Neuronal ensemble control of prosthetic devices by a human with tetraplegia

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Motivation

- Many people suffer from the motor impairment due to damage to the spinal cord, nerves, or muscles
- They have intact movement related areas of the brain
- Current assistive technologies have some limitation

- Neuromotor prostheses (NMPs) can be a solution.

Neuromotor Prostheses (NMPs) (1)

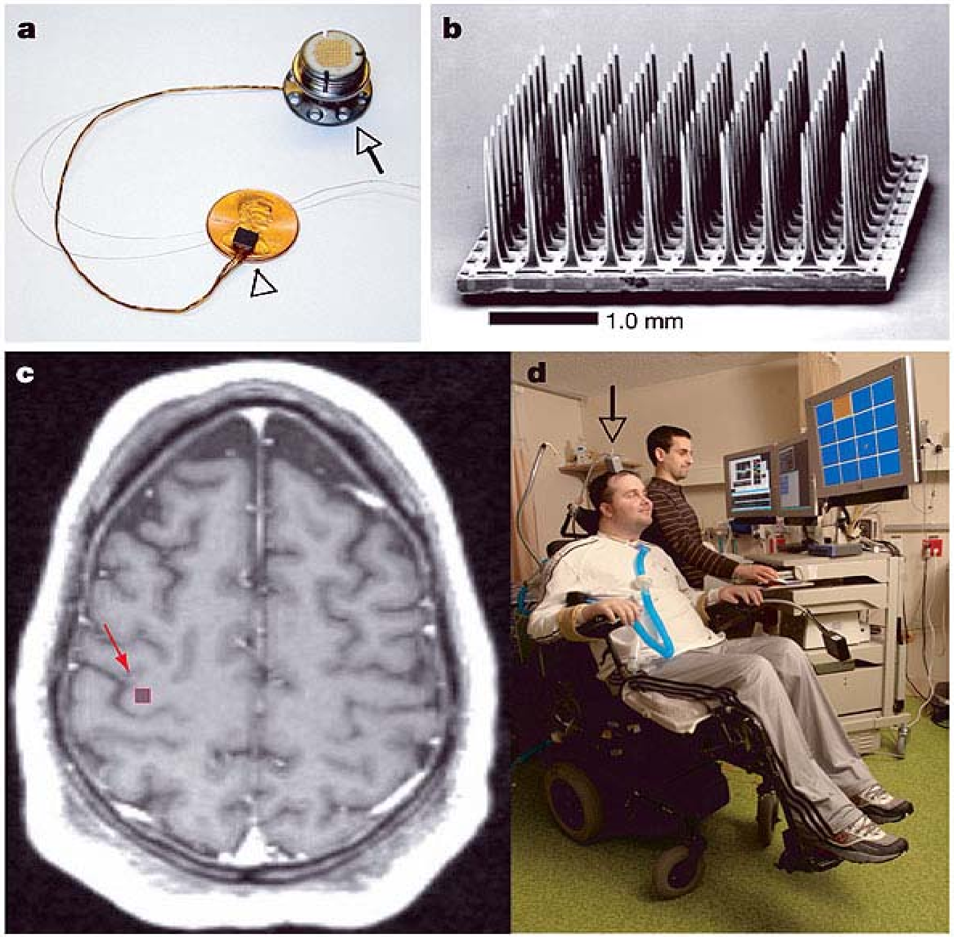
- Brain-Computer Interface (BCI)
- Use the existing neural substrate for that action
- Produce Safe, unobtrusive and reliable signal

- Case of using neurons in the primary motor cortex (MI) arm area of monkey

Neuromotor Prostheses (NMPs) (2)

- Requirement
  - 1. sensor
  - 2. decoder
  - 3. Computer gateway

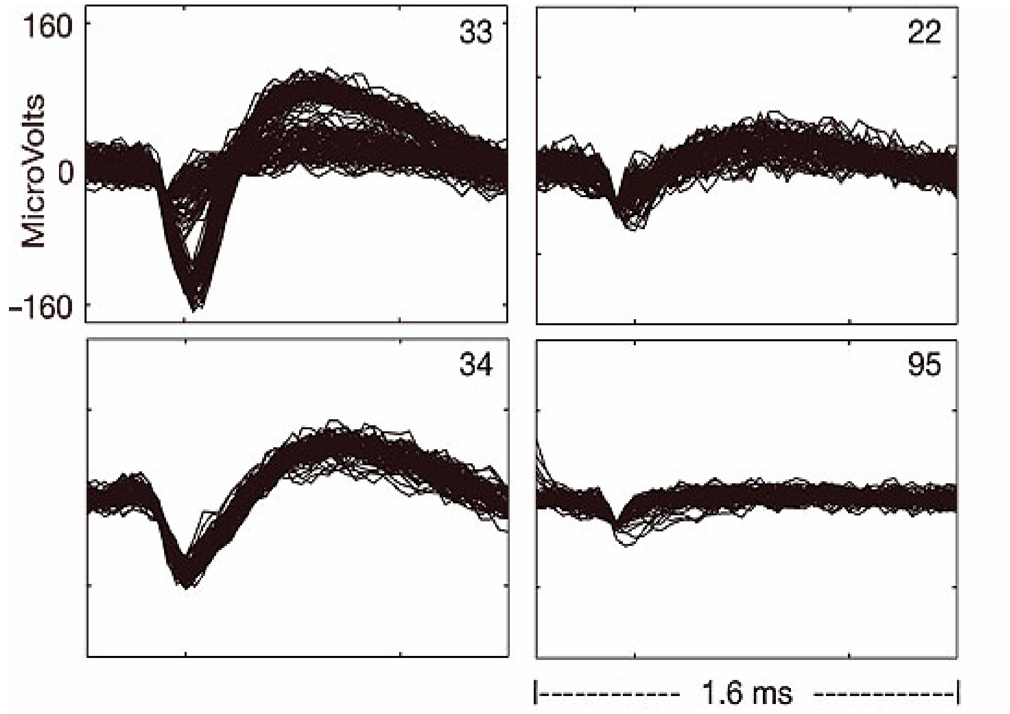
BrainGate and placement, and the participant



BrainGate demo

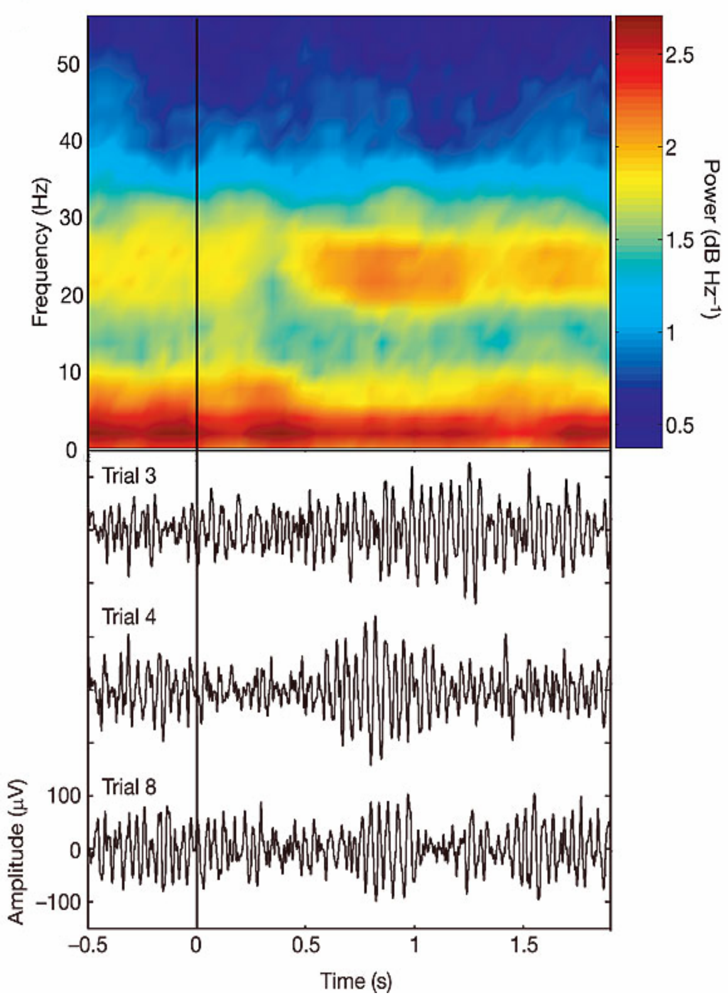
Signal quality and variety (1)

- Discriminated neural activity at electrode 33,34,22,95



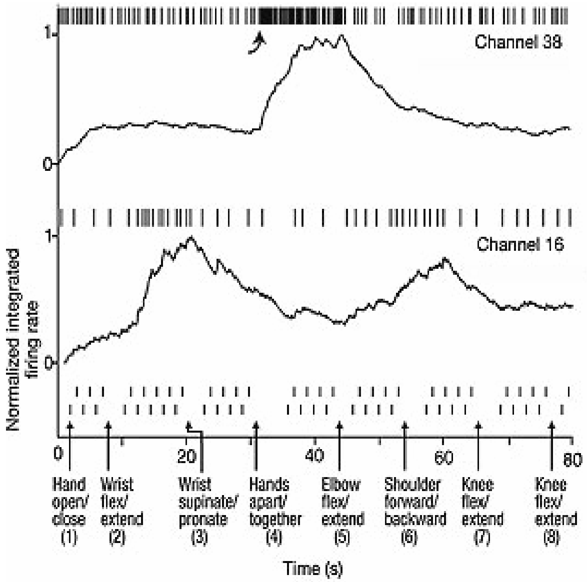
Signal quality and variety (2)

- Local field potentials during neural cursor control



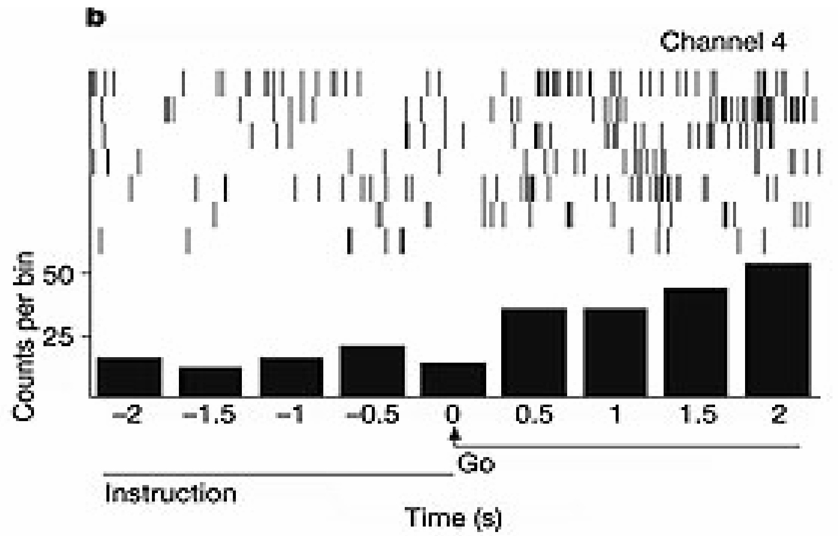
Modulation by intent (1)

- Evaluated Modulation while MN imagines a series of movements



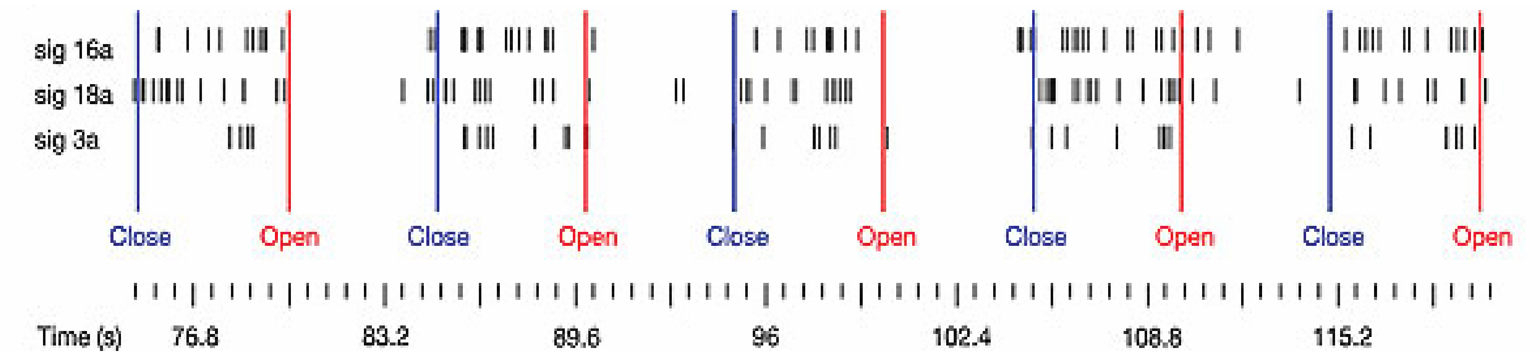
Modulation by intent (2)

- Activation of the non-selective neurons



Modulation by intent (3)

- Hand-instruction-related modulation for three simultaneously recorded neurons



Linear filter construction

- Transform between firing patterns and intended action
- Basis of instructed actions
- By tracking a technician`s cursor
- Use the least-squared formulation

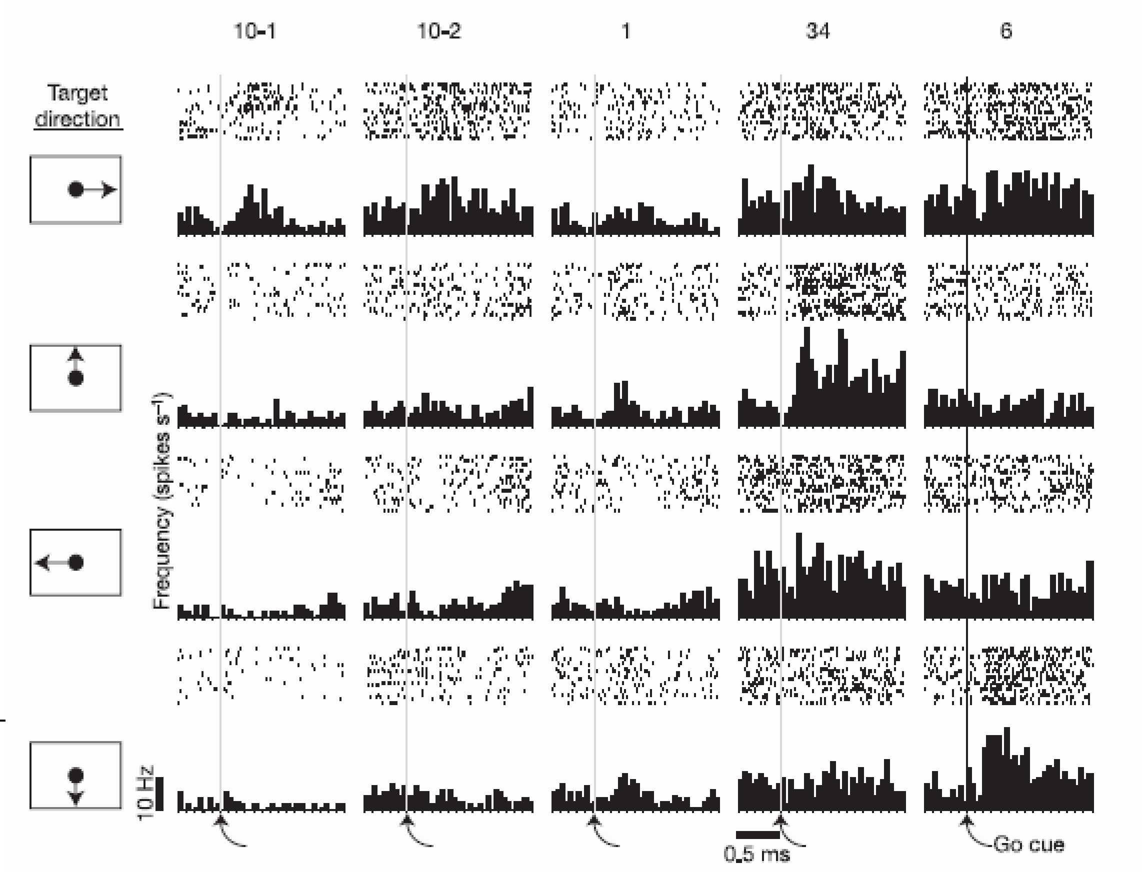
MI activity during neural cursor control

- Intact monkey's MI neurons became to modulate firing before movements onset, activity is tuned to hand movement direction
- To compare this neural activity with MI of a human with spinal cord injury, MN performed a step tracking, 'center-out' task using the neural cursor

"Center-out" task

MI activity during neural cursor control (Cont'd)

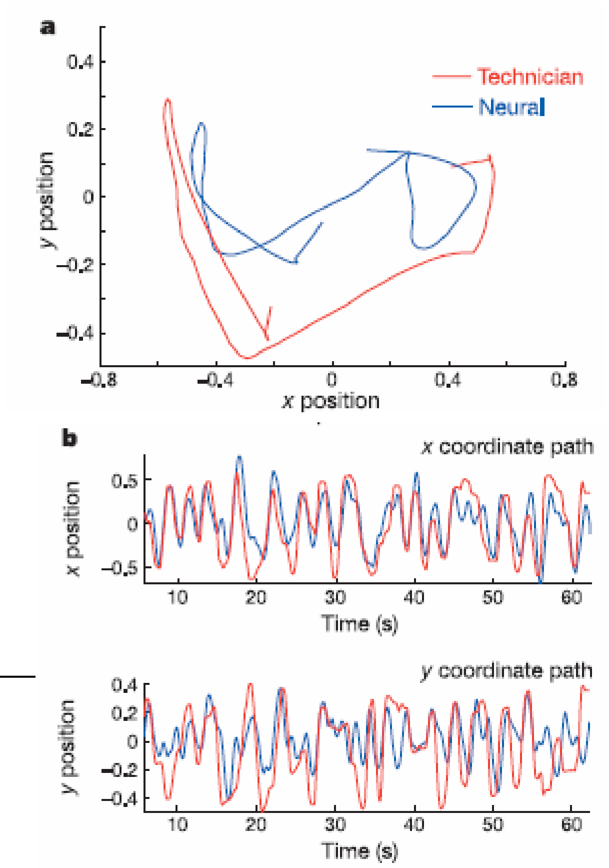
- MI neurons can be actively engaged and encode task related information even after spinal cord injury and in the absence of kinaesthetic feedback and limb movement

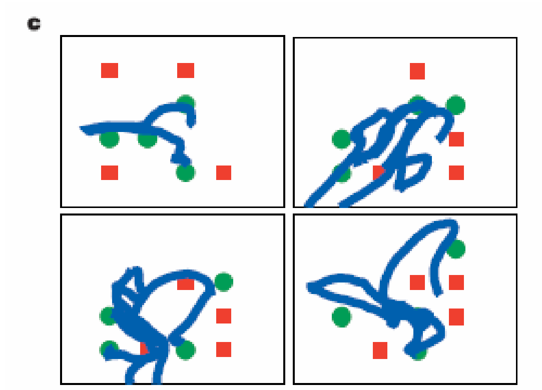


Directional tuning during center-out task

Quality of neural cursor control

- Reconstruction of neural cursor position during pursuit tracking



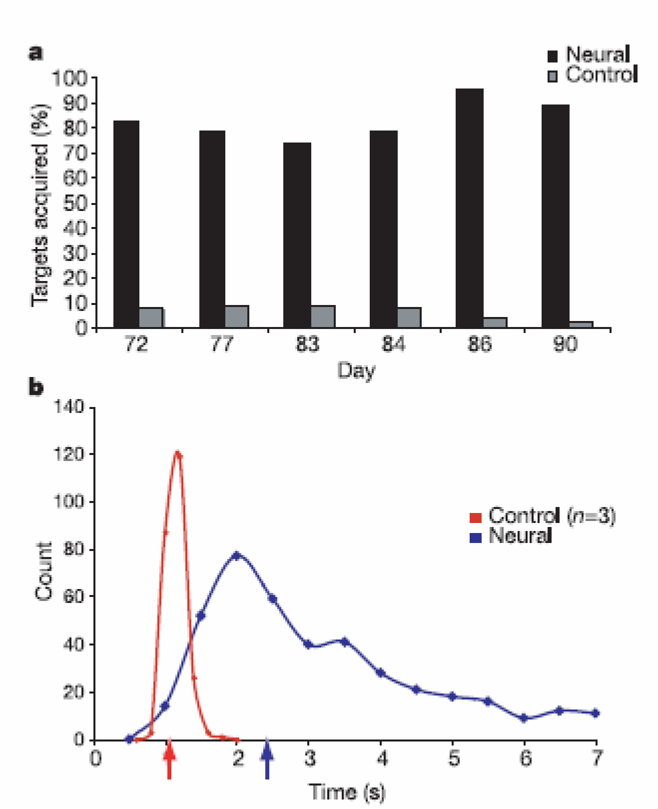


Target acquisition/obstacle avoidance

Quality of neural cursor control (Cont'd)

- Center-out task performance
  - To evaluate the speed and accuracy of cursor control which are essential design parameters for practical NMP
  - MN tried 80 times, paired t-test $p<0.0001$

Figure 6 | Centre-out task performance. a, Target acquisition accuracy during the centre-out task. For each of six sessions, MN acquired between 73–95% of the radially placed targets. Control targets were not present on the monitor during task performance, but were marked as acquired if, during post-hoc analysis of the cursor movement, the cursor had traversed the location of one of the other three pseudo-randomly selected targets before the correct target (see Supplementary Video 1). Data from days 72, 77, 83, 84, 86, 90 are shown. **b**, Time-to-target performance during centre-out task for MN (blue) and three able-bodied controls (red). Only successful target acquisitions in <7 s are shown for MN. Arrows on the abscissa represent median times to target for each distribution. Controls' performances ($n = 3$ controls, 80 trials each) are collapsed into 0.2-s bins. MN's performance (398 trials) is collapsed into 0.5-s bins for visual clarity.



Center-out task performance

Direct control of prosthetic devices

- Control signal can operate external physical assistive devices
  - MN used a simplified computer interface to

Open simulated e-mail
& draw a circular figure

Adjust the volume, channel, and
power of TV

Play video games (Neural pong)

Control the coupled prosthetic hand

Direct control of prosthetic devices (Cont'd)

Control the robotic limb

- These demonstrates control of physical devices without computer cursor feedback is possible in tetraplegic humans
- MI-based NMP may have the property of allowing external device control with little more disruption than encountered in able-bodied humans

Conclusion

- Human unable to move or sense his limbs can operate a NMP using MI neuronal ensemble spiking activity as a control source

- Neural spiking remains in the MI area and can be modulated by intention years after spinal cord injury.

- Cursor and external device control may also be improved through learning.

- They believed that NMPs can be used scaled so that parallel commands could be derived simultaneously from multiple sensors each in separate cortical regions.

- A wireless, implantable and miniaturized system combined with automation will be required for practical use.