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Scientific Contribution

Use of Brain-Machine Interfaces as Prosthetic Devices: An Ethical Analysis

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Abstract :

Brain-machine interfaces (BMIs) convert internal/neural information into external/functional control and transduce external/functional information into internal/neural activity. Ethical arguments over BMIs have often been connected with their potential impact on human nature and integrity. In that context, they are regarded as a threat to personal identity and autonomy in exchange for improved limb and brain function. BMIs can also be regarded as social resources that enhance the capabilities of both disabled and healthy people. This paper argues that non-invasive BMIs can be morally justifiable within a healthcare context for not only prosthetic use but also as physical enhancers, as exemplified by Robot Suit HAL. For example, BMI prosthesis can help recover physical performance in a paralyzed patient or enable a female family caregiver to lift an elderly relative. A list of suggested central principles, technological requirements, and power output limitations is provided for at least the early applications of prosthetic and enhancement uses of HAL-type BMIs.

Keywords : brain-machine interface, prosthetic, enhancement, autonomy

1. Introduction

Brain-machine interfaces (BMIs), also known as brain-computer interfaces (BCIs), convert internal/neural information into external/functional control and transduce external/functional information into internal/neural activity. Rapid developments in this relatively new field have resulted in a wide range of pre-clinical and clinical applications. Schermer has indicated five BMI categories that are either already possible or under development: (1) *sensory prostheses* such as cochlear implants and artificial retinas, (2) *deep brain stimulation (DBS)* of specific areas by inserted electrodes, (3) *neuroprostheses* that enable the control of objects with thought (e.g., cursors, computers, robotic arms), (4) *neurofeedback* that detects brain activity to warn of or prevent physiological episodes (e.g., epileptic attacks), and (5) *exoskeletons* that are worn to provide additional strength and power. [1]

In the neuroethics branch of bioethics literature, arguments over BMIs have often been connected with the potential impact of the technology on human nature. [2-3] In these arguments, BMIs are seen as a threat to personal identity and autonomy in exchange for improved limb and brain function. Once BMIs have the capability of uploading memories to a chip, for example, personal identity could be cloned and even immortalized digitally. [4] A third-party human or machine could also directly control and monitor the thoughts and movements of a person whose brain is connected to a computer network.

In spite of the negative implications, BMIs are simultaneously regarded as positive social resources that could enhance the capabilities of people with disabilities (e.g., an artificial retina for the visually impaired, DBS for those with Parkinson's disease or depression). The aim of this paper is to illustrate the moral arguments with clinical BMI applications for Japanese patients with neurological disabilities and their families. With the current positive and negative visions of BMIs, a wide range of perspectives are needed to cover normative and empirical ethical viewpoints.

2. BMIs as healthcare resources - Robot Suit HAL

The bright horizon of BMIs has inspired international rivalry since the 1990's, with Japan attempting to maintain its competitive position. Japanese neuroscientists have repeatedly expressed anxiety about losing ground to the United States (US) and Europe due to insufficient government research funding, which has decreased over the years after peaking in 2000. While the 2007 neuroscience budget was $347 million USD in Japan, it was $660 million USD in the US and $278 million USD in the United Kingdom (UK). [5] Scientists also pointed out that the annual neuroscience budget as a percentage of total expenditures for the life sciences was only 7% in Japan, but 17% in the US and 19% in the UK.

Requests for government support led to several major projects organized by agencies such as the Ministry of Education, Culture, Sports, Science, and Technology (MEXT), the New Energy and Industrial Technology Development Organization (NEDO), and the Japan Science and Technology Agency (JST). Robot Suit HAL (for Hybrid Assistive Limb) was one of these projects, developed by Sankai and colleagues at the University of Tsukuba and the venture company Cyberdyne Inc. [6] as part of MEXT's "21st Century COE Program" and the government's "Funding Program for World-Leading Innovative R&D on Science and Technology." HAL is a union of the *neuroprosthesis* and *exoskeleton* BMI categories. The system is designed to supply deficiencies in muscular movement according to the user's mental intent, like a neuroprosthetic, but is also worn around the body to provide strength and power not intrinsically possessed, like an exoskeleton.

> "Robot Suit HAL" is a cyborg-type robot that can expand and improve physical capability. When a person attempts to move, nerve signals are sent from the brain to the muscles via motoneurons, moving the musculoskeletal system as a consequence. At this moment, very weak biosignals can be detected on the surface of the skin. "HAL" catches these signals through a sensor attached on the skin of the wearer. Based on the signals obtained, the power unit moves the joint in union with the wearer's muscle movement, enabling support of the wearer's daily activities. [7]

On one hand, HAL is a "voluntary control system" that interprets the wearer's own intentions and provides movement in accordance with their intentions only. On the other hand, HAL is also a "robotic autonomous control system" programmed to provide independent, human-like movement.

(1) *Benefits to patients – BMIs as prostheses*

HAL-type BMIs are expected to benefit a wide range of patients who have paralysis caused by various etiological factors, as long as the bio-electrical sensor can read signals from the patient's brain. Neuroprostheses typically require electrodes or chips implanted into the brain or other parts of the body, which must be surgically removed for repairs. In contrast, HAL is a non-invasive neuroprosthesis that can be easily attached to and detached from the body. HAL also provides options for patients with more severe physical conditions. Conventional robotic assistive devices are limited by the necessity for residual motor ability; however, HAL is significantly less dependent on residual motor ability because it detects brain-to-muscle signals via the skin surface. Patients who lack even limited muscle control could be rehabilitated with HAL as long as brain-to-muscle signals are detectable on their skin.

(2) *Benefits to caregivers – BMIs as enhancers*

Robotics can benefit caregivers as well as patients in healthcare settings by providing additional strength and power to accomplish tasks. Many industrialized countries such as Japan are rapidly aging and suffer from a shortage of resources for the elderly and disabled. This scarcity has provoked ethical controversy across generations and genders over the cost and labor of caregiving. In Japan, primary caregivers for elderly invalids have predominantly been female family members. As the family system has shifted from an extended family headed by older parents to older parents functioning as an independent family unit, the role of primary caregiver has shifted from younger daughters-in-law to spouses (mainly older wives).[8] HAL worn by caregivers can supply the additional power for even female caregivers to carry their parents or husbands.

3. Ethical arguments on BMI use

(1) *Justification of BMIs as enhancers to improve healthcare*

Limiting BMIs to therapeutic use only has been widely accepted in bioethics literature, while BMI enhancement of otherwise healthy people has less been accepted. As described in the previous section, however, BMIs can be utilized not only as prostheses for patients, but also as enhancers for caregivers in a healthcare setting. Rawls' second principle of justice, fair equality of opportunity, requires that citizens with the same talents and willingness to use them have the same economic opportunities regardless of whether they were born rich or poor. BMI enhancers can be convincingly justified if the recipients are family caregivers, who would fit into Rawls' "worst off" groups – that is, the least-advantaged members – in the context of Japanese healthcare. If this principle is applied to the enhancement discussion, caregivers are entitled as the least-advantaged members in healthcare to use robotic exoskeletons so they can be of the greatest benefit.

The application of Rawls' second principle of justice to healthcare issues has also fueled controversy over the definition of "worst off" in a healthcare context, as well as the benefits given to the worst off compared to others.[9] According to Daniels, Rawls' claim needs to account for a fair process of setting limits or rationing care under conditions that comprise reasonable accountability.[10] It must therefore be demonstrated that HAL can be utilized with reasonable public expenditures - including initial investment costs financed by the government, running costs for electricity and mechanical maintenance, and subsidies for distribution of the device - compared to other medical options that would provide similar benefits to family caregivers.

(2) *Are BMIs a threat to personal autonomy?*

In bioethics literature, autonomy can be defined both narrowly and widely. Autonomy in the narrow sense is regarded as the right to make informed and voluntary decisions, which in turn requires healthcare providers to obtain informed consent from patients. The wider concept of autonomy requires healthcare providers to see patient autonomy from multiple angles. European scholars claim autonomy should be understood as the capacity for (1) creation of ideas and goals, (2) moral insight, "self-legislation," and privacy, (3) rational decisions and actions without coercion, (4) political involvement and personal responsibility, and (5) informed consent. [11]

HAL is not immune to the criticism that BMIs can threaten personal autonomy when it was narrowly conceptualized. As previously mentioned, all its computer-assisted movement originates from and is controlled by the patient ' s own will. Because neural signals are often unclear and unstable, however, they may need to be compensated for or amplified by computers. In those cases, the computer calculates what kind of movement and how much power the patient intends to generate. When a HAL-type BMI is connected to a computer network, another person on the network can remotely monitor and even control the patient's movements. Taken further, BMIs could easily be converted into weapons that give its wearers super-human output controlled by them or someone else. Personal autonomy can be analyzed for BMIs in a similar manner as conventional automotive vehicles. Cars today are controlled by not only the driver but also computers. In four-wheel steering systems, for example, the rear wheels do not turn as far as the front wheels due to computer calculations. Also, a car could theoretically become a weapon if the driver acts in bad faith or the car is controlled by hacking into its computer system. Ethical deliberations need to be addressed in both autonomous and heteronomous directions because harm can be done from the reckless handling of the user or outside manipulation by a third party. The range of user control must be limited to only the justifiable purposes of the machine - transportation for a car and prosthesis for HAL. BMI prostheses for paralyzed patients should therefore be justified as long as power output is within the range of an average person's movement, while enhancement for caregivers should be set within the range of daily caregiving (e.g., the power of a healthy young man to enable a female or older caregiver to carry one person). In addition, the core system of the BMI should be secured from heteronomous control by third parties or even a computer, which illustrates popular BMI concerns discussed in the next section.

The broader aspects of autonomy can justify prosthetic use of HAL if the device reinforces the social and political capacities of the wearer. HAL-type BMIs could provide easier access to social resources (e.g., a supermarket or hairdresser) or political activities (e.g., attendance at town meetings on a new policy) without the aid or interference of others. However, use as an enhancer for these purposes would require further discussion on the extent of human capacity achievement that would be ethically acceptable. Even if HAL was used by a family caregiver to assist his/her elderly mother, some aspects of autonomy could be enhanced beyond his/her reach when s/he is not in the exoskeleton. This should be viewed as a human nature matter, which is discussed in the next section.

(3) *Can BMIs alter human nature?*

The symbolic impact of BMIs has been frequently discussed in bioethics literature with the implication that the blurry distinction between man and machine might lead to the creation of cyborgs or monsters, endangering human morality by demolishing the concept of the person. [12] Western moral philosophy is often discussed as presupposing the subjectivity of human mind over human (and non-human) bodies and objects (such as machines). The modern concept of subjectivity in Western philosophy first emerged with Descartes' *cogito* (I think), which in effect equates a subject with a thinking subject, and then expanded with Kant's rational being, who is honored with the highest value of dignity as an autonomous subject as long as he self-legislates moral law.[13] In a previous study, I noted that European philosophy, especially Kantianism, and current bioethics share viewpoints that dissociate mind from body and subjectivity from objectivity, leading to absolute human subjectivity.[14] We as subjects thus (1) have ruling power over not only cognition, but also the use of our objects, and (2) are never supposed to be turned into slavish objects. These viewpoints may explain the concern that BMIs could jeopardize human morality.

Considering that HAL was designed as both a neuroprosthesis and an exoskeleton, the question is whether it can obfuscate the border between man and machine to alter the human nature of the wearer. This argument can be connected to the European concept of autonomy mentioned in the previous subsection, which emphasized a wide range of individual capacities and social or political conditions, as well as a basic principle of integrity. European scholars proposed the concept of integrity as an independent principle of bioethics that accounts for the inviolability of the human being, referring to "the coherence of life in time and space (in memory and corporeal life) that should not be touched and destroyed."[15] Rendortff gave four meanings for integrity: (1) a narrative totality, wholeness, and completeness; (2) a personal sphere of self-determination; (3) a virtue of uncorrupted character, expressing uprightness, honesty, and good character; and (4) a legal notion, expressing moral coherence of the legal or medical system.[16]

This integrity-based argument supports HAL for not only prosthetic use but also as an enhancer for caregivers, with some limitations. First, proposed prosthetic users of HAL would be patients with paralysis who lack physical wholeness. They are therefore entitled to recovery of this wholeness by any available medical procedures, including HAL. Family caregivers who need HAL-type BMIs can be reasonably assumed to suffer from the hard labor of caregiving, which is considered to be an uncoerced moral or social obligation. These caregivers would thus reasonably require

HAL to alleviate their burden. However, use of HAL as a prosthetic or enhancer requires prudent ethical guidelines to secure the status of BMI users as autonomous subjects and prevent them from becoming heteronomous objects, ruled by a third party or computer. Practical strategies to prevent an override of the human user's intentions include monitoring the operation and level of power support given by the devices, and including a means to shutdown the device by not only by the wearer but also an external person in case of mishaps.

4. Conclusion and Suggestions

This paper has outlined arguments proposing that both therapeutic (or prosthetic) and enhancement uses of non-invasive BMIs can be morally justifiable within a healthcare context, as exemplified by Robot Suit HAL. I conclude with a list of suggested central principles, technological requirements, and power output limitations for at least the early applications of HAL-type BMIs in healthcare settings:

A. Central principles
- *safety* (do no harm)
- *autonomy* (secure status of the user as the controller)

B. Technological requirements
- *easy to detach and remove*
- *remote monitoring and shutdown*

C-1. Power output limitations for prosthetic use
- within the range of an *average person's movement*

C-2. Power output limitation for use as an enhancer
- within the range of *daily caregiving*

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