The University of Texas at Austin
Environmental Science Institute

Hot Science - Cool Talk # 122

Robots Controlled By Your Mind

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November 15, 2019

Wearable Robots (Powered Exoskeletons)

Robots Controlled By Your Mind

- Why should we develop Brain-Machine Interface (BMI) systems?
- How do BMI systems work?
- Examples of robots that can be controlled by your mind
- Novel applications of BMI
- Q & A

Brain-Machine Systems Have Multiple Names

- Brain-Computer Interfaces, Neural Interfaces, Brain-Body Interface, NeuroRobotics, Neural-Machine Interface, Cybernetics..
- The Food and Drug Administration, a federal agency that regulates medical devices, has a working definition

  "Neuroprostheses that interface with the central or peripheral nervous system to restore lost motor or sensory capabilities"
- Can be Cortical and/or Peripheral, Invasive and/or Noninvasive

Source: J Neural Eng. 2016

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Why Create Brain-Machine Interfaces?

Goals:

- Improve the quality of life and independence of people with movement disabilities due to brain injury, neurological disease, or limb amputation.

- Understand how the brain encodes body movements in the patterns of brain activity

- Design direct communication channels between the brain and robots, machines, computers, digital avatars, wheelchairs,…, etc.

Neurological injury and amputation are disabling conditions that cause activities of daily living to become difficult or impossible.

- **Paralysis: 6 million people**
- **Limb loss: 2 million people**

Secondary Complications Due to Lack of Mobility

- Spasticity (certain muscles are continuously contracted)
- Contractures (muscles become shorter and inelastic)
- Urinary tract infections
- Impaired bowel movements
- Reduced heart and circulatory function
- Pressure sores and other skin conditions
- …

>> Reduced Quality of Life and Loss of Independence

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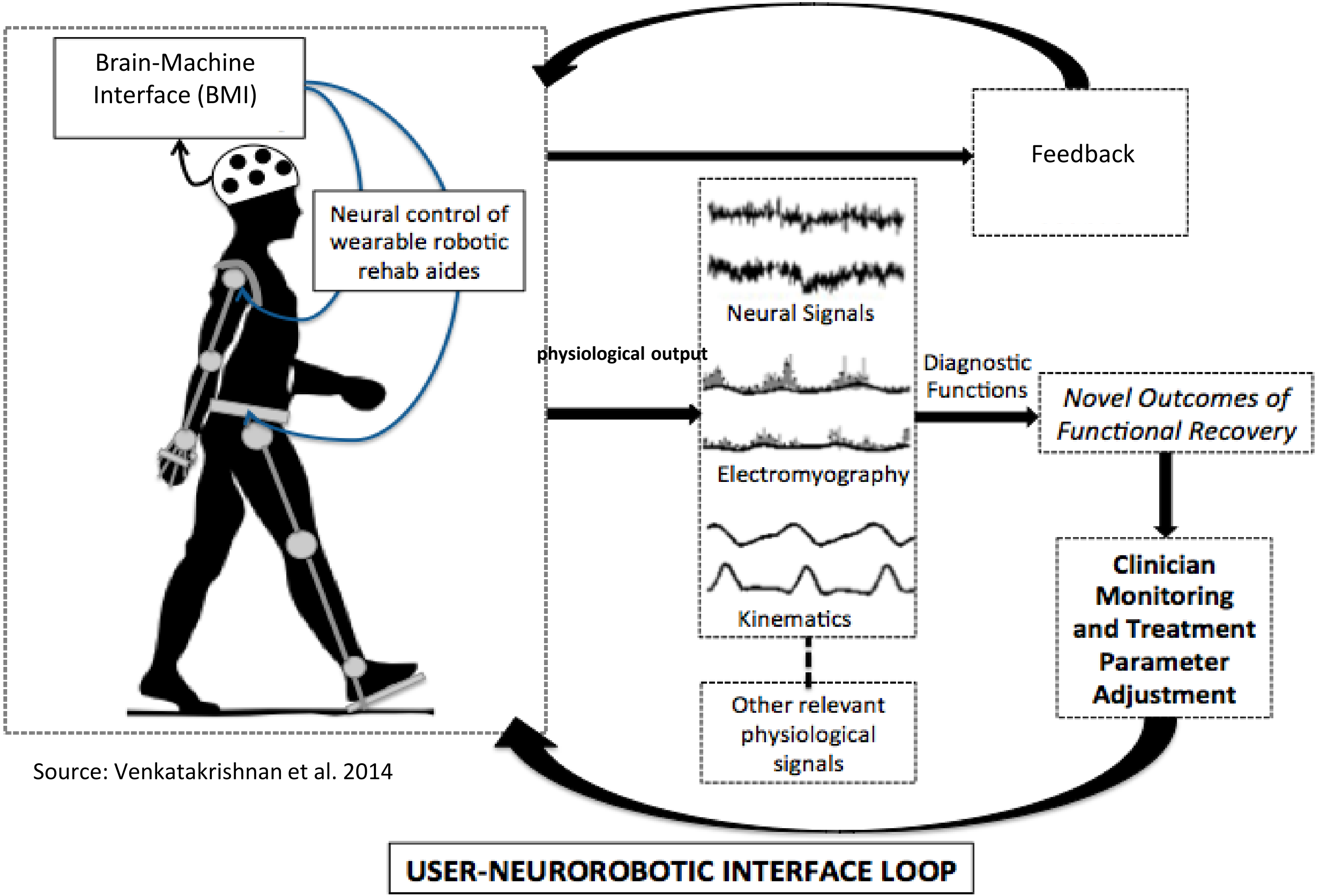
How BMIs work



Source: Venkatakrishnan et al. 2014

Brain-Robot Systems Have Multiple Functions

- **Diagnostic:** Sensors in brain-robot system can provide information about type, extent, speed and amount of body movement and associated brain activity.

- **Rehabilitation**: System can promote neuroplasticity, which is essential to relearn body movements.

- **Assistance**: Brain-Robot systems can assist with activities of daily living. Advanced systems can provide ‘assist-as-needed’ support.

How Do BMI Systems Work?


Credit: Science News

Surface EEG electrodes

– Non-invasive
– Whole head
– Can listen to the neural 'symphony'

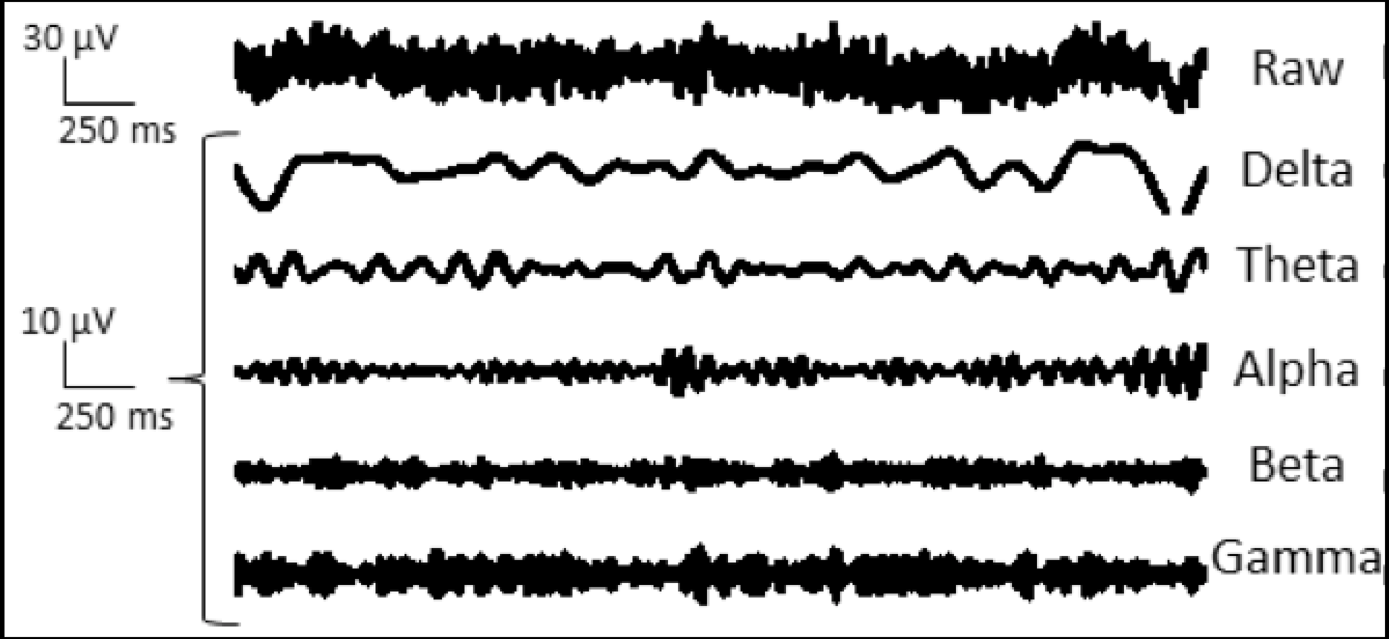
Penetrating electrodes:

– Invasive, placed above or inside your brain (surgery needed)
– Limited access to a few brain areas

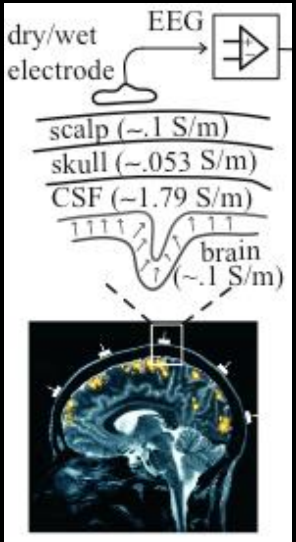
Dummy BrainGate Interface
Credit: Paul Wick/Wikimedia Commons

Electroencephalography (EEG)

- EEG records brain waves of different frequencies and amplitudes across large areas of your brain



'Closed-Loop' Brain-Machine Interface



Credit: Science News

Neural Interface :

Recording electrodes

(EEG brain cap)

Neural Decoder:

Translates brain activity into motor commands

Robot

Desired Action?
(e.g., grasp bottle)

Feedback

Sensory, error & reward signals

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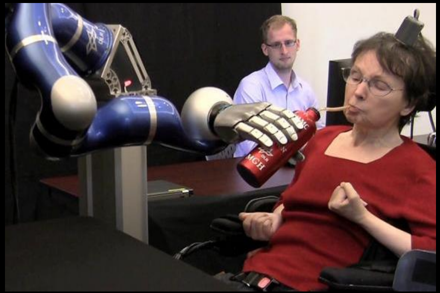
Examples of Robots That Can Be Controlled By Your Mind

Prosthetic Upper Limbs (for amputees and SCI survivors)

Univ of Houston

from brain waves
(Surface EEG)



Brown University

from brain signals
(Implanted cortical)

DEKA arm
Dept. of Defense

from muscle activity +
other inputs

Modular Prosthetic Limb
Johns Hopkins Univ

from reinnervated
muscle activity

Decoding Grasping from Brain Waves (EEG)

Grasping Components

PC1: Grasp opening/closing
PC2: Hand spreading
PC3: Thumb rotation

N: # of EEG sensors
L: # of lags

$$PC_i[t] = \beta_{0i} + \sum_{n=1}^{N} \sum_{k=0}^{L} \beta_{nki} EEG_n[t-k]$$

time index

lag index

grasp component prediction

constant

weight

sensor

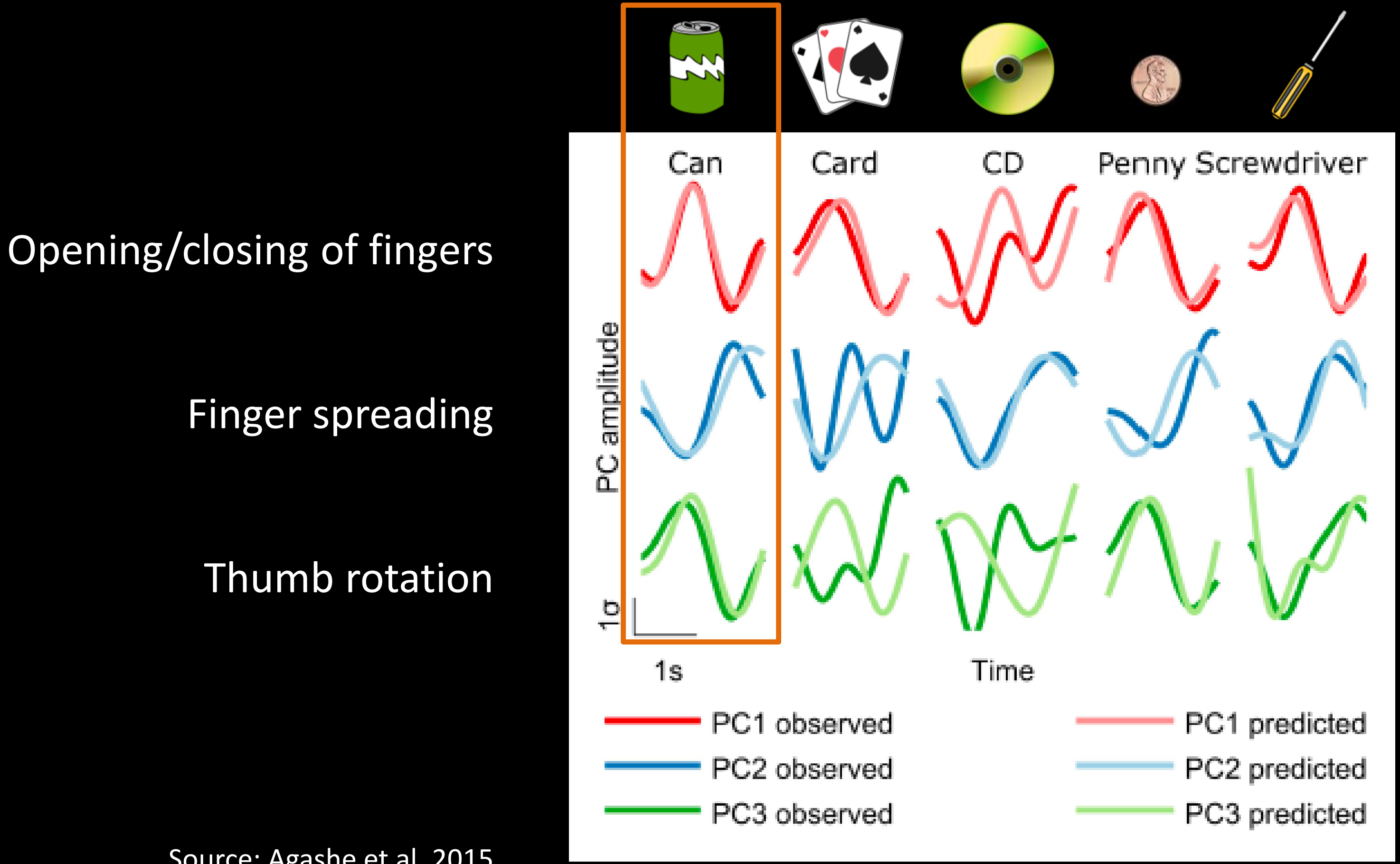
brain wave activity

Source: Agashe et al. 2015

Recipe for Predicting Movement Intent From EEG

- Movement intent can be extracted from the fluctuations in the amplitude of slow brain waves in the delta band EEG.
- Use delta waves across whole head sensors (space) and recent past (time).
- Teach computer to find neural patterns in the EEG brain waves that predict certain motor intent.

Decoding Hand Grasping Kinematics From Brain Activity (EEG)



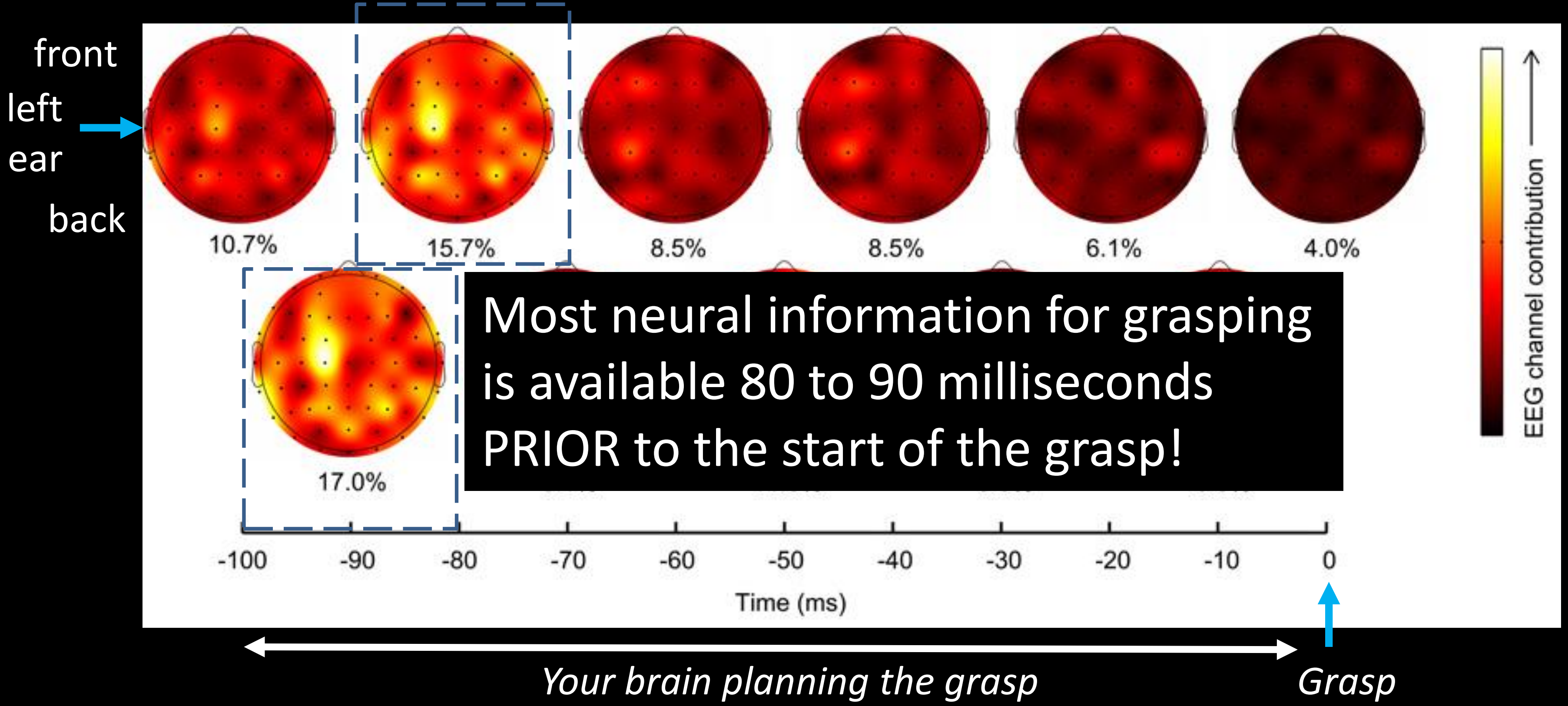
Source: Agashe et al. 2015

Closed Loop, Real-Time, Hand Neuroprosthesis

Harsha
Agashe

Source: Agashe et al. 2015

Neural Head Maps for Decoding Grasp Opening/Closing (PC1)



Examples of Robots that can be Controlled by Your Mind

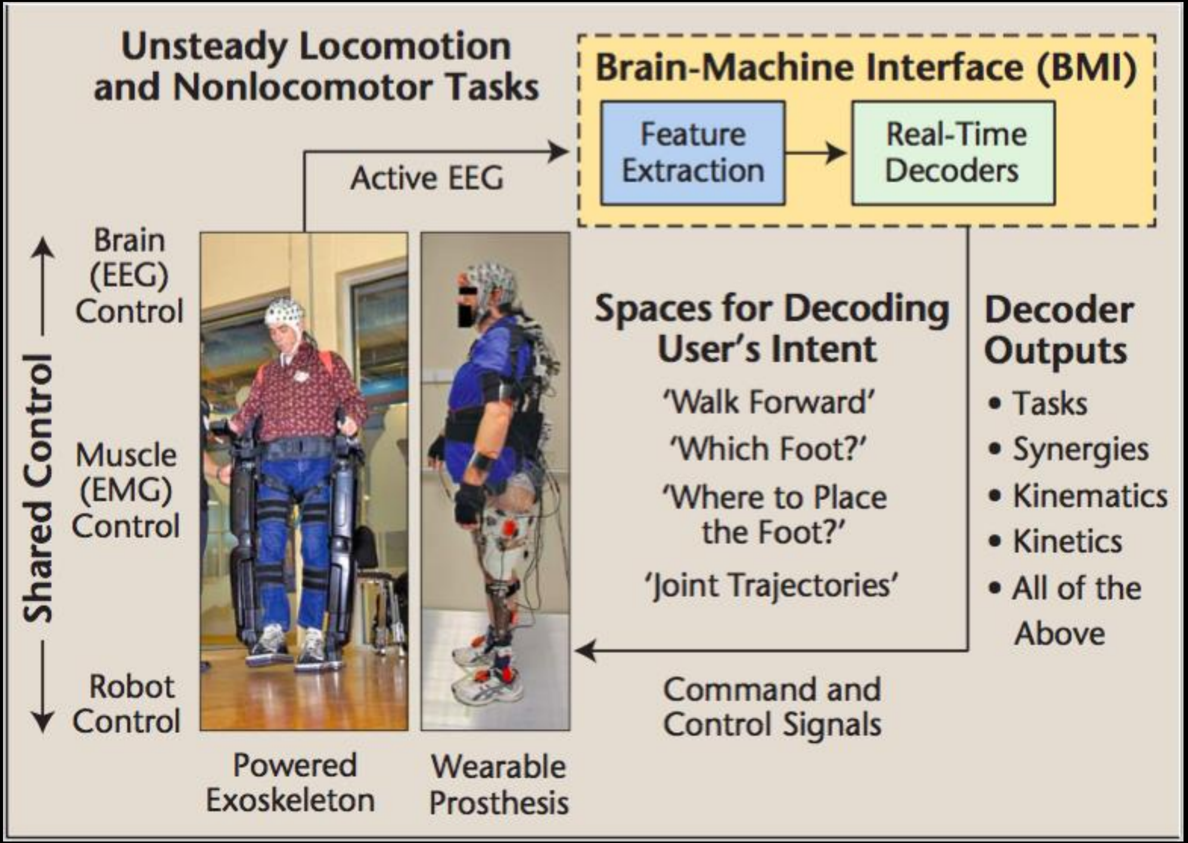
Powered Exoskeletons for walking (for people with paralysis)

NeuroRex

NASA X1

CSIC/ Technaid H2

NeuroRobotics for Restoration of Walking



Source: Contreras-Vidal et al. 2015

Mobile Brain-Body Imaging (MoBI) Technology

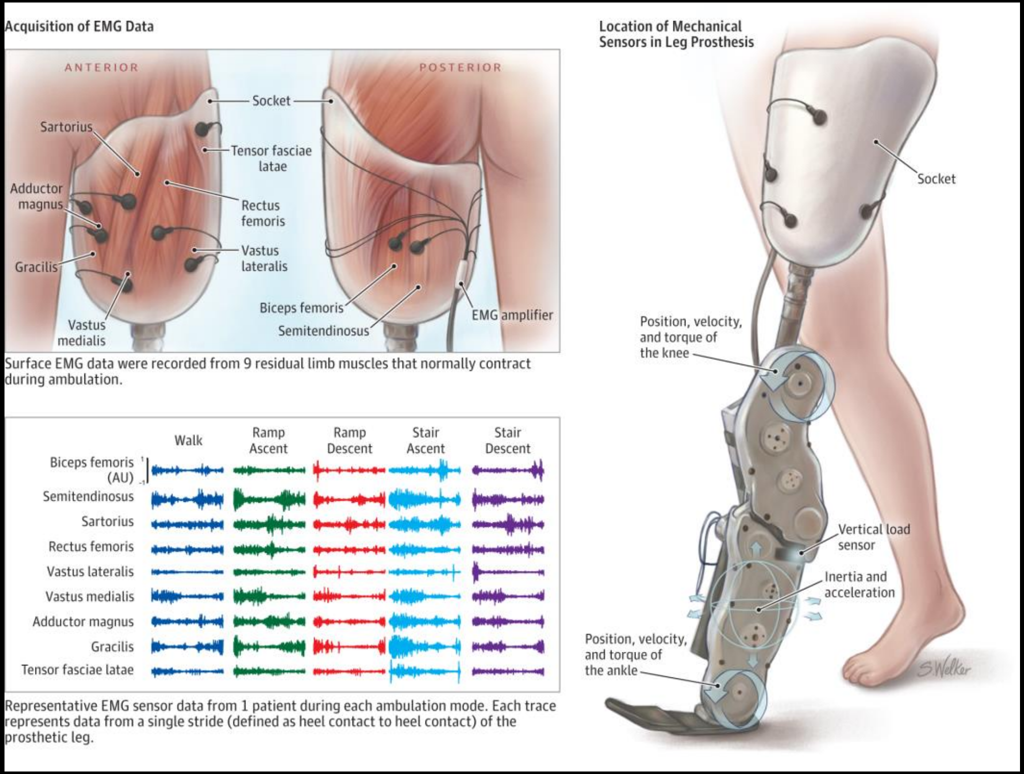
Justin Brantley

Source Brantley et al. 2018

Myoelectric (EMG) Protheses

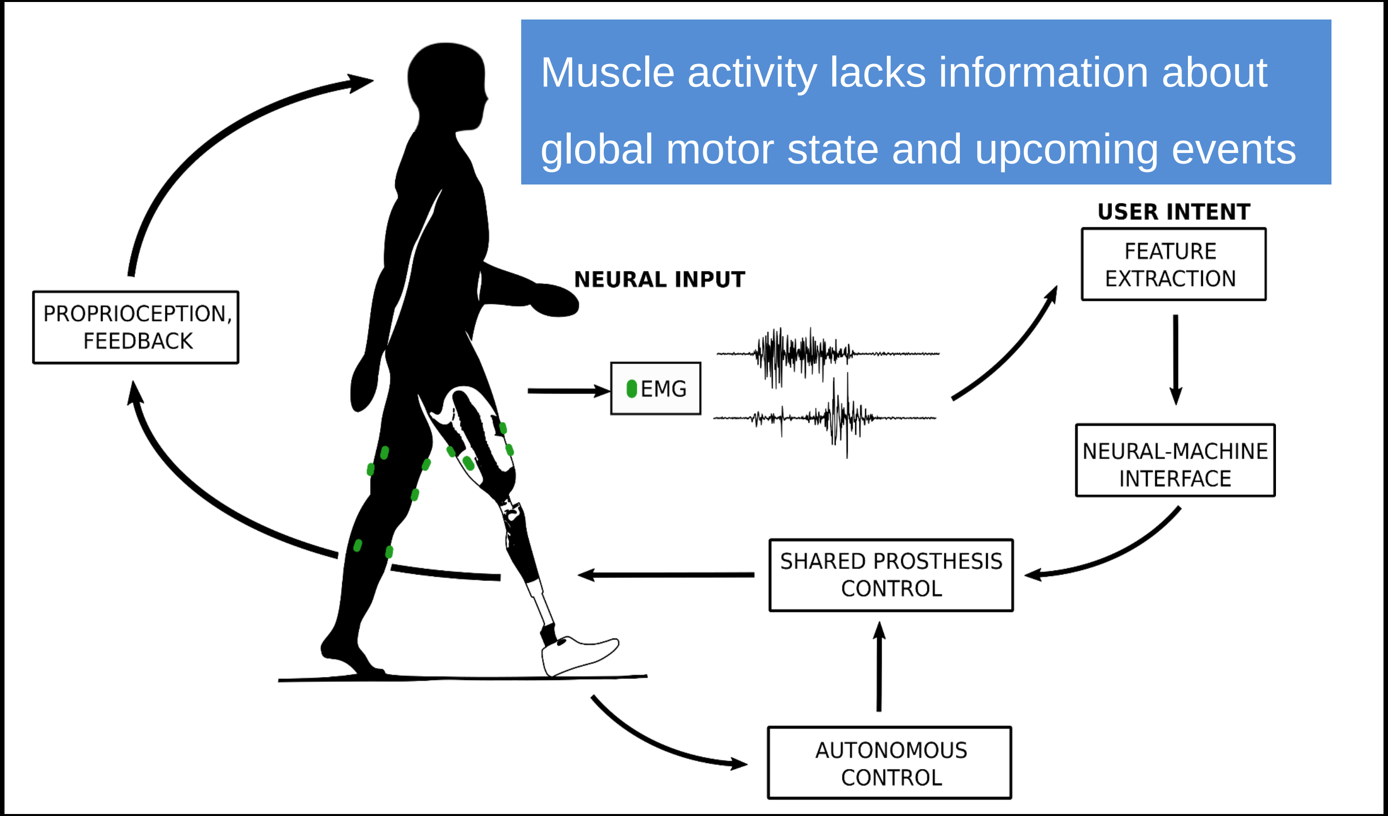
- Muscle activity can be used to detect user's intent during walking
- EMG has relatively high quality (SNR) and high spatial localization
- Effective continuous controller during locomotion
- Limited to local motor control

Muscle activity lacks information about global motor state and upcoming events

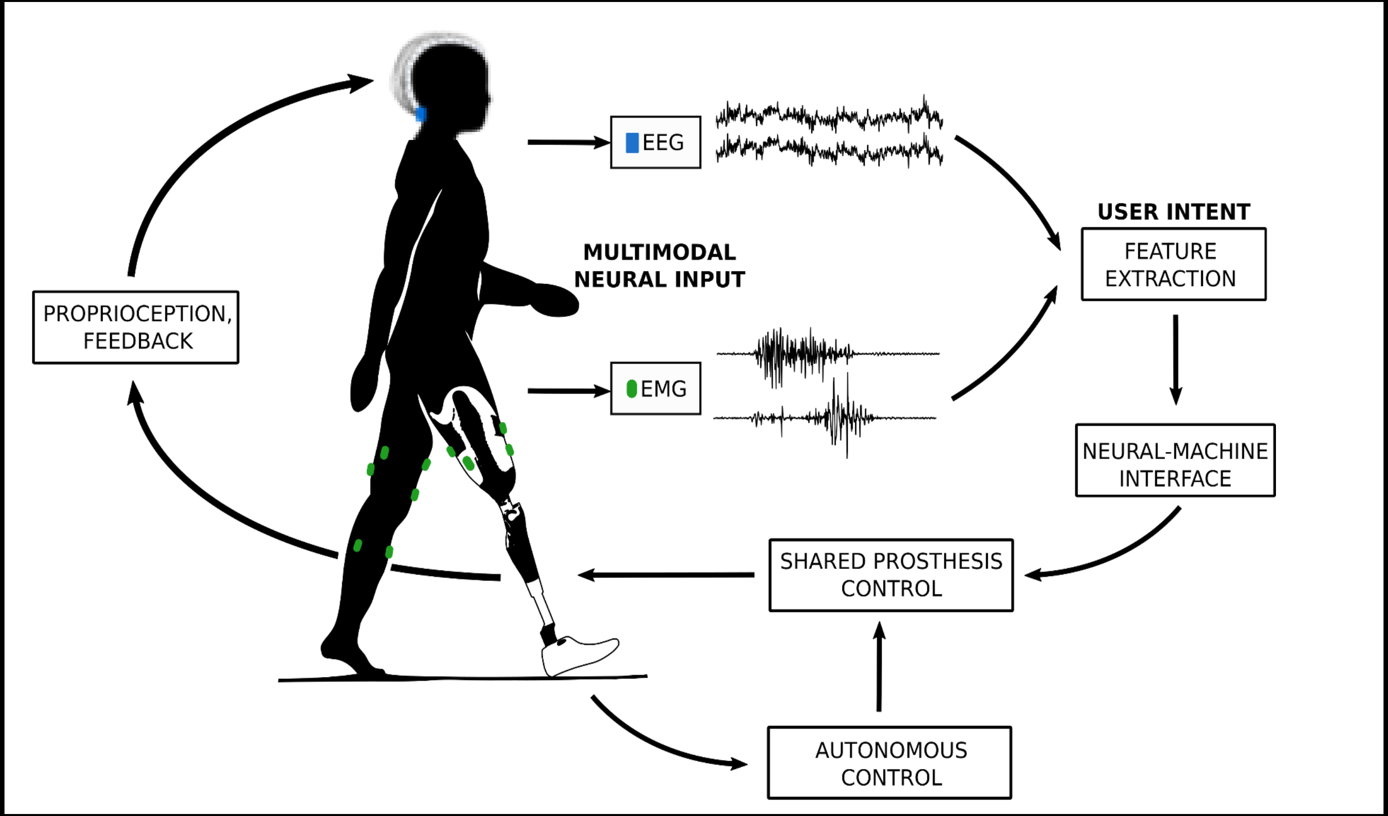


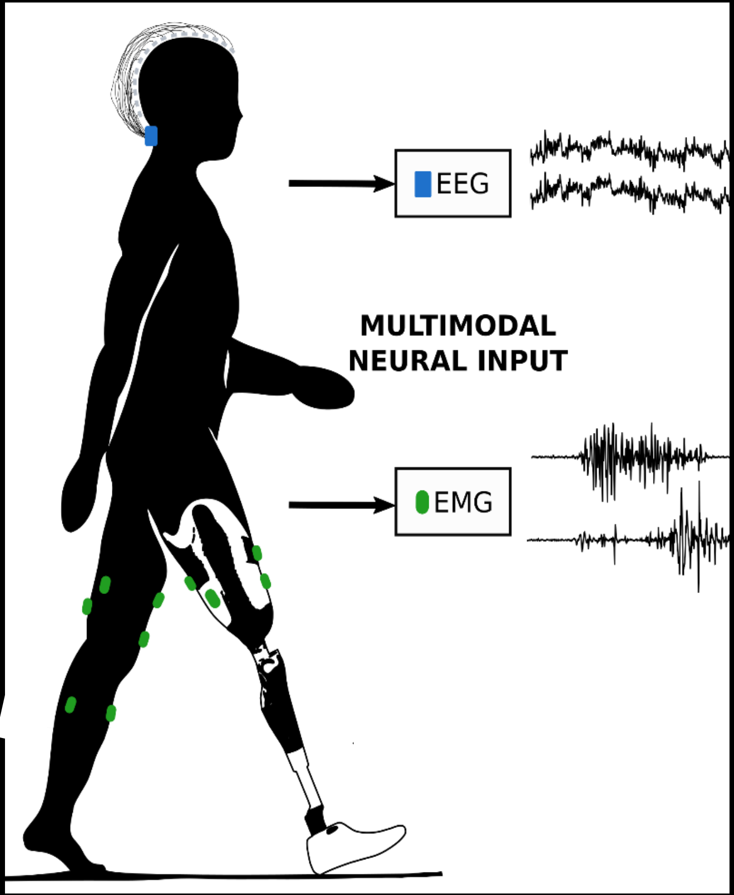
Source: Hargrove et al. 2015

Peripheral (Myoelectric) Neural-Machine Interface



Multi-modal Neural-Machine Interface





- Lower SNR
- Low spatial resolution but high spatial coverage
- High temporal resolution
- Measures brain activity directly
- Represents activity of entire brain

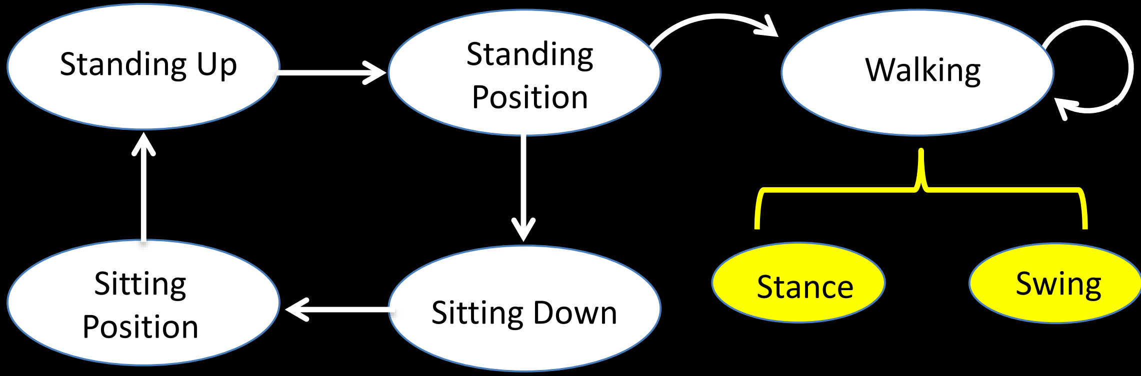
- Higher SNR
- Represents activity of individual muscles
- Limited muscle after amputation

EEG-EMG
Neural-Machine Interface

- Representation of movement at cortical, muscular, and joint levels
- Reduced influence of artifacts from neural signal fusion
- Improved neural decoding performance during continuous movements
- Advanced notice of state transitions

Neural Classification of Gait States from EEG

NeuroRex



Walking — EEG-identified states (intended action)

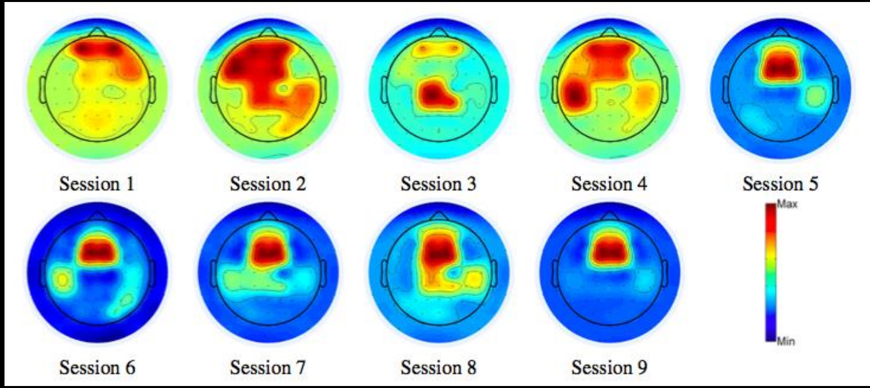
Stance — Robot's pre-programmed movements

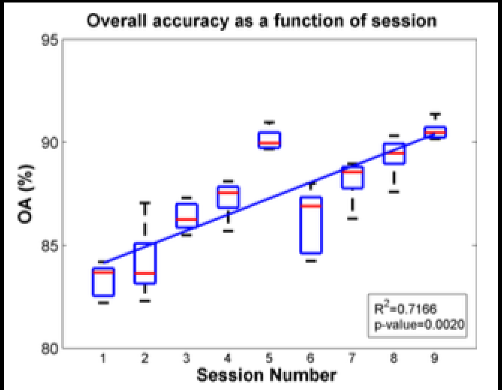
Example of Brain-Robot Interface

Collaborator:
Robert Grossman, M.D.

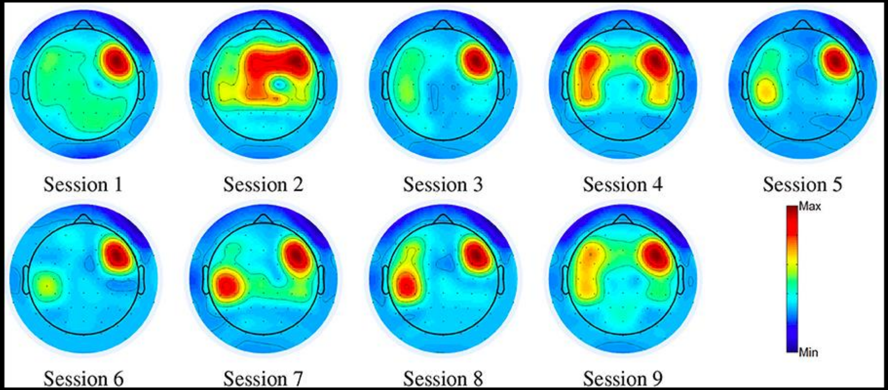
HOUSTON Methodist LEADING MEDICINE

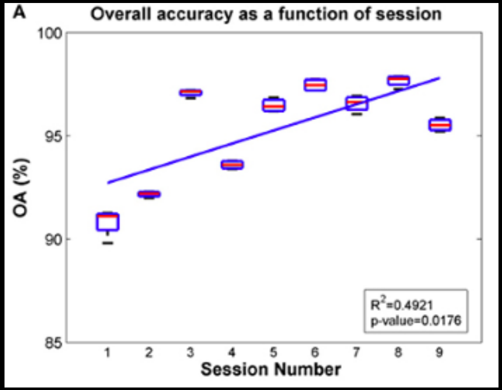
Able bodied





Spinal cord injury survivor





Source: Zhang et al. 2017

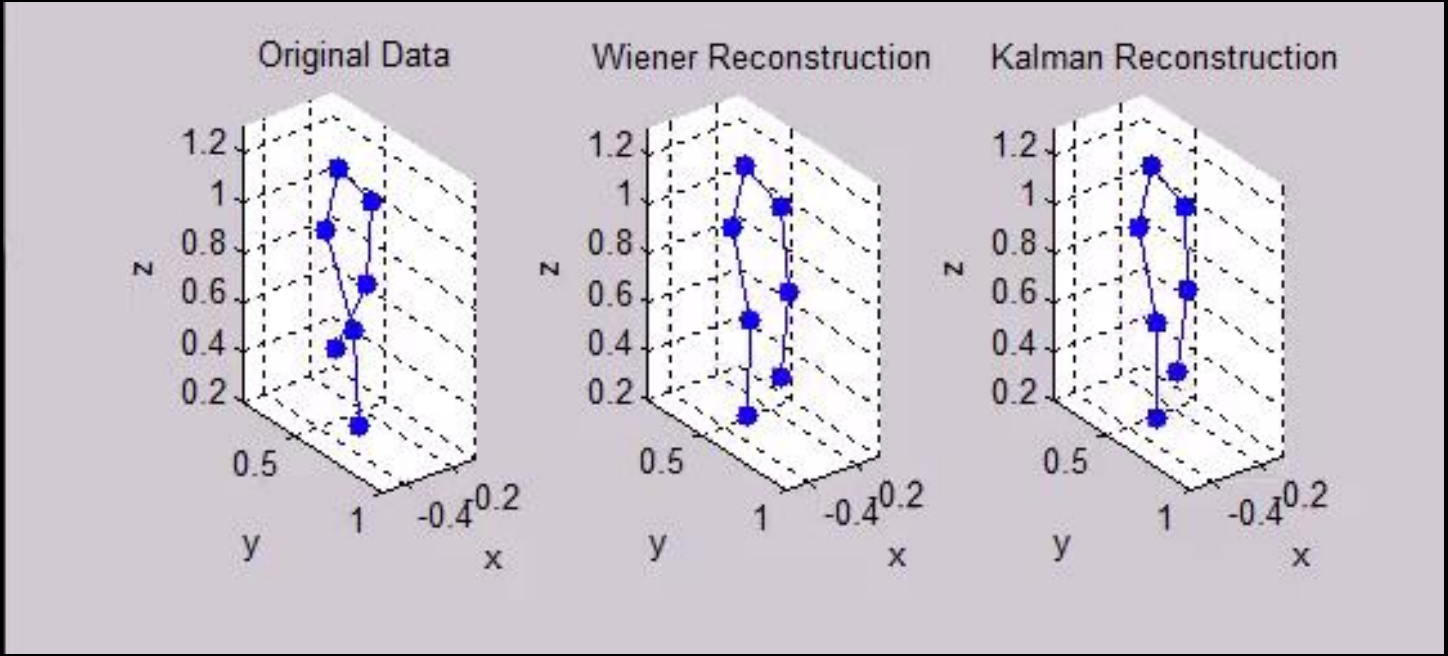
Gait Rehabilitation After Stroke Based on the H2 NeuroExo

TIRR MEMORIAL HERMANN
Rehabilitation & Research

CSIC

Source: Bortole et al. 2015

Continuous Gait Decoding from EEG of Patient with Stroke (avatar)



Examples of Robots that can be Controlled by Your Mind

Powered Exoskeletons for walking (for children)

Pediatric neurotechnologies can promote and support child’s development and well-being.

Devices need to ‘growth’ with the child.

Source: Nature 555, S12-S14 (2018)

Credit: Carlos Landa
University of Houston (2018)

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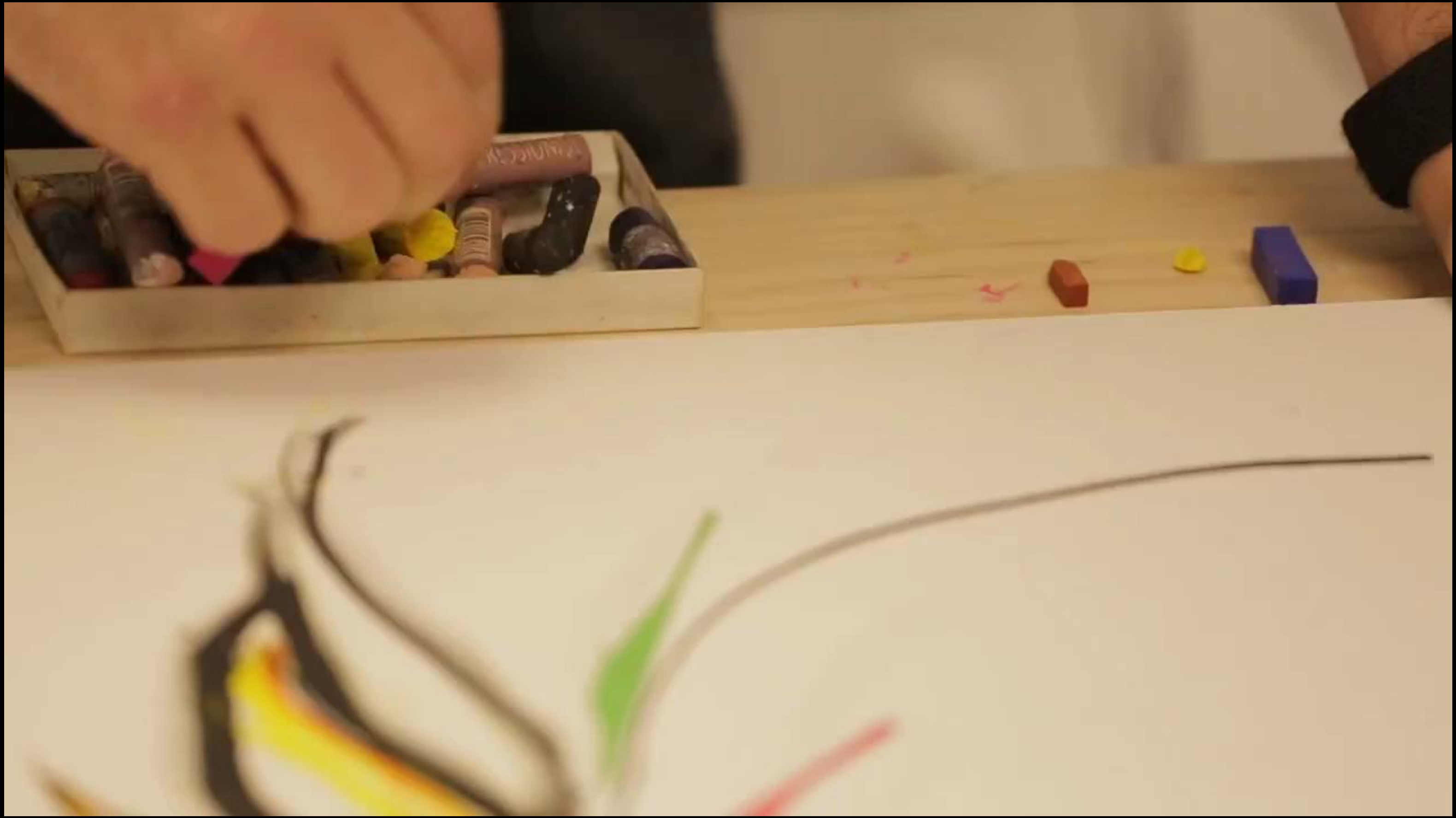
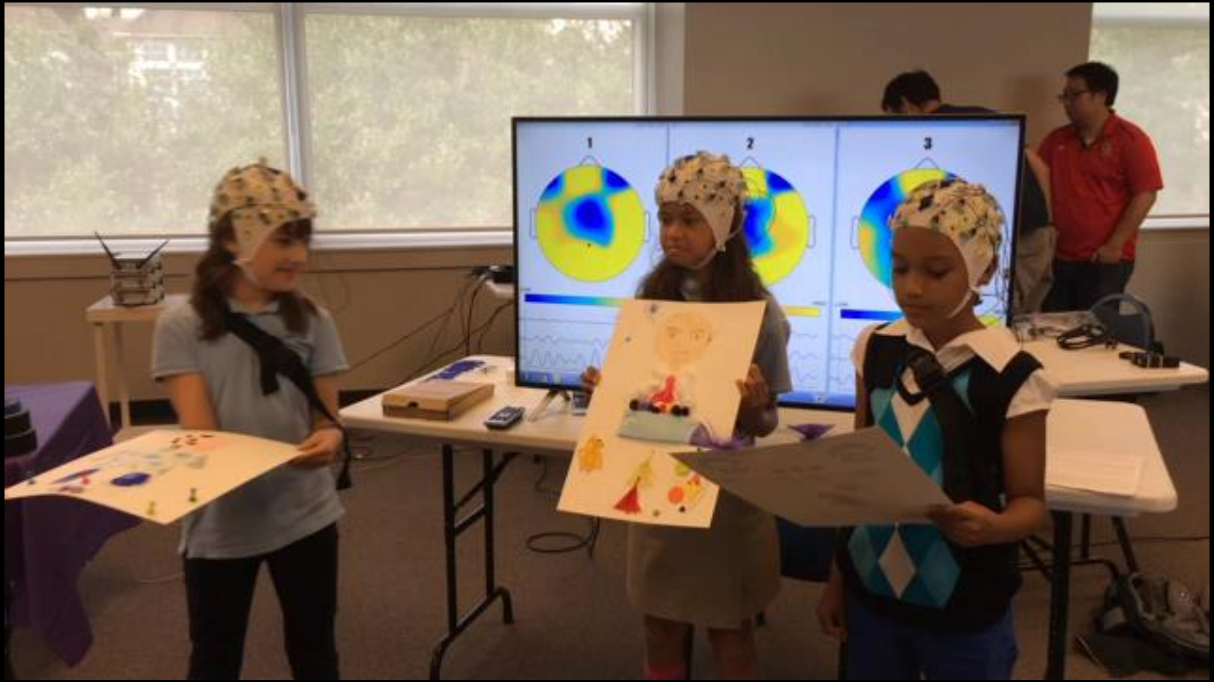
Artistic BCIs: Neuroaesthetics and Creativity



Exquisite Corpse Visual Art



Convergent Art-Science-Engineering Approach

Art Education
Informal Learning

Art

Interactive Art
Art Therapy

Judgments,
Preferences,
Emotions

BCI, ART, AI

Neuroaesthetics

Responsive Environments

Creativity

Neural
Individuality &
Variation

Neuroscience

Brain-Computer Interfaces

Engineering

Reverse-engineering
the brain

Intentionality

Novel medical devices
Computational models

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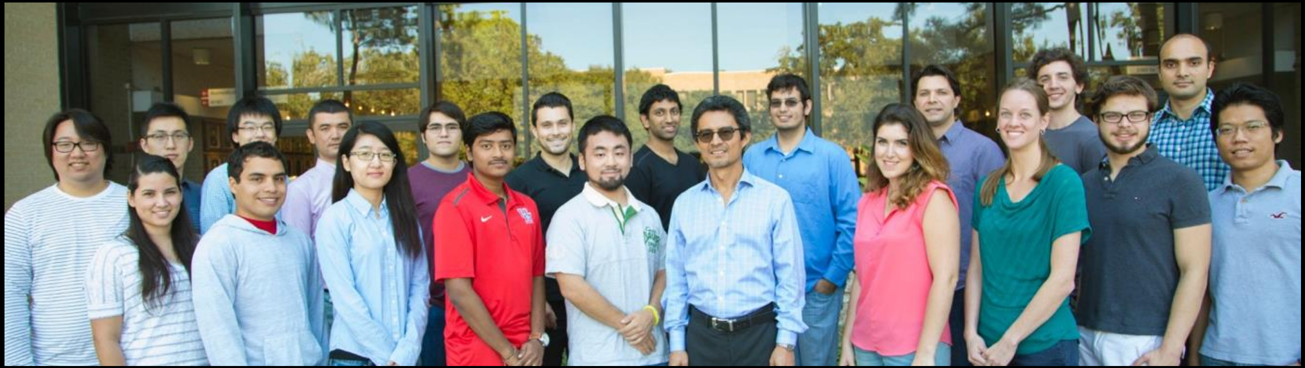
Acknowledgments

Noninvasive Brain-Machine Interface Systems Team
University of Houston



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