Cognitive Based Neural Prosthetics

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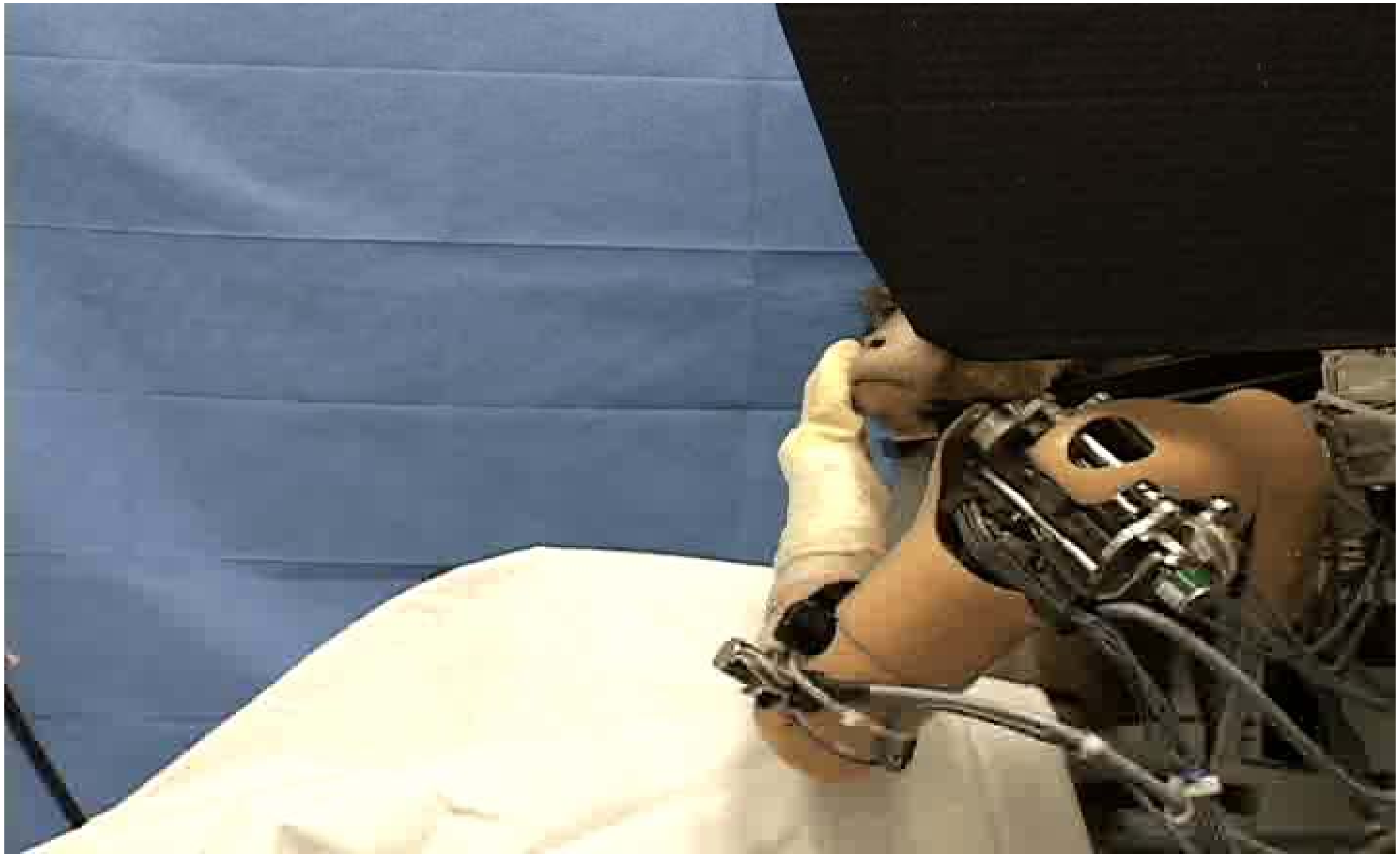


–http://motorlab.neurobio.pitt.edu

Introduction

- Recent advances in neural prosthetics research
  - Computer interface, robot arms
  - Interact directly with human nervous systems
  - Rehabilitation of motor function, communicate or interact abilities
  - Human-robot interface – extension of sense

Introduction

- Many challenges remain!
  - many disciplines
  - maintaining signal quality for long period
  - signal use that brain encoded
  - safety and effectiveness

Introduction

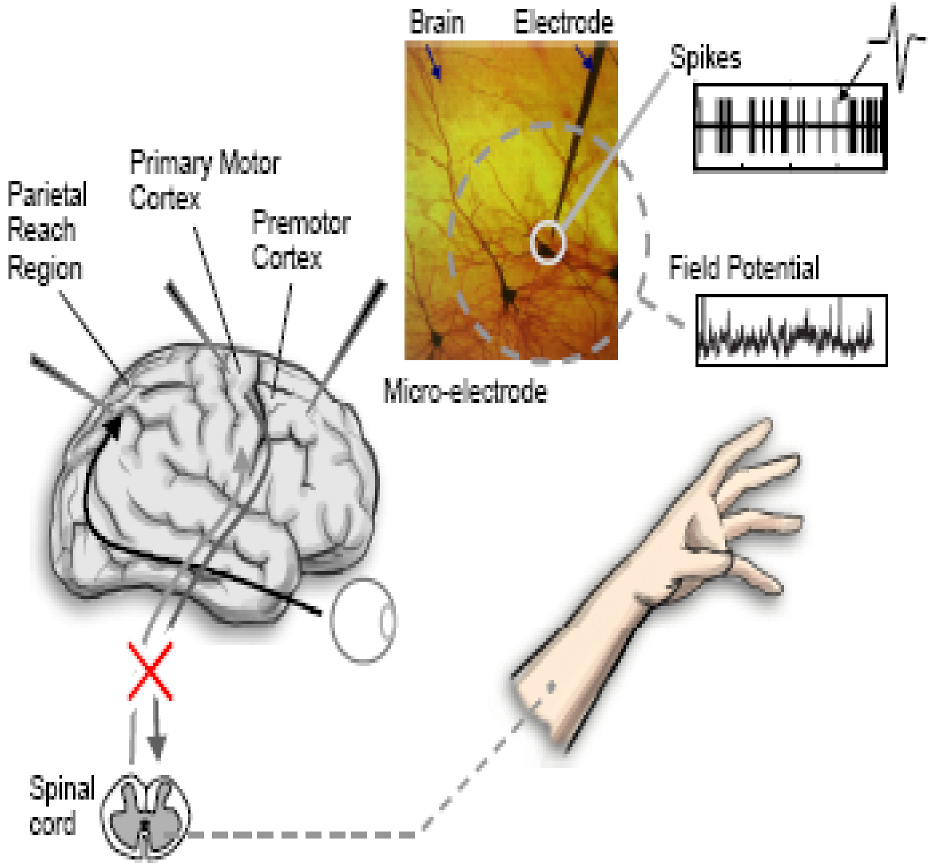
- Recent research of robot arm
  - motor and pre-motor cortex signal is used directly
  - More number and higher quality of signal should be needed for wide variety of movement
- Neural prosthetics should acquire signals to instruct external devices, rather than to control every detail of their movements
- Use Cognitive signal!

Introduction

- What is cognitive?
  - High level signal of goal of movement
  - Goals, intention to reach, expected value, preference, motivation can be cognitive variables
  - Not directly control rather instruction
  - Utilizing such cognitive variables may decrease the effort required of the user and reduce the informational burden placed on the neural recording interface.

Recent advances in neural prosthetics

- Control of end-effector using neural signal
- Record neural activity while movement task
- Build calibration model
- With model, predict end-effector movement
- Similar progress with EEG
- With adapting, performance was improved



Recent advances in neural prosthetics

- Neural activity as control signal
- Velocity as primary signal
- Trajectories were result of velocity control
- Visual feedback
  - Closed loop task

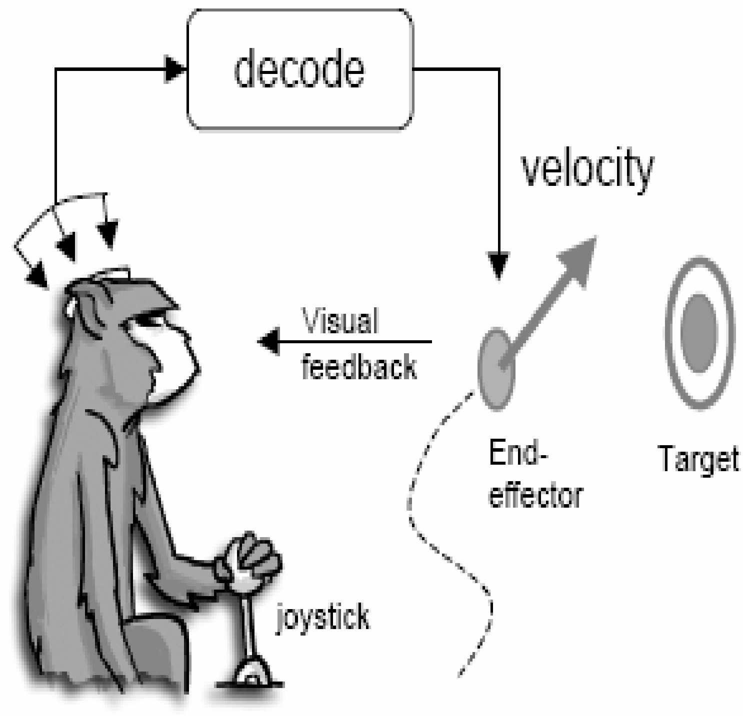


Figure 2. In current studies, non-human primates learned to control an end-effector using brain signals alone. Signals recorded during normal arm movement tasks were used to build a decode model that could predict the desired trajectory (primarily the instantaneous velocity of the end-effector).

Recent advances in neural prosthetics

- Motor cortex neurons should be used exclusively for interfacing to external devices

- Two reasons not to depend solely on motor cortex areas.

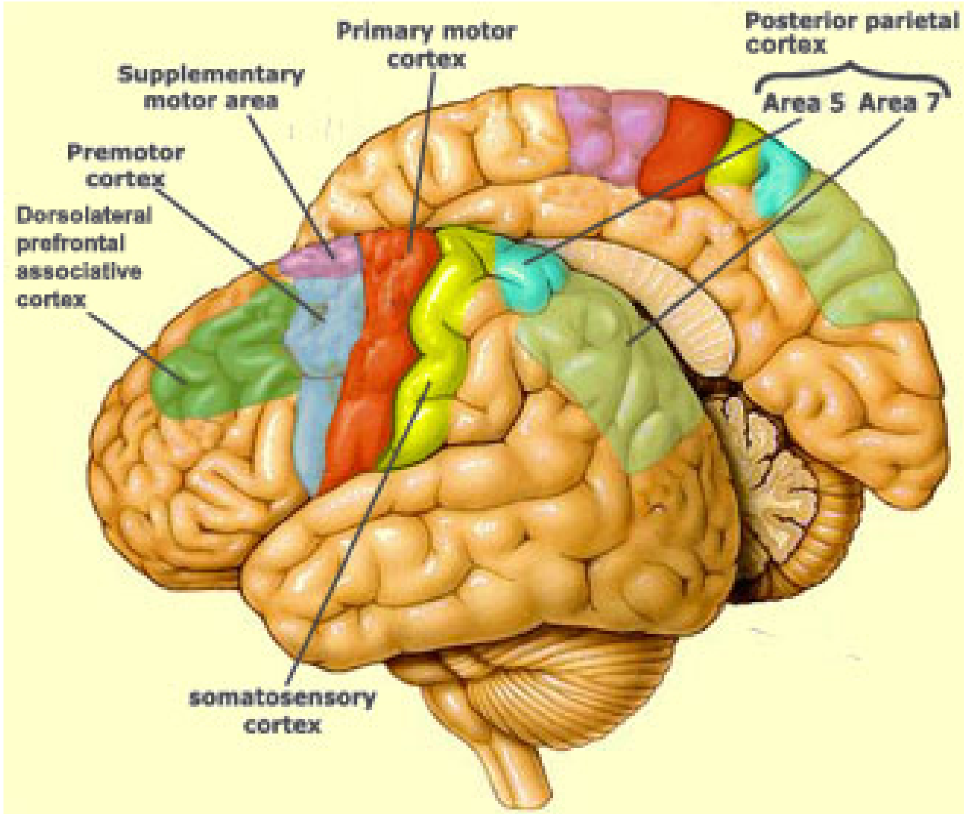
1) Informational bottleneck

   – reduce the number of cognitive variables that can be read out at any one time

2) Trained large number of task, poor activity is obtained

Cognitive Neural signals

- Cognitive signal could be derived from PRR and PMd
- PRR
  - In PPC
  - Primary active when preparing and executing movements
- PMd
  - Carrying signals related to visual control of reaching movements



http://thebrain.mcgill.ca

Cognitive Neural signals

- Neural activity in PRR
  - encode the visual coordinates relative to the current direction of gaze
  - this area contains information about where the subject is planning on reaching towards.
  - This coding of planning information in visual coordinates underscores the cognitive nature of the signal within PRR. It is coding the desired goal of a movement, rather than the intrinsic limb variables required to reach to the target.

Decoding the goal of a reach

- Recording electrodes
  - Placed in MIP, PRR, area5, PMd
    - Major pathway for visually guided movement
- Experiment setup
  - Sitting motionless in the dark and were not making eye movement
  - Planning activity exists apart from any visual or movement-related signal

Decoding the goal of a reach

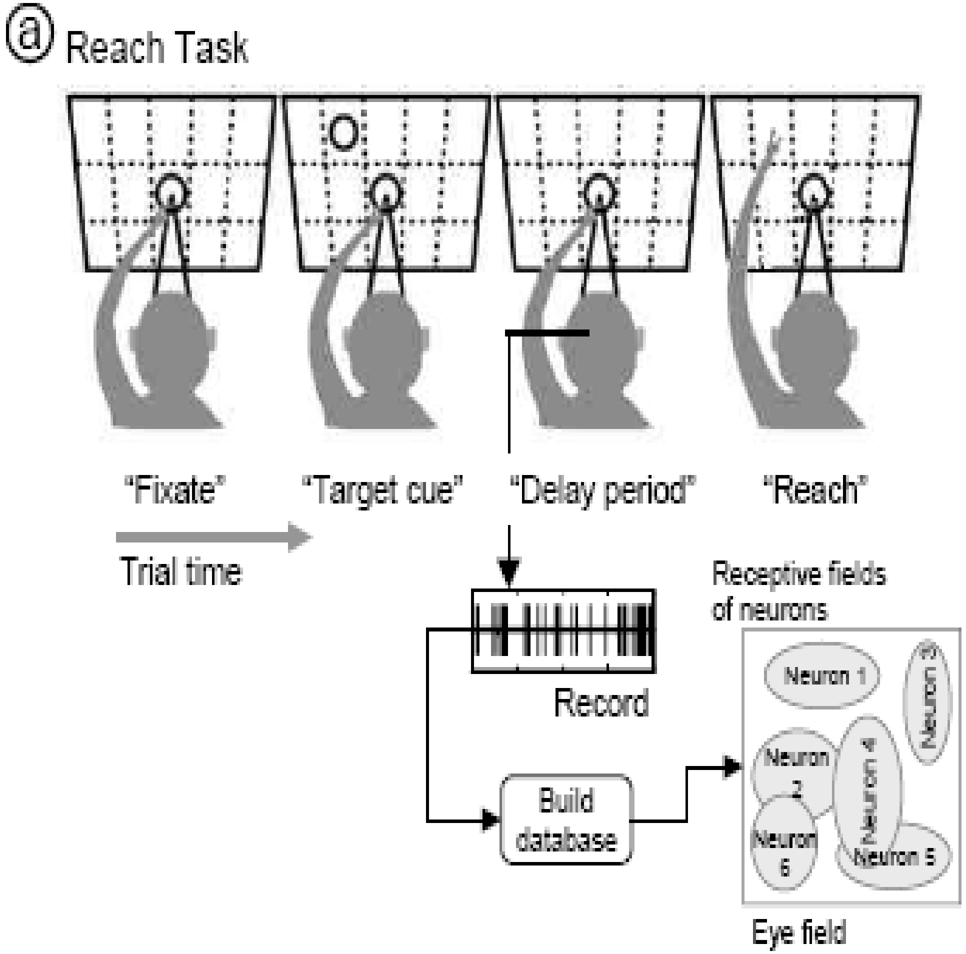
- Reach task

  1) fixate center cue

  2) target appear

  3) target disappear
  with delay period

  4) reach



Decoding the goal of a reach

- Brain control

  1) fixate

  2) target appear

  3) target disappear
     with delay period

  4) think about reach

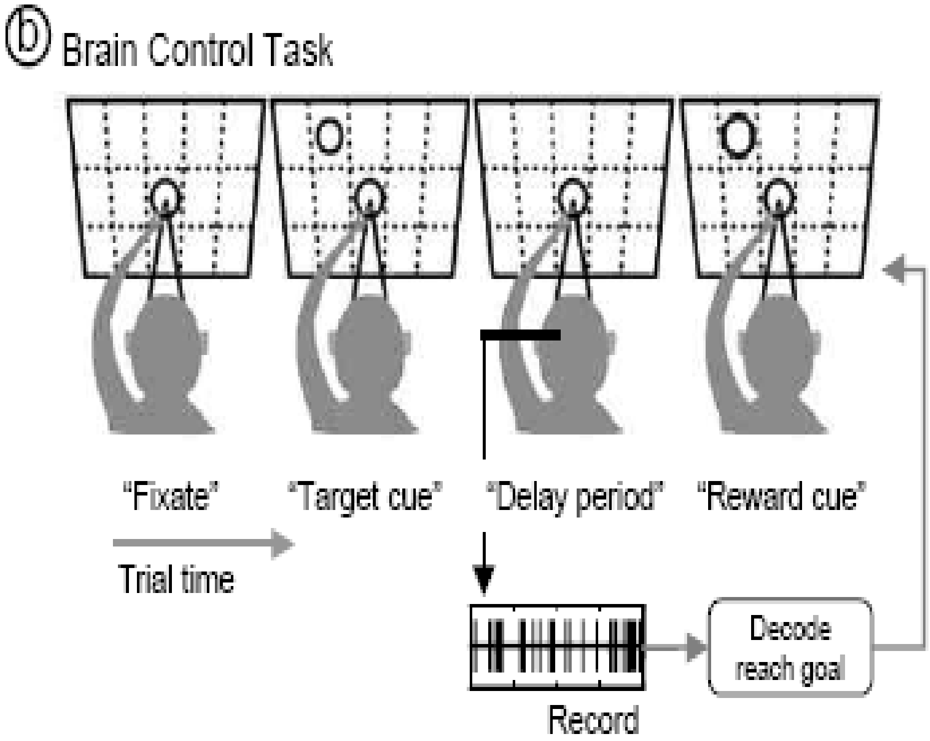
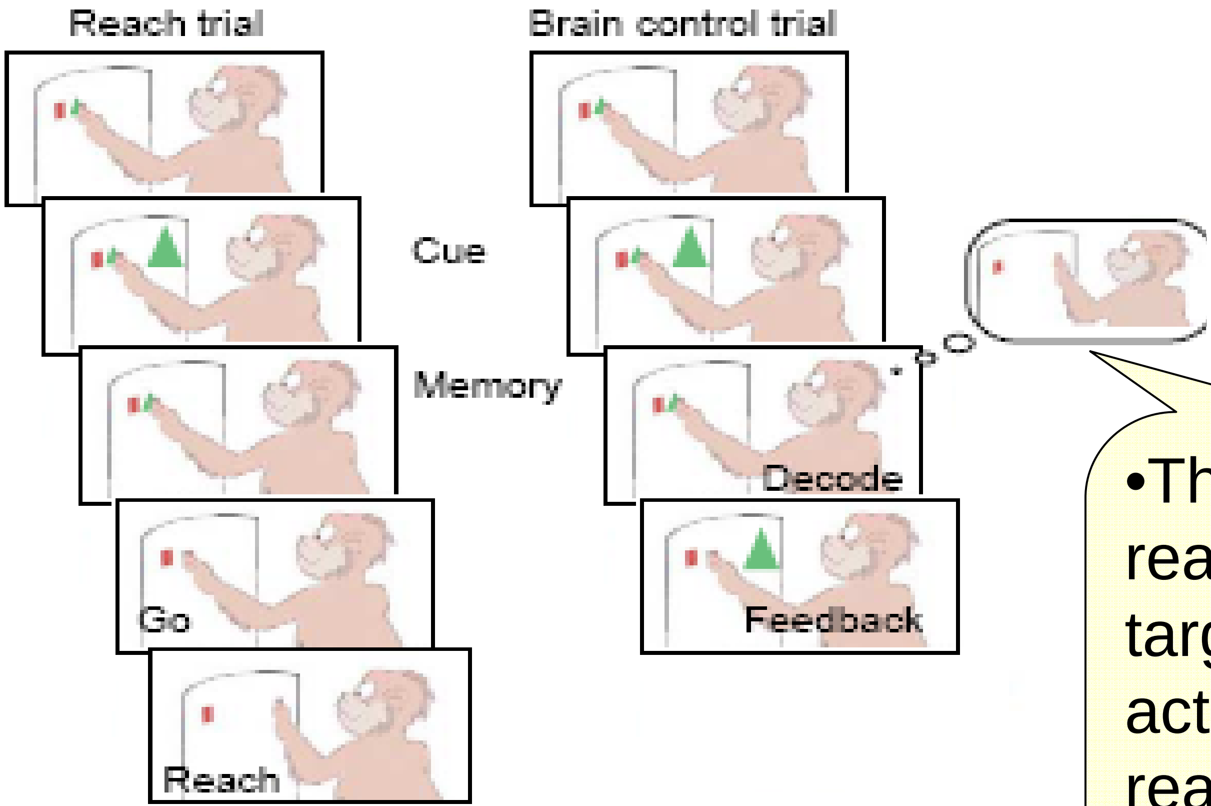


Figure 3. Normal reaching and brain control tasks used in decoding reach goal and expected reward cognitive signals. Adapted from [19].

Decoding the goal of a reach

- What happened in delay period?
  - The neural activity is recorded
  - In delay period, the monkey presumably plans the reach movement or think about reaching to the target
  - In reach task, database that relates the firing rate to the target location is build
  - In brain task, the activity during delay period was compared to database and predict the location monkeys were planning

Decoding the goal of a reach



- Think about reaching to the target without actually reaching to it

Decoding the goal of a reach

- Experiment results
  - Cumulative accuracy
  - Performance increase with number of firing
  - Cognitive signal were free of sensory-motor activity

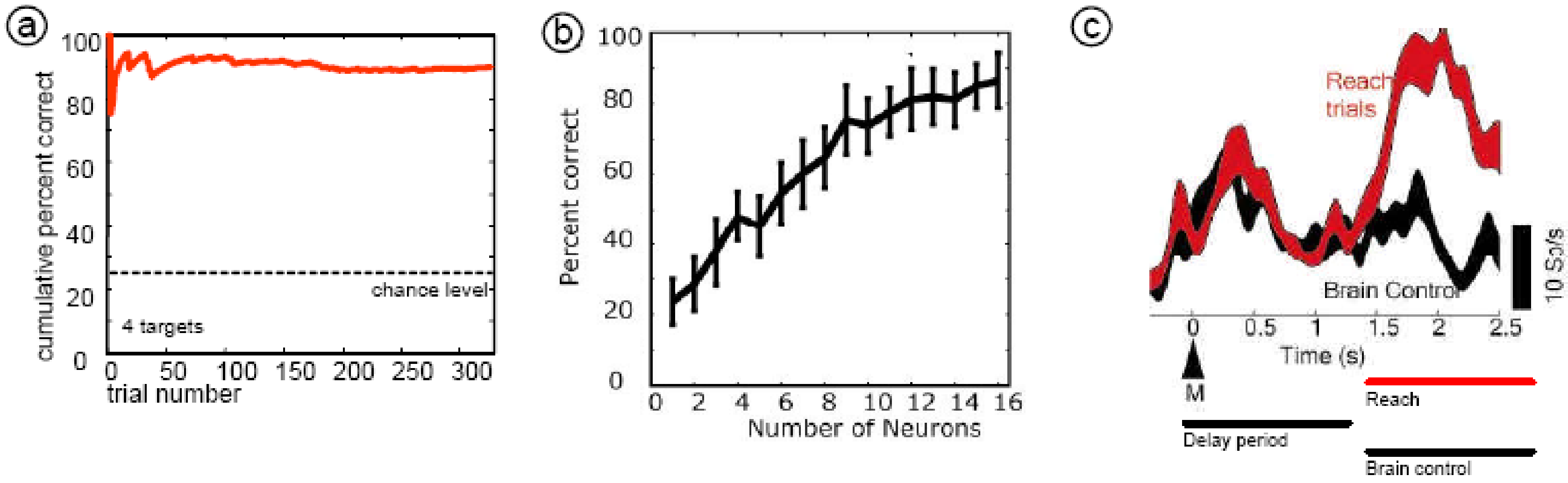


Figure 4. Results of brain control tasks in which cognitive signals (reach goals) were used to drive a cursor to target positions on a screen. a) Task performance as a function of time for an eight-target brain control task. b) Performance as a function of the number of neurons used in the decode model. c) Comparison of neural activity during normal reaching and brain control tasks (b and c adapted from [15]).

Decoding the goal of a reach

- Plastic behavior
  - Performance increase over one to two months
  - Performance improvement was related to an increase in the amount of information encoded by the neurons in the brain control task.
  - Plasticity will be important in enabling patients to optimize neural prosthetic systems with training.

- The medial intraparietal (MIP) area neurons encode the location of a reach target in eye-centered coordinates
- **Brodmann area 5** is one of Brodmann's cytologically defined regions of the brain. It is involved in somatosensory processing.

Review

- Current studies
  - Use electrode arrays to record the electrical activity of neurons primarily in motor and pre-motor cortex.
- Reading the neural activity in PRR
  - has proven to be possible by monkey test
  - has been found to encode the targets for a reach in visual coordinates relative to the current direction of gaze.

Decoding the expectation

- Decoding expectation
  - Signals related to reward prediction are found in a number of brain areas[17]
    - dorsolateral prefrontal cortex
    - parietal cortex

[17] Schultz, w., Neural coding of basic reward terms of animal learning theory, game theory, microeconomics and behavioural ecology. Current opinion in Neurobiology, 2004. 14: p. 139-147.

Decoding the expectation

- LIP of the PPC
  - LIP (lateral intraparietal) is involved in planning and executing eye movements.
  - The neurons increased their activity when the animal expected a larger reward[18]

PPC : Posterior Parietal Cortex

[18] Platt, M.L. and P.W. Glimcher, Neural correlates of decision variables in parietal cortex. Nature, 1999. 400(6741): p. 233-8.

Decoding the expectation

- PRR neurons increased their activity for amount of reward in both the reaching and brain control task[15]
  - More active and better encode reach goals
  - Also encode reward preference
    - Higher activity when the monkey expects delivery of a preferred citrus juice reward rather than water.

PRR : Posterior Parietal Reach region

[15] Musallam, S., B.D. Corneil, , B. Greger, H. Scherberger, and R.A. andersen, Cognitive control signals for neural prosthetics. Science, 2004. 305: p. 258-262

Neuroprosthetic control systems based on intelligent devices and supervisory control

Can the sole use of motor-based signals provide enough information for such subtle and complex interaction?

Maybe NOT !!

a FRAMEWORK for the control of neural prosthetics that takes advantage of the high-level nature of cognitive signals could be the solution.

Neuroprosthetic control systems based on intelligent devices and supervisory control

- Schematic of the proposed framework

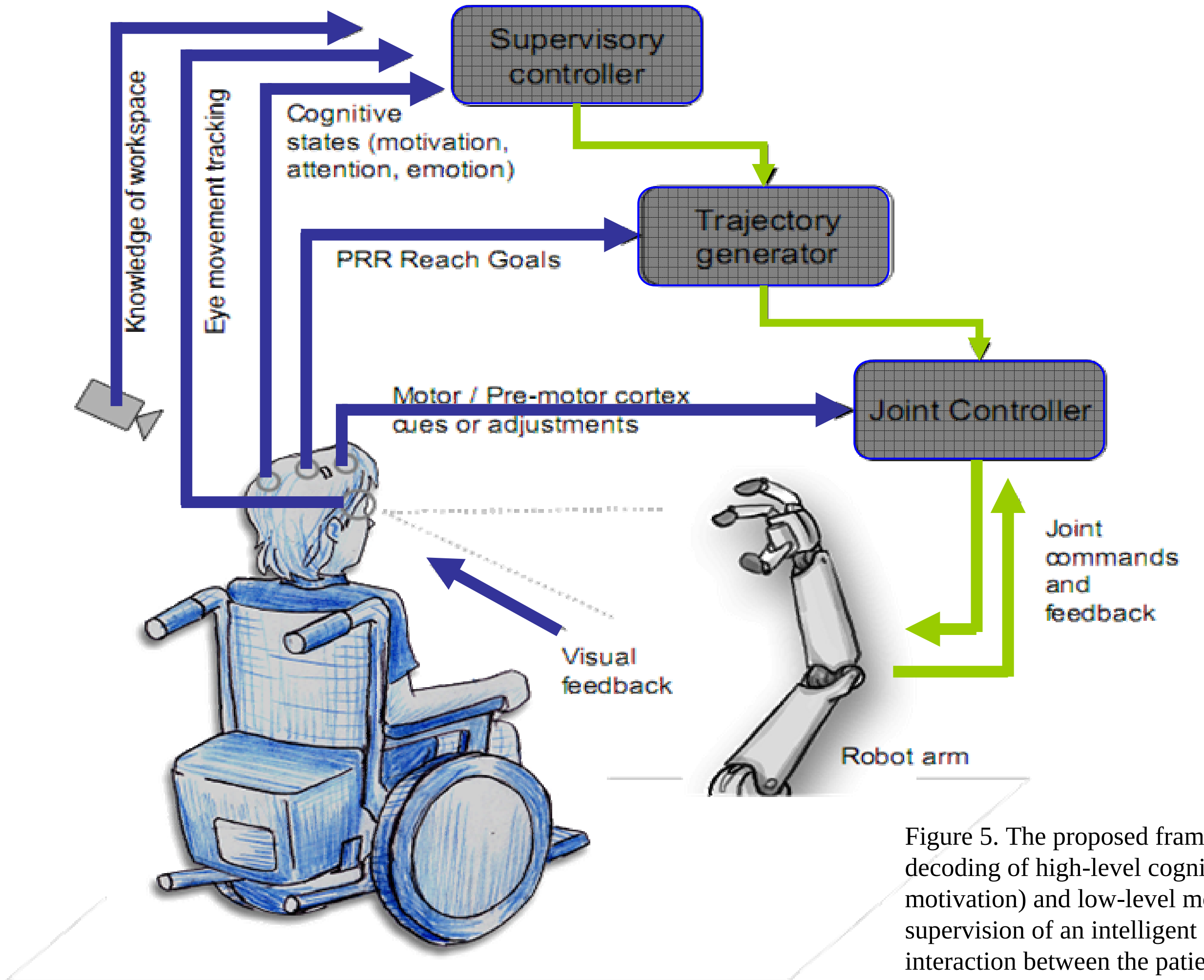


Figure 5. The proposed framework emphasizes parallel decoding of high-level cognitive variables (reach goals, motivation) and low-level motor variables under the supervision of an intelligent system, which manages the interaction between the patient and the robot arm.

Conclusion and Future work

- Cognitive signals can be directly read from the nervous system.
- These neural signals are used to instruct an intelligent supervisory system, rather than directly control an external device such as a robot arm.

Conclusion and Future work

- The Proposed framework
  - Reduces the effort required of the user in executing tasks such as reaching.
  - Has the benefit that to adapt the neural interface to different electromechanical devices.
    (e.g. different types of robotic arms or communication devices)
  - Reduces the number of signals needed to be extracted from the nervous.
  - Takes advantage of research in robotics that focuses on intelligent systems, autonomous navigation, path planning, and human-robot interaction.

DL-PFC

- DL-PFC
  - DL-PFC serves as the highest cortical area responsible for motor planning, organization, and regulation. It plays an important role in the integration of sensory and mnemonic information and the regulation of intellectual function and action. It is also involved in working memory. However, DL-PFC is not exclusively responsible for the executive functions. All complex mental activity require the additional cortical and subcortical circuits that DL-PFC is connected with.