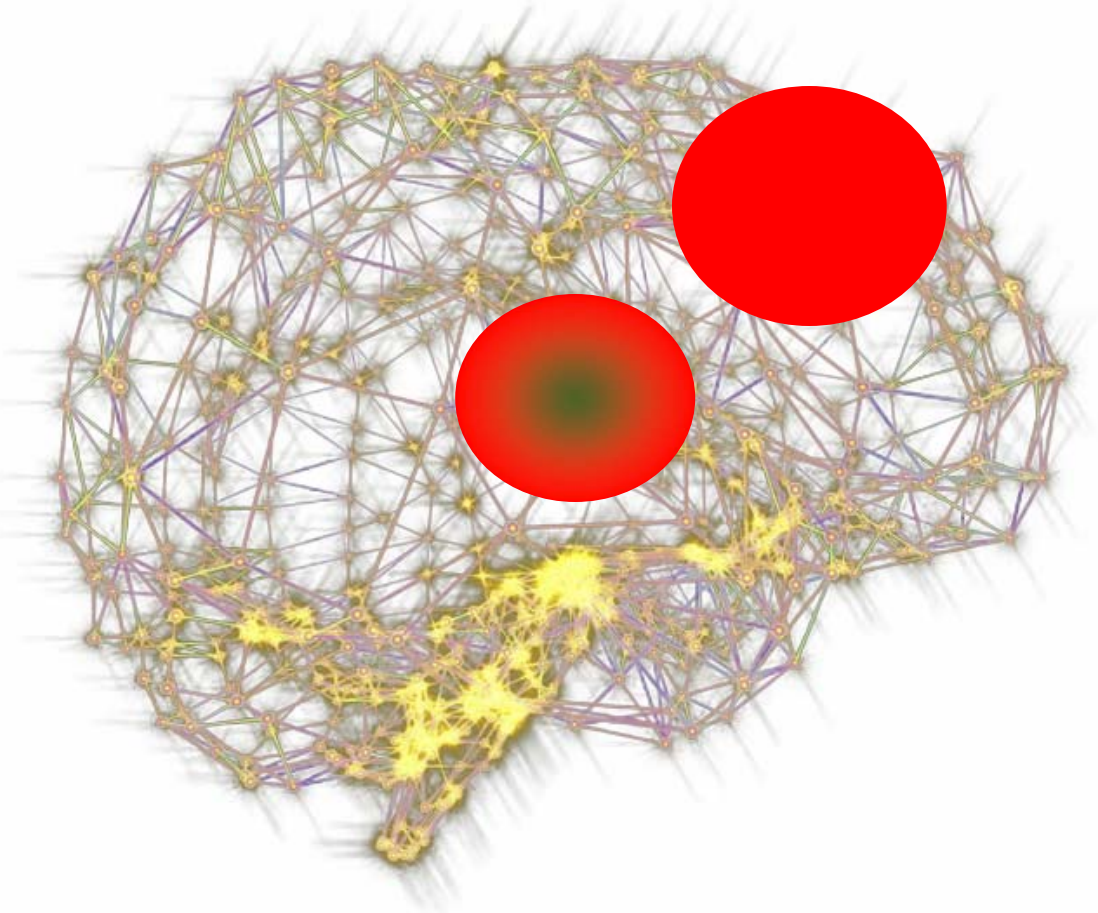
Katherine Craster in *Pinafore Poems,* 1871





control of over-trained movements

your thoughts

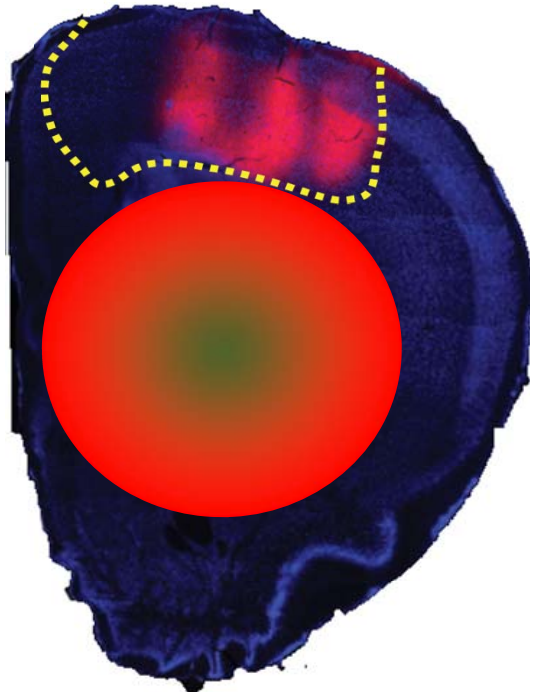


control of over-trained movements

motor cortex

perturbing motor cortical activity

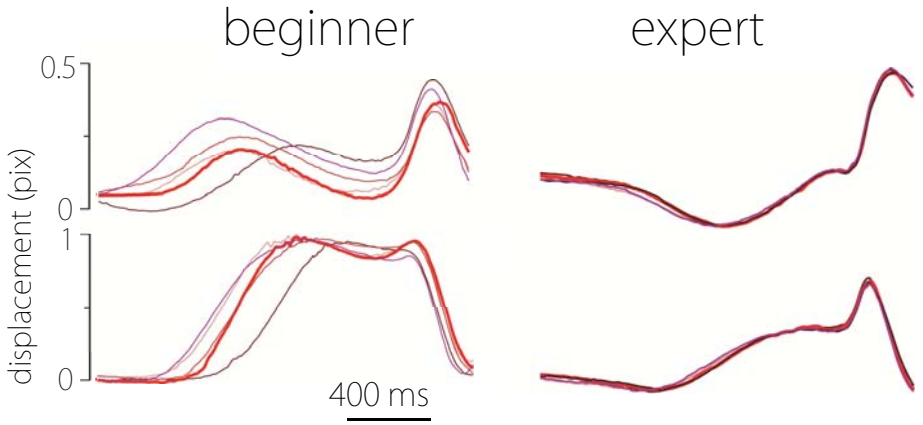
light-sensitive ion channel

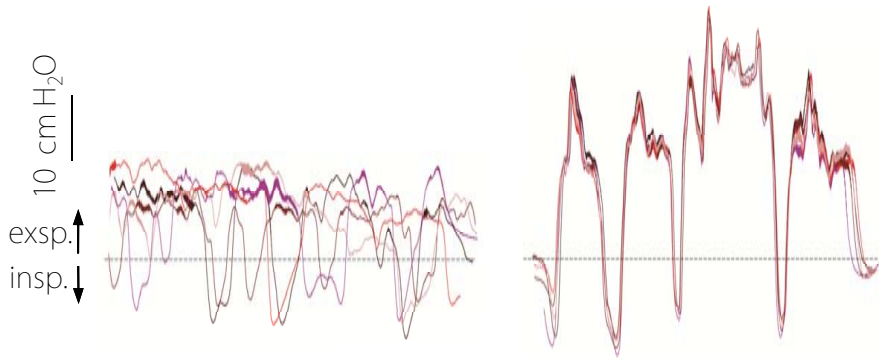


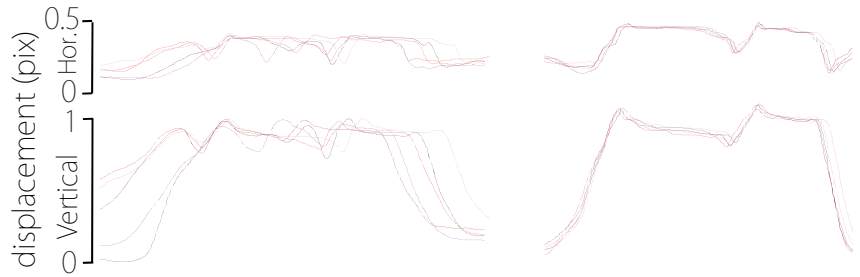
control of over-trained movements

motor cortex

understanding complex motor sequence learning







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Risa Kawai (Biophysics)

Rajesh Poddar (Neuro)

Ashesh Dhawale

Raymond Ko (OEB)

Tim Markman

Steffen Wolff

the lab
past and present

funding

mcknight endowment fund for neuroscience
klingenstein fund NIH HSFP
sloan foundation LSRF