Prosthetics in Motion: a Comprehensive Review of Current Limb Interfaces

Cameron Bertomeu, Dr. EC Cline (mentor)

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ABSTRACT

The field of prosthetics interfacing is an ever-evolving subfield of research in medicine. Each design is weighed and compared on its value to cost to the patient both in the short and long term. Additional research moving forward in the field suggests that the progression to a fully articulated limb is growing nearer, but at current standards needs refinement before application. Brain-computer interfaces which hardline a connection between the prosthetic and the brain, peripheral nerve electrodes which connect local existing nerves to the prosthetic, and myoelectric cuff electrodes around the surface of the residual limb, each form the basic connections from a patient to their prosthesis, though each has its own challenges. Myoelectric cuffs remain the safest option due to their lower risk-to-benefit ratio at the current state, with the other methods approaching efficacy as research continues.

INTRODUCTION

The use of complex interfaces in the design of prosthetic devices creates a problem exclusive to the kind of medical treatments within the surgical and therapeutic field:
How do we safely make a motorized prosthetic hand move?
This was the focus of research studied and after analysis in my literature review the three primary methods were myoelectric cuff electrodes, peripheral nerve implants, and brain-computer interfaces. The risks were evaluated, and the efficacy of each method was compared, along with those risks was an analysis of the patient evaluation system for motorized prosthetics. In the conclusion of my review, I found specific benefits and risks inherent to the forms used.

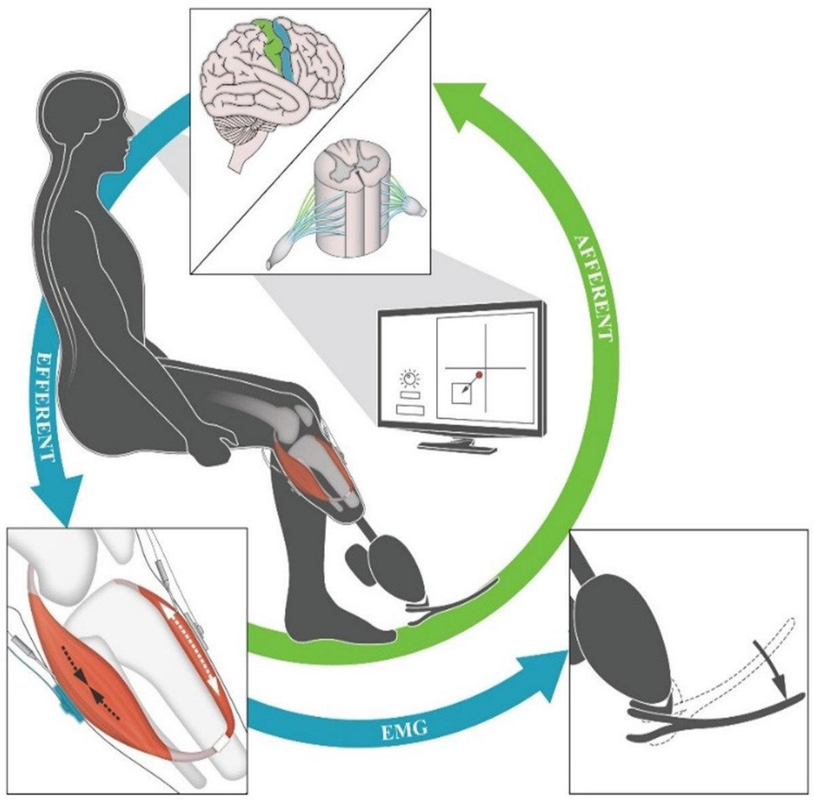

Figure 1. A diagram of the process of integrating a signal and moving a prosthetic foot. (Massachusetts Institute of Technology 2018)

TYPES OF INTERFACE

There are three forms of interface that encompass the field of study.

- Myoelectric Cuff Electrodes (MCE)
  - Can be attached superficially to the patient dermally or just beneath soft tissue in larger replacement (Gstoettner et al. 2022)
  - Usually costs less to fit onto the body of the patient than the other methods

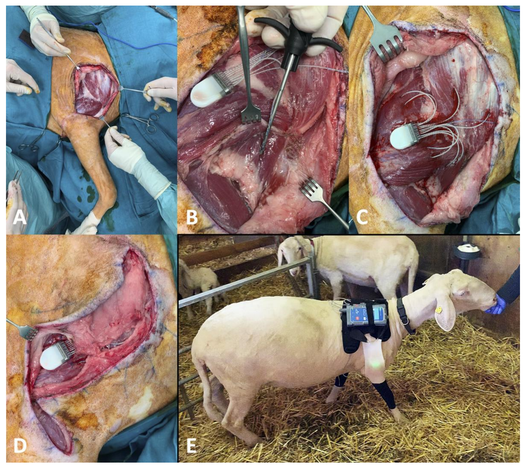

Figure 2. Image of an Implanted Myoelectric Electrode array in sheep subject (Gstoettner et al. 2022)

- Peripheral Nerve Implants (PNT)
  - Signal is direct from nerves that are already performing the function of the neuron they are mimicking (Vaskov et al. 2022)
  - Signal speed is close to the signaling speed of a native motor neuron after sufficient recovery and physical therapy

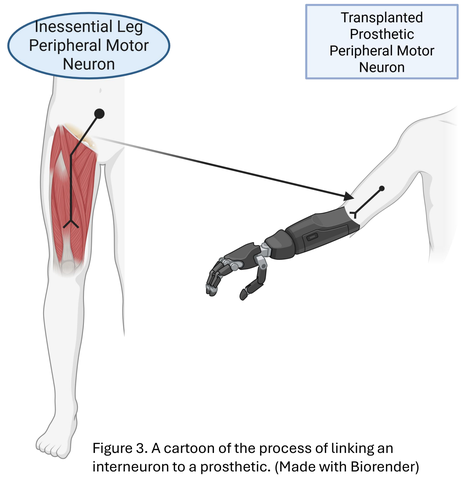

Figure 3. A cartoon of the process of linking an interneuron to a prosthetic. (Made with Biorender)

- Brain-Computer Interface (BCI)
  - Clearest signal of the methods as it is a direct connection to the patient's motor cortex (Mitchell et al. 2023)
  - Fastest integration of nerve signal to motor units as the individual is performing the tasks at the pace of their electrical impulses are firing.

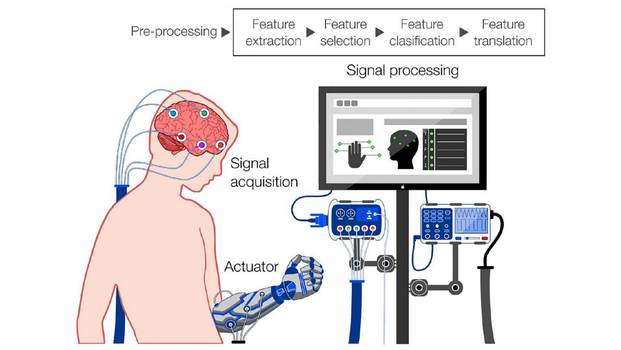

Figure 4. A cartoon of a prosthetic controlled with a Brain-Computer Interface. (Nielson 2021)

DISCUSSION

While there are issues with each form of interface, there is a clear leader in the safety aspect. The importance of a safe treatment plan also allows for better recovery and mental health post application. My conclusions land on there being a need to focus on the use of the current safest form of interface.

RISKS

- MCE have the longest latency and least precision in their functional activity (Zhuang et al. 2019)
- PNT have the risk of enhancing or causing phantom limb pain and require complex surgery to properly connect to a patient (Sando et al. 2022)
- BCI have risk of encapsulation and risk of nerve feedback that could be catastrophic (Musleh et al. 2006)

Figure 4. An image of a modern motorized prosthetic hand. (Chant 2016)

OUTCOME

The risks and inherent detriments of the interfaces are on different scales, and at current research the most safe and effective is MCE. The development of research suggests that in the near future PNT will be safe and effective enough to use instead. BCI can be used, but even in the safest conditions it requires an understanding that catastrophic failure can mean nerve damage and even in extreme cases brain death.

FUTURE RESEARCH

Research focus currently is on all the forms near equally, but not in the facets that most distinguish them from each other. It would be the recommendation to study ways to increase both fidelity and speed in the Myoelectric Cuffs and Peripheral Nerve Implants to help increase speed of signal transduction, as well as in Brain-Computer Interfaces

REFERENCES