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The Emerging Neurotechnologies: Recent Developments and Policy Implications

Jeremy Geelen, PhD [1]
Project and Public Affairs Manager, Institute for Science, Society and Policy (ISSP), University of Ottawa

Archenemy of the heroic Spider-Man, Doctor Octopus terrorized the world with mechanical tentacles wired to his brain. When he thrilled moviegoers in one of the highest grossing films of 2004, the notion of thought-controlled robotic arms was pure science fiction. It isn't anymore.

Thought-controlled prosthetics, as well as deep-brain stimulation and 'mind reading' technologies are among the most exciting recent advances in neurotechnology. Such advances may bring profound medical and economic benefits (the neurotech market is currently valued at $145 billion and growing 9% annually (Merian, 2011), but they also present significant public policy challenges.

What is Neurotechnology?

Researchers at the **University of Freiburg** (Germany), provide a good definition of neurotechnology. They define it as:

- Technical and computational tools that measure and analyze chemical and electrical signals in the nervous system, be it the brain or nerves in the limbs. These may be used to identify the properties of nervous activity, understand how the brain works, diagnose pathological conditions, or control external devices (neuroprostheses, 'brain machine interfaces'); and
- Technical tools to interact with the nervous system to change its activity, for example to restore sensory input such as with cochlea implants to restore hearing or deep brain stimulation to stop tremor and treat other pathological conditions.

The Merger of Brain and Machine

Researchers at Pittsburgh Medical Center recently developed a robotic arm that can be controlled through brainwaves alone. Placing an electrode on the surface of a patient's brain, the researchers worked with the patient as he 'taught' the arm how to respond to his thoughts. He then used the arm to touch his girlfriend's hand for the first time in seven years – something he couldn't do with his natural arms since a motor accident left him a quadriplegic (Carollo, 2011).

Pittsburgh might be Steel City, but it has no monopoly on thought-controlled metal limbs. A team led by researchers at Brown University recently built a robotic arm that allowed a quadriplegic woman to serve herself coffee for the first time in 15 years (Coxworth, 2012). Researchers at the Long Beach Veterans Affairs Medical Center and the University of California (Irvine) have developed thought-controlled mechanical leg braces (Lewis, 2012). Toronto-based **Bionik Laboratories** intends to take thought-controlled prosthetics to the market at a bargain price. [2]

Brain-Machine interfaces aren't only revolutionizing prosthetics. They're also opening new vistas into the treatment of psychotic disorders and addiction.

Deep brain stimulation (DBS) has been used as a treatment of movement disorders for over 20 years. This involves the placement of a 'brain pacemaker' into the patient, a device that emits electrical impulses to the areas of the brain corresponding to the disorder. This procedure is now showing promise as a treatment of various psychiatric disorders, including obsessive-compulsive disorder, Tourette syndrome and depression.

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2. See also CBC News (2011).

Some researchers also believe that DBS shows promise as a treatment of addiction (Luigies et al., 2012).

From Crystal Ball to MRI: Mind Reading Redeemed?

Mind reading used to be a vain pursuit, the stuff of soothsayers and snake oil salesmen. But the latest advancements in neurotechnology seem to be making even this a reality.

In recent work at the University of California (Berkeley) researchers created a model that enabled a computer to reconstruct "mind movies" after scanning the brain using functional magnetic resonance imaging (fMRI). For example, when a test subject viewed a human face on a television screen the computer read the subject's brain activity and constructed an image similar in outline to the image on the screen.

In a study conducted at the University of Western Ontario, researchers using electro-encephalography (EEG) reported that 19% of their test subjects – patients thought to be in a vegetative state – may actually have some degree of consciousness (see Cruse et al., 2011).[3] Another similar study using fMRI technology suggests that one patient could even communicate with the researchers, who scanned the patient's brain patterns for responses to questions (Monti et al., 2010). Interpreting the meaning of such brain activity is a tricky business, but these studies suggest that the age of mind reading may be on the horizon.

The private sector would be remiss not to cash in on the profit potential. Neuromarketing firm **Neurofocus** promises access into the deepest thoughts of consumers, and **Cephos Corp.** provides brain-based lie detection services to anybody whose "word, reputation or freedom is in dispute". Not to be outdone, **No Lie MRI** claims to offer "the first and only direct measure of truth verification and lie detection in human history".

Researchers are also actively seeking to discover the neural correlates of pedophilic arousal, psychopathy and other behavioural traits.

Governments and Public Affairs

The US Government has taken note of emerging technologies and wants to probe their policy implications. In 2010 it established the **Emerging Technologies Interagency Policy Coordination Committee**. A joint effort of the Office for Science and Technology Policy, the Office of Management and Budget's Office of Information and Regulatory Affairs and the Office of the US Trade Representative, the Committee aims to "give special attention to technologies so new […] that their policy implications are still being gauged". You can bet that neurotechnologies have and will be discussed by the Committee.

Here's how the Berkeley researchers made the "mind movies": First, they placed test subjects in an fMRI machine and had the subjects watch several hours of movies (call this movie 1), all the while recording the subjects' brain activity. Next, they had the test subjects watch several hours of different movies (call this movie 2). Using the data collected from the scan of the brain activity during movie 1, the model the researchers developed could reconstruct, in broad outline, the image each test subject was viewing when watching movie 2 (see Anwar, 2011).

3. See also Western University's **Brain and Mind Institute** for more information. Interested readers may also want to keep an eye on the University of Ottawa's new **Brain and Mind Research Institute**, which aims to conduct multi-disciplinary research into cognitive functioning.

Neurotech companies are active in the public affairs arena, their trade association being the **Neurotechnology Industry Organization** (NIO). Formed in 2006, the NIO is "spearheading creative and effective legislation focused on accelerating innovation, increasing funding and speeding regulatory approval". It recently spurred and participated in a Congressional Hearing on The Future of Neuroscience Research and Development.

While the public has at times shown discomfort over emerging bio- and nanotechnologies (see, for example, North Caroline State University, 2008), it is unclear how it will react to the latest (and future) neurotechnologies. But more information should be available soon. The **Nuffield Council on Bioethics** has established a Working Party to conduct public consultations on the ethical issues raised by novel neurotechnologies, with the report to be published in summer 2013.

Potential Military Applications

Researchers at Zhejiang University in China have recently created a thought-controlled aerial device (Williams, 2012) – in time such technology could be used in military drones.

The potential military application of brain-machine interface (BMI) technology isn't lost on the Pentagon. The US Army's Synthetic Telepathy project – carried out by researchers at the University of California, Irvine, and the University of Maryland – intended to enable soldiers to control weapon systems through thoughts alone (Noor, 2010). And the Silent Talk project of the Defense Advanced Research Project Agency (DARPA) aimed to enable communication during combat through the analysis of neural signals (ibid.). While the current status of these projects is unclear they nevertheless give a sense of the military applications of the emerging neurotechnologies.

Policy Implications

While emerging neurotechnologies may bring substantial benefits, they may also pose significant public policy challenges, particularly in the areas of security, privacy and rights. They may also challenge the notions of freedom and responsibility that form the foundation of our legal system, as well as profoundly influence our conception of what it means to be human.

Death by Neurohacking?

A researcher at McAfee Security recently showed the ease by which insulin pumps can be hacked, potentially delivering fatal doses of the hormone to the diabetic patients who rely on these devices (see Goodin, 2011). Thought-controlled prosthetics and brain pacemakers will likely have wireless components (e.g. allowing users to remotely troubleshoot with a technician) that would make them susceptible to similar assault or even to abuse from their own users (e.g. addicts who hack their brain pacemakers to provide a 'high' by electrically stimulating the brain's reward centres (see Leggett, 2009).

The desire to harm through hacking is as popular as ever among the more malevolent members of our species. This was evidenced in 2008, when hackers infiltrated an epilepsy support message board with flashing animal graphics. Their intent was to trigger migraine headaches and seizures – and they succeeded (see Poulsen, 2008). It is likely there will be people who won't think twice about targeting devices inside the brain.

The likelihood that brain-machine interfaces will be subject to potentially deadly hacks has led some researchers to insist that 'neurosecurity' concerns be factored into the design of neuro-devices (see Denning, Matsuoka, and Kohno, 2009). This speaks to the need for governments to develop neurosecurity strategies.

Discrimination by Neuro-scan?

Technologies identifying the neural correlates of behavioural traits – such as lying, pedophilic arousal and psychopathy – raise questions about what employers, governments and the courts will do with this neurological information if and when it is available.

Will people come under pressure (whether direct or indirect) to submit to these technologies? There have been debates over the ethics of submitting employees to drug tests, but obligatory neuro-scans could be an even greater invasion of privacy – for example, they could reveal a person's propensity to act in a certain way, not whether the person does or ever will act in that way.

If a neuro-scan showed a person to be disposed to pedophilic arousal, should authorities be informed? Would governments strive to collect such information? This could infringe on the person's rights – but it could also prevent sexual abuse.

Will defendants seek to use these technologies to show that they are not the type of people to commit the crimes they stand accused of? Will they admit to the crimes but claim that their neural makeup disposes them to such behaviour and so they are not responsible? Such claims may challenge the very notions of freedom and responsibility that form the foundation of our legal system.

How will the courts react to the prospect of neuro-based lie detection? Even if neuroscientific evidence is deemed reliable, the history of admitting technology into the courtroom (such as polygraph testing and DNA evidence) suggests that there would be concerns over the potential 'dehumanization' of the legal system if neuro-based lie detection is permitted (see Chandler, 2010).

Humanity Dehumanized?

The potential for 'dehumanization' may be the greatest, most difficult challenge facing policymakers and society as a whole. Beyond threats to security, rights and privacy, the emerging neurotechnologies – thought-controlled prosthetics, deep-brain stimulation, 'mind reading' and the like – may call into question our very conception of what it means to be human. How will we view ourselves when our rational faculties, the faculties we cherish as the source of our humanity, are wired to machines, perhaps even enhanced or controlled by machines? How will this affect our society, our politics, and our economic systems? How will governments respond, if at all? Only the future will tell.

Preparing for the Future

Though it is unclear where the development of the emerging neurotechnologies will lead, we should reflect on – and prepare for – potential challenges on the horizon, both with respect to innovation and regulatory agendas.

Governments in Canada and around the world will support the neurotechnology sector in various forms (in June 2012 the Government of Canada **pledged nearly $11 million in support of neurotech commercialization activities in southern Ontario**). But as technologies are developed with an even greater potential to affect and augment the users, governments may be called to reflect on which technologies to foster and support – both on economic and ethical grounds.

For innovation and regulatory agendas to move together and not at cross-purposes in a world of accelerating neurotechnological development (as well as other emerging technologies), policymakers on each side will have to make an ethical commitment to open dialogue, to acknowledge the concerns and aims of each side.

We may be only experiencing the first steps in a "Neuro Revolution" (Lynch, 2009). It is unclear just how revolutionary and transformative it will be. But policymakers should be prepared for whatever is on the horizon. In the words of Doctor Octopus, referring to the fusion reactor that gave his thought-controlled mechanic limbs a consciousness of their own, "It can't be stopped".

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