HOTTOPICS

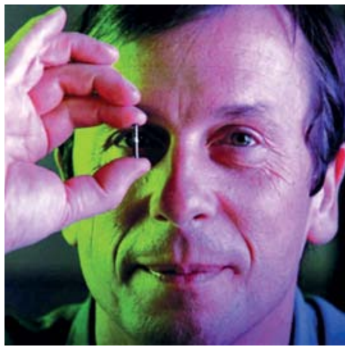
NESTA Making Innovation Flourish

NESTA Hot Topics

Mind over matter: Will computers enhance or limit our brains in the 21st century?

Introduction

Hot Topics is a series of NESTA events focused on the new ideas and technologies that will change business and society in the next few years. September's event *'Mind over matter – will computers enhance or limit our brains in the 21st century?'* focused on the new wave of technology that can interact with our brain, exploring potential applications and considerations for the future. The report draws together some of the key ideas covered on the day, with further examples, links and videos available on the event resources page.



Hot Topics is a series of NESTA events driven by ideas and technologies. They aim to introduce the technological tools that will change how we do things in the coming years, and are designed to bring together the best of business, academia, start-ups and investors.

Find out more at: http://www.nesta.org.uk/events/hot_topics

Background

From advanced prosthetics to revolutionary treatment for Parkinson's, Brain-Computer Interfaces (BCI) have recently been central to a variety of huge medical breakthroughs. With companies like Neurosky now producing 'brain sensors for everybody', the technology is moving into the mainstream, entering the realms of gaming, marketing and even online dating. This event will look at the new wave of technology that can interact with our brains, exploring potential applications and considerations for the future.

Although we have had a form of remote brain-to-brain technology for thousands of years (writing and reading effectively conveys ideas from my brain to yours without speech), these new techniques allow the electrical activity of the brain to be interpreted more directly, although rarely by 'reading our minds'. More often, the user is asked to think about specific things (playing tennis, moving your arm, stroking a cat) and the different brain responses are then linked through training to new actions. This sort of training can be used to spell out words, to control wheelchairs or prosthetics, or more generally to control a cursor on a screen.

While electroencephalograms (EEGs) have been used with humans for more than 80 years, only recently have they been used for purposes outside of diagnosis and medical applications. This opens up a wide range of new opportunities, as well as difficult questions in ethics, freewill, our dependence on technology and our relationship with memory.

This report breaks down the discussion into three main themes:

- Novel applications and the current state of play.

- Mind reading: how much do we understand about how the brain works?
- Mind over matter: the challenge (innovation and ethics).

For more information about consumer BCI devices, see the box on page 5.

The event

Joining us on the panel to share their perspectives were Kevin Warwick, Professor of Cybernetics at the University of Reading, Emlyn Clay, Director of Openvivo, the UK partner of g.tec which developed the first commercially available BCI system, and Dr Anders Sandberg from the Future of Humanity Institute at Oxford University.

From novel to future applications

With the grand majority of BCI technology and research focused on medical indications, the discussion began with novel applications in this sector before building up to future applications and the potential for human enhancement.

Emlyn Clay is Director of Openvivo, the distribution and technical partner of Austrian biomedical engineering company, g.tec.[1] Established in 1999, g.tec is the first and oldest BCI company in the world. Their work centres on BCI for medical indications and life sciences research; applications built around the non-invasive EEG, one of the most common and long-standing BCI interfaces. The g.tec Intendix[2] personal speller is one of their most advanced products. The system enables paralysed or locked-in patients to communicate using an EEG cap enabling their brain activity to be translated in words and phrases as they concentrate of a matrix of letters on a computer screen. With much BCI technology, described by Emlyn, as 'holed up in universities', a focus of g.tec is getting the technology out into the open so it can be start being useful and benefit people. The Intendix system is designed to be simple enough to be set up and operated by caregivers or the patient's family. One of the original applications in the field of BCI, spellers previously required a day's worth of training data to be used successfully, it now takes just 5-10 minutes.

Demonstrating the scope of BCI applications using EEG, he described a tool developed for stroke rehabilitation by the winner's of g.tec's 2010 BCI awards. Aiming to supplement existing therapies, an actuating arm is used to enhance feedback as the patient attempts to regain use of a paralysed limb.[3]

With links to 'mind control' and 'enhancement', the discussion of ethics and responsibility is never far away (to be discussed further in section 3). Emlyn's final example looked at currently unpublished work by Dr Niels Birmbaumer at the University of Tübingen. Using BCI to classically condition unconscious patients to answer a series of yes/no questions, the work raises questions about our current processes for both pain medication and power of attorney for the unconscious.

Computer enhancement

A subject not without controversy, human enhancement goes beyond the treatment of illness or disability, to explore how we can augment our brains and bodies with the aim to enhance or benefit our lives.

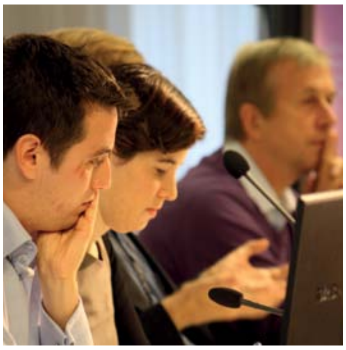
We have all known that dreaded moment of realisation that you have forgotten something important. In terms of memory storage, computers have us outclassed; Kevin suggested that in terms of efficiency, we could consider 'outsourcing completely'. Humans can only perceive 5 per cent of the signal in our surroundings, but electronic sensors cover a much wider range, including radio signals and infra-red. Why not take the opportunity to expand our sensory range? Kevin Warwick is one of the most well-known figures in BCI research.

1. See: http://www.gtec.at/
2. See: http://www.intendix.com/
3. For further details and other nominees see: http://www.intechopen.com/articles/show/title/state-of-the-art-in-bci-research-bci-award-2010

Demonstrating a certain level of dedication to his research, he had a series of implants inserted into his forearm as part of Project Cyborg, to test their functioning and potential for future applications. He has also persuaded a number of the researchers in his lab to have magnets implanted in their fingertips, so that new sensory signals can be sent to them.

Exploring the potential to enhance human's ability to interact with our environment, his first implant contained an RFID identity chip. This link to the university computers allowed them to pre-empt actions as he moved around the building, opening doors and switching on lights on his behalf. Thought-controlled wheelchairs for the paralysed as well as new research into hands-free cars demonstrate the incredible possibilities for direct neural control. Yet the Braingate that Kevin Warwick had implanted allowed him to go one step further into the realms of body extension, BCI that allows our brains not to be restricted by the physical location of our bodies. While seated in Columbia University in New York, Kevin was able to use his neural signals to control a robot arm located on another continent in a lab at Reading University. Control was not limited to the direction of movement; he was also able to feel the amount of force he was exerting.

The rat brain robot is an example of another important facet of Kevin's work; understanding and ultimately developing treatments for conditions that affect the brain, from Parkinson's to Tourette's syndrome and schizophrenia. Whilst there is an obvious connection to cyborg development, culturing a collection of 100,000 rat neurons capable of controlling a robot is an important aid to studying Alzheimer's and dementia, conditions characterized by the loss of neurons in certain areas of the brain. These conditions could be transformed if new neurons could be added to the degenerating brains of patients.



Emlyn Clay, Openvivo; Louise Marston, NESTA; Anders Sandberg (hidden), Future of Humanity institute; Kevin Warwick, University of Reading.

His most recent research has focused on the treatment of Parkinson's using deep brain stimulation. Initial trials have been extremely promising; stimulation via an implant has relieved patients of the tremors and latter stage symptoms associated with the condition. Infection and associated problems are an ongoing challenge with invasive devices, and Parkinson's stimulators are some of the only successful examples of implants are being used successfully for long-term and everyday use.[4]

From sci-fi to real world applications

As we look forward to the future of BCI, it is easy to jump to the problematic or scary examples, said Dr Anders Sandberg. But whilst transgression, drones and chunks of metal under the skin make 'good film posters', we should focus on applications a little closer to home. Indeed the interfaces themselves should not be considered an alien or foreign concept. Our lives are already filled with simple interfaces: glasses act as an extension of our eyes, clothes act as a 'super skin' protecting us from the elements, not to mention the range of applications that smartphones provide. Dr Anders Sandberg is research fellow at the Future of Humanity Institute at Oxford University. With a background in computer science, neuroscience and medical engineering, his work now focuses on the social and ethical issues of human enhancement and new technology. One of the earliest outcomes from the EU's ENHANCE project was that any technology that enhances our ability to communicate is a big deal, as it is communication that strings our brain together. Kevin commented that direct brain-to-brain communication was inevitable. Prof. Christopher James has already created the technology to make this possible for binary figures; fast forward a few technological steps and it could be colours, concepts, images and emotions we are communicating directly from one brain to another.

4. See: http://www.ninds.nih.gov/disorders/deep_brain_stimulation/deep_brain_stimulation.htm

Mind reading: how much do we understand about how the brain works

As the set of envisaged BCI applications for the future gets ever more diverse, an important consideration is whether our knowledge of the brain itself could be a stumbling block. How much do we actually know about the brain and do we know enough to confidently predict the outcomes of making changes within the brain? Emlyn likened using an EEG cap to look at a patient's brain activity to watching UK traffic patterns from space; you cannot make out individual cars or roads, but can gauge general patterns from the movement of flickering lights. Implanting electrodes into the nervous system, like the Braingate implant, improves signal resolution (our skin acts as an insulator), but the biggest challenge remains encoding the data collected. Brains are incredibly complex, even the activity of a small brain like that of a seaslug, composed of just nine neurons, is difficult to interpret – so imagine the challenge, said Kevin, of understanding the human brain at 100 billion neurons. Especially, as some of the most well-known BCI experiments by Miguel Nicolelis with monkeys suggest there may not even be a set neural code – our brains may be making it up as they go along.

The specifics of the neural code aside, increasing evidence for the brain's plasticity and adaptive qualities are a big consideration for the future. Neurons can have incredibly specialized functions, yet have shown the ability to change function very quickly. Kevin Warwick explained that neurons laid out in a dish will begin to branch out with the aim to create new connections within only 20 minutes. This plasticity could be a double-edged sword; whilst it allows stroke patients to regain brain function, Emlyn highlighted that if you focus on further enhancing this plasticity, there may be losses in other areas. The trade-off for decreasing plasticity could be increasing wisdom, and enhancing adult plasticity could prevent you from looking back and learning from situations. We should keep in mind the issue of 'fighting against your own design'.

Dr Anders Sandberg from the Future of Humanity Institute, Oxford University.

Overriding this issue of knowledge of the brain, there was a consensus from the panel in asking 'do we know enough to do what?' Anders highlighted that now we have the ability to communicate between brains and software, we can only push the technology forward if we focus on specific applications. Once we know the task in hand, we can decide which interface is best for the job, and whether we know enough. There is always an element of the unknown in scientific research, so it is inevitable that the gaps in our knowledge will become more apparent as we pursue new applications. Implants are a great development but require surgery and carry the risk of infection. External interfaces have the difficulty of signal resolution but this is not to say that they may not be good enough for some applications (as demonstrated by the new wave of consumer devices – see the box on page 5). Anders also emphasised that novel interfaces are being developed that could pave the way for unexpected applications. An example is optogenetics, the activation and silencing of neural circuit elements with light, in which gene therapy is used to make neurons light-sensitive. This technique is being used to develop further understanding of neural mechanisms.

In spite of the unknowns and undoubtedly a steep learning curve, Kevin urged that we should not focus on potential negative outcomes or an 'us versus brain' situation. During the three months in which his implant was in place for Project Cyborg, his body built fibrous tissue that surrounded the device. This tissue not only acted as 'bubble wrap' protecting the implant mechanically, it actually pulled it into a position in which it could better interact with his nervous system. The signal actually improved over time, the impedance reduced by the tissue. This example of the human body's acceptance of BCI is not unique: John Donoghue (Rhode Island) and Philip Kennedy (Georgia Tech) have both found similar phenomena in the cortex.

This is not say that there have not been some unexpected effects. A small number of patients with implants have developed depression, become gamblers or even voyeurs; the thalamus and sub-thalamic nucleus, with which the implant interfaces, playing a key role in motivation. Kevin Warwick highlighted that as our understanding develops, we must be aware that even small changes can have a knock-on effect. In terms of considerations for the future, Anders gave the example of 'a warning system' to provide guidance for which parts of the brain we should interface with. For example, the cortex (the surface of the brain, where most of the processing happens) might be a good area – it's very adaptive; areas responsible for motivation should be approached with caution, whilst the hypothalamus could be a no-go area, too much 'sex, drugs and rock 'n' roll' in there. This trade-off a simple indication of how as we explore BCI further, we will have to consider efficacy and ethics in parallel.

Consumer Brain Interfaces

Two San Jose-based companies, Emotiv and NeuroSky, lead the way in bringing BCI devices into the hands of consumers. They have both produced affordable headsets (recently profiled in Wired), that work in a similar way to EEGs, to allow gamers to control a variety of software and games with the power of their mind.

Emotiv's Epoc is a wireless headset (currently retailing at $299) that uses 14 sensors to detect a player's brain activity, allowing them to communicate with their computer without touching a key. Emotiv's CEO, Tan Le, gave a talk about the Epoc at TED Global 2010.

NeuroSky's Mindwave headset uses a single electrode to measure your levels of attention and relaxation as you complete a series of maths and memory games. The chip has already been licensed to companies including Mattel, whilst the US Archery Team are said to have been using the headset to improve their concentration during training

NeuroSky now have several UK partners who use the technology for a range of gaming applications. Myndplay is a mind-controlled media player and platform which connects with NeuroSky technology. This gives the user the ability to interact with a video or movie, choosing who lives and dies, or whether the good or bad guy wins, just by relaxing or focusing their mind.

Roll7 are a London-based 'small digital agency with big ideas'. In partnership with Neurocog and the University of Wollongong, they have created Focus Pocus a game designed for the 5 per cent of young people worldwide who suffer from ADD/ADHD (Attention Deficit Disorder). Using a NeuroSky headset, you play the role of a wizard in training, focusing or relaxing your mind to cast spells and defeat your enemies. The game brings together neurocognitive and neurofeedback training to provide an environment where children can train to improve important psychological processes that underlie their behaviour, while having fun at the same time.

Kevin Warwick, Professor of Cybernetics at the University of Reading.

Blame, responsibility and ethics

A discussion on the future of BCI cannot escape philosophical and ethical dimensions of the development of this type of technology. The responsibilities of mind control, blurring the lines between human and machine and even the potential for creating a subset of humanity with a competitive advantage or 'superpowers' are all potential considerations for the future. Questions of this type are impossible to resolve in an event (or report) of this kind, but below are some key elements from the debate to provide food for thought.

> *"If we can outsource memory or even processing power, what does it mean to be human…is it just a pattern of data?"*

At one extreme, Kevin suggested with an outsourced memory, you are essentially a cyborg; you become dependent on that data store and so do others. That said, writing and computing form external memory stores on which we are already dependent. He believes we need to consider how far you are going to go, because there may be a line where your values would change.

So with this in mind how much influence would a collective memory have on our brain or our 'self'? Anders gave the work of the philosopher David Chalmers as an example. He believes that if you write everything down in a notebook and cannot go without with it, then why not consider it a part of your mind? We previously relied on books, now we have smartphones, the internet, video and computers to keep our memories and would feel bereft without them. Ultimately it will depend on how far we choose to go; the brain devoid of memories or as extension of current capabilities?

"Who is to blame if something goes wrong?"

We have used computers to outsource all sorts of processes in our daily lives and 'the computer says no' or 'there has been a technical fault' is a common refrain. When it comes to more complicated hardware and brain implants, where do we draw the line between personal responsibility for our actions and technical intervention?

Kevin Warwick highlighted two different scenarios, extrapolated from his work. The first looked at the rat-brain robot, a collection of 100,000 neurons with a simple robot body. At this level of simplicity, you would think the responsibility lay solely in the hands of its creators. But pretty soon we could be creating 30 million neurons within a robot or even 100 billion human neurons (equivalent to our brains). It does begin to raise questions of this robot with a human brain – is it conscious? If it kills someone, who should go to jail? Should it vote? Asimov's laws of robotics start to come into play.

Whilst undoubtedly these questions would require a leap in terms of technology, others could become real considerations as implants become widespread. Kevin's second example concerned Parkinson's stimulators and the possibility of it picking up other signals. Michael Crichton's book 'The Terminal Man' has already discussed the possibility of an implant causing its wearers to run amok. g.tec are legally responsible for any electric shocks from their equipment, but would the manufacturer be responsible if they made implants and a wearer killed people due to signal interfering with their implant? Or would it be the surgeon who implanted the device, the radio station responsible for the signal or even possibly the presenter on the station at that time? David Eagleman, a neuroscientist at Baylor College, and author of 'Sum' and 'Incognito', directs a Neuroscience and the Law initiative which examines questions of responsibility such as this.

*"With DARPA the biggest funder of BCI,
should we have more civilian funding for this area?"*

The Defense Advanced Research Projects Agency (DARPA), a US agency responsible for the development of new technology for use by the military, is currently the biggest funder of research into human enhancement. Drones, as Kevin pointed out is a friendly name for 'autonomous fighting machines.' This has been a major area of funding for DARPA and has created many advances. With a mission 'to keep US military technology more sophisticated than that of the nation's potential enemies', the conversation turned to whether this should be a cause for concern, both in terms of PR and the direction of technological developments. In spite of the 'scary' nature of the organisation, Emlyn emphasized that DARPA had produced technology that was also useful in peace time – the hypertext (http) protocol that forms the basis of the World Wide Web originated within DARPA. Examples such as unmanned drones and eye-tracking technology are interesting simply as they push the industry forward (a fair bit of g.tec technology is used for military research), but the technology may also be used for other indications, particularly medical or social care. He gave the example of developing the mechanics for soldier-operated avatars, that could be of great use to locked in or disabled patients to enable them to control their own avatar.

For Kevin the issue was the need to make the research and its uses as open and transparent as possible. He is happy to accept this sort of funding if it will allow him to pursue the research he wants to do anyway.

As the ethics of human enhancement are a worry for many people, Anders expressed his disappointment that there was no civilian counterpart funding this type of research on the same scale. A military example will ultimately produce technology best suited to the battlefield, but less useful in daily activities around the house. A civilian organisation would most likely focus on apps for the living room or kitchen, a good thing both in terms of perception and the production of technology that will benefit people on a day-to-day basis.

Conclusions

Kevin summarised the challenge by describing BCI as a new continent where we are still in a tent pitched at the edge. We have discovered it but know very little; going further can be intimidating and we must anticipate unexpected challenges but it is nonetheless very exciting to explore. It is an incredibly exciting field in terms of the potential for positive change. *"Yes we don't know much, yes we have lots to learn but that's science!"*

In terms of human enhancement, Emlyn urged us to reap the benefits of what we already have before making changes. Although artificial intelligence may offer advantages, we have yet to create a computer that can rival the human brain in many respects. Computers are excellent at indexes, lists and counting, but are choked by pure maths and 'infinite problems'. There have been recent breakthroughs in facial recognition, where computers still pale in comparison to the human brain. As someone working in a field that tries to make computers that work like our minds, he has yet to come across anything that rivals the human brain in terms of sophistication, not even close.

For more about this event, visit the NESTA website to watch the video, access a list of links and videos on the resources page, and find out more about upcoming events.

Further reading

How Stuff Works – Brain Computer Interfaces.
http://computer.howstuffworks.com/brain-computer-interface4.htm

The New York Academy of Sciences meeting report (2011) 'Building Better Brains – Neural Prosthetics and Beyond.'
http://www.nyas.org/Publications/Ebriefings/Detail.aspx?cid=1914df78-19ec-440e-8d0d-19a8bf81140c

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