Neural interface technologies: non-medical applications inside the body

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This chapter discusses potential near-future technological advances that are likely to have an impact on the emergence of non-medical applications of neural implants in areas such as lifestyle, human interaction, and commerce.

Enabling technologies

Non-medical applications for implants will be enabled by several technological advances, particularly modularisation, miniaturisation, and connectivity.

Modularisation refers to the emergence of universal standardised modules and components such as batteries, microprocessors, radio chips, antennae and operating systems that are utilised in various types of implants. Modularisation is critical in making the implants suitable for mass production by lowering their cost without sacrificing their reliability and functionality[i] [ii].

Miniaturisation is also critical for mass adoption of the implants, as it addresses two major concerns with existing implants: poor cosmesis as a result of skin scarring at the implantation site and the high cost of implantation. By making the implant, and particularly the battery, small enough to fit inside an injecting needle or an arterial catheter, it can be placed inside the body in an outpatient procedure without the need for a surgeon or anaesthetist. Miniaturisation also lessens the possibility of side-effects by placing the miniaturised implant next to a specific nerve branch where it stimulates only the intended organ or tissue, thus reducing the risk of activating other nearby organs and tissues.

Finally, connectivity is critical for implant's configurability and responsiveness. Most existing neural implants are currently like televisions in terms of configurability and responsiveness, being limited to turning the device on and off, switching stimulation channels, and adjusting the level of stimulation. The implants of the future will be more like mobile phones in their configurability and responsiveness, with the stimulating implant being accompanied by a variety of sensors for monitoring the effects of stimulation on individual organs, bodily functions, and the user's overall state. These sensors could be either embedded with the stimulating device or distributed throughout the body as standalone sensing implants or wearable devices. Such sensors would have wireless connectivity, either with the stimulating implant or with a body-worn controller such as a smart watch, which would act as a hub for integrating the information from the sensors and stimulating device. The richness of the information collected from the sensors, combined with algorithms for its integration and conversion into intuitive graphical indicators, would allow users to engage in interactive control of their implants to achieve a desired level of functionality and satisfaction.

Non-medical applications

There are three principal modes of operation for neural implants: neuromodulation, neural sensing, and neural replacement.

Neuromodulation refers to using electrical or optical stimulation to tune the gain in existing neural circuits of the brain, spinal cord, and/or peripheral nerves. Such gain adjustments can be used to enhance or suppress emotional, sensory, or cognitive perception or to boost muscle activity. Possible non-medical applications could include: entertainment and gaming[iii]; mood and stress control; cognitive enhancement in terms of memory and learning;[iv] and muscle conditioning for military and athletic performance. Due to its ease of implementation among the three modes, neuromodulation would likely be utilised in the majority of non-medical applications.

The neural sensing mode could enable an additional range of non-medical applications by utilizing multiple sensing implants distributed throughout the body or the cortex. Such implants can be placed on the surface or inside various internal organs for monitoring their functions and, as sensing technology evolves, also on the nerves controlling these organs. Another type of sensing implant can be placed on the surface or inside the cortex for monitoring its functions. In the near term, the implants would likely be placed on the cortical surface, epidurally or subdurally, while in the longer term, the implants would eventually be small and flexible enough to be placed directly inside the cortical tissue. See the descriptions of neural dust and neural lace in the paper on medical applications inside the body). Possible non-medical applications for neural sensing implants could include: self-assessment and tracking of physical and metabolic states for personalized health and neurofeedback in wellness, sports and fitness training[v]; sensing of a user's mental and physical state in entertainment and gaming; and eventually, perhaps, communicating user's emotional and mood states to companies (with appropriate regulation and users' consent) – so-called 'neuromarketing' and to other humans where users could deepen social interaction (upon mutual consent and options to conceal certain emotions).

The third mode of operation for implants is neural replacement. Like the cochlear, retinal, and vestibular implants that are in use today, as well as the body suits and gloves with tactile feedback, these sensory-augmenting implants would provide novel artificial channels of input into the brain. Such implants would consist of multiple stimulation electrodes that are placed either peripherally near the nerve endings, for example inside the fingers or the mouth, or centrally in the sensory cortical regions, for example auditory or visual. These stimulating implants can convey information representing a variety of sensory modalities, such as: electromagnetic waves (from ultraviolet to visible, infrared, microwave, and radiofrequencies); acoustic waves; tactile feedback and motion (such as pressure, vibration, temperature, velocity, acceleration); magnetic and electric fields; radioactivity; and even the presence of various chemicals - the so-called 'electronic nose'. In addition to providing new sensory modalities, such implants can enhance the perception of existing modalities, for example increasing the directionality and sensitivity of auditory or visual information. The speed of sensory perception can also be enhanced, for example by routing visual information through the cochlear receptors, which have a considerably shorter time delay – or latency - for traveling to the cortex, compared with retinal receptors. Possible areas for non-medical applications of neural replacement implants could include: creating immersive environments for entertainment and gaming[vi]; hospitality[vii]; surgery; architecture; arts; education and training; shopping;

enhanced sensory perception and telepresence for military and police personnel; sports; travel[viii]; manufacturing; and work in hazardous environments.

Challenges and opportunities

Non-medical applications for neural implants are presently non-existent, despite their widespread medical use. The three technological advances described above – modularisation, miniaturisation, and connectivity - have potential to catalyse the emergence of initial non-medical applications in the near future. Following their initial adoption into consumer market, non-medical applications are likely to experience an exponential speed of market penetration and growth, as observed recently in the market for wearable devices such as smart watches in accordance with Moore's law.

In addition to this projected technological evolution, there is also likely to be an evolution in the acceptance of implants in our daily lives, as perceived risks with safety, privacy[ix], and security are outweighed by vastly expanded human capabilities and comfort, not attainable with non-implanted devices. The ethical and social dimensions of that process would require fundamental changes in personal attitudes as well as public policies[x] [xi] [xii] (as described in the paper on ethical and social considerations). Lastly, the emergence of non-medical applications is likely to trigger fundamental changes in their regulation and distribution. Non-medical implants may follow a similar path to the existing practice of direct-to-consumer marketing for health-monitoring wearable devices and DNA diagnostic tests, allowing them to better cater to users' values and needs.

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