Chapter 3

Neurotechnology
I. VARIOUS APPLICATIONS OF NEUROTECHNOLOGY


Small firms specializing in new medical technology are beginning to change the way that we live. For example, Massachusetts-based Cyberkinetics Neurotechnology Systems is developing a state-of-the-art brain implant that may one day enable quadriplegics to move a computer cursor using only their thoughts. The implant is approximately the size of a baby aspirin. Once attached to the human brain, it is used in conjunction with advanced software to effectively interpret brain signals. To date, however, it has only been tested with one such individual. Four additional patients will begin using it soon.

Neurotechnology is also being used in a variety of other new innovations. For instance, surgeons are now beginning to help accident survivors regain their mobility through the use of nerve transplants. In addition, new electrical stimulators are being developed that can be implanted in the wall of the stomach to send signals to the brain that a person is full (even when he or she actually is not) to prevent overeating and combat obesity.


Over the past decade, rapid advances in diagnostic medical technologies have revolutionized neuroscience. Scientists continue to learn more about how the brain functions, is structured, and influences human behavior. Today’s advanced techniques can be used reliably to measure noteworthy changes in brain activity that are associated with various behaviors, feelings, and thoughts.

Emerging neurotechnologies that record electromagnetic signals from the brain offer new hope for detecting deception and truth-telling. Some hold the potential for being superior to conventional polygraphy. As a result, the ethical issues associated with the use of reliable brain-imaging deception technology are quite complex, and they include matters of personal privacy, security, and acceptable forms of evidence in legal cases. In addition, techniques in the field of neuroscience tend to lack standardization and may be vulnerable to countermeasures that are currently unknown. As a result, it is possible for individuals to misapply such technologies either intentionally or because they misunderstand them.

Researchers in the United States have successfully trained monkeys to control a robot arm using only their brainwaves. This reality is being viewed as a substantial step forward in creating “neurobots” and brain-operated devices for paralyzed individuals and others. Most notably, the researchers found that the monkeys’ brains came to regard the mechanical add-on as a part of their own bodies. This offers new hope and directions for the further development of brain-machine interface technologies.

In their studies, the researchers connected a computer, as well as the robot arm, to two monkeys via the use of numerous microelectrodes that were implanted in their brains. They then trained the moneys to maneuver the robot arm using a joystick in response to visual cues on the computer screen. Eventually, they took the joystick away from the monkeys, who were then found to be able to move the robot arm by their thoughts alone.


A group of researchers being led by Professor John Donoghue at Brown University is investigating the interpretation of neural activity as it pertains to the field of neurotechnology. Based on the findings of previous studies, which have determined that specific regions of the brain generate signals that are used to command the arms, legs, and face, they hope to learn more about ways that nerve networks that have been damaged by injury or disease can be successfully replaced by electronic counterparts. Doing so, however, tends to be quite complicated because the task of interpreting all of the information that is gathered can become a bit overwhelming. The researchers do believe that it is worth all of their hard work as their results promise to provide new insights into the treatment of spinal-cord injury, brain-stem trauma, muscular dystrophy, stroke, and related medical conditions.


Researchers have found that a “Pacemaker for the brain” can assist patients in overcoming severe clinical depression, even when other therapies have failed. The technique, called deep brain stimulation (DBS), involves the use of brain implants to combat clinical depression. It uses electricity to reduce excessive activity in a specific region of the brain known as area 25 of the cingulate gyrus (Cg25), which tends to be overactive in clinically depressed individuals.

Statistics reveal that clinical depression afflicts approximately one in every five people at some point in their lives. It is regarded as being a serious illness that often leads to suicide. Deep brain stimulation is performed under a local anesthetic, which enables patients to indicate when the electrical current is having a positive effect. One individual has described the procedure as being similar to a “black cloud lifting” after which the patient experienced increased spontaneity and a lighter state of mind. Early patients who underwent the procedure still remain free from depressive symptoms more than a year after their electrodes were initially implanted.

Today’s multi-electrode devices continue to evolve in terms of both complexity and reliability. If current trends continue, in the near future neurotechnology may be used to enable blind people to recover partial vision. Ever since it was discovered that visual sensations can be produced using direct electrical stimulation of the visual cortex, researchers have been working to create and perfect a visual cortical stimulator that could potentially enable the blind to see. They continue to explore various image-processing strategies that mirror real-life processes and situations in their quest to achieve this goal.


Effective neuroscience and the development of new forms of neurotechnology require accurate measurement of processes that humans experience every day. Achieving such accurate measurement, however, is always a challenge, particularly when children are involved. Researchers who wish to understand the processes involved with physical activity in children are finding that combining various approaches to the study of physiology and body functioning is often more effective than relying on individual methods alone. For example, in a recent study it was found that combined heart-rate and body-movement sensing is the most valid way to estimate physical activity energy expenditure in children when they are walking or running as compared with analyzing either heart-rate sensing or body-movement sensing alone.

In the early 1970s, Jose Manuel Rodriguez Delgado of Yale University was one of the world’s leading and most controversial neuroscientists. Noting the “frightening potential” of his research, a cover story in the New York Times Magazine referred to Delgado as an “impassioned prophet of a new ‘psychocivilized society,’ whose members would influence and alter their own mental functions.”

Delgado is perhaps best known for pioneering the development of the brain chip, which is defined as “an electronic device that can manipulate the mind by receiving signals from and transmitting them to neurons.” In his heyday, Delgado implanted what he called “stimocoeivers” into bulls, cats, chimpanzees, monkeys, and even humans and proceeded to demonstrate that he could control his subjects’ bodies and minds simply by pushing a button. Today, various forms of brain chips are being used in neuroscience to explore possible treatments for blindness, epilepsy, paralysis, Parkinson’s disease, and a range of other disorders.

After Delgado moved to Spain in the mid 1970s, his work and reputation in the United States faded from public memory. In the mid 1980s, however, articles in scientific magazines and scientific documentaries produced by the BBC and CNN introduced a new generation of audience members to Delgado’s work. These media offerings cited his research as providing circumstantial evidence that both the United States and the Soviet Union had secretly developed advanced methods for modifying people’s thoughts remotely in desired ways. In response, Delgado dismissed such claims as being pure “science fiction.”

Delgado stopped conducting his own research in the early 1990s; however, he continues to follow developments in neurotechnology with particular interest in the field of brain stimulation. He believes that neurotechnology holds the potential to free humans from psychiatric diseases as well as aggressive tendencies. At the same time, he predicts that most forms of neurotechnology will never advance as far as many people have feared.


Recent advances in neurotechnology have resulted in the development of a tiny brain implant that may ultimately provide relief to millions of migraine sufferers around the world. Powered by a battery that re-charges automatically at night while its user sleeps on a special pillow, the wireless device has already been implanted in other kinds of chronic headache patients with encouraging results. It is now being tested for the treatment of migraines.

This wireless brain implant appears to be suitable for use by a wide range of patients, including individuals who suffer from conditions such as angina, arthritis, epilepsy, incontinence, and sleep apnea. Experts believe that it may also be used effectively to assist patients who are experiencing the after-effects of a stroke. Called the Advanced Bionics Microstimulator, this advanced nerve stimulator weighs less than a gram and is regarded as the world’s smallest implantable neuromodulator. All of its advanced microelectronics are contained within a sealed cylinder that measures just 27 mm by 3.2 mm.

Cognitive neuroscientist, Frank Tong, has been conducting experiments at Vanderbilt University that are designed to read a person’s thoughts by monitoring subtle changes in that person’s brain activity. He and his colleagues pay careful attention to noteworthy patterns of blood flow in the brain and make note of those spots at which neurons most vigorously release electric pulses. Using the process known as functional magnetic resonance imaging, Tong and his associates are using the principles of neurotechnology to identify precisely what an individual is seeing or perceiving. He hopes to use this type of “mind decoding” to learn as much as possible about visual consciousness in humans.


Ian Hunter is a professor of mechanical and biological engineering at the Massachusetts Institute of Technology. Rodolfo Llinas is a professor of neuroscience at New York University. Together, these two researchers are developing a nanowire brain implant that can be used to treat Parkinson’s disease. The implant uses electrodes to deliver electrical impulses to the brain and disables the neural systems that produce the tremors that individuals with Parkinson’s disease typically experience. It can be inserted through an artery in either the arm or the groin and connected to the brain.

II. PARALYSIS AND NEUROTECHNOLOGY


Cybernetics Neurotechnology Systems, Inc. is recruiting patients with amyotrophic lateral sclerosis (ALS), more commonly known as Lou Gehrig’s disease, to test its new brain implant. The implant, called BrainGate, is a tiny sensor that is capable of converting brain-cell impulses into computer signals.

If the tests are successful, the sensor may one day be used to help individuals with ALS or similar types of motor-neuron diseases to control computer keyboards, wheelchairs, and other devices with their minds. Currently, approximately 30,000 Americans suffer from ALS, which does not have a cure.

Katulak, Ronald, “Scientists Report Progress with Brain-Chip Implants,” *Chicago Tribune,*

Over the past five years, a 25-year-old man who is paralyzed from the neck down has learned to use his thoughts to successfully operate a computer, read his e-mail, turn on a television set, play video games, and control a robotic arm. A Massachusetts woman who is also a quadriplegic, in the aftermath of a stroke that left her unable to speak, is able to use her thoughts to type messages with the assistance of specialized software. Both of these people, using chips that are implanted in their brains, have become quite adept with their mind-over-matter movements.

According to John Donoghue, director of the Brain Science Program at Brown University, both of these individuals provide “proof of the concept that you can get signals out of the brain that can provide useful controls.” He regards their accomplishments as opening the door to entirely new kinds of neurotechnology that will benefit people who are paralyzed or afflicted with other kinds of movement disorders.


After an attacker stabbed him in the neck, Matthew Nagle became paralyzed from the neck down as a result of sustaining serious injury to his spinal cord. Today, he is using a custom-built computer to translate his thoughts into actions. In addition to moving a computer cursor and turning on appliances with his mind, he recently was successfully able to open and close a prosthetic hand using his thoughts.

Currently, Nagle must be attached to a cart filled with electronics in order to achieve these feats. However, researchers hope that one day this will no longer be necessary. They believe that his accomplishments provide increased hope that individuals with injured spinal cords will one day be able to regain significant functioning without the need for large computers by their sides.


Matthew Nagle from Massachusetts is a living, breathing example of how sensors that measure brainwaves can considerably improve the quality of life of paralyzed people. He has had a 4 mm-square chip implanted in his brain that reads signals in its primary motor cortex, which is the region that controls movement for individuals who have regular use of their limbs.

The implant contains 100 different sensors that record the activity in Nagle’s brain and then transmits those signals to a computer that controls several devices, including a television and a video-game system. Currently, Nagle is able to move a cursor to a desired target on the nearby computer screen with between 75 percent and 85 percent accuracy. He is also able to perform such actions while simultaneously carrying on a conversation. Experts say this suggests that total concentration is not required to successfully operate mind-controlled prosthetic limbs.
Neuroprosthetics researchers around the world are working to help paralyzed people live more normal lives. A recent study conducted using two monkeys demonstrated that brain implants enabled by recent advancements in neurotechnology will soon allow paralyzed individuals to type the equivalent of 15 words per minute. The study, conducted by a team of researchers at Stanford University, found that the speed of implants used to transmit brain-cell firings into useful signals exceeds existing, non-implanted brainwave readers by more than four times. However, at the moment, a major limitation is that such sensors tend to work for only one year or less, which means additional work needs to be done to perfect them and avoid the need for frequent re-implantation.

Ongoing developments in the field of neurotechnology hold the potential to help all sorts of individuals with disabilities to use their brains to control household devices, robotic arms, and prosthetic limbs. Injured U.S. veterans returning home from the Iraq War with disabilities are likely to benefit substantially from such developments in the coming years, especially as brain implants from Cyberkinetics Neurotechnology Systems and other companies become more widely available and increasingly advanced.

Matthew Nagle has emerged as the face of successful advances in the field of neurotechnology. Medical authorities agree that his achievements are remarkable and offer hope for disabled patients everywhere. At the same time, it is important to acknowledge that in order to achieve such impressive feats Nagle underwent very risky surgery.

Surgeons drilled a hole into Nagle’s skull and then inserted a tiny chip containing approximately 100 electrodes into his motor cortex, the region of the human brain that controls bodily movement. This type of operation poses various risks, including those pertaining to infection and brain damage. The implant itself has also not yet been fully perfected as its electrodes currently can sample only a fraction of Nagle’s relevant brain activity.
Recent neurotechnological research findings have found that brain activity pertaining to body movement can be controlled voluntarily several years after serious spinal-cord injury has been sustained. These findings differ from assumptions of the past which predicted that the human brain would alter its functioning substantially in the aftermath of spinal-cord injury. That no longer appears to be the case as movement-related signals are still being sent long after such injuries occur.

If current trends in the field of neurotechnology continue, it is likely only a matter of time before paralyzed individuals will be able to achieve full communication and set countless activities in motion simply by imagining them into being. In fact, once regarded as comic-book fantasies, electronically-aided telepathic transmissions hold the potential to one day become just as natural as breathing. The possibilities of what such technological advances can do, with regard to improving the lives of the disabled, appear to be boundless. Today, modern science appears to be transporting humankind into new worlds that were unimaginable even just a generation ago.

Researchers with Cyberkinetics Neurotechnology Systems, Inc., based in Foxborough, Massachusetts, have used research findings pertaining to neurons to create their BrainGate Neural Interface System. It is intended to restore functionality to individuals with severe motor impairments. How does it work? The BrainGate system uses a sensor the size of a baby aspirin, which is implanted on the motor cortex of the brain, to gather and transmit information pertaining to its recipient’s desired movements. Wires linked to 100 electrodes are connected to a pedestal, which protrudes through the user’s scalp and is connected, using an external cable, to a set of nearby computers. The computers use various signal-processing software algorithms to analyze the information they receive and then translate that information into control signals that allow users to control devices around them using only their thoughts.

Today’s advancements in neurotechnology with regard to treating paralysis will result in giant steps forward in the coming years. “This is the dawn of the age of neurotechnology,” explains John Donoghue, a professor at Brown University. “When we look back 10 years from now, we’ll see that there was this explosion.”

By comparison to the developments that are expected to surface within the next few years, the options available to paralyzed people today appear to be quite crude. In the near future, it is expected that amputees as well as people with paralysis will be able to function in ways that are not possible using the current technologies. The U.S. Department of Defense is regularly providing funding that enables researchers to explore new ways to effectively provide movement in prosthetic limbs. However, at the moment the regulatory process for such innovations is quite challenging, putting up obstacles to bringing new products to the public.


The cranium of a paralyzed man from London has been “Borgified.” His brain is now connected to a controller chip, smaller than a penny in size, that enables him to use various devices around him simply by thinking about doing so. The chip is intended to improve the lives of the paralyzed and infirm. However, there is nothing to say that it can’t one day also be used to improve the playing of video games or even to enslave the entire human race.


Officials with Cyberkinetics Neurotechnology Systems, Inc. have announced that the U.S. Food and Drug Administration has designated one of their products, the Andara Oscillating Field Stimulation Device, as being a Humanitarian Use Device for immediate use following various kinds of spinal-cord injuries. This special designation by the Food and Drug Administration will enable the company to file a Humanitarian Device Exemption application in the coming months, which will make it easier for the device to be used to treat patients with recent or acute spinal-cord injuries.
Eight years ago, the once-robust homebuilder Stephen Heywood was diagnosed with amyotrophic lateral sclerosis, more commonly known as Lou Gehrig's disease. Today, at age 37, Heywood is confined to a wheelchair and he is losing command of his muscles. However, Heywood is beginning to use new technology to overcome some of his bodily limitations. He recently endured surgery to have a tiny silicon chip implanted on the surface of his brain's motor cortex as part of a clinical trial for the BrainGate Neural Interface System. Heywood's implanted chip serves as a sensor that allows him to control various types of devices with his thoughts. Its maker, Cyberkinetics Neurotechnology Systems, is also currently exploring its potential for more accurately diagnosing individuals with epilepsy.

The BrainGate device from Cyberkinetics Neurotechnology Systems, Inc. is currently undergoing subsequent testing involving several spinal-cord patients as well as individuals with amyotrophic lateral sclerosis (ALS). Recently, the company also acquired another technology that holds the potential to restore movement and sensation in a damaged spinal cord by stimulating new growth in it. Initial testing of this latter technology has produced encouraging results in humans and an alternate version of it is currently being tested in dogs, as well.
III. ETHICAL ISSUES AND NEUROTECHNOLOGY


Ethical issues surface commonly with regard to scientific and technological advancements. To date, however, little public attention has been focused on the ethical implications of neuroscience and neurotechnology. Without question, recent breakthroughs pertaining to cognitive neuroscience raise a variety of noteworthy ethical issues. Some of these issues are practical in nature, raising important concerns about the current and future applications of neurotechnology and their resulting effects on individuals and societies. Other issues are more philosophical in nature as they touch upon the way people think about themselves and others as individuals and spiritual beings. If not monitored carefully, the ongoing developments in neurotechnology could potentially produce a variety of social and philosophical problems that most people have not yet taken the time to envision.


Recent advances in neuroscience regularly involve implanting tiny forms of information and communication technology (ICT) within the human body. According to a new report prepared by the European Group on Ethics in Science and New Technologies, the use of neurotechnological implants poses “large and important ethical consequences.” With regard to non-medical applications of such implants, the members of this ethics group have stated that “non-medical applications of ICT implants are a potential threat to human dignity and democratic society.”

The members of the European Group on Ethics in Science and New Technologies acknowledge that ICT implants can be used to influence the nervous system and brain in desired ways, such as to alleviate tremors in individuals afflicted with Parkinson’s disease. However, they simultaneously acknowledge that the implantation of microchips can be used to achieve negative and harmful ends, possessing the potential for deleterious and undesirable forms of individual and social control.

The report from the members of this ethics group states, “The use of ICT implants in order to obtain remote control over the will of the people should be strictly prohibited.” They believe that implantable devices for both medical and non-medical purposes should be strictly regulated. They are also especially concerned about the use of implantable devices that are accessible using digital networks.

Recent developments in the field of neurotechnology raise numerous ethical, social, and legal challenges that are similar in scope to those posed by modern genetics. However, some experts believe that the ethical issues surrounding neurotechnology go well beyond those associated with the “genethics” debates.

Bioethics, which encompasses neuroethics as one of its components, requires careful philosophical analysis as new developments in neurotechnology continually surface. Achieving this goal requires a precise understanding of the mind and the brain conceptually, which can be acquired both empirically and philosophically using the methods of neuroscience. Possessing such knowledge will be useful for avoiding some serious mistakes such as introducing new forms of neurotechnology based on misleading information. For example, it is not uncommon in the literature pertaining to neurotechnology for researchers to use the expressions “brain maps” and “thought-maps” interchangeably, even though they are not equivalent terms.

Future applications of neurotechnology raise important ethical concerns. For instance, it would be possible to use a form of neurotechnology to screen out potentially violent travelers at airports. If someone was suspected by airport personnel of being dangerous, he or she could be required to sit through a brain scan in order to demonstrate that this is not actually the case. However, because such a requirement would be regarded as deeply offensive by many travelers, it is likely that the brain scan would reveal an individual who is currently agitated and on the verge of exploding with anger. Should such individuals be turned away and not allowed to travel on to their desired destinations? It is also important to note that brain scans designed to detect an individual’s propensity to violence would most likely fail to identify the most dangerous individuals of all, those who are capable of committing violent acts without any emotional involvement whatsoever.


Recent developments in neuroscience raise ethical challenges that exceed the scope of related challenges in the field of “genethics.” Many researchers believe that neuroscience and neurotechnologies have ethical implications that differ in both kind and degree from those of previous sciences and technologies, such as genetics. Others, as can be expected, disagree with such claims, especially those who reject the assumption that the human mind is identical to the human brain.

Neuroscience researchers Judy Illes and Eric Racine believe that neurotechnology “will fundamentally alter the dynamic between personal identity, responsibility, and free will in ways that genetics never has. Indeed, neurotechnologies as a whole are challenging our sense of personhood and providing new tools for society for judging it.” Critics of such claims argue that it is unlikely that neurotechnologies will have such wide-reaching effects. Individuals on both sides of this debate, however, tend to agree that neuroscience and neurotechnologies do indeed have noteworthy ethical implications that are not yet fully known, even if they do not agree on the specifics of those implications.

A number of ethical concerns have been raised about the use of neurotechnologies for lie detection. According to some researchers, many of those concerns result from hype surrounding the topic, rather than being based in fact. For example, it is important to consider the current limitations of neurotechnologies for lie detection when engaging in any form of thinking about their ethical implications.

Many people fear that the use of neurotechnologies for lie detection is somehow equivalent to the process of “mind reading.” Such an assumption is inherently inaccurate. The current neurotechnological processes involved in the physiological recording that characterizes the process of lie detection fall far short of “mind reading,” no matter how that term is defined or used. The primary distinction is that mind reading would allow researchers or investigators to identify any thoughts that are going on in a person’s mind without correlating the resulting information to the formal query procedure that is used as part of a guilty knowledge test. Currently, no form of neurotechnology exists with the ability to read minds in that way. Perhaps none ever will.


All technological revolutions proceed through three distinct stages: (1) the introduction stage, (2) the permeation stage, and (3) the power stage. In general, when it comes to ethical issues and concerns, ethical problems tend to increase dramatically as any technological revolution progresses toward and enters into the power stage. Like genetic technology and nanotechnology, neurotechnology is a leading candidate for an impending technological revolution. As such, in the coming years we will need effective ethical responses to adequately address and monitor its ongoing development and potentialities. Generating such ethical positions should begin today rather than in the future.


Neurotechnologies that employ transcranial magnetic stimulation raise a variety of ethical concerns. They can be used effectively in clinical medicine to treat a range of psychiatric diseases. At the same time, while doing so, they can alter the personalities of their users in ways they may not understand or desire.

A growing body of literature in the field of neuroethics deals with managing unexpected findings, such as those that pertain to the use of transcranial magnetic stimulation as well as other ground-breaking forms of neurotechnology. From an ethical perspective, the use of transcranial magnetic stimulation requires informed consent from patients as well as processes to ensure their safety. In addition, the patient’s personal values and other sociocultural factors must be carefully considered before employing such technologies on any individual.

The range of existing and potential ethical concerns stemming from the use of neurotechnologies in relation to brain research has led to the emergence of the new discipline called neuroethics. Important questions are raised whenever such technologies are used. Is it ethical to use neurotechnology to predict future diseases? Is it ethical to use neurotechnology to enhance an individual’s attention, memory, or mood without his or her explicit consent? Is it ethical to use brain implants or deep brain stimulation in individuals who do not fully understand the surgical or other risks involved in doing so? In all of these situations and related others, the individual’s safety, sense of privacy, autonomy, and identity may be at risk. While it is true that the use of neurotechnology can change a society’s views pertaining to illness and mental health in desired ways, it is also important to keep in mind that issues of freewill, personhood, responsibility, and the self come into play whenever various forms of neurotechnology are used.

IV. FINANCIAL ISSUES AND NEUROTECHNOLOGY


It appears that neurotechnology is becoming big business. According to statistics provided by the research firm NeuroInsights, investment in neurotechnology companies by venture capitalists increased by 225 percent during the period from 1999 to 2004. In addition, the science of using neurotechnology to develop treatments for various neurological and psychiatric illnesses currently accounts for approximately 25 percent of all funds being invested in the life sciences.


Cyberkinetics Neurotechnology Systems, Inc. continues to develop cutting-edge brain-monitoring equipment and related applications that enable disabled people to operate computers and other devices using their thoughts. Six months ago, the company went public by executing a reverse merger, using the shell of a company based in Vancouver and registered in the state of Nevada to mine various metals. In the business world, reverse mergers with shells are not new. Under such an arrangement, the shell company buys the other business and swaps all of its stock as part of the transaction.

Some investors are leery of a company that goes the shell-game route. Since both public and private investors today are seeking to invest their money in promising companies with bold ideas and innovations, it is not always clear why a company such as Cyberkinetics Neurotechnology Systems — which is promoted as being a leader in “brain-machine interface technology” — would prefer to go this route rather than seeking out additional investors.

As the U.S. population continues to age, nearly a billion elderly people are reaching the stage of life when they are at the greatest risk of developing brain-related illnesses such as Alzheimer’s disease or various kinds of chronic pain. Out of approximately 300 companies developing brain-related products that utilize neurotechnology, more than 30 of them are based in the San Francisco Bay Area. The majority of these companies focus primarily on the so-called “brain industry,” and they are devoted to developing treatments for ailments and illness that aging baby boomers are expected to encounter.

According to figures provided by NeuroInsights, a San Francisco research firm, worldwide revenue for companies specializing in this particular neurotechnology niche reached $100 billion in 2004, a 13 percent increase from the previous year. However, even though the brain business potentially can be quite lucrative, it is also quite risky. Several of the companies working in the “brain industry” do not yet have any products on the market, which means they may not generate adequate profits for several years. In addition, as new neurotechnological medical devices begin to flood the market in the coming years, they will require a substantial number of neurosurgeons to implant them in patients if the various companies marketing the devices will be successfully able to stay in business and grow.


For decades, venture capitalists have been finding and funding brainy ideas and innovations. Increasingly today, the brain itself is becoming big business. Many contemporary venture capitalists are very enthusiastic about the prospects of investing in the neurotechnology arena. According to figures provided by NeuroInsights, a San Francisco research firm, investments in neurotechnology companies during 2004 totaled $1.5 billion up from approximately $500 million in 1999.

Neurotechnology companies typically market drugs and devices to treat various diseases and disorders of the central nervous system with a particular emphasis on the brain. Some also develop and sell software and other tools that are used to measure and understand the workings of the central nervous system. As the world’s population continues to live longer than people in the past, the need for neurotechnological solutions to battle age-related diseases (such as Alzheimer’s disease, Parkinson’s disease, and stroke) continues to grow. Neurotechnological innovations will also be increasingly required to help elderly individuals maintain higher levels of brain functioning later in their lives.

Currently, neuroscience is a young field, and it remains immature when compared to other, more established areas of the life sciences. Nevertheless, it already represents a sizeable and growing opportunity for venture capitalists who hope to generate windfall profits in the coming years. That is especially the case because approximately 20 percent of the U.S. population experiences some form of brain disorder every year, and another 25 percent of the U.S. population experiences at least mild mental illness each year.

For venture capitalists, several neurotechnological companies currently represent outstanding investment opportunities. One such company, Somaxon Pharmaceuticals Inc., develops and markets various forms of neuro-psychiatric treatment devices. The list of the top-10 venture capital deals in the U.S. neurotechnology market as of August 2005 also includes Calypso Medical Technologies Inc., which specializes in cancer solutions; Therion Biologics Corporation, which specializes in cancer therapeutics; and Verus Pharmaceuticals Inc., which focuses on pediatric medical solutions.


Cyberkinetics Neurotechnology Systems, Inc. has announced the acquisition of the Andara Life Science company with the goal of accelerating Cyberkinetics’ desire to create a profitable, high-growth neurotechnology company. The acquisition strengthens Cyberkinetics’ position within the mainstream of neurostimulation. In addition, it provides Cyberkinetics Neurotechnology Systems with the ability to further develop and market the Andara Oscillating Field System Device, which has been shown to effectively stimulate nerve-fiber growth. It is regarded as a relatively simple device that is easy to implant because it does not have to be placed within the spinal cord. Instead, it gets attached to a surrounding bone, eliminating the need for a surgeon to get close to the spinal cord while implanting it.

V. THE FUTURE OF NEUROTECHNOLOGY


In a post-9/11 world filled with increased awareness of security and terrorist threats, it is perhaps not surprising that the U.S. federal security agencies have embraced emerging neurotechnologies for lie detection. Their hope is to use such technologies to weed out people who pose threats to our national security. However noble their intentions, there is nevertheless cause for concern that the premature adoption or misuse of such neurotechnologies will violate the same freedoms and civil liberties of individuals that the “war on terrorism” seems intended to protect. Accordingly, the law must become more prepared to deal with the unintended or undesirable consequences of the introduction and use of such technologies. Constitutional and legislative limitations pertaining to such technologies must be considered in order to effectively balance the need for physical security with the protection of Americans’ cherished freedoms and liberties.
Horsnell, Michael, “Sony Takes 3-D Cinema Directly to the Brain,” The Times, April 7, 2005, p. 15.

Sony, a Japanese leader in entertainment devices, has patented an idea for transmitting entertainment data directly into the human brain. The goal of this technique will be to allow individuals to watch movies and play video games in which they can taste, smell, and possibly even feel things. The patent is based entirely on theory, rather than a specific invention. Will it be impossible to turn the theory into reality? Nobody knows for certain, but people used to say that man would never fly.

The idea behind Sony’s patent is similar in concept to those underlying neurotechnologies. The primary difference, though, is that Sony’s proposed technique would be noninvasive since it would not require brain implants or surgery to work. It would use a device that fires bursts of ultrasound at an individual’s head in order to modify the firing patterns of neurons that are occurring in specific parts of the brain. The goal is to create effective “sensory experiences” within entertainment environments.


As various forms of neurotechnology become more common, it will be important to safeguard the technologies and their users from becoming victims of crimes. That is the lesson that a woman in Great Britain has learned. She has been unable to sleep since Christmas when the remote control to the anti-tremor device implanted in her brain was stolen. During the day, the device keeps the brain active so that tremors will be avoided. At night, however, the user must turn it off with the on/off switch located on a remote control in order to sleep. The woman kept the remote control in her purse, which got stolen on December 23, 2004.
The future of neurotechnology may result in the introduction of engineered human innovations including brain chips that allow people to control machines with their thoughts which are already being developed and tested on human subjects. It appears that we have entered a century during which medical science will go beyond simply treating ailments and diseases to creating new innovations that will make human beings “better than well.”

The potentialities of neurotechnology are both exciting and somewhat disturbing. What will the world be like when athletes can augment themselves with artificial muscles? What will it be like when ordinary individuals can purchase implants that allow them to see the world in new colors or to never forget anything at all? In the coming decades, will humans really end up merging with machines? It appears so as today’s advances in medical science, over time, are likely to result in the creation of individuals with more-than-human capabilities. The typical pattern will likely continue: After researchers develop effective technologies to assist the ailing, healthy people co-opt them and use them to make themselves faster, smarter, and stronger.

ChipTx, based in Lexington, Kentucky, is developing a system that delivers medication automatically whenever its user needs it. It comes in the form of a matchstick-sized device that is filled with a patient’s prescription and inserted into the chest.

At the University of Southern California, neural engineer Ted Berger is working on a way to enhance human memory. It employs a microchip that sends signals among only healthy brain cells, bypassing damaged tissue that would prevent messages from being transmitted successfully. The device will be used first to assist Alzheimer’s patients in regaining their ability to form memories and then later to benefit individuals who are simply forgetful.

A team of researchers being led by Gerald Loeb at the University of Southern California has developed the Bion, a device used to strengthen muscles in stroke victims and people with arthritis. One-hundredth the size of a standard AA battery, it is intended to allow paralyzed limbs to begin moving once again.

Over the past three decades, computer chips that connect with neurons in order to overcome memory loss have been in development. They can be especially useful in compensating for changes that occur in the brains of Alzheimer’s patients. Although great strides have been made to date, one major challenge remains: making a reliable and long-term connection between the required hardware and the wetware. The key lies in creating such a connection that remains unaffected by various factors including scar tissue, corrosion, and dying cells in the brain. Currently, neuroscientists are searching for the most ideal places in the brain where electrical implants can be positioned to alleviate the deleterious effects of injuries and diseases.

The neurotechnologies of tomorrow will offer individuals unprecedented opportunities to enrich their emotional, intellectual, physical, and spiritual capabilities. According to Zack Lynch, a recognized expert on the biotech industry and publisher of neurotechnological market reports, “Future neurotechnologies will have the capacity to extend all aspects of what makes us human, from self-centeredness to radical empathy.” An overarching goal of many neurotechnological advancements is to create human beings that are “better than well.” As such, in the coming decades, it is expected that individuals will demand and expect the right of access to advanced technologies that increase their baseline levels of happiness and well-being. In doing so, they will end up challenging the basis of the philosophical tradition, which is grounded in grief and suffering.


Two key questions frequently arise as neuroscientists, computer scientists, and other experts attempt to develop effective new technologies: (1) Do we have enough computational power to provide an accurate and complete model of human cognition? and (2) Are such accurate and complete accounts actually neurologically plausible and knowable? Without a doubt, today’s advanced connectionism models are more “brainlike” than the traditional cognitive models of the past. However, additional strides must still be achieved in order to develop the most effective neurotechnologies possible.


The U.S. Pentagon is providing funds for research on brain implants with the hope that such implants will one day be able to turn sharks into “stealth spies.” The idea is that, once equipped with such implants, the sharks can swim undetected in the ocean and follow vessels without being spotted.

According to a report published in New Scientist magazine, “The Pentagon hopes to exploit sharks’ natural ability to glide quietly through the water, sense delicate electrical gradients, and follow chemical trails.” The implants would be controlled by a transmitter that could cause the sharks to move left or right as desired by stimulating either the left side or right side of their brains. In the near future, blue sharks containing the implants will be released into the waters off the coast of Florida.

A motor neuroprosthetic device, more commonly referred to as a brain-computer interface, is defined as “a machine that can take some type of signal from the brain and convert that information into overt device control so that it reflects the intentions of the user’s brain.” Accordingly, such devices are capable of effectively decoding signals in the brain that suggest motor intent. In the coming years, motor neuroprosthetic devices will become a practical reality for individuals with severe motor impairment, whether it be the result of spinal-cord injury, stroke, limb loss, or various neuromuscular disorders. More so than ever before, the time has come for neurosurgeons to deepen their understanding of what brain-computer interfaces are, how they work, and the range of surgical issues they need to consider before deciding to implant them.


The human body typically contains a “sixth sense” that enables the brain to comprehend the relative positions of different parts of the body in actual physical space. Neuroprosthetic engineers are currently working to determine how sensory feedback signals can be used in various neurotechnologies to make up for deficiencies in an individual’s “sixth sense.” They hope to determine the most effective ways to stimulate the sensory nervous system so that it can produce the same sorts of information that a limb could send to the brain.


A leading goal of neuroscience in the coming years will be to develop advanced brain-implantation technologies that are capable of enabling individuals with brain damage and spinal-cord damage to communicate and interact with others most effectively. Researchers have already made impressive strides at developing devices that can convert brain signals into commands and improve the lives of paralyzed people. Neuroprosthetics, also known as brain-computer interfaces, are intended to provide another promising approach to allow people with serious neurological injuries to interact most effectively in their environments.