



Stimulation for somatosensory restoration

Jeneva Cronin

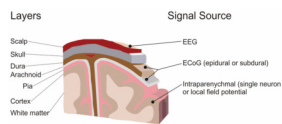
+ Brain-computer interfaces

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Record brain
signals

Computer
DECODES

Control signal



Leuthardt et al., *Neurosurg Focus*, 2009

External Feedback
(visual, audio...)

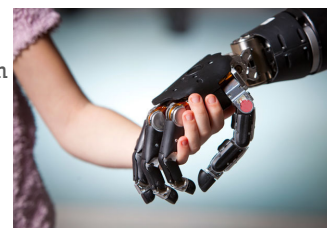


Johns Hopkins Applied Physics Laboratory

+ The need

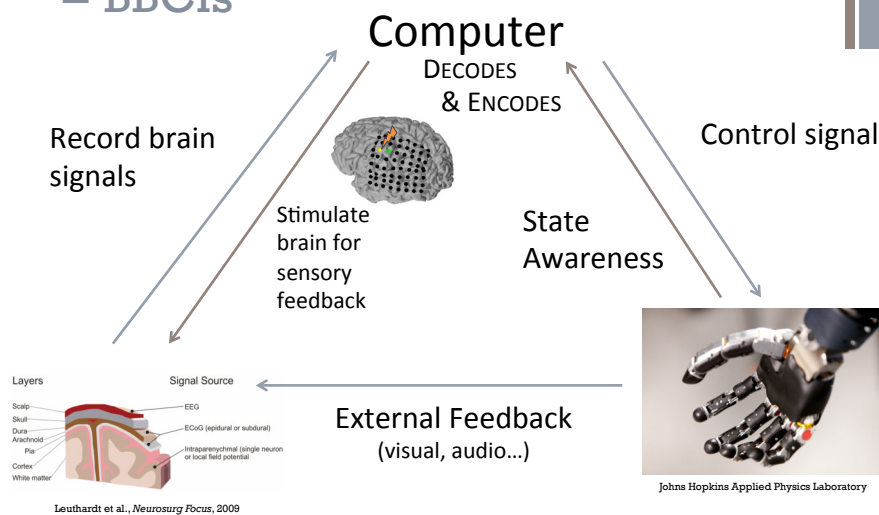
- Loss of limb:
 - 2 million Americans
- Paralyzed to some degree:
 - 5.5 million Americans
- Priorities:
 - Quadriplegics: gaining arm and hand function
 - Paraplegics: regaining sexual function
 - Bladder and bowel function

Anderson et al., 2014



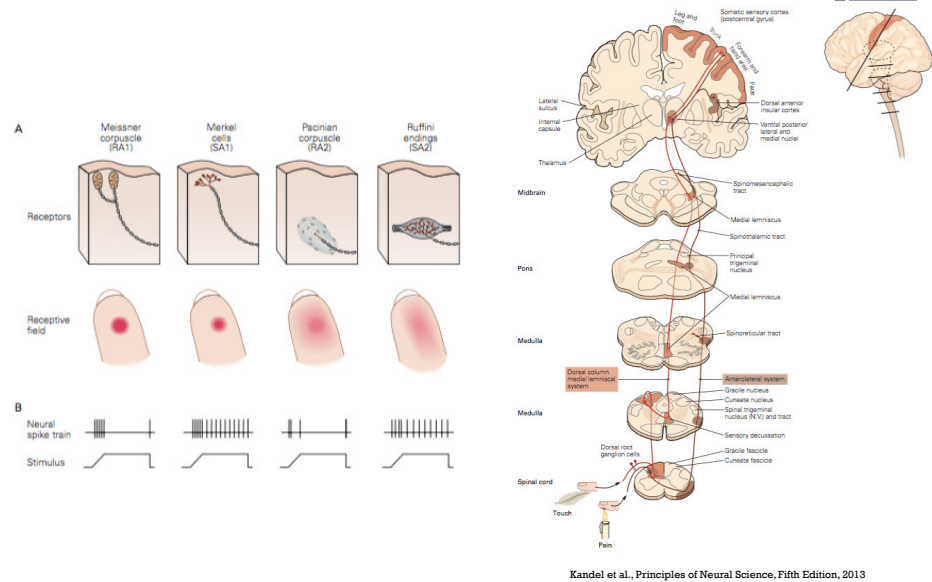
Johns Hopkins Applied Physics Laboratory
<http://www.jhuapl.edu/newscenter/stories/st120824.asp>
<http://www.jhuapl.edu/prosthetics/>

+ BCIs with somatosensory feedback = BBCIs

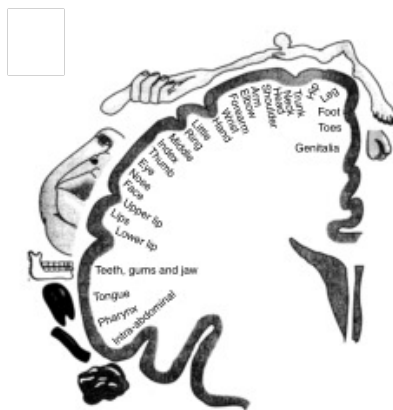


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+ Sensory Pathway

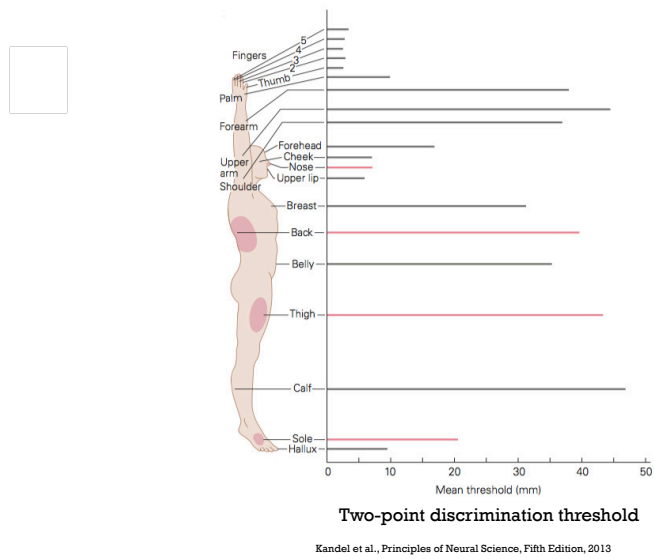


+ Tactile Perception



Haggard et al., Current Biology, 2003

+ Tactile Perception

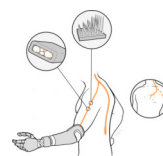


+

Sensory Feedback in BCIs

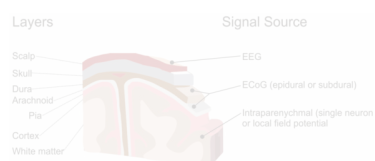
+ Sensory Feedback Approaches

- Peripheral approaches:
 - Targeted muscle reinnervation (TMR)
 - Peripheral nerve stimulation



Modified from Saal and Benabisa, *Neuropsychologia*, 2018

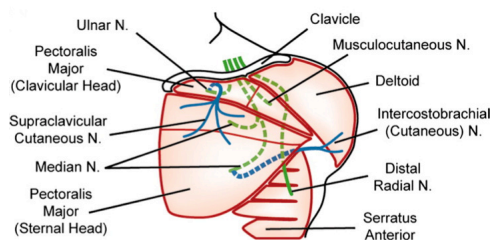
- Cortical approaches:
 - Intracortical microstimulation (ICMS)
 - Direct cortical stimulation (DCS)
 - Micro-ECoG
 - Macro-ECoG



Leuthardt et al., *Neurosurg Focus*, 2009

+ Targeted Muscle Reinnervation (TMR)

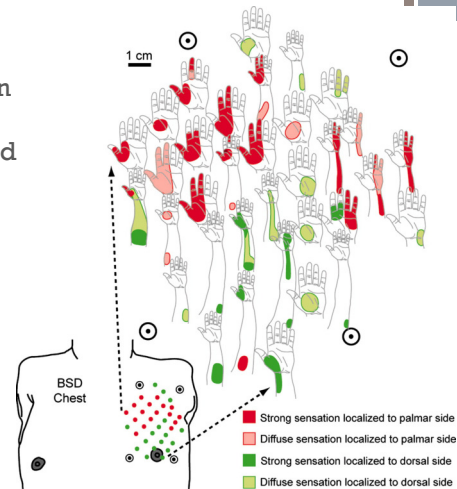
- Uses residual nerve endings from the amputated arm
- When patient tries to move their amputated arm, their chest muscles respond and electrodes can pick up this signal, send it to a computer, and control a prosthetic



Kuiken et al., *PNAS*, 2007

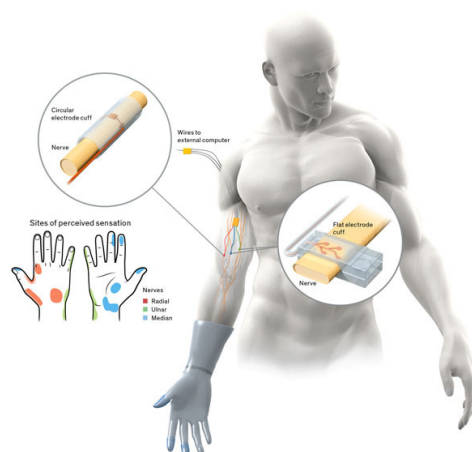
+ Targeted Muscle Reinnervation (TMR)

- Touching the chest muscles can also cause sensation to be localized to the amputated hand



Kuiken et al., *PNAS*, 2007

+ Peripheral nerve interfaces

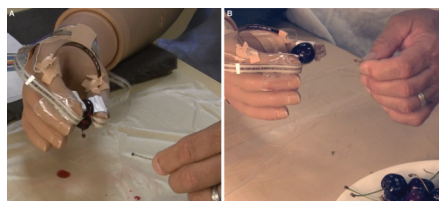


Tyler, *IEEE Spectrum*, 2016, "Creating a Prosthetic Hand That Can Feel"
2-D Hand Illustration: James Provost; 3-D Illustration: Bryan Christie Design

+ Peripheral nerve interfaces

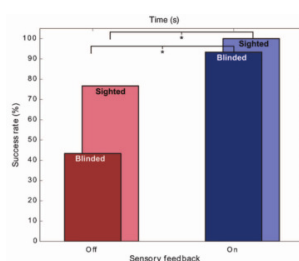
Sensory feedback improves performance

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Feedback off

Feedback on

Tan et al., *Sci. Transl. Med.*, 2014

+ Peripheral nerve interfaces

Sensory feedback improves performance

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Principal Investigator: Dustin J. Tyler, PhD

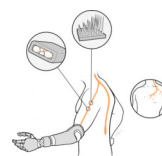
Louis Stokes Cleveland VAMC
and
Case Western Reserve University

Schiefer et al., *J. Neural Eng.*, 2016

+ Sensory Feedback Approaches

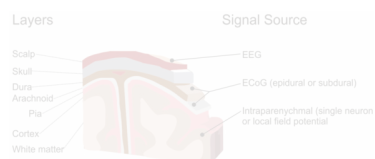
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- Peripheral approaches:
 - Targeted muscle reinnervation (TMR)
 - Peripheral nerve stimulation



Modified from Saal and Benabisa, *Neuropsychologia*, 2018

- Cortical approaches:
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 - Macro-ECoG



Leuthardt et al., *Neurosurg Focus*, 2009

+ Sensory Feedback Approaches

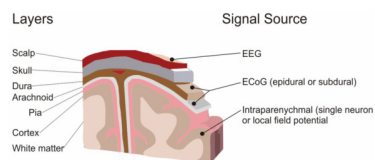
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Modified from Saal and Benabisa, *Neuropsychologia*, 2018

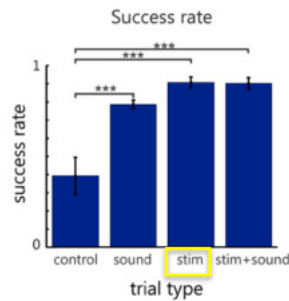
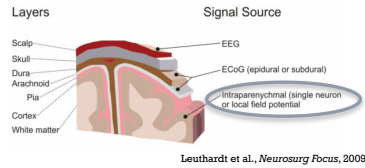
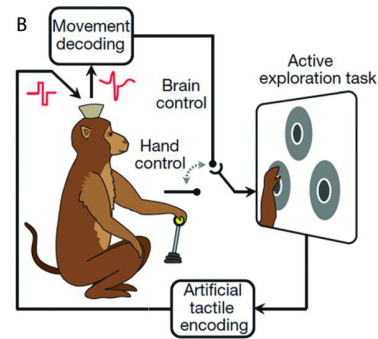
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Leuthardt et al., *Neurosurg Focus*, 2009

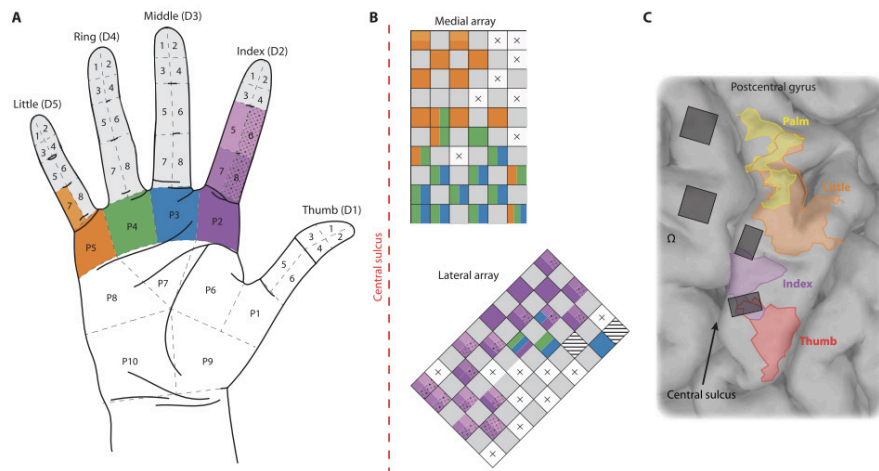
+ Sensory feedback through ICMS

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Klaes et al., *J Neural Eng.*, 2014

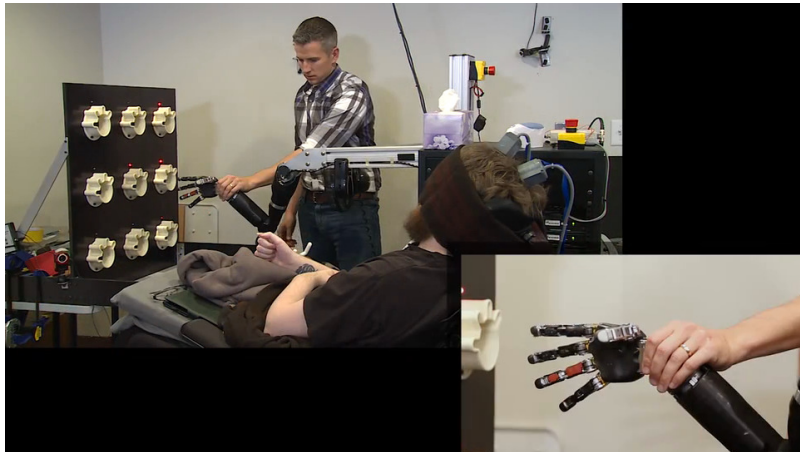
+ Sensory feedback through ICMS in a human

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+ Sensory feedback through ICMS in a human

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Folshwer et al., *Science Translational Medicine*, 2016

+ Intracortical electrodes for movement

Collinger et al., *The Lancet*, 2013
From: <http://motorlab.neurobio.pitt.edu/multimedia.php>

BrainGate Pilot Clinical Trial
Drinking From a Bottle Using a Robotic Arm
Participant S3
Trial Day 1959 / 12 April 2011
Hochberg et al., 2012

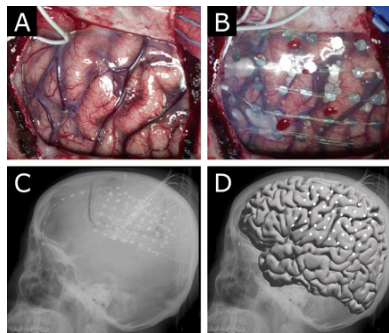
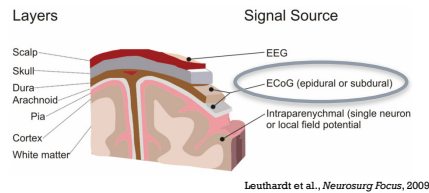


Caution: Investigational Device. Limited by Federal Law to Investigational Use.

Hochberg et al., *Nature*, 2012
From: <http://www.nature.com/nature/journal/v488/n7398/full/nature11076.html#supplementary-information>

+ Electrocorticography (ECoG)

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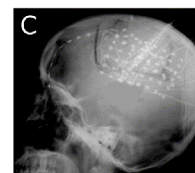
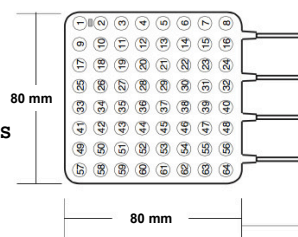


+ Micro-ECoG & Macro-ECoG

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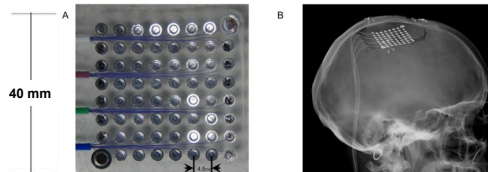
Macro-ECoG:

- 10 mm spacing
- 4 mm diameter electrodes
- 2.3 mm exposed surface

Miller et al., *J. Neurosci.*, 2007

Micro-ECoG:

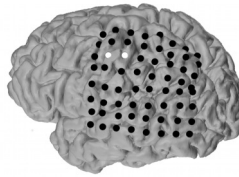
- 1.5-4.5 mm spacing
- 2 mm diameter electrodes (SI DCS study)

Hirerath et al., *PLOS ONE*, 2017

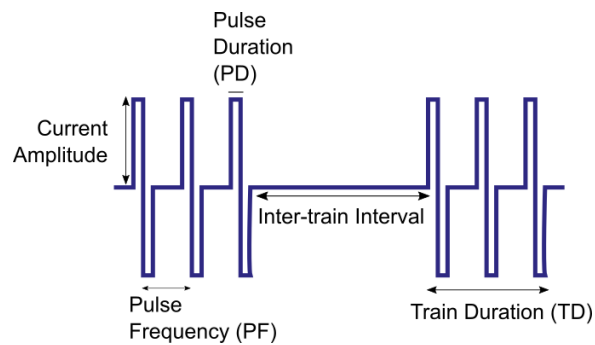
+ Stimulation parameters

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■ Bipolar



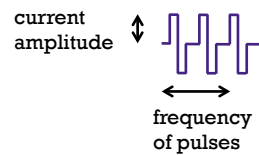
■ Biphasic



+ Sensory feedback through Macro-ECoG

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Stimulation waveform:



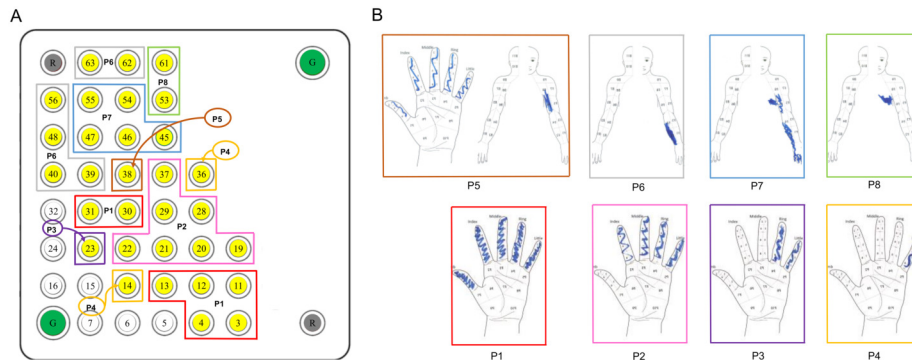
Frequency 1 (Hz)	Reported relative intensity	Frequency 2 (Hz)	Comments
75	= correct	75	'close'
100	< incorrect	100	
100	< incorrect	100	
75	< correct	100	
100	> correct	75	
75	> correct	65	
65	< correct	100	
50	= correct	50	
100	>> correct	50	
75	= correct	75	

Amplitude 1 (mA)	Reported relative intensity	Amplitude 2 (mA)	Comments
3.0	< correct	3.8	Initially said '=' but changed to '>'
3.8	> correct	3.4	
3.2	= incorrect	2.8	
3.4	> correct	2.8	
3.4	> incorrect	3.4	
3.4	= correct	3.4	

Johnson et al., J Neural Eng., 2013

+ Sensory feedback through Micro-ECoG

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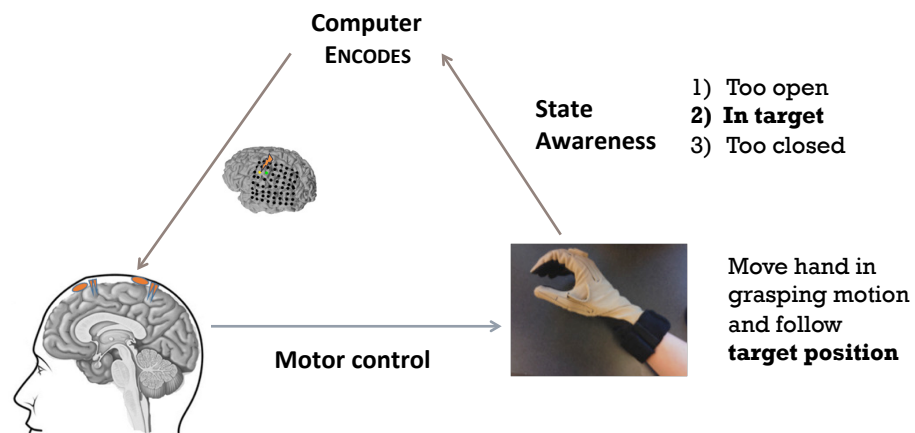


Hirremath et al., PLOS ONE, 2017

+ Aperture Task

Can subjects use DCS as **feedback in a task**?

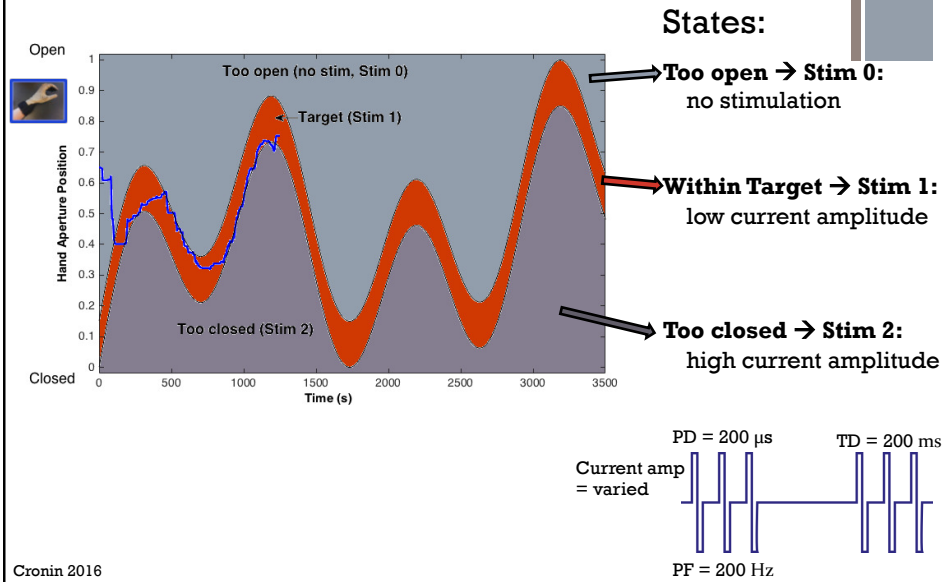
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Cronin et al., IEEE Transactions on Haptics, 2016

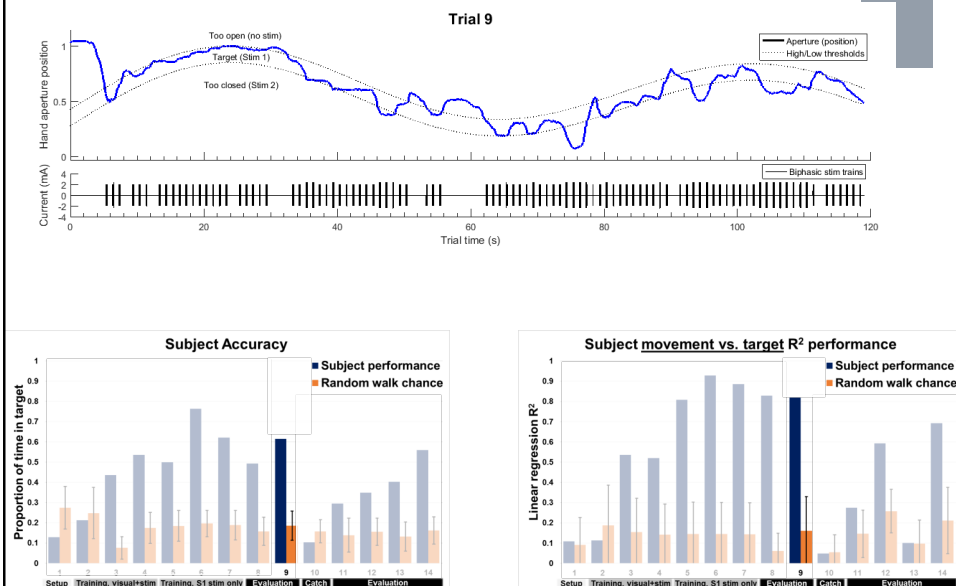
+ Aperture Task: Methods

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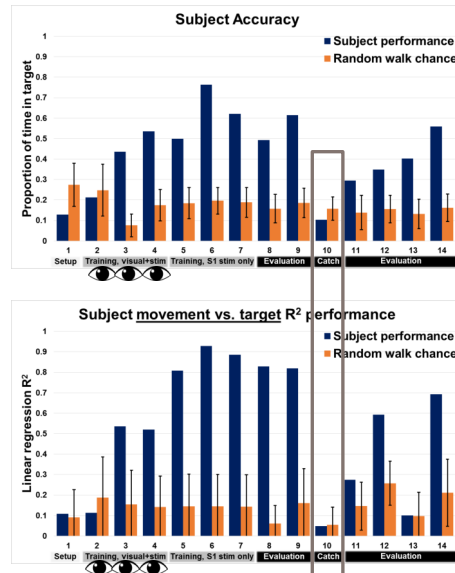
+ Aperture Task: Results

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+ Aperture Task: Results

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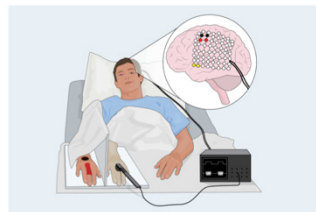
Catch trial:
Subjects received the same current amplitude waveform during the whole trial (independent of the state)

Performance drops!

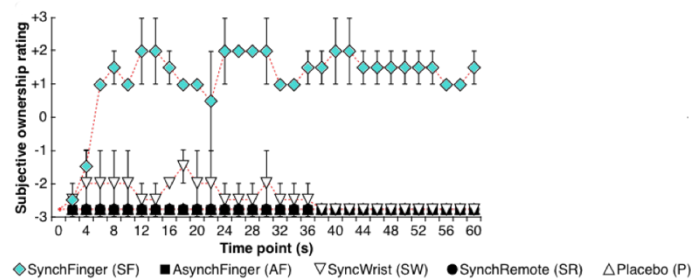
Cronin 2016

+ Rubber Hand Illusion

Can cortical stimulation elicit a sense of ownership?



It feels as if the rubber hand were my own hand

Collins et al., *PNAS*, 2017

+ Is somatosensory stimulation a *useful* feedback signal

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- How natural does the DCS percept **feel** and where is the percept **localized**?
- Can subjects use DCS as **feedback in a task**?
- How often can users **perceive DCS** and with what **parameters**?
 - What if users aren't paying close **attention**?
- What range of DCS trains can subjects **discriminate** between?
 - How many percepts can we encode with DCS?
- **Can we improve its usefulness?**