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Mini Review Article

# Neuroprosthetic Devices: i-HAND

**Mustafo Mingbaev**

*King's College of London, AA 6005611, UZB*

***Corresponding author**
Mustafo Mingbaev, King's College of London, AA 6005611, UZB. E-mail: mingbaev.mustafo@gmail.com

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## Abstract

*Millions of people are paralyzed or have suffered an amputation. Although these people can still see the object they may want to reach, for example a glass of wine, and can still process in their brains the specific commands to pursue this goal, the action cannot be completed due to, for example, a spinal cord injury or due to the fact that the arm has been amputated. Given that in most cases the brain of these persons is intact, the possibility of reading brain signals would allow the development of Neuroprosthetic devices, such as a robot arm that is driven by neural activity.*

*These technological and scientific advances connect the amputee more intimately with their prosthetic limb, meaning we can now focus more on how the prosthesis is embodied. In other words, to what extent does the prosthetic limb feel like part of the biological body? Does your brain treat it as such?*

*We have a good understanding of how our body is mapped in our brain. Both our motor cortex – the movement control centre, if you like – and the somatosensory cortex where we process a wide range of touch sensations are organisedsomatotopically. This means each area of our body corresponds to a specific area of the primary motor and sensory cortices. Importantly, this mapping does not disappear after the loss of a limb.*

*This means we have an opportunity to connect prostheses, through muscles and peripheral nerves, to the parts of the brain that would have controlled and sensed the biological body part. But it may also allow us to measure embodiment, how successfully the brain accepts the prosthesis as part of the body.*

*Ultimately this line of research, bringing together cognitive neuroscience and biomedical engineering, is not only important for designing better prostheses. It is a unique window for understanding how our brain creates and maintains the image of our bodies – mechanisms that apply equally to amputees and non-amputees.*

## Introduction

The human hand is able to perform a complex repertoire of sophisticated movements that enables us to interact with our environment and communicate with one another. The opposable thumb, a rarity in nature, has helped us achieve high levels of dexterity allowing our evolution to proceed rapidly over other creatures. To perform complex hand movements we need to synthesise an enormous amount of somesthetic information about our environment including fine touch, vibration, pain, temperature and proprioception. The sensory and motor cortices span large, complex areas of the brain and are devoted to interpreting the vast sensory input and using it to fine-tune the motor control of over forty separate muscles of the forearm and hand. This delicate, sophisticated arrangement allows us to perform precision activities such as writing and opening doors whilst simultaneously avoiding noxious stimuli. Loss of a hand can be devastating and unlike losing a leg the functional limitations following hand loss are catastrophic. The primary causes of hand loss are trauma, dysvascularity and neoplasia.

Men are significantly more likely than women to lose their hands with 67% of upperlimb amputees being male. Upper limb amputations most commonly occur during the productive working years with 60% between the ages of 16 and 54. The functional demands in this patient group are high and their expectations of a prosthetic limb mirror this. A few hundred years ago a hand amputee would have been condemned to a hook prosthesis that had limited function and carried significant social stigma. However, in today's society a hand amputee can expect a replacement hand that replicates a whole host of normal hand functions and looks remarkably life like. Significant advancements in bionic hand technology have occurred and this field is now considered to be a triumph of medical engineering excellence. The alternative option to a bionic hand is a hand transplant, which was first performed in 1999.

There have been successes in this field but there are major drawbacks to the widespread use of transplantation. The requirement for a donor limb that matches the recipient in terms of size and shape mean suitable donor limbs are rare.

The recipient's reliance on long-term immunosuppression and the complexity of transplant surgery are likely to limit transplantation as the major reconstructive option for amputees. Therefore, the more widespread option for an upper limb amputee is to opt for an artificial replacement. The modern prosthetic hand has been designed to closely approximate the natural limb in both form and function.

Despite the fact that the bionic hand was recently hailed as a triumph of engineering excellence it remains an inferior replacement to the real thing and consequently there are a number of barriers to its uptake amongst the upper limb amputee population. These prevent the prosthetic hand from achieving the ultimate goal of any prosthesis: 100% acceptance by its users. So, how close are we to creating an artificial hand that is a perfect replica of the real thing? Can we expect that medical and engineering advancements will continue to improve upon nature and eventually deliver a bionic hand that enhances our strength, speed and abilities far above human norms?

## Sensation

Our hands allow us to interact with our environment. We use the sensory input for touch, to fine-tune movements and to avoid harm. A continuing challenge for prostheses developers is to replicate the sensory function of the hand. Sensation in a bionic limb can be divided into two distinct categories esensory information interpreted by the device itself and sensation that is perceived by the user. Modern units have developed simple techniques for interpreting tactile sensory information that the devices use intrinsically to modify their activity. For example information on grasp strength ensures a user will not break objects by holding them too tightly whilst information provided by detection of sound from microphones embedded in the hand ensures that the object will not slip out of the grip and bedropped. This information, required for direct control of the device, can be interpreted via a low-level control loop thus decreasing the cognitive load of the user and increasing patient acceptability. These features improve the functionality of the device but do not provide the user with any sensory information about their surroundings. Providing a sensory input from a bionic limb that is capable of being perceived by the user is far more complex. One approach is to utilise the concept of multimodal plasticity where loss of one sensory modality can be compensated byanother. For example hearing can partly compensate for the loss of touch if auditory feedback is given when a bionic limb comes into contact with an object. Another approach is to try to replicate sensation by transferring stimuli from electronic sensors in the bionic limb to natural sensors on the skin of the limb stump which the patient perceives as coming from the amputated limb. This has been difficult to achieve but recent work has successfully replicated more complex sensory modalities such as cutaneous proprioception alongside fine touch and pain sensation. We hope that this technique can be further developed to provide a complete range of sensations. Direct interfaces with the peripheral or central nervous systems may provide the solution to enhanced sensation from bionic hands and ultimately come closest to restoring the original sensory perceptions of the hand. The use of intra-neural electrodes that are capable of delivering information directly to the peripheral afferent nerves within the residual limb has shown promising results in delivering meaningful sensations to amputees. Delivering sensations through this approach has been shown to improve control as it allowed amputees to control the grip force and joint position of their artificial limb more accurately without relying on visual input. One of the main advantages of a sensitised bionic limb is the accelerated rehabilitation program as the patient finds it more intuitive to learn how to control when they are receiving tactile feedback from the device. With advancements in these technologies we may soon be able to re-wire the sensory input to the peripheral nervous system so that the central nervous system can perceive sensations coming from a bionic limb as if it were the natural limb. The idea is that we no longer want the prosthetic hand to feel like a tool, we want it feel like an extension of the body.

Prosthetic arms that offers nerve stimulation have sensors in the fingertips, so that when the user comes in contact with something, an electrical signal on the skin corresponds to the amount of pressure the arm exerts. For example, a light touch would generate a light sensation, but a hard push would have a stronger signal.
However, there have been many problems with giving users reliable feedback, during ordinary wear over time, the electrodes connected to the skin can begin to peel off, causing a buildup of electrical current on the area that remains attached, which can give the user painful shocks.

Alternately, sweat can impede the connection between the electrode and the skin, so that the user feels less or even no feedback at all. So we have designed a controller (stimulator) to monitor the feedback the patient is experiencing and automatically adjust the current level so that the user feels steady feedback, even when sweating or when the electrodes are 70 percent peeled off.

What we found is that when we didn't use our controller the user could not feel the sensation anymore, However, when we had the controller on, after the activity the user reported that he could still feel the sensation [1-11].

This is a step toward making a prosthetic hand that becomes an extension of the body rather than just being another tool.

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