Brain computer interface and transcranical stimulation: frontiers, reliability, safety and threats

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ABSTRACT: EEG-based Brain Computer Interface (BCI) and Transcranial Stimulation represent one of the frontiers in brain studies, promising great potential in practical application in several fields. Indeed, compared to other brain-imaging techniques, BCI and Transcranial Stimulation are non-invasive, low cost and portable, leading to design applications in individuals' daily life, spreading from health care to politics and defense. Indeed, Science is running fast towards unpredictable results and the implications are global across industries, in every field, but low attention is given to protect individuals' privacy and wiliness from abuse of data and related information.

KEYWORDS: Brain computer interface; transcranial stimulation; cognitive science; biological data protection; biological data hacking

1. Introduction

In the Big Data Era, human biology-related information represent a great opportunity for research to investigate frontiers in human-being and across industries to develop applications both to improve our daily life and wellness, and to predict inclinations and preferences. A great challenge consists in decoding brain mechanisms so that the information could be collected without language or sensory filters, truly corresponding to the real mental state condition of an individual.

Without entering in a detailed description of the working of brain, we wish to recall that our neurons perform two types of actions, namely fire and inhibit: they fire when the input signal exceeds a given threshold or they inhibit if it is below the threshold value[1].

According to Korbinian Brodmann's definition of the cerebral cortex, brain is assumed to be divided into 52 discrete local areas, the so called cyto-architectural map[2], each processing specific type of data. When data are processed by neurons, the related area generates electric pulses of signals and

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[2] E.R. KANDEL, J. H. SCHWARTZ and T. M. JESSEL, *Principles of Neural Sciences*. Center for Neurobiology and Behavior, College of Physicians & Surgeons of Columbia University and The Howard Hughes Medical Institute, Fourth Edition, 2000.

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magnetic fields[3] to perform actions by actuators of the body. Apart from the involvement of pumping of ions in brain, this process can be read by several techniques in brain imaging, spreading from functional Magnetic Resonance Imaging (fMRI) to Electroencephalography (EEG), allowing to reconstruct brain processes.
In this context, EEG-based Brain Computer Interfaces, shown in figure 1, represent a great opportunity and for scientific research and for commercial applications.

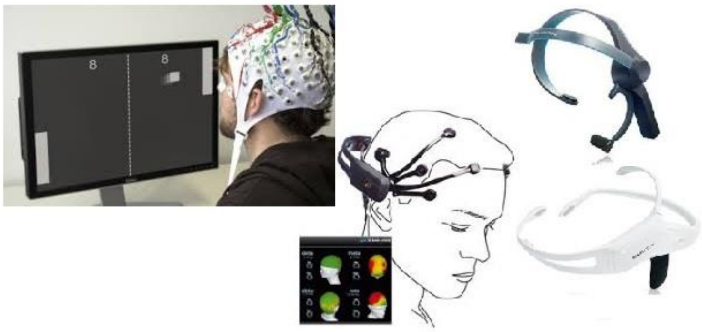

Figure 1: different models of Brain Computer Interface headsets

A Brain Computer Interface (BCI) headset is a simplification of the EEG medical equipment[4], allowing to detect, record and analyse the cerebral rhythms. For their high accuracy, BCIs are comparable to the medical EEG and moreover, they are widely used in research for their low cost, high portability and non-invasiveness. Wireless or bluethoot, they allow the individual to a wide movement freedom in the experimental environment and they collect the same brain frequencies recorded by a medical EEG: alpha rhythms (7 Hz – 14 Hz) associated to meditation, relaxation, contemplation; beta rhythms (14 Hz – 30 Hz), related to attention, active thinking, concentration; the delta band (3 Hz – 7 Hz), registered in children and associated with continuous attention activity, as in Leeb et al.[5]; the theta rhythm (4 Hz – 7 Hz), generally related to emotional engagement[6]; the gamma signal (30 Hz – 80 Hz), usually related to the cognitive interpretation of multi-sensory signals.
Often, research on brain-computer interaction and on brain manipulation/data collection involves also transcranial magnetic stimulation devices (figure 2).

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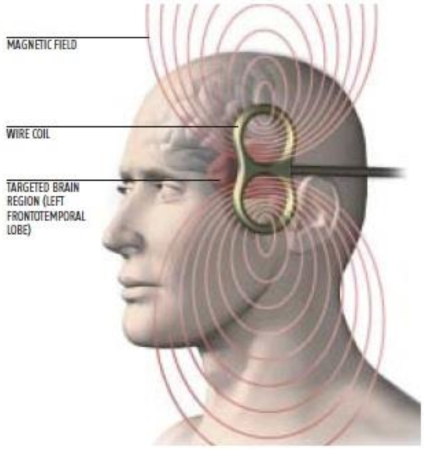

Figure 2: a transcranial magnetic stimulation device.

In this paper we will see the state-of-the-art in BCI and transcranial stimulation related research and application (paragraph 2) and what are the potentialities and threats (paragraph 3), considering limitations. In paragraph 4 we will conclude and present some possible topics needing great attention in this field and we will conclude with our consideration.

2. BCI and Transcranial Stimulation: state-of-the-art and applications

EEG-based BCIs and Transcranial Stimulation are currently in the focus of research and industries for the wide possibilities on one hand to deepen the knowledge of brain processes, on the other to apply results in daily life developing commercial applications.

BCIs allow to investigate the mechanisms of brain while in action, so that, they are particularly useful in research to register the response to musical and visual stimuli and recognize the emotional valence[7, 8, 9, 10], but also to reveal the mechanism of visual creativity[11]. In some experiments the objective is to evaluate the response to colours[12, 13], to stereoscopy and monoscopy[14] and also the cogni-

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tive response to visual-perceptive stimuli[15], based on the concept of priming[16, 17, 18]. Other scholars focus on the human-machine interaction through cerebral rhytms, such as in Carlson and Millan[19] showing the possibility to develop brain-controlled wheelchairs, or to control car[20] or a robot[21]. Moreover, the most surprising application is related to the possibility to reconstruct images and video seen by an individual, starting from his/her brain rhythm[22, 23] collected by a BCI jointly with fMRI. In this latter work, scholars demonstrate the possibility to reconstruct visual data from the brain of people who cannot communicate verbally, such as stroke victims, coma patients and people with neurodegenerative diseases and the opportunity to realize brain-machine interface for individuals with cerebral paralysis, who could guide computers with their minds.

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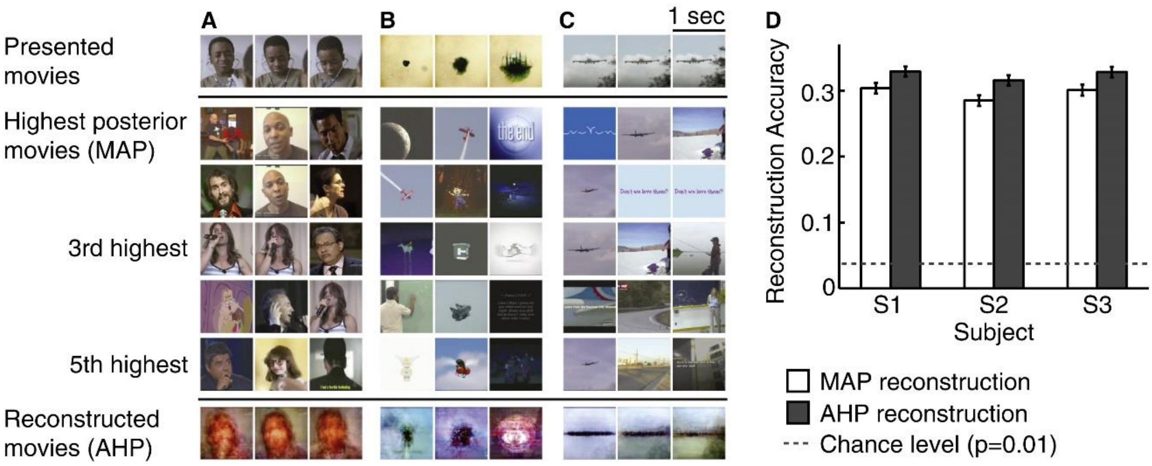

Figure 3: Reconstructions of Natural Movies from BOLD Signals in the work of Nishimoto et al.

Other applications of EEG-based BCI technology are related to the possibility to realize a human-human communication mediated by BCI technology[24, 25, 26]. In their work, Yoo et al.[27] and Rao et Al.[28] have shown that a person's thought of movement can be transferred to a second, which actually brings it to completion, realizing, in this way, a telepathy process mediated by technology. One of the researchers, put up in front of a video game, was responsible for thinking of pressing a button that would hit a shot. Another researcher, who was in another room and did not see the gaming screen, received the stimulus to move his finger and press the button. Two different technologies were needed to complete the transfer of this message. On the one hand an EEG-based BCI, on the other, a transcranial magnetic stimulation device. The latter stimulated the motor cortex to lead to finger movement. The means of transferring the message was the Internet.
In another study[27] scholars have been able to realize a real telepathic communication from one individual to another. It consisted in a simple greeting: a person in India thought of the words "hola" and "hello", transformed into a binary code message thanks to the association between some foot and hands movements translated into 0 and 1. The electrical signal in the neurons during the movement was first recorded through an EEG-based BCI and then sent to a person who was in France. Here, the code has been translated into visual stimulation, transmitted by the other person through transcranial stimulation targeted at the brain area responsible for vision. This second person was able to correctly translate the greeting message sent to the other 5,000 miles away.

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Last, but not least, scholars[28] have been able to let two individuals interact telepathically in an exchange of questions and answers. Also in this case, researchers used EEG-based BCI and transcranial magnetic stimulation to allow two individuals to ask a question and perceive the response, which was limited in these cases to a yes or a no.

All these applications, ranging from reading the emotional state of people, their tastes and preferences, to the reconstructions of mental images and telepathy, and making a tool as simple as am EEG-based BCI as a powerful truth-machine, open a wide ethical and jurisprudential discussion. Unfortunately, in this area and despite the commercial application run, little has been done and prepared by lawmakers and law scholars.

3. Potentialities and threats

Inputs from the academy's world often remain isolated or relegated to basic research, while industries and some great innovators such as Regina Dugan, or Elon Musk are ready to seize it to turn them into commercial products that are already penetrating the market and will revolutionize our future and daily life. This different speed of research and industries and the lack of technical information to the jurisprudential world, lead tangible threats for individual freedom, in general, in choices and in managing their own data. People often don't really know the potential threats due to circulation of sensitive biological data, today collected in a massive way, especially in the health sector, and they are not informed about all the way these data could be collected, shared and used by industries. Law makers and Jurisprudence have the responsibility to protect individuals from abuse or inappropriate use of their own data.

So far, we remain in the generic field of data protection, but the nature of the data itself poses greater dangers than simply "privacy". Let's think, indeed, of the possibility of hacking the human body and our minds provided by the new technologies. In the previous paragraph we have shown how it is already possible, though in its basic form, to induce a distance movement, transfer a greeting, locate and catalog perceptions and the human mental state. Although in some ways the canonical applications of this technology can bring benefits, such as in the case of rehabilitation and support for degenerative neural diseases, we cannot help but think of the possibility of inducing an individual to reveal, even unconsciously, his/her own preferences and inclinations, if not even to perform gestures, movements or actions he/she would normally be adverse. Telepathy in the strict sense, meaning communication between one person and another only by thought, will have to be based on a brain-brain interface (BBI). Large companies are not yet investing in this field, but there are major universities that in recent years, as we have seen, have shown how it is possible to pass a message from an individual's brain to that of another. Hacking the human system is still science fiction, but we do not know what the future holds for us, and, moreover, at the moment it would be possible to influence a remote automatic system with brain impulses, making it difficult to prove the intentionality or paternity of the action.

[28] A. Stocco, C. S. Prat, D. M. Losey, J. A. Cronin, J. Wu, J. A. Abernethy, R. P. Rao, *Playing 20 questions with the mind: collaborative problem solving by humans using a brain-to-brain interface*, in *PloS one*, 10(9), 2015, e0137303.

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With regard, however, to the use of preferences and inclinations of unconscious subjects to provide such personal and non-verbal indications, the use of BCI technologies in politics and neuromarketing should be mentioned. In these two fields, knowing the true end-user thinking is extremely important and there are already cases of use of EEG-based technologies.

Especially in areas outside the most under observation, systems of analysis, and hence, of diversion of voters' preferences, have already been used. In 2015, Kevin Randal, a New York Times reporter, went to Mexico City to analyze one of the most advanced neuropolitics systems[29]. The system includes meetings where cerebral preference, collected through mapping technologies, reveal whether a political campaign really works, beyond what the respondents say. Billboards containing political messages are also another tool used to interpret and influence political preferences. As Randal writes, «Inside the ad, a camera captured their facial expressions and fed them through an algorithm, reading emotional reactions like happiness, surprise, anger, disgust, fear and sadness. With all the unwitting feedback, the campaign could then tweak the message — the images, sounds or words — to come up with a version that voters might like better».

Indeed, the use of new technologies like facial coding, biofeedback and brain imaging by political parties and governments is a growing phenomenon, evoking futuristic scenarios in which well-informed billboards scan commuters' eyes and call out to them personally.

Moreover, this system is already widely used in neuromarketing, where future customer panels are monitored by bio-feedback and BCIs to interpret real purchasing attitudes and preferences[30]. In affective computing context, Rosalind Picard and Rana el Kaliouby[31] founded Affective, a startup company working on emotion measurement to create application able to identify emotions in real time, through facial recognition algorithms, BCIs and Artificial Intelligence systems. Affectiva operates especially in the advertising field and is cooperating with specialized companies to detect in a video-negotiation if the participants are deliberately hiding information. During the presidential Election, in 2012, the software Affdex, developed by Affectiva, analyzed more than two hundred people while watching Obama-Romney debates, forecasting the voting preferences with a reliability of 73%.

4. Conclusions

In this paper, we have seen how BCI and transcranial magnetic stimulation technologies can be a great opportunity for research and human progress, but at the same time conceal dangers for the protection of civil rights.

Moreover, the latest frontiers of research are focusing on the use of these technologies to identify a brain fingerprint, which could be an opportunity both to safeguard the human mind, transferring, for example, such imprint into an automatic system, and to uniquely identify an individual.

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[30] L. IACOVONE, R. FOLGIERI, *Consistency and impact of brand management decisions: the neurosciences perspective*, in *Finanza Marketing e Produzione*, 31(1), 2013, 124-154.

[31] D. MCDUFF, R. EL KALIOUBY, R. W. PICARD, *Crowdsourcing facial responses to online videos*, in *Affective Computing and Intelligent Interaction* (ACII), 2015 International IEEE Conference on, 2015 September, pp. 512-518.

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Reconstruction of images and videos by collection of cerebral rhythm opens other questions of ethical and jurisprudential nature. How much will this impact the application in defense and justice? Can we admit, saving human civil rights, such a proof of guilt or innocence? Are they acceptable tools in the fight against terrorism?

Although research is studying these methods also as a support of justice, law makers lack regulations on the matter and are currently ignoring this scenario, even if not so far from its actualization.

Important applications could be in Justice: think, for example, to the possibility of collecting testimony from individuals affected by locked-in syndrome, coma or stroke, starting from images, video and language reconstruction, or to the possibility of applying these technologies to criminal and terrorism prevention. In this context, cerebral fingerprint could be as good an identifier as DNA, an admissible evidence in a courtroom.

Actually, we should also consider the threats deriving from the abuse of BCI and TMS cognitive technologies, which could be used to perform real hacking activities of unconscious individuals or, in less extreme cases, to engage in discrimination based on brain abilities and characteristics, such as in a job-selection or military-selection procedure.

Certainly, considering this potential (technical) capability of getting more and more into the brain and therefore inside the human mind, we need to conduct a careful reflection on the ethical and legislative limits to protect individuals.

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