Targeted muscle and sensory reinnervation

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Humans are never broken, Technology is.

So, how can we deal With such cases?

Jesse Sullivan

Classical Prostheses

- The functionality of prosthetic arms remains limited due to the loss of neural-control information during amputation
- Unintuitive control since conventional methods rely on residual muscles to perform physiologically unrelated movements, causing high cognitive burden
- Complete Lack of sensation

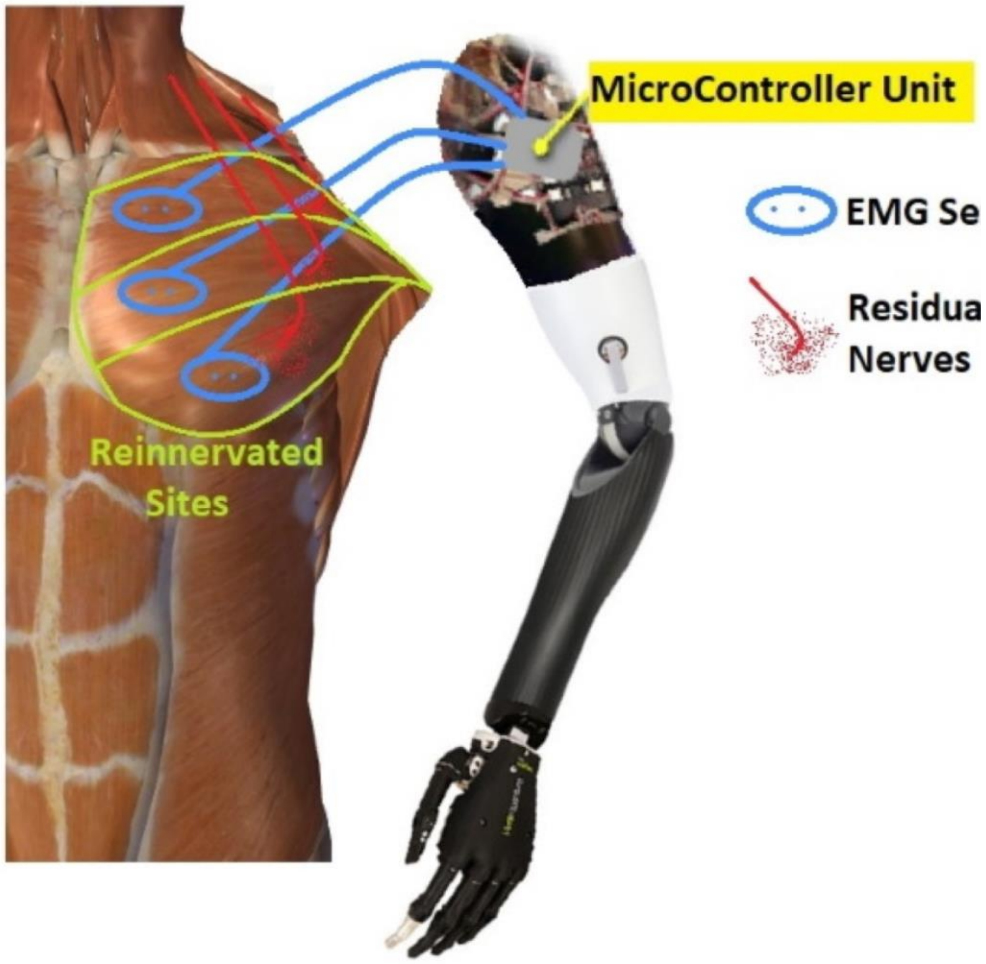
ToddKuiken Ted Talk in 2011

Neural Plasticity and Cortical Reorganization

TMR

The process goes through 3 important steps:

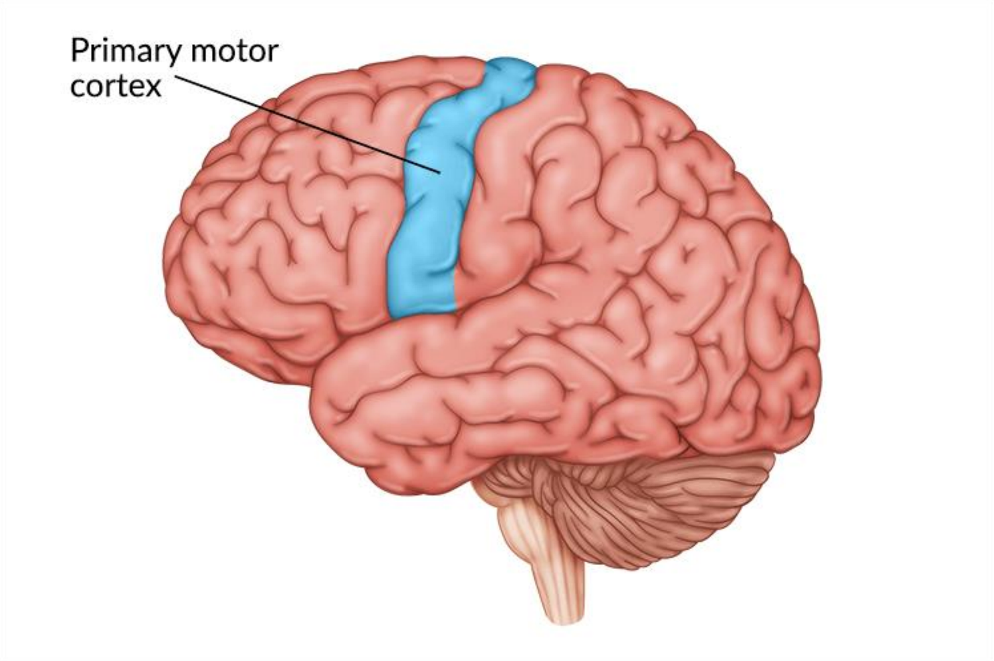
- Nerve Transfer: Transferring remaining arm nerves to target muscles.
- Muscle Reinnervation: Reinnervation of muscles over months to respond to nerve signals.
- Signal Capture: Generating measurable electromyogram (EMG) signals for prosthetic control.



Primary Motor Cortex (M1)

Responsibilities:

- Initiates and Controls voluntary movements
- somatotopic Organization and mapping on the body
- coordination and adjustments (interacts with other parts of the brain)



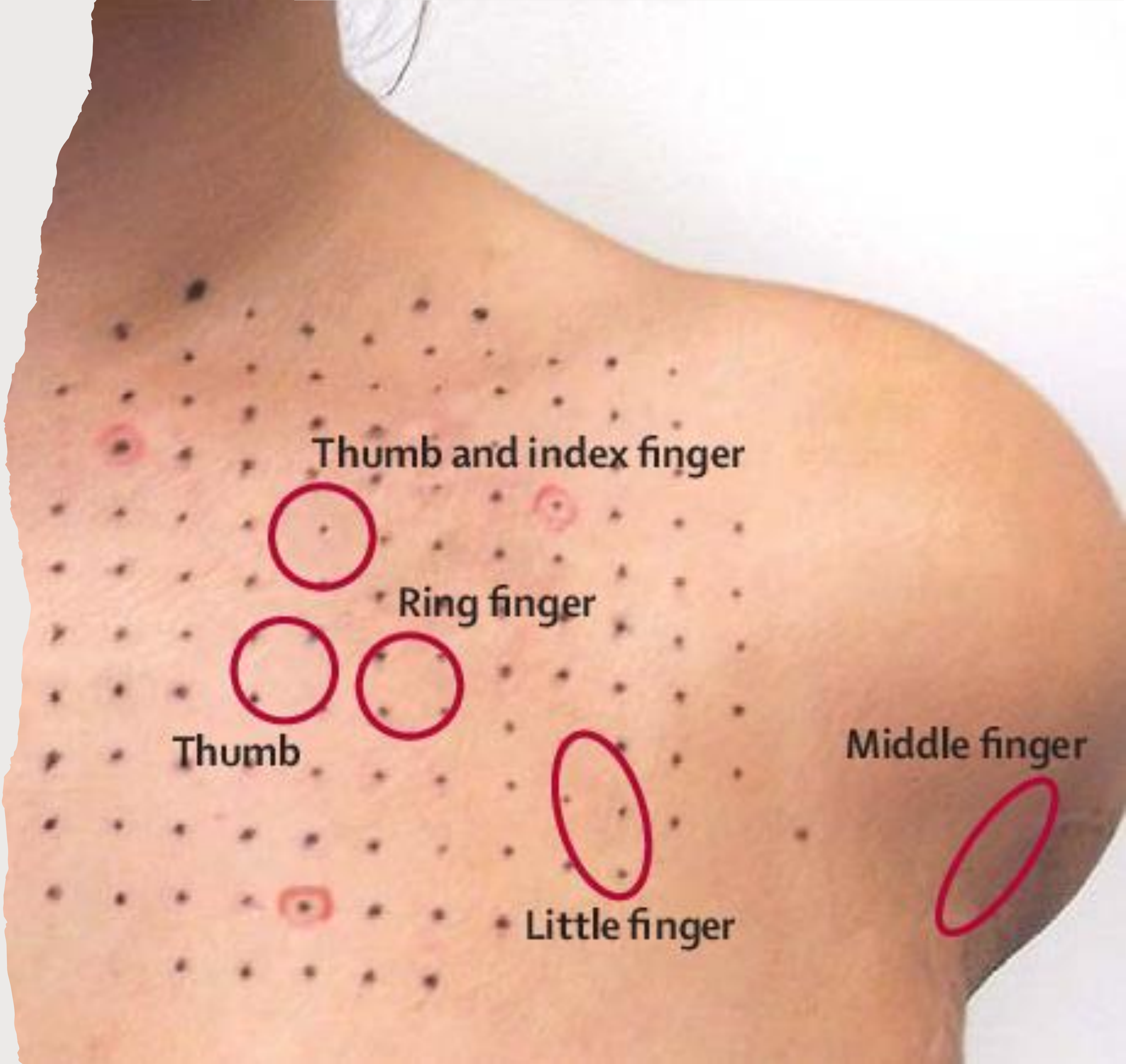
2.4 Impact of TMR on the Motor Cortex (M1)

Aspect	TMR Patients	Non-TMR Patients	Healthy Controls
Extent (Mapping)	Comparable to healthy controls.	Reduced extent of activation for movements of the amputated limb.	Normal, robust mapping.
Strength	Comparable to healthy controls. Peak t-value difference is positive and not significantly different	Weaker than healthy control. The Index negative or near zero.	Consistently Strong activations.
Distance	Comparable to healthy controls. And symmetrical distances	Altered distances, reorganization. And Asymmetrical	Symmetrical distances

TMSR

The process goes through several steps:

- **Sensory Nerve Identfication**
- **Nerve Redirection**
- **Reinnervation**
- **Prosthetic Integration**



The Crucial Role of Sensory Perception in Daily Life

Grasping and Handling Objects

Recognizing Danger

Balancing and Walking

Interacting with Others

How TMSR Should Enhances Sensation for Amputees

Establishes a sensory link between the prosthetic and the brain

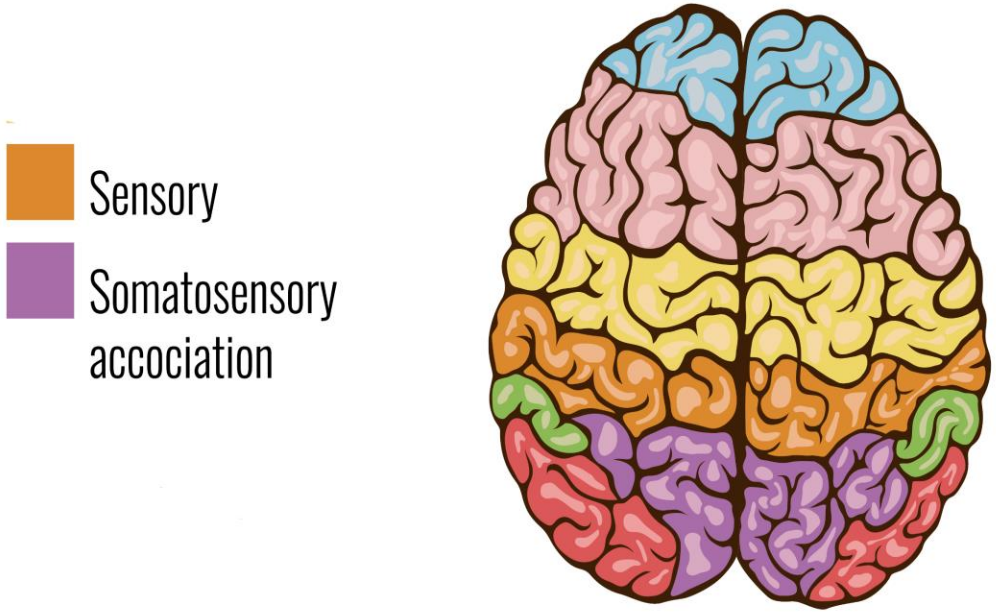
Enhances coordination and precision in daily tasks

Promotes a more natural and intuitive experience for amputees.

Primary Somatosensory Cortex (S1)

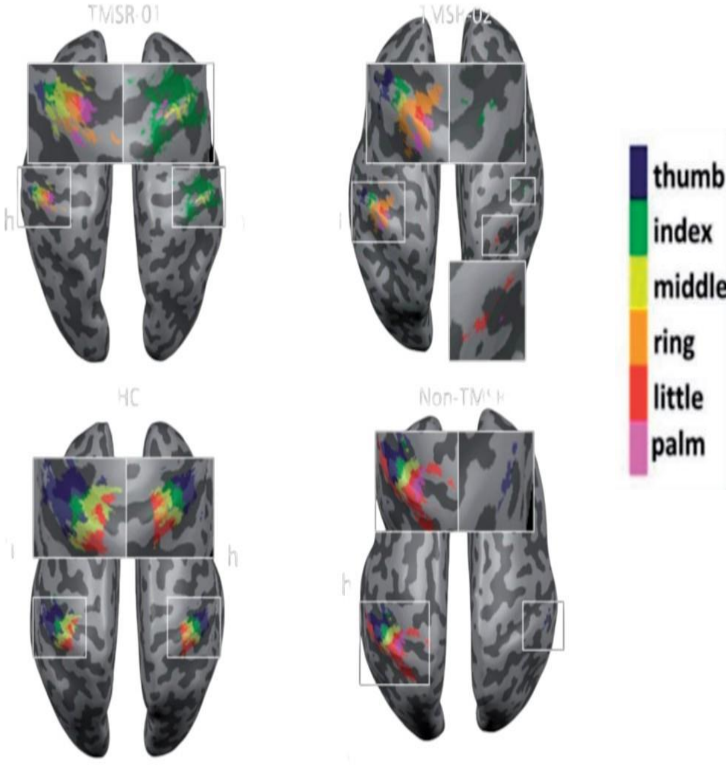
Responsibilities:

- **Tactile perception**
- **Proprioception**
- **Pain and temperature**
- **Somatotopic organization**



Impact of TMSR on the Somatosensory Cortex (S1)

Aspect	TMR Patients	Non-TMR Patients	Healthy Controls
Extent (Mapping)	No Significant difference with HC	Significantly smaller extent compared to HC	POS BASELINE EXTENT
Strength	Lower Intensity compared to HC	Significantly Weaker Intensity Compared to HC	High Intensity
Distance	Symmetrical distances similar to HC	Reduced distances	Symmetrical distances



Objectives of TMR research

Patient Assessment: The focus is on identifying improvements after surgery.

Performance metrics for prostheses: Different types of robotic arms are used

Software improvements: *For EMG signals decoding.*

Exploring the limits of complexity: Tests are made to understand how complex the prosthetic control can be achieved.

Experimental Procedure

Elegibility, surgery and recovery phase (3-9 months)

Experimental Procedure

Initial calibration phase

Signal Generation

When a person thinks about moving his lost limb, a reinnervated muscle will contract.

Signal Capture

Surface electrodes are placed to detect the generated EMG signals.

Signal Processing

EMG signals are amplified and filtered. **Pattern Recognition** is required.

The Role of Pattern Recognition

- After TMR, multiple nerve branches can be connected to a single muscle.
- Each nerve may trigger a slightly different part or intensity of the muscle.
- The variations are subtle but distinct enough to create different EMG signals
- Advanced pattern-recognition software maps EMG signals to specific movements (e.g., grasping, flexing, or rotating).

Experimental Procedure

Post-surgery Usage and Data acquisition phase

Findings: Phantom Limb

Phantom Limb Position

- Pre-TMR
  - Hand feels “trapped” or in a closed/semi-closed fist.
  - Fingers may feel “wrapped” around each other.
  - Minimal ability to move or wiggle fingers.
- Post-TMR
  - No change whatsoever.
  - ‘Slight’ increase in finger movement.
  - Hand position feels ‘slightly’ more open.

Phantom Limb Pain

- Pain is usually rated using the Numerical Rating Scale (NRS), where 0 = no pain, 10 = worst possible pain.
- Research compares TMR group to Standard Pain Treatment. Results are analyzed after 1 year.
- ***For TMR Group***: PLP score dropped by 3.2 points
- ***For Standard Treatment Group***: PLP score had almost no change (dropped by 0.2 points)

Current Availability

- TMR was developed in the early 2000s.
- It's still not an internationally or even commonly available procedure.
- TMR for prosthesis control is only found on select locations:
  - Shirley Ryan AbilityLab (Chicago, USA)
  - Royal National Orthopaedic Hospital (London, UK)

Functional Outcomes and Dexterity of TMR

Advanced Technologies Driving Hand Dexterity

Seamless Prosthetic Integration:

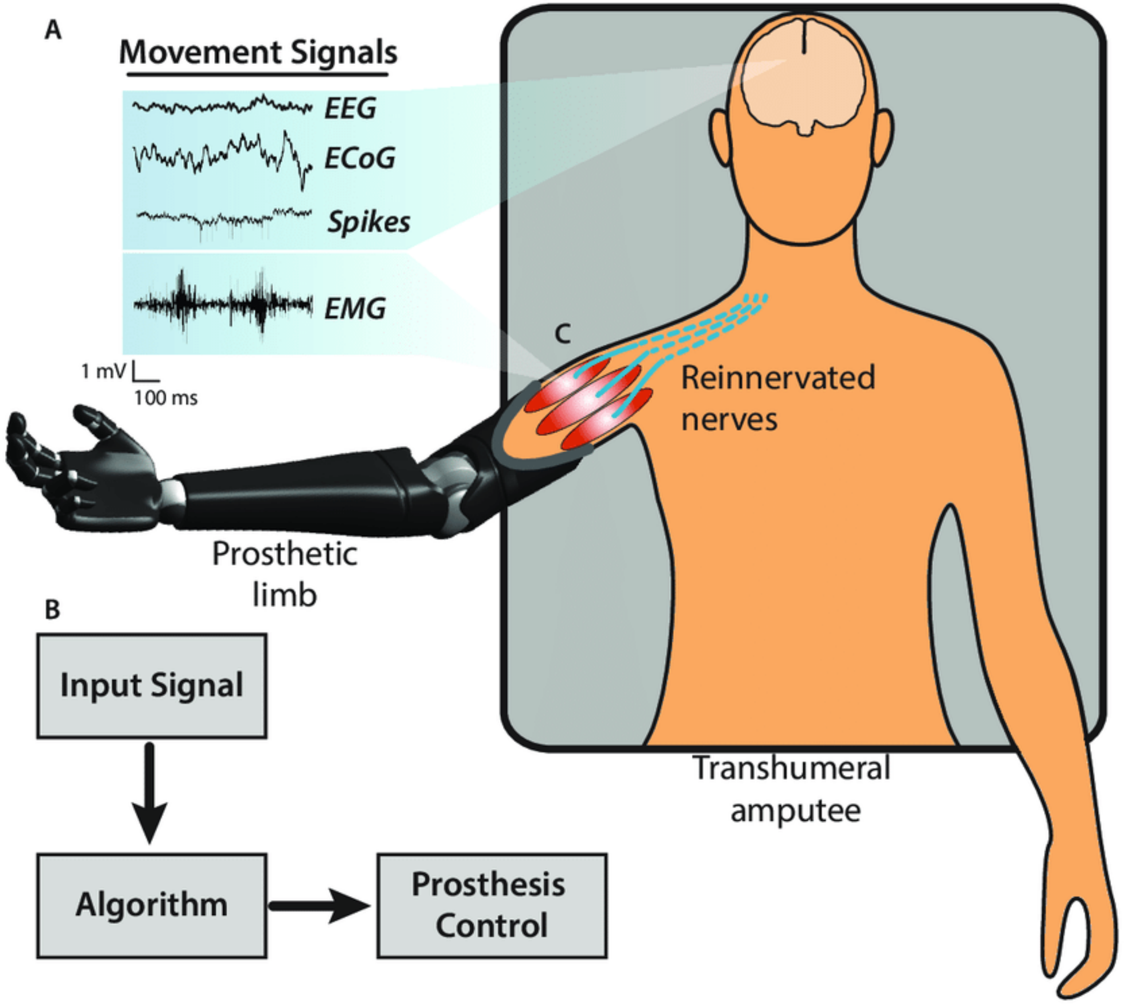
- Making hand movement adaptive and natural.

Machine Learning Adaptation:

- Prosthetics that learn user habits for better performance over time.

Pattern Recognition Algorithms:

- Learn movement intentions by interpreting signals.



Reducing the Cognitive Burden in TMR Prosthetic Use

Simplified & Intuitive Interfaces:

- Prosthetics that can predict movement with minimal thought.

Machine Learning:

- Devices adapt in real-time based on neural signals.

User Training Programs:

- Structured rehabilitation reduces learning challenges.

Pattern Recognition for Intent Prediction:

- Prosthetics interpret a user's intended motion by analyzing natural movement signals.

Improving Hand Functionality with TMR Prosthetics

- Multi-articulating prosthetic hands
- Allow individual finger control.
- Improved grasp types:
- Precision grip for tasks like typing or eating
- Power grasp for carrying objects
- TMR enables users to perform complex hand movements with minimal effort.

Why Reducing Mental Strain Matters

- **Improved daily functioning:** Users can complete everyday activities without unnecessary mental effort.
- **Enhanced confidence & independence:**

Simpler prosthetic use empowers users to perform more tasks autonomously.

- **Better mental health outcomes:** Cognitive strain is linked to stress and fatigue. Reducing this can lead to a better quality of life.

How does TMR Improve quality of life

Enhanced independence by performing tasks without assistance.

Restored ability to enjoy hobbies, sports, and daily work.

Enables nuanced hand movements and dexterities, like fine motor grasping or tool use.

Examples: Cooking with ease, Playing sports or musical instruments, Working with technology

Challenges to Overcome

- **Signal Noise:** Background signals may interfere with prosthetic responsiveness.
- **Adaptation Time:** Learning to use prosthetics can take time and effort.
- **Individual Variability:** Each user has different needs, physical conditions, and prosthetic responses.
- **Technological Integration:** Ensuring technology aligns seamlessly with the body's natural intent remains a hurdle.

Main References

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Additional Resources

- DARPA Research on Neural Prosthetics: https://www.darpa.mil/
- Amputee Coalition: https://www.amputee-coalition.org/
- Machine Learning Applications in Prosthetics: *IEEE Journal on Neural Systems and Rehabilitation Engineering*
- Recommended Book: *Neural Prostheses: Execution of Movement and Posture*
- DARPA Research on Neural Prosthetics: https://www.darpa.mil/
- The Amputee Coalition: https://www.amputee-coalition.org/
- Key studies from *IEEE Transactions on Neural Systems and Rehabilitation Engineering*.
- Books: *Neural Prostheses* by Smith & Hooper, *Machine Learning Applications in Prosthetics*.