Present and Future Developments in Cognitive Enhancement Technologies

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Abstract

The last two decades has witnessed an exponential growth in neuroscience and molecular biology, which have opened the way for various cognitive enhancements. Current cognitive enhancements are in three main areas; brain-machine interfaces, cosmetic neurology and neurosurgery. With improvements in gene technology, information technology and nanotechnology these three areas will become more widespread. This article will explore current and future cognitive enhancement technologies with a focus on brain-machine interfaces (BMIs) and cosmetic neurology. My aim is to provide the reader an insight into the cutting edge arena of cognitive enhancement technologies.

Keywords: cognitive enhancement technologies, brain-machine interfaces, cosmetic neurology

Introduction

The last twenty years have seen the rise of neuroscience, molecular biology and brain imaging technologies which have changed our understandings of the human brain. Neuroscientific disciplines are currently underway in developing an array of therapeutic cognitive enhancements for humans. The aforementioned technologies are in their pioneering stage with the promise of further insights into understanding the brain. By some accounts the twenty first century will be to neuroscience as the twentieth century was to physics.

Present developments in cognitive enhancement technologies are in three areas; brain-machine interfaces, cosmetic neurology and neurosurgery. While brain-machine technologies are in their infant stage, cosmetic neurology and neurosurgery are being increasingly used for the treatment of mental illness (Farah, Cook-Degan, Gardner, 2004, p.421). Alternatively, transcranial magnetic stimulation (TMS) is targeting brain areas with the promise of developing new treatments for depression and other psychopathology (Farah *et al*, 2004, p.421).

New developments in cognitive technologies will inevitably push them beyond their therapeutic treatments and into the realm of enhancement treatments. The availability of such enhancement technologies will have a profound effect on the socio-ethical dimensions of societies. For example, the increasing use of neural prosthetic devices may predictably become normalised as a necessary interface in order to function normally in future high tech societies. While there is concern about the direction of current and future biotechnologies given by Fukuyama (2002), the increasing use of biotechnologies in defining human beings will probably be inevitable. This is mainly due to the medicalisation of the human body in bio-western medicine which tends to view the human body as a machine. Lupton (2000, p.72) notes that the western 'machine metaphor' has routinely subjected the human body to a clinical gaze with its entourage of surveillance techniques.

According to Bostrum and Sandberg (2006, p.1), a cognitive enhancement may be defined as "the amplification or extension of core capacities of mind through improvement or augmentation of internal or external information processing systems.". In contrast, a therapeutic intervention aims at "correcting a specific pathology or defect" (Bostrum & Sandberg, 2006, p.2). Notwithstanding these definitions, the line between therapeutic and cognitive enhancements is becoming increasingly blurred (Pieters & Snelders, 2009). For example, amphetamines are being increasingly prescribed for improving mental tasks while some serotonin reuptake antidepressants (SSRIs) are being used by healthy individuals to improve mental well being (Farah *et al*, 2004). Furthermore, Naam (2005, p.175) avers that current neuro-scientific research is learning which neurons in the brain respond to different kinds of visual, audio and sensation stimuli. Such investigations have begun in order to comprehend the workings of complex neural systems. The next step will be to ascertain how the brain endows higher functions such as memory, emotion and language.

This article will explore current and future cognitive enhancement technologies with a focus on brain-machine interfaces and cosmetic neurology. My aim is to provide the reader an insight into the cutting edge arena of cognitive enhancement technologies. The first section will discuss current work in brain-machine interfaces. The second section will examine cosmetic neurology and its increasing use in non-therapeutic treatments.

Brain-Machines Interfaces

Recent work on brain-machine interfaces (BMIs) investigates "capturing and using improvement signals from the brain and carrying sensory inputs to the brain" (Farah *et al*, 2004, p.41). Present research is based on the need to better understand neural coding, sensory and memory information. A second aim is to assist paralysed patients and those individuals suffering from "peripheral sensory impairments" (Farah *et al*, 2004, p.41). A third motivation for BMI research is to be able to ascertain cognitive advantages of having neural prostheses within a military arena where split second decision making is vital (Farah *et al*, 2004, p.41; Hoag, 2003).

BMIs have been developed over the last eighteen years with considerable research being done on them. Most BMIs are currently in their developmental stage with applications for humans in the not too distant future (Anderson, Birdick, Musallam, Pesaran, & Cham, 2006). The next ten years will be a pivotal phase for BMI development, both in the areas of invasive (intra-cranial) and non-invasive (electroencephalograms). Recent development in BMIs is promising. Scientists can now clinically create conditions under which "the brain undergoes experience – dependent plasticity," whereby prosthetic devices may become a part of a subject's body (Lebedev & Nicolelis, 2006, p.539). Neural interfaces may eventually enable humans to tinker with the inner workings of the brain and connect them to computers. This process may offer enhanced intelligence and greater emotional control (Naam 2005, p.176). The future effectiveness of BMIs lies in their ability for greater precision than mind-altering drugs. Here, BMIs are aimed at specific neural tissue, thereby promising fewer side effects which may faster than pharmacological substances (Naam, 2005, p.195).

The futurist Ray Kurzweil states that neural implants will be able to interact with virtual environments providing a range of sensory perceptions and sensations which are beyond the range of the biological body (2000, p.144). Such a range of sensations may in turn lead to a dramatic increase in intelligence and understanding of the world (Kurzweil 2000, p.144). In addition, determining the neurological correlates for spiritual experience will render humans greater spiritual experiences in the future via stimulating cortical centres such as the frontal lobes (Kurzweil, 2000, p.153). Kurzweil's vision corresponds with Newberg and Lee who point out that neural implants could tap into the brain centres which co-ordinate religious experiences and myth making proclivities in humans (2005, p.481). Inevitably, future humans will be able to use various kinds of brain-machine interfaces such as neural implants for experiencing new kinds of virtual realities. Greenfield proposes that future humans will share highly interactive virtual environments with robots and with advanced IT (2003, p.48). Like Kurzweil, Greenfield suggests that future humans may "experience states of consciousness that current human brains cannot access" (2003, p.48).

While Kurzweil, Greenfield and Naam provide fascinating insights into the potential of BMIs for steering future human evolution, current work on BMIs has been pioneered by the neuro-therapeutic work of Edward Schmidt (1980). Schmidt proposed that "voluntary motor commands" could be drawn from the electrical activity of the brain's neurons, thereby bypassing spinal cord lesions (Nicolelis, 2003). This was an innovative idea at the time and has been mainly developed by the work of leading BMI neuroscientists Phillip Kennedy and Miguel Nicolelis. In relation to the future of neural prostheses and future humans, Kennedy remarked:

> *If we can provide the brain with speedy access to unlimited memory, unlimited calculation ability, and instant wireless communication ability we will produce a human with unsurpassable intelligence. We fully expect to demonstrate this kind of link between brain and machine (Baker, 2008, p.52).*

Kennedy also predicted that future neural implants being able to download information to the brain in order to augment intelligence. Kennedy also hopes that in the future a neural prosthesis will be implanted in the brains of great apes which may endow them with "synthesized speech" (Naam, 2005, p.54). This would be an unprecedented breakthrough in inter-species communication.

In 1989 Kennedy patented a device, called a neurotrophic electrode, which he had tested on monkeys. The device could "amplify neural signals about 10,000 times" and convert them to radio waves which were then transmitted to a computer (Baker, 2008, p.52). In 1996 Kennedy used his device on the first human, called Johnny Ray - who had suffered a brain stem stroke which had left him paralysed with the exception of a few facial muscles. A neuroptrophic electrode was implanted in the part of Ray's brain which controlled his left hand. Ray was encouraged to think about moving the computer mouse with his left hand. Rays' intentions had triggered neural activity which controlled mobility. Within six months Ray could control the cursor on the monitor through intention alone (Baker, 2008, p.54). In 2000, Nicolelis had implanted 100 wires into the motor cortex of a monkey called Belle. Belle was given a joy stick which sent signals to a computer. The computer then sent signals to a robotic arm which had "precisely mimicked" the movements of Belle's arm.

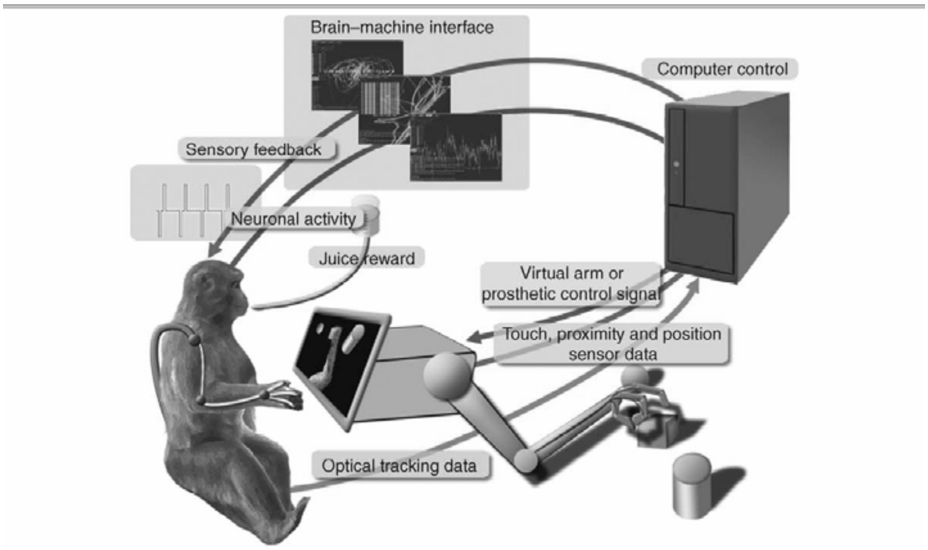

Figure 1. Monkey using manipulator

"A BMI with multiple feedback loops being developed at the Duke University Center for Neuroengineering. A rhesus macaque is operating an artificial robotic manipulator that reaches and grasps different objects. The manipulator is equipped with touch, proximity and position sensors. Signals from the sensors are delivered to the control computer (right), which processes them and converts to microstimulation pulses delivered to the sensory areas in the brain of the monkey, to provide it with feedback information (red loop). A series of microstimulation pulses is illustrated in the inset on the left. Neuronal activity is recorded in multiple brain areas and translated to commands to the actuator, via the control computer and multiple decoding algorithms (blue loop). Arm position is monitored using an optical tracking system that tracks the position of several markers mounted on the arm (green loop). We hypothesize that continuous operation of this interface would lead to incorporation of the external actuator into the representation of the body in the brain. Figure designed by Nathan Fitzsimmons" (Lebedev & Nicolelis, 2006, p.542).

In 2003 researchers implanted 700 electrodes in the motor cortices of rhesus monkeys. Each monkey was trained to control the joystick using a robotic arm. A computer attached to the electrodes discovered a pattern between neural firing and the robotic arm's movements. In essence, this experiment had revealed the "neural encoding of motor control," and the existence of a feedback loop between human and machine (Naam, 2005, p.117). A similar brain-interface development was reported by Wolpaw and McFarland (2006) which employed 64 electrodes to subjects who were asked to control a computer cursor using "EEG signals recorded from the surface of the head" (Foster, 2006. p.189).

In January 2008 Nicolelis advanced his research by implanting electrodes in a rhesus monkey's brain which controlled leg movement. In the experiment neurons seemed to "anticipate movement, allowing the system to transmit to an internet connection" at Kyoto, Japan "and into the actuations of a robot named CB-1 (computational brain)" (Baker, 2008, p.54). An alternative approach which may yield higher BMI performance is to predict neural activity of an intended target and immediately placing a cursor precisely in that location (Santhanam, Kyu, Yu, Afshor, & Shenoy, 2006, p.195).

Despite these developments in BMIs there are some technical problems. The first problem is that patients have to submit to brain surgery in order to have electrodes connected to neural tissue (Foster, 2006, p.189). This also poses the possibility of infection. Next is the bandwidth of an EEG signal. EEG signals are much smaller than implanted microelectrodes. At present EEG transfer information is relatively slow at about 20-30 bits/min (Foster, 2006, p.189). Positioning of microelectrodes is also critical in order to optimise on signals from cortical neurons (Foster, 2006, p.189). Furthermore, present technology can only record a small amount of neurons, in comparison with the thousands of neurons which are involved in basic body movement (Foster, 2006, p.189).

Between 1994 and 2003 there have been 19 approved neurological devices and as many as 59,000 human recipients of these since 2002 (Foster, 2006, p.185). Many of these have been cochlear implants which transduce sounds to electrical signals via electrodes implanted within the cochlea (Foster, 2006, p.185). A newer neural device is the auditory brainstem implant which was first used in 1979. This device is connected to the brainstem and employs a speech precursor and microphone (Foster, 2006, p.186). The auditory brainstem implant is used on patients whose auditory nerves do not function due to surgery (Foster, 2006, pp.185-186).

By comparison, visual prostheses are in their developmental stage. Several types of these devices are currently being developed by stimulating the human "visual system at different levels" (Foster, 2006, p.186; Hossain, Seetho, Browning, & Winifred, 2005). Two devices being developed are the artificial retina and the Optobionics device. The artificial retina converts light from outside sources which stimulates the retina and is used by patients who are suffering from retinal degeneration (Foster, 2006, p.186; Chow, Chow, Packo, Pollack, Peyman, & Schuchard, 2004).

Alternatively, the Optobionics device, which has been in the clinical trial stage since 2000, is composed of approximately 5000 micro electrode-tipped photodiodes and is powered by light on the retina (Foster, 2006, p.186).

Another BMI development is the artificial hippocampus, which was given wide media coverage in 2003. This neural prosthesis has been developed by Theodore Berger at the University of Southern California (UCLA). Berger and colleagues mapped hippocampal signal patterns by via stimulating rat's hippocampus with electrical signals in order to determine neural outputs (Kurzweil, 2005, p.188). From there a mathematical model was developed of the transformations performed by hippocampal layers. The model was then programmed onto a chip (New Scientist 2000). The ultimate aim is to create a chip which would be placed on a patient's skull and which could communicate with the brain via two electrode arrays, located on either side of the damaged hippocampal area (Kurzweil, 2005, p.188). The electrodes would "record electrical activity from the rest of the brain," as well as sending instructions back to the brain (Kurzweil, 2005, p.188). Such a chip would be used by patients who have suffered hippocampal damage due to stroke, Alzheimers, epilepsy, and psychopathology.

Cosmetic Neurology

I want to begin this section with a vignette as a way of unpacking some of the major issues of cosmetic neurology. The narrative is taken from Chatterjee (2006), who is seeing a specific patient. The patient is an adult male who is a businessman, and is intending to go to Saudi Arabia in order to clinch a business deal. As a way of edging his competitors he begins to learn Arabic. He has approached Chatterjee with the hope that the latter can prescribe him with pharmaceutical substances which will improve his cognitive skills. Chatterjee then prescribes him a small dose of Dextro-Amphetamine, the hypnotic Zolpidem, and a stimulant, Modafinil. Chatterjee's decision to prescribe dextro-amphetamine (a noradrenergic agonist) is partly based his knowledge of it as being a putative memory improver, fostering neuro-plasticity, and boosting language learning (Breitenstein, Wailke, Bushuven, Kamping, & Zwitserlood, 2004; Chatterjee, 2006, p.110; Stroemer, Kent, & Hulsebosch, 1998).

The use of pharmacological substances to enhance 'normal' neurocognitive function is an increasing trend in many societies (Farah *et al*, 2004, p.421). These include Methylphenidate for Attention Deficit-Hyperactivity Disorder (ADHD), which has become prevalent among children in the United States and Australia (Diller, 1996; Farah *et al*, 2004, p.421). The significance of the rise of ADHD among children may be suggested as a relevant example of medicalising behavioural traits such as disorderliness and boisterous behaviour (Diller, 1996). This process of medicalising behaviours is concomitant with the growth of cosmetic neurology. What is significant here is the increasing use of pharmacological substances for non-therapeutic purposes by healthy adults. For example, studies indicate that prescription stimulants (Dextro-Amphetamine and Methylphenidate) are being used as study aids by approximately 18% of American campus students (Babcock & Bryne, 2000; Farah *et al*, 2004, p.421).

Different types of drug therapies are being currently used to enhance motor systems such as dopamine agonists for improving motor performance. These agonists are known to improve neural plasticity in motor learning, especially the use of dextroamphetamine in conjunction with therapy for brain trauma and stroke patients (Chatterjee, 2006; Walker-Batson, Smith, Curtis, Unwin, & Greenlee, 1995; Grade, Redford, Chrostowski, Toussaint, & Blackwell, 1998; Crisostomo, Duncan, Propst, Dawson, & Davis, 1988; Goldstein, 2000; Long & Young, 2003). In the forthcoming decades novel ways to manage cognitive disorders will be available for various diseases such as Alzheimers and Parkinsons to name a few. Improvements in cosmetic neurology will increase due to refinements in neuroscience in combination with molecular biology and nanotechnology. Moreover, attention-modulating drugs such as Cholinesterase Inhibitors may be prescribed for cognitive performance improvement (Connemann, Mumenthaler, Yesavage, Taylor, Friedman, O'Hara, Sheikh, Tinklenberg, & Whitehouse, 2003), Modafinil for increased vigilance (Turner, Robbins, Clark, Aron, Dowson, & Sahakian, 2003), and Atomoxetic for augmenting arousal levels (Babcock & Byrne, 2000). Modafinil has been "found to increase forward and backward digit span" "reaction time/latency on different working memory tasks", spatial planning and visual pattern recognition (Bostrum & Sandberg, 2006, p.8; Turner *et al*, 2003). Clinical studies have also shown that Modafinil, which was originally developed to treat narcolepsy, "improved attention and working memory in sleep deprived physicians" (Bostrum & Sandberg, 2006, p.8; Gill, Haerich, Westcott, Godenick, & Tucker, 2006), and aviators (Caldwell, Chaldwell, Smythe, & Hall, 2000).

Another major area of cosmetic neurology is in mood modulating pharmaceuticals, which include anti-depressants. It has been estimated that one in five Americans are believed to suffer from depression (The National Institute of Mental Health, 2003), while nearly half of Americans suffer from affective and substance abuse illnesses (Kessler, Wat Tat Chiu, Demler, & Walters, 2005). According to Pieters and Snelders (2009) and Barber (2008), treatable depression has risen five fold in the last twenty years. Major anti-depressants presently used are serotonin reuptake inhibitors (SSRIs) for promoting mental well being, while beta blockers are used to manage anxiety and post traumatic stress syndrome. There is some speculation that in the future antidepressant drugs could be used to reinforce social conformity and diminish certain 'deviant' behaviours. The "transformative potential" of such drugs to alter brain chemistry should not be dismissed, considering their popularity among the mentally ill and a growing number of healthy individuals (Caldera, 2008). Despite rising consumption of certain SSRIs such as Zoloft and Prozac there is a concern that they could be linked iatrogenic caused addiction (Pieters & Snelders, 2009). There is little doubt that the pharmaceutical industry has been able to capitalise on antidepressants, sedatives and hypnotics based on the mantra that "individual management" of illness is crucial to recovery (Pieters & Snelders, 2009). Importantly, however, is how individuals are turning to various drug therapies as a part of personal health management. Keeping this in mind, the question arises whether "neuropsychopharmacological semantics" is redefining the boundaries between healing and enhancing (Pieters & Snelders, 2009; Moncrieff, 2008).

In the near future various neuropeptide substances will be used for modulating affective states (Holmes, Heilig, Rupniak, Steckler, & Griebel, 2003), including Vasopressin, Corticotropin Release Factor (CRF) (Kosfeld, Heinricks, Zak, Fischbacher & Fehr, 2005), Neuropeptide Y., and Galanin. Oxytocin (the 'cuddle hormone') is presently being prescribed via inhalators in order to foster feelings of trust, which affects other behaviours (Walker, Toufexis, & Davis, 2003).

Conclusion

Advancements in BMIs and cosmetic neurology have progressed due to increasing understandings in the function of the human brain. Both technologies will continue to improve as they incorporate nanotechnology and information technology. As Foster claims: "We can assume that, as time goes on, implants will become smaller, smarter, more effective, and less expensive, and their implantation in the brain will be less destructive of brain tissue" (2006, p.190).

There is considerable speculation about the role of nanotechnology in future developments of BMIs and cosmetic neurology. For example, Kurzweil predicts that by the 2020s nanobot technology will expedite our knowledge of the brain via the incorporation of nanobots inside neural tissue. Such nanobots would be carbon based and diamond shaped and would be more resilient than biological tissues, allowing their movement into neural tissue with minimal brain intrusiveness (Freitas 1999; Kurzweil, 2005, p.164).

Another important area of interest is the convergence of nanotechnology, biotechnology, information technology and cognitive science (NBIC). NBIC is a rapidly growing area and has been the topic of various conference and reports, among them the National Science Foundation report by Roco and Bainbridge (2002). In 2004 the European Commission issued a report "panelled by 25 high-level scientists", which discussed potential technological developments in NBIC (Foster, 2006, p.191). The European panel predicted that NBIC would take "between 10-20 years to mature" (Foster, 2006, p.191). The current state of BMIs, for example, which can only record a few dozen neurons at a time, needs greater development (Foster, 2006, p.191).

The sheer size of the brain's neural network, comprising of approximately 100 billion neurons and over 100 trillion synaptic connections will be an enormous challenge for NBIC in the future. Fantasies about mind control will remain elusive since science has yet to determine "how the brain encodes memory" and, more fundamentally, how the mind works (Foster, 2006, p.193). Developments in BMIs, for example, will probably comprise two phases; the current phase consists of therapeutically based BMIs for disabled persons, and in the second phase BMIs will be developed to enhance cognitive and motor skills in healthy humans (Foster, 2006, p.193). McGee and Maguire (2001) also predict a third phase in BMI development which will involve the use of neural devices for "information transfer capability." While this phase is still a long way off it does indicate future BMI possibilities once the technology is developed.

In relation to cosmetic neurology, a new generation of mind altering pharmacological substances is being presently developed with increased capability and neural precision. While the use of pharmacological substances is increasing in some societies due to a rise in mental illness and age onset neurological diseases in mainly OECD countries, their cognitive enhancement inducing properties may probably supersede their therapeutic uses. The use of Dextro-Amphetamine by American college students is a good example of this genre. With improvements in brain understanding, cosmetic neurology may offer a range of novel developments in the areas of psychotropic drugs which could be used in comprehending altered states of awareness. For example, if in the future a drug could be developed which influences the rate of neural activity in the Posterior, Superior Parietal Lobe then we could better understand the neural substrate of transcendental states, which may have far reaching ramifications for religion. Also, in the near future special drugs may be developed for use in tandem with virtual realities. Such a combination will probably have various recreational and military purposes. In the distant future developments in cognitive enhancement technologies may prove to alter human evolution. If this is the case, then, we may be currently witnessing the nascent stage of a new human evolution.

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