Neuroscience in ergonomics and human factors research and practice

This article explores the possible application of neuroscientific knowledge in human factors research and pratice. Can this knowledge be implemented to improve the design and evaluation of systems and functional environments? Or - to take it one step further - could it bring about the integration of brain and system wihtin online applications?

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Beyond physical and cognitive fit

Exactly a decade ago, Parasuraman coined the term neuroergonomics referring to studying the brain 'at work' (Parasuraman, 2003). Parasuraman pleaded for the integration of neuroscience and ergonomics to study brain structure and function in everyday environments, predominantly with the goal of using neuroscientific discoveries to improve the design of technologies in the workplace and at home. Not much later, Boff (2006) stated that we are in a (long) transition in human factors and ergonomics (HFE) research. Following the two classical generations 'Physical Fit', i.e. adaption of equipment, workplace and tasks to human capabilities and limits, and 'Cognitive Fit', i.e. harmonious integration of humans, technology and work to enable effective systems, Boff identifies the new generation 'Neural Fit'. Neural fit is concerned with the symbiotic coupling of man with technology to amplify human physical and cognitive capabilities.

A key implication of Parasuraman's and Boff's views is that we should no longer consider the human brain as black box and study only the information that goes in and the resulting behavior coming out. Fortunately, advanced neuroscientific imaging techniques provide us with the option to observe the brain, not only in the laboratory but also during daily life and at work. Time for us to get acquainted with the potential and the restrictions of neuroscientific knowledge and techniques and to investigate what role it can play in improving our quality of life, in helping society to cope with challenges like aging, and in advancing HFE theory and practice. In this article we explore (potential) applications, industrial involvement (through the results of a patent analysis), and the challenges we are facing.

Science fiction?

Science fiction has since long been playing with the concept of a device (a 'brain plug') that connects your brain to a computer through such a high-quality connection that you can experience and interact with virtual or remote realities directly, i.e., without using your normal peripheral sensory-motor systems. Such a connection will remain science fiction for some time, but we do see that the tools to have a look at our brain signals are moving into our everyday lives, even to the extent that games claiming to use those brain signals are commercially available for home use (like Uncle Milton's Star Wars Force Trainer (http://company.neurosky.com/products/force-trainer/) and Mattel's Mindflex (http://mindflexgames.com/)).

Several hardware technologies are available to measure brain activity outside the lab, among which ElectroEncephaloGraphy (EEG) and functional Near InfraRed Spectroscopy (fNIRS) are the best known. EEG provides measures of brain activity from electrical potentials and fNIRS from blood flow (brain areas in action require oxygenated blood and return de-oxygenated blood). Although both measures are susceptible to movement and external disturbances, they can potentially be used to study the brain at work and large progress is made in making systems more robust and user friendly (Van Erp et al., 2012).

Now that the instruments to observe brain activity become available, how can we put them to use in HFE? Parasuraman and Boff hinted at two different focus areas: Parasuraman proposes to use neuroscientific knowledge to improve design and to evaluate systems, task environments, and task allocation. Boff hints towards a far reaching integration of brain and system as two entities operating in a symbiotic relation. We will present two examples of both approaches in the next section. Additional examples can be found in the future BNCI roadmap (2012).

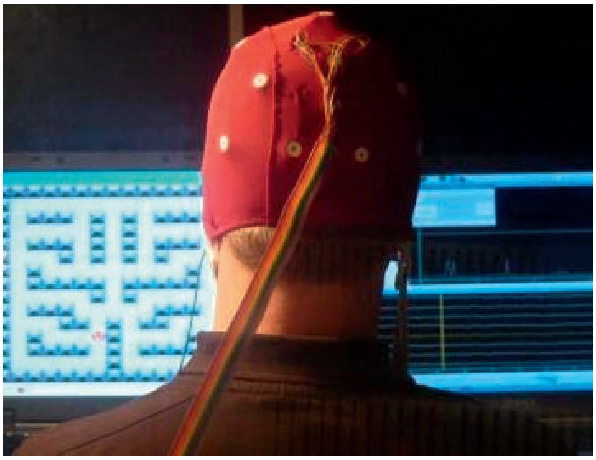

Figure 1. Playing Pacman with a Brain Computer Interface in which users mentally focus on one of sequentially presented tactile stimuli around the waist in order to guide pacman in the right direction (Thurlings, 2013; © TNO)

Neuroergonomics: the brain at work

Evaluation

Brain imaging may assess variables that reflect subjective judgments or information about cognitive or emotional state that are not revealed by overt behavior and these may supplement physiological and performance measures on aspects such as workload, attention, engagement, surprise, satisfaction, frustration or even beauty and hedonic quality. In addition, they provide a continuous measure without interrupting the user, as opposed to for instance questionnaires. Evaluation applications can be used in an off-line fashion (i.e. the data can be analysed afterwards). A proven example in this area is the use of EEG indices of drowsiness. These indices are often based on the spectral power in the different frequency ranges in the EEG like the alpha (8-13 Hz) and theta (4-8 Hz) bands. Almost twenty years ago, Stampi and colleagues (1995) developed the Alpha Attenuation Test (AAT) as index for sleepiness with sleep deprived subjects. The AAT is based on the observation that when operators get sleepier, alpha activity increases with open eyes and decreases with closed eyes.

A more recent example is the brain-imaging research on cell phone use during simulated driving that indicates that even the hands-free or voice activated use of a mobile phone strongly affects brain areas that are relevant for driving (Just et al., 2008). The listening-and-drive situation produced a 37% decrease in activity in the parietal lobe, which is associated with spatial processing. Activity also decreased in the occipital lobe, which processes visual information. Comparable approaches are taken to ultimately increase the safety of older drivers (Lees et al., 2010).

Seeing the unperceived

Eye tracking indicates where someone is looking but not what he or she is perceiving. Brain measurements may aid to determine the actual focus of (visual) attention (Bahramisharif et al., 2010), and even whether what is being looked at is relevant or not (Brouwer et al., 2013). This information can be of use in many applications. For instance, EEG alone or combined EEG and eye movement data of expert observers could support the detection of deviant behaviour and suspicious objects. In an envisioned scenario an observer or multiple observers are watching CCTV recordings or baggage scans to detect deviant (suspicious or criminal) behaviour or objects. EEG in combination with eye movements might be helpful to identify potential targets that may otherwise not be noticed consciously. Also, images may be inspected much faster than normal (so-called Rapid Serial Visual Presentation paradigm).

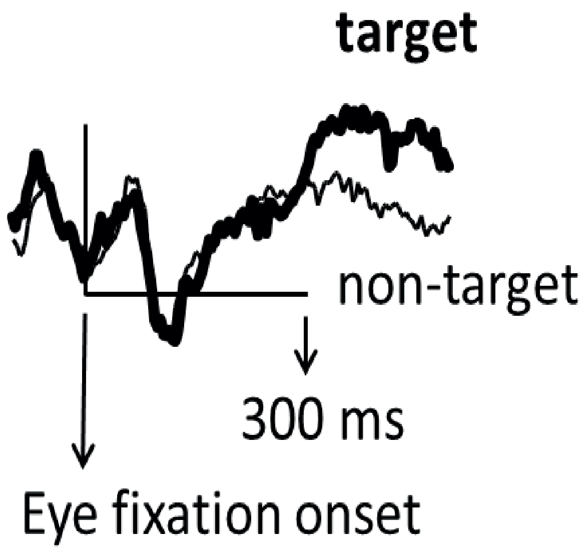

Figure 2. Averaged EEG traces synchronized at eye fixation onset and separated for cases in which observers are looking at looked-for targets and other, non-target objects (adapted from Brouwer et al., 2013; © TNO)

Neural fit: Brain Machine Interfaces

User-system symbiosis

In the same year that Boff introduced 'neural fit', *Nature* predicted that the achievements of computing power, networks and humans will grow beyond human creativity within the next 15 years (Vinge, 2006). This prediction illustrates the capacities that computing systems are developing, leading to inevitable changes in the way humans cooperate with them. From a Human Computer Interaction (HCI) perspective, system and user will not remain separate entities but will merge into a symbiotic cooperation. Adequate knowledge about the user's capacities, emotions and intentions is indispensable to reach this symbiosis, an area where we foresee an important contribution from neuroscience.

To create symbiosis, the future generation user-system interfaces needs to understand and anticipate user's state and user's intentions. For instance, automobiles should intervene before driver drowsiness occurs and virtual humans could convince users to adhere to their diet. These applications require systems to gather and interpret information on mental states such as emotions, attention, workload, fatigue, stress, and mistakes. Brain-based indices of these user states are extending indices based on for instance facial expressions and physiology. An important difference with applications mentioned previously for evaluation purposes is that the analysis must be done in real time and is used to interactively adjust the system or the user-system interaction.

Only recently, efforts are made to identify estimate e.g. emotional state in real time for a specific individual based on neural correlates (Petrantonakis et al., 2009). The latter is an interesting new development towards user-system symbiosis: emotions are both critical to 'understand' the user and also interacts with cognitive capabilities such as attention and reasoning (Dolan, 2002).

Human enhancement

According to some, the intimate connection between brain and technology paves the way for radically improving our cognitive and physical capabilities. Currently, applications like neurofeedback training (brain activity alteration through operant conditioning, for instance to improve attention, working memory, and executive functions) are relatively common among healthy users, despite the fact that their effectiveness has not been proven. A direct connection between one's brain and the environment is the playing field of Brain Computer Interfaces (BCIs). One of the driving forces behind the development of BCIs was the desire to give users who lack control of their limbs access to devices and communication systems. For healthy users, that have full muscular control, a BCI currently cannot act as a competitive source of control signals due to its limitation in bandwidth and accuracy. However, it is possible, that these users could – for very limited application scenarios – also benefit from either additional control channels or hands-free control in specific situations. Examples include drivers, divers, and astronauts who need to keep their hands on the steering wheel, to swim, or to operate equipment. Brain-based control paradigms are developed for these applications in addition to, for instance, voice control. The time needed to realize viable implementations in this direction is expected to be long though (Coffey et al., 2010; Thurlings et al., 2013). Magnetically stimulating the brain is mainly studied in the context of treatment of disorders but may eventually also be used to improve capabilities of healthy people. First exploratory studies with healthy participants are already reported (see McKinley et al., 2012 for an overview).

Industrial involvement

To get a view on the industrial involvement, and therewith the applications mature enough for use and valorization, we present some highlights of a patent analysis we performed in 2012 on neurocognition and applications for healthy users. A patent search showed that the field of applied neuroscience shows continuous growth over the last two decades with more than 3000 patent families. We categorized the 90 patents that were most relevant to the current topic in ten application areas presented in table 1, including the dominant players.

Table 1. Results of a patent analysis performed in 2012 on neurocognition and applications for healthy users resulting in 3000 patent families. The categories below represent the top 3% based on relevance for the Human Factors and Ergonomics community

Application area	Dominant players
Interface, product and environment evaluation	DaimlerChrysler, Microsoft, Nielsen
Attention, alertness, fatigue and drowsiness detection	SAM technologies, Panasonic, JP Agencies, Chiao Tung, Chung Yuan Christian, General Electric, Honeywell, ESA
Mental and affective state detection	Panasonic, Emotiv, Searete, Nielsen
Cognitive state detection	Panasonic, Yamaha, IBM
Detection of unconscious processes like deception	New York University, Drexel University
Enhancement of perception and cognition	MIT, Cheng Kung, Philips
Measuring capabilities, training and selection	SAM technologies, DaimlerChrysler, Nijmegen, Panasonic, Lockheed Martin Corp, US Navy, Seoul
Brain Computer Interfaces for control	Florida University, Drexel University, Leuven, Maryland, Seoul, KAIST, JP Agencies, Philips, Panasonic, US DHHS / NIH, US NASA, US Airforce, Toyota, Honda, IBM, Sony, Nokia, Mattel, Siemens, Fraunhofer
Image and database annotation	Colombia University, Toyota, IBM, Microsoft
User identification	Siemens, DaimlerChrysler, IBM

The results of the patent analysis indicates is that the technology – especially with respect to evaluation – has matured enough to be of interest to commercial companies and indicates that it already is or might be used in the near future in (HFE) practice.

Ethics

A subject that is closely related to measuring and using brain data is ethics. We can hardly be complete and will only mention three issues (more information on this topic is given by Schuijff et al., 2012). The first is privacy. Systems that gather potentially sensitive information such as cognitive and physiological functioning, lifestyle and preferences must be designed with the utmost care to protect privacy. This certainly holds for critical brain information. The second concerns areas of applications like human enhancement through brain stimulation that may be frowned upon. Some argue that improvement of performance through affecting the nervous system is an everyday reality, for instance through the use of coffee or tea. However, the debate about human enhancement has gained importance, amongst others through the increased use of prescription drugs like Modafinil and Ritalin without a medical indication by both students and professional workers. Finally, there is a general concern about our increasing dependence on technology and the fear that we will soon lose ability, memory, and creativity and ultimately become slaves to the machines. An ever more intimate coupling between brain an system may increase these concerns.

Challenges

Despite some remarkable results, neuroergonomics and neural fit are still young research areas facing several challenges. We list the five most prominent ones:

- Identify the neural markers of some of the very specific states (e.g., mood, fatigue, creativity, flow, happiness) or processes (e.g., decision making, information processing, wanting, linking, recognition). These markers should have good sensitivity and specificity, and their reliability and validity should be known over different users and environments.
- Realize robust measurements outside the lab. This requires breakthroughs in the areas of usability, hardware and software, and system integration.
- Examine the potential societal, ethical and economic impact of neuroergonomics. Define potential user groups and their characteristics, including their feeling about this new technology.
- Translate fundamental neuroscientific results obtained with lab equipment like MRI scanners to markers and measures for wearable sensor systems like EEG and NIRS equipment.
- Develop ways to integrate neuromarkers with other physiological, behavioural, and subjective measures.

Conclusions

Successful integration of neuroscience and ergonomics could have far-ranging effects, from safer cars to computers that finally understand your intentions and mood. Neuroscience can contribute to our domain through advancing current models of human cognition, providing us with additional objective evaluation measures and enabling user-system symbiosis. Affirmative examples are reported in relation to for instance driving and cell phone use, and the patent scan shows that industry is also getting involved. There are important challenges to solve, but we believe that developing significant and feasible applications of neuroscientific knowledge and bringing its benefits to healthy users is in the interest of both fields: ergonomics as well as neuroscience.

Samenvatting

In dit artikel verkennen we (mogelijke) toepassingen van neurowetenschappelijke kennis binnen de ergonomie. Neuro-wetenschappelijke kennis kan worden ingezet om systemen en taakomgevingen beter te ontwerpen en evalueren. Een stap verder is het realiseren van een integratie van brein en systeem binnen online toepassingen. Hoewel dit werk nog in de onderzoeksfase verkeert en we een vijftal belangrijke, nog deels te overwinnen uitdagingen noemen, brengt een patentanalyse de interesse vanuit de industrie al naar voren. Ontwikkeling van neurowetenschappelijke toepassingen kan zowel de ergonomie als de neurowetenschappen een belangrijke impuls geven.

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GESPOT

De schilder heeft blijkbaar duidelijk willen maken dat je met deze lift echt alleen naar beneden kunt ....
of heeft hij het welbekende puntje op de i willen zetten?