RIVISTA INTERNAZIONALE DI FILOSOFIA E PSICOLOGIA
DOI: 10.4453/rifp.2020.0011

ISSN 2039-4667; E-ISSN 2239-2629
Vol. 11 (2020), n. 2, pp. 169-189

RICERCHE

Extended mind and the brain-computer interface. A pluralist approach to human-computer integration

Federico Zilio(α)

Ricevuto: 29 novembre 2019; accettato: 24 aprile 2020

Abstract This paper uses *Extended Mind Theory* (EMT) to explore *Brain-Computer Interfaces* (BCIs), demonstrating how this conceptual framework provides a wide-ranging interpretation of the potential integration of user and computer. After a preliminary analysis of first- and second-wave EMT arguments and other pragmatic criteria, I present BCI technology, addressing the issues that arise. Can BCIs extend our mental processes and to what degree? What EMT criteria should be applied to this technology? What is the role of the body in the process of integrating user and computer? What are current limits to complete cognitive and bodily extension by BCIs? In line with this discussion, I suggest a pluralist approach to BCIs, allowing for specific and appropriate application of the various models and paradigms. I also advocate greater focus on the integration of body and tool, primarily for clinical purposes, but also for applications that will meet daily needs in the future.

KEYWORDS: Extended Mind; Brain-Computer Interface; Embodiment; Parity Principle; Cognitive Artefacts

Riassunto *Mente estesa e brain-computer interface. Un approccio pluralista all'integrazione uomo-macchina* – Il presente articolo fa uso della *Extended Mind Theory* (EMT) per indagare le *Brain-Computer Interfaces* (BCIs), dimostrando che questo framework concettuale offre un'interpretazione ad ampio raggio della potenziale integrazione tra utente e computer. Dopo un'analisi preliminare degli argomenti della EMT di prima e seconda generazione e altri criteri pragmatici, presenterò la tecnologia delle BCIs, affrontando alcune questioni a essa collegate. Le BCIs possono estendere i nostri processi mentali e fino a che punto? Quali criteri della EMT dovrebbero essere applicati a questa tecnologia? Qual è il ruolo del corpo nel processo di integrazione utente-computer? Quali sono gli attuali limiti per completare l'estensione cognitiva e corporea da parte delle BCIs? In linea con questa discussione, suggerirò un approccio pluralistico alle BCIs che permetta un'applicazione specifica e appropriata dei vari modelli e paradigmi. Sosterrò inoltre la necessità di una maggiore attenzione all'integrazione tra corpo e strumento, principalmente per scopi clinici ma anche per applicazioni future che soddisfino le esigenze quotidiane.

PAROLE CHIAVE: Mente estesa; Brain-Computer Interface; Incorporamento; Principio di Parità; Artefatti cognitivi

---

(α)Dipartimento di Filosofia, Sociologia, Pedagogia e Psicologia Applicata, Università degli Studi di Padova, Palazzo del Capitanio, Piazza Capitanato, 3 - 35139 Padova (I)

E-mail: federico.zilio@unipd.it

1 Introduction

OVER THE LAST FEW DECADES, several philosophical theories have been brought together under the name of 4E Cognition. 4E (embodied, embedded, enactive and extended) Cognition is a field of interdisciplinary research based on the idea that mental activity is structured by dynamic interactions between the brain, body, and environment (in both a physical and social sense).[1] It brings together a series of approaches which challenge neuro-centric and internalist positions, such as computational and cognitive theories of mind.[2] In contrast to classical cognitivism, 4E theories argue that the mind is not a passive box receiving neutral physical stimuli from the environment by means of the body. Rather, the mind seems intrinsically linked to these bodily actions, which always occur in an environmental context (embedment, enactment). The body – and not just the brain – processes information and plays a representational role in a sensory-motor (embodied) way, so that mental representations are action-oriented and body-skill-relative.[3] According to some radical theories, there are no mental representations at all in a classical sense. Instead, sensory-motor contingencies, bodily affects, postures, and movements enter cognition in a non-representational way.[4] One of the most important implications of the 4E paradigm is the belief that mental processes are not skull- or skin-bound but actively incorporate environmental structures such as symbols, tools, artefacts, media, cultural practices, norms, groups, and even institutions.[5] This is generally called the Extended Mind Theory.

The Extended Mind Theory (EMT) was introduced in 1998 by Clark and Chalmers[6] and claims that the separation between brain, body and environment is a mere assumption, since there is no reason to confine our cognition within the skin and skull. The mind cannot be described only by means of neural activity; rather, our mental processes are distributed in the environment through the use of instruments. In this way, we find support in the external world through tools that become part of our cognitive (e.g. memory, calculation, communication) and bodily (e.g. movement and perceptual) capacities. During our daily life we often make use of notebooks, paper and pencil, smartphones, and laptops to lighten our cognitive load, e.g. by taking notes, using the calculator app, finding information on the Internet, using GPS, etc. In the last fifteen years, EMT has been further developed along various lines. But these different versions agree in sustaining that our cognitive and bodily interactions with the world are not limited by the processes inside our heads. Theoretical differences generally arise with respect to the criteria that define how the mind can be extended beyond the skull. This is a crucial issue for the theoretical and practical relevance of EMT and its reliability; some people entertain a broader conception of the extended mind, considering any object – analogical or digital – can be a potential tool in cognitive and bodily extension, while others use a more narrow definition, including only a selective set of devices.

After this Introduction, Section 2 presents a theoretical analysis of EMT in different forms. The aim is to provide a wide-ranging framework for the interpretation of cognitive artefacts, i.e. devices that shape, transform, and contribute to our cognitive practices.[7] In particular, I will introduce the first- and second-wave EMT arguments on mental extension, also adding some pragmatic criteria and a taxonomy of cognitive artefacts. Section 3 then presents brain-computer interface technology (BCI), focusing on three models that interact differently with mental activities. A brain-computer interface (BCI) is a direct connection between a brain and an external machine which operates through the acquisition and classification of brain signals. This makes it possible to develop devices that interact directly with the environment without requiring the use of any other body part. BCIs are generally applied in severe clinical situations where there is some level of bodily paralysis, e.g. Locked-in syndrome,[8] but recently they have also been developed for entertainment and experimental purposes.[9]

Since BCIs create (restoring or enhancing) a specific connection between a person and an environment, but also involve a connection between that person's body and the very same device, can we consider BCIs to form a unified system with the human being? If this is the case, according to which criteria and version of EMT can a BCI be (or become) a tool for the extension of cognitive and bodily abilities beyond the brain? In this respect, Section 4 offers an interpretation of the models for BCIs presented in Section 3, using the extended mind framework and other criteria to analyse and discuss the structure, limits, and potentialities of specific BCIs. The paper ends by suggesting that a high-performance user-device coupling should aim to improve the ergonomics of the technological tool itself and its interaction with the body.

2 The extended mind theory

EMT adheres to an externalist view that conceives of cognition as crucially related to the body and environment, opposing the idea that only the brain plays a constitutive role in producing cognition and experience. According to the proponents of externalism, brain-bound and neuro-centric cognitivism is based on classical Cartesian internalism, which can be principally characterized by the *possession claim*, i.e. the possession of any mental phenomenon by a subject does not depend on any feature that is external to the physical boundaries of subject, and the *location claim*, i.e. any mental phenomenon is spatially located inside the boundaries of the subject that has or undergoes it.[10] Depending on whether only one or both claims are rejected, there are two different versions of externalism, one moderate and one radical. Questioning the possession claim is linked to so-called content externalism, according to which mental contents depend on elements that are not merely internal to the subject that possesses such contents, but also on bodily, environmental, and social factors. In this sense, content externalism disputes the idea that mental contents depend exclusively on the subject but does not oppose the location claim. By contrast, vehicle externalism is more radical and also challenges the location claim, maintaining that there is no reason to believe that mental processes themselves exist exclusively within the subject, seeing them instead as operations distributed in the world (of which the subject himself is a part).

This distinction between alternative versions of externalism can be linked to different levels of extendedness, depending on whether someone considers that mental processes are limited to the body or go beyond it, through tools and environmental objects. The first level of extension refers to so-called embodied cognition and has two different sublevels: the soft version claims that cognitive processes partially depend on bodily processes; the hard version that cognitive processes are partially constituted by bodily processes. As for extrabodily influences on mental activity, the abovementioned content externalism adheres to what Rupert has called the Hypothesis of Embedded Cognition,[11] the view that cognitive processes strongly depend on or are constituted by factors external to the human being, while vehicle externalism adheres to the Hypothesis of Extended Cognition, according to which cognitive processes literally extend into the environment, such that a human cognitive system without the inclusion of environmental elements is inconceivable. Furthermore, in relation to both these externalist positions, we can describe how the mind goes beyond the head in various ways: in a semantic sense (meaning is external to the brain, totally or in part);[12] in a phenomenal sense (experience depends on factors external to the brain and body, totally or in part); or in a functional sense (bodily and extra-bodily mechanisms can replicate, improve, or substitute for specific cognitive functions

Extended Mind Framework	
Theoretical Background	
Externalism: cognition is crucially related to body and environment	*Content Externalism*: mental contents depend on elements that are not merely internal to the subject that possesses such contents *Vehicle Externalism*: there is no reason to believe that mental processes themselves exist within the subject, rather they are operations distributed in the world
Approaches	
Embodied Cognition	*Soft version*: cognitive processes partially depend on bodily processes *Hard version*: cognitive processes are partially constituted by bodily processes
Embedded Cognition	Cognitive processes strongly depend on or are constituted by factors external to the human being
Extended Cognition	Cognitive processes literally extend into the environment

Table 1. The theoretical background and different approaches within the *Extended Mind Framework*

usually related to the brain).[13]

Taken together, these characteristics suggest that externalism is continuously being updated, making it difficult to define a univocal version of EMT (Table 1 describes a number of versions). One could consider that mental processes depend on external factors without being concretely generated outside of the brain (content externalism and embedded cognition), or that these processes consist in transactions between a human being and environment within a unified system (vehicle externalism and extended cognition). One can consider this extension to be purely semantic, or believe that only high-order cognitive processes are subject to extension, or indeed that all of phenomenal experience goes beyond the boundaries of human skin. In this work, I will use "extended mind" not only in a cognitive sense, but also to include broader bodily and experiential factors.

Now, we need some criteria to identify when we are dealing with cognitive artefacts that can extend our mental activity. The Parity Principle delineated by Clark and Chalmers states that a process that involves the body and/or environment extends cognition beyond the head if it is functionally equivalent to an intracranial cognitive process, i.e. we would have no hesitation in recognizing it as part of the cognitive process.[14] The Parity Principle (PP) has been intensively discussed and criticized, e.g. for being difficult to apply and for the rigidity of the functional equivalence criterion for defining the integration between extra- and intracranial processes. In particular, Adams and Aizawa argued that EMT proponents commit the coupling-constitution fallacy, i.e. they neglect to acknowledge that because an object or a process is constantly used and coupled to a cognitive process does not mean that it has become an integral part of this process. In other words, one cannot infer functional equivalence between an external object/tool and an intracranial process simply by virtue of their coupling, since coupling does not necessarily imply a constitutive relationship.[15]

2.1 Second-wave EMT

More recently, EMT proponents have been developing a second-wave version of the theory,[16] based on different principles than PP, such as the Complementarity Principle or Cognitive Integration.[17] Departing from the functional equivalence of the first wave, the second wave aims to define complementarity and integration in a single system between functionally different parts (internal and external),[18] including other perspectives besides extendedness, i.e. embeddedness, enactment, and embodiment. In this view, a human-device coupling need not be functionally identical to a mental process, but can still improve or extend cognition by means of an external object, or a fruitful interaction involving a body-environment continuity, such that it becomes hard to tell where the cognitive or experiential process ends (head, body, tool?), and to what degree it extends. As PP is strictly specific, concepts such as "cognitive integration" may be too vague. In this regard, Fasoli's interaction-centered taxonomy offers three essential categories that describe how cognitive artefacts carry out their functions: *complementarity*, i.e. the tool enhances performance but is neither sufficient nor necessary (e.g. a map or a compass), *constitution*, i.e. the tool is necessary for performance (e.g. a written text for reading), and *substitution*, i.e. the tool is almost sufficient for the performance (e.g. a GPS navigator or calculator).[19]

In addition, we may look at the non-cognitive use of tools and how they extend our bodily and phenomenal abilities, by adding other specific criteria. For example, Heersmink, referring to the Heideggerian distinction between "ready-to-hand" and "present-to-hand",[20] argues that only ready-to-hand objects are embodied and integrated in a cognitive or experiential system. He points to some keywords that reveal ready-to-hand objects: trust and transparency, i.e. the use of the tool is automatic and it is not necessary to focus on it; incorporation, i.e. the capacity to include the tool within the body schema; and mediation, i.e. the ability of the object to function as a link between the person and the surrounding environment.[21]

2.2 The principle of ergonomics and extended bodily awareness

Closely related to these criteria, we may define a further one, the principle of ergonomics, which claims that a human-tool coupling assembles an integrated system if, under the same physical conditions and potential for success, it is preferable to carry out the task using the object, than without it. In other words, in the event that I have to do something and I have the opportunity to do it on my own or with the support of a tool and in both cases success is assured, if I choose to use the tool it means that I am integrating my own skills with the use of the object. On the contrary, if the object allows for better performance but entails so much effort that I prefer to perform the task on my own, then it probably would not be a case of an integrated system. Taken together, an external object that meets these supplementary criteria and principles can therefore be considered to form part of an integrated system, although it does not necessarily comply with PP. This does not mean that the second-wave criteria are softer than PP, but rather that they are broader and aim for a conception of integration that it is not necessarily achieved by parity-based arguments.

As mentioned above, the extension of some mental processes can be defined not only in a functional sense, but also in a phenomenal one, so I would add one last criterion, a sort of extended bodily awareness, i.e. when a tool becomes part of our perceptual experience. What permits me to distinguish my body from the devices I use in the environment is the cenesthetic affectivity with which I feel the former but not the latter. For example, my experience of driving my car is quite transparent (e.g. if I am an expert driver, I do not have to pay attention when I shift gears) and I also receive, at a certain level, proprioceptive feedback (e.g. I can feel the rough road through the car). Nevertheless, if I have an accident, it is my body that hurts, not the hood of the car. Thus, we may hypothesise a phenomenological parity or similarity for devices designed to extend, improve, or substitute for bodily parts, stating that the extrabodily device can actually extend bodily awareness only if it is phenomenally equivalent/similar to a cenesthetic process of the body, i.e. we feel it to be a part of our body schema (pre-reflectively), and we have no hesitation in recognizing it as part of our body image (reflectively).[22]

To sum up, there are several ways in which we can determine whether an artefact (e.g. paper and pencil, smartphone) or an environmental object (e.g. a tree branch) can form part of an extended mind process, depending on the typology of the criteria used. We may look for functional equivalence between external and mental processes or for different degrees of integration. We may use supplementary criteria to verify whether the coupling of human being and object produces a truly integrated system or, on the contrary, the use of the object is not transparent, embodied, or ergonomic. We may investigate whether this integrated system produces phenomenal coupling with our body.

I have outlined the general characteristics of externalism and the EMT criteria. The purpose of this paper is to discuss brain-computer interfaces in light of these theories of extended mind. Thus, instead of theoretically identifying which version of EMT would embrace the largest set of BCIs (while excluding other potential candidates), I will use EMT as a kit of lenses which allows for a more nuanced investigation of the issue, offering a range of interpretations based on inner-outer couplings.[23]In fact, by differentiating BCIs according to the specific technologies and paradigms they use, we will see that BCIs can take on different roles in their interactions with our mental processes. Some models are more ergonomic than others, some contribute not only to cognitive but also bodily processes, and so on. For this reason, as I explain in detail below, it is better to provide a pluralistic approach to BCI technology.

3 Brain-computer interfaces

In this section, I describe the external objects in question in more detail. Until now, I have discussed extra-cranial objects in very general terms. This generalization now needs further consideration, given that the theoretical and practical value of EMT also depends on what kind of external objects/processes we are talking about. Surely, a notebook relates to our body and brain differently than a smartphone; and the cane we use for hiking has a different impact on us than a neuroprosthetic hand. Thus, as Hibbert explains, it is necessary to adopt a local approach to particular kinds of devices that constitute Brain-Computer Interfaces, with reference to specific examples, rather than to the BCIs in general.[24]

Brain-Computer Interfaces (BCIs) are devices that directly connect a brain to a computer without using the normal efferent pathways (from brain to body), such as movements by muscles. Basically, after a training phase, the patient learns to select items on a screen or command a wheelchair, etc. by modifying his brain activity. This is possible because the psychological tasks (e.g. an active task of imagination or a passive brain reaction to external stimuli) are associated with brain signal modifications that can be measured in real time using neuroimaging techniques, such as electroencephalography (EEG), functional magnetic resonance imaging (fMRI), magnetoencephalography (MEG), electrocorticography (ECoG), functional near-infrared spectroscopy (fNIRS), etc. Task-related brain activity is recorded, background noise and artefacts are estimated and removed,[25] and the relevant signal is classified into messages or commands that run an interactive application, e.g. selecting letters or figures on a screen, or moving real objects in the environment.[26] Once a task is completed, the BCI may send feedback to the user, e.g. visual, auditory, or tactile stimuli that indicate if the operation was successful and allow the user to improve his performance or correct errors.[27]

We need to distinguish between invasive and non-invasive BCIs. Invasive BCIs (ECoG) measure intra-cortical neural activity by means of electrodes surgically implanted directly into the brain, which penetrate a few millimetres into the cortical tissue. This method allows the signal to be detected with great accuracy and precision and improves overall BCI performance. Non-invasive BCIs require wearing caps or headsets (EEG, fNIRS) or exploit classical neuroimaging instruments (fMRI, MEG). They are easier to use and can be flexibly adapted to many paradigms, without any need for surgical intervention.[28]

Non-invasive BCIs based on EEG technology are the most widespread, because they are easy to use and inexpensive compared to the demanding and often prohibitively expensive laboratory-based methods. These BCIs detect specific electrical activity in the brain – event-related potentials (ERPs) such as P300 waves, slow cortical potentials (SCP), or sensorimotor rhythms (SMR) – which the user learns to modulate by imagining movements or performing other cognitive tasks. We should also make a distinction between dependent and independent BCIs. Dependent BCIs require an external event/stimulus (e.g. steady-state visually evoked potentials, SSVEP) and some control over peripheral nerves and neuromuscular channels (e.g. gaze control) in order to generate the specific brain activity that will be classified as a message. An independent BCI relies only on brain activity (e.g. motor imagery, SMR, SCP), thereby bypassing any neuromuscular pathway that might be damaged. These can be used, for example, with patients who suffer from locked-in syndrome (LIS), whose residual eye movements are not sufficiently reliable for communication and interaction.[29]

The history of BCI is not as recent as some might imagine. Indeed, shortly after the advent of computers in the 1960s, Jacques Vidal referred to direct brain-computer communication in a 1973 article.[30] From that time until today, there have been two main goals driving the development of BCIs: the assessment of residual consciousness in patients with disorders of consciousness (e.g. unresponsive wakefulness syndrome or a minimally conscious state); and rehabilitation of motor skills and communicative functionality in patients with motor impairments or paralysis.[31] These issues have pushed research towards the development of new techniques for assessing consciousness and communication characterized by their independence from behaviour and reportability.[32] In these situations, neuroimaging techniques (EEG, fMRI, PET, etc.) used with BCI paradigms – both independent endogenous (e.g. motor imagery)[33] and exogenous dependent (e.g. auditory or visual stimulation)[34] – have become crucial tools for the detection of neural activity that could be associated with residual or preserved consciousness. Furthermore, after assessing the presence of consciousness in people with severe motor-disabilities, the next step is to identify a method to re-establish communication with these patients, and in this sense BCIs take on an important clinical, as well as ethical and existential, value.

3.1 The BCI-human coupling

As we have seen, in most cases BCIs are currently used for clinical and experimental reasons, in order to detect the presence of consciousness in the absence of behavioural responses or to re-establish a lost relationship with the environment and social context. Thus, one might say that BCIs are not a good example for an analysis using the extended mind framework, since they refer to the recovery of lost or undetected mental or experiential processes rather than to genuine cases of mental extension. However, if we think of BCIs as a substitute for lost bodily abilities, we may then conceive of them as a hypothetical extension of mental processes. Just as my ability for mental calculation is extended by means of my hand clicking on the calculator app, it can also be extended by classification of my brain signals to select those numbers of the calculator on a BCI screen.

This argument does not yet establish that BCIs always contribute to the extension of cognitive processes beyond the head. We must still apply the various criteria set out above (parity principle, cognitive integration, transparency, incorporation, mediation, extended bodily awareness, the principle of ergonomics). At the very least, it seems reasonable to conclude that BCI is a possible candidate for EMT. Indeed, the word "interface" denotes an interaction or mediation between at least two different processes or entities, and this connection could be interpreted as a way for the mind to extend beyond the body. Given that even bodily actions, language, and gestures can be conceptualized as interfaces between one human being and other human beings or the environment,[35] it does not seem unlikely or incoherent to investigate BCI through the EMT lenses. Furthermore, the last decade has seen an interesting debate on which 4E cognition framework is best suited to understand and interpret BCIs designed for locked-in syndrome patients:[36] the influence of BCI on the patient's sense of self-ownership and self-agency, the role of BCI in maintaining effective interactive dynamics with environmental and social contexts, the re-extension of impaired or eliminated actions, etc.

However, although a local approach must focus on specific BCI paradigms and models, this does not mean that the relationship between BCIs and EMT should be analysed only with respect to the current use of these devices. Indeed, we should also examine what roles BCIs has started to play and will likely play in everyday contexts. After all, this is not the first time that artefacts and technologies specifically designed for clinical, scientific, or military purposes have subsequently undergone a process of diffusion for general users in normal social and civil contexts. Interestingly enough, a few BCIs are already used for purposes that are not strictly medical. These include BCI-driven devices (e.g. drones, home equipment, cell phones, computer cursors, cars) and BCIs for entertainment (videogames, brain painting, web-access, etc.).[37] Thus, without forecasting the future of BCIs and slipping into sci-fi, I believe it is also necessary to consider current and potential uses of BCI within a non-experimental and non-clinical context, in particular with respect to the question of whether such human-device coupling can actually extend our mental abilities according to EMT and consequently constitute an integrated system (with all the related ethical and existential issues).

3.2 Three paradigmatic examples of BCI

As mentioned above, BCIs can be distinguished in terms of the kind of technologies they use, the paradigms they apply, and their level of invasiveness. Here, I will focus on three paradigmatic instances of EEG-based BCIs, which are easy to use, affordable (e.g. unlike fMRI-based BCIs) and perhaps the most diffused of all BCI technologies. These EEG BCIs are based on: steady-state visual evoked-potentials (SSVEP), P300 evoked-potentials,[38] and motor imagery. SSVEP is a non-invasive, dependent, and exogenous BCI (i.e. it does not require surgery). A typical SSVEP paradigm might involve stimuli flashing at different frequencies. When the patient moves his gaze to attend to a specific stimulus, a visual evoked brain response (e.g. in visual cortex) at that specific frequency can be detected and decoded by the EEG BCI system. This model of BCI does not usually require long and intensive training sessions; it is easy to use and highly reliable.[39] The P300 evoked-potential model provides a non-invasive, independent, and exogenous paradigm. It differs from SSVEP BCI because it does not depend on any output pathways, that is, peripheral nerves or muscles for the selection of the relevant stimulus (gaze, in the above example). Instead, the signal required by the system (P300 wave) is evoked by external conditions that the user passively receives (e.g. flashing letters without gaze control, auditory stimuli, vibrotactile stimuli, or any of these in combination); as for SSVEP, P300 BCI also does not require a long training phase.[40] MI BCI is non-invasive, independent, and endogenous. Like P300 BCI, it is independent, but unlike both previous models it does not rely on external stimuli to generate brain responses. Instead it captures spontaneously generated brain activity elicited, for example, by means of motor mental imagery. Imagining a stimulus first generates a decrease (event-related desynchronization) and then an increase (event-related synchronisation) in sensorimotor rhythms.[41] For this reason, the user must first become familiar with the device and learn how to elicit these specific brain patterns. This requires a long training session and appropriate feedback (usually, on-screen indicators such as extending bars, objects that move, etc.).[42]

In the first part of this article, I discussed the principles and criteria for establishing an extended mental process: the parity principle, cognitive integration, transparency, incorporation, mediation, extended bodily awareness, and the principle of ergonomics. Then, I briefly described the main characteristics of brain-computer interfaces. In the next section, I will analyse the abovementioned BCIs using the EMT framework. Let us start with the principles of first wave EMT, then gradually shift to the criteria for the second wave (note that first and second waves are not incompatible but rather complete and support each other).

4 Using the extended mind framework to understand BCI technologies

4.1 Parity principle

The Parity Principle (PP) is a rigid criterion which stipulates that cognitive states extend beyond the brain only if a specific external process functions in the same way as the comparable cognitive process functions in the brain. In this sense, BCI tasks should be composed of elements that we would have no hesitation in considering parts of an equivalent internal process. It is generally difficult for many artefacts and external processes to achieve this goal, so in this analysis we consider a broader category embraced by the complementarity principle. This principle stipulates that an external process does not need to mimic or replicate the formats or functions of the comparable inner cognitive processes, but rather should help, sustain, or improve that cognitive process by means of different properties and roles.

MI BCI is based on demanding tasks – the user must imagine a specific body action (e.g. moving their right hand) to produce an external result (e.g. moving an on-screen cursor or selecting a button on the right of the screen). This imaginative act is an additional process that differs from normal mental selection. It is as if I had to think of a dog or a goose to select the numbers three and five, respectively. Or like having a keyboard that instead of letters has figures and colours which correspond to letters and numbers; before typing, I have to remember this mapping from letters and numbers to figures and colours. But this is not the way our mental processes work. Thus, MI BCI relies on processes that are not functionally equivalent to the related cognitive process. By contrast, the tasks used in P300 (e.g. focusing on the selected item when it flashes or makes a sound) and SSVEP BCIs (e.g. selecting an item in the array by moving the eyes) seem to be functionally equivalent or at least similar to the related mental process. Just as I "select" numbers and letters by writing them down by hand on paper, I can select them by means of my gaze or my attentive capacity; the process is functionally isomorphic, because what changes is only the way in which I accomplish the task, i.e. by using my hands as normal or by means of my evoked potentials that are translated into a message for the BCI. Also, just as I partly outsource my memory to paper and pencil to keep track of what I have in mind, similarly the selection of items and their maintenance on the screen helps me to distribute the cognitive process beyond my head.

4.2 Integration

Some might say that these BCIs and the correlated cognitive process have the same function only at a course-grained level of abstraction, that a mere analogy or similarity does not constitute a concrete functional isomorphism. However, even in such cases, surely P300 and SSVEP models meet the requirements for integration, as indicated by second-wave EMT: they help the brain perform specific tasks of computing, storage, and communication in the absence of bodily movements. According to second-wave EMT, integration can be also achieved between artefacts and mental processes that are functionally different, as long as the human-device coupling improves or extends cognition by means of the external object and allows for fruitful interaction with the environment. If this is the case, then the P300 and SSVEP models qualify as possible tools for specific cases of embedded (not extended) cognition, given that the mental event is not externally replaced by the BCI process but, at most, partially depends on it inasmuch as BCI helps with the realization of the same mental process that the user previously accomplished alone. More specifically, BCIs can be taxonomized in relation to the type of interactions they require, without the need for functional isomorphism. Thus, following Fasoli's interaction-centered taxonomy of cognitive artefacts, we may apply the same framework to BCI by considering the different ways in which the user interacts with the external device. Under these circumstances, P300 and SSVEP BCI – and possibly also MI BCI – can be considered constitutive in the case of a paralyzed patient, who cannot otherwise communicate, and complementary in normal situations, where a person can also perform the same task without the BCI (see table 2).

BCIs	**Fasoli's Interaction-centered Taxonomy**		
	Complementarity	*Constitution*	*Substitution*
SSVEP BCI	Yes	Yes*	No
P300 BCI	Yes	Yes*	No
MI BCI	Yes	Yes*	No
*In the case of paralyzed patients, who could not otherwise communicate and interact.			

Table 2. Fasoli's Interaction-centered Taxonomy applied to SSVEP BCI, P300 BCI, and MI BCI

The same framework can be applied to BCIs that are not strictly cognitive artefacts but provide assistance by replacing lost bodily actions. Brain painting or brain playing are examples where two types of P300 BCIs have been created specifically to allow users to paint or compose music by modulating their brain activity.[43] Acts of painting or composing necessarily include bodily actions in the environment and are not exclusively produced inside the head while contingently performed by the body. Thus, I would consider these activities to be both cognitive and bodily.[44] While such BCIs involve mechanical actions that substitute for bodily movements, the main process of painting or composing is accomplished through continuous feedback loops between the person acting via BCI and the results on the screen, so it seems more plausible to consider them constitutive artefacts (like reading and studying a written text) rather than substitutive ones. The narrow, functionalist version of extended cognition faces some difficulties in accounting for these specific cases, while an enactivist approach more suitably interprets them as flows of interaction between brain, body, tools, and environment.[45] For these reasons, I reiterate the importance of endorsing a pluralist perspective on BCI topics; we do not want to get stuck in rigid interpretations that might not always fit specific concrete situations (see Section 5 below).

4.3 Supplementary criteria

Now, it is not necessary to consider the parity principle as the pinnacle of EMT. There may be cognitive artefacts that respect PP but are far from reliable for potential mental extension at deeper levels; simply replicating a cognitive ability does not entail literally become part of one's mind. Besides PP and integration, previously noted, there are other supplementary criteria that help us to understand the degree to which a BCI becomes integrated with the user, such as transparency, incorporation, mediation, ergonomics, and the extended bodily awareness principle. From these criteria, it can be seen that some BCIs, which are not functionally isomorphic to the correlative mental process, may still be transparent or well-integrated with the body when in use. Let us reconsider MI BCI, which does not comply with the requirements for PP. In this case, it is merely the paradigm that is an obstacle, not the technology *per se*. The imaginative act adds an additional cognitive step, making the process that much more complex and opaque. However, this problem can be overcome in specific cases, e.g., when MI BCI is used to move a human-like robot.[46] In this case, the user can vividly connect with the robot by imagining a movement and watching the robot perform that specific act; this can produce a strong illusion of body ownership transfer and a sense of embodiment and integration that also speeds up the learning process for the motor imagery task.[47] Hence, I would again stress the idea that this genre of investigation must be based on a local approach, since even a small change in a paradigm can be crucial and make all the difference with respect to the theoretical interpretation and practical consequences of such technologies.

The last example illustrating the relation between a BCI and body ownership introduces us to the supplementary criteria, which relate to the level of integration between the human body and the device. Next, I analyse the BCIs in question using the additional criteria and principles noted above: transparency, incorporation, mediation, ergonomics, and the extended bodily awareness principle. As for transparency, the use of an MI BCI – even after several sessions – is not automatic; the tool always remains at-hand during the session, because the user must keep focusing on modulating brain activity through motor imagery, e.g. I want to select item x, therefore I need to imagine y (but see the robot-BCI example described above). By contrast, both SSVEP and P300 BCIs permit the user to directly focus on the items on the screen while the neuronal modulation is taking place, rather than on the BCI task. Moreover, these last two models are less demanding and do not require intensive training. Transparency is strongly related to incorporation, i.e. the capacity to include the tool in the body schema; indeed, the more the tool is incorporated, the more transparent its use becomes. We are able to incorporate everyday objects such as walking canes, pencils, hammers, and screwdrivers so well that they "disappear" while we are using them, they become ready-to-hand.[48] This, however, does not seem to occur in the same way for MI BCI: the annoying presence of cables, the cap with gel and electrodes, the long preparation times, the need to maintain a precise position and not to make excessive movements that could influence the recording, the inaccuracy of BCI, etc.[49] can make it difficult to fully incorporate these technologies. Nevertheless, this is a contingent problem. As technological progress makes BCIs less cumbersome (e.g. dry electrodes, discrete headsets, wireless parts, more efficient data processing, user-centered design, neurofeedback, etc.), they will increasingly improve in terms of incorporation as well as transparency.

As for mediation, the main purpose of BCIs is to connect the user to the surrounding environment and people. While all three models in question can surely achieve this, the kind of connection they afford strictly depends on model characteristics and the paradigm used. Communication, for example, is still a rather complicated process. It takes a long time to write even one word, and the selection of items on the screen is limited by the features offered by the software, as well as by the restricted number of stimuli that can be presented by a dependent device such as SSVEP BCI. However, in addition to the criteria of transparency and incorporation, mediation issues are also not intrinsic to the BCIs *per se*, but rather to the current technological context – which continues to rapidly evolve. Moreover, the mere fact that current BCIs make it possible to put Locked-in syndrome (LIS) patients in touch with loved ones and give them an opportunity to live a meaningful life expresses the moral value of this technology.[50]

4.4 Extended bodily awareness and ergonomics

The last two principles presented here are extended bodily awareness (EBA) and the principle of ergonomics (PE). According to EBA, the three BCIs are not phenomenally equivalent or similar to a cenesthetic bodily process. Indeed, following what has been said about the previous criteria, the user does not receive appropriate proprioceptive feedback. He does not feel or even recognize the BCI as an extension of the body, as happens when we use common tools like a walking cane or pencil, which we interact with as a supplementary body part. Leaving aside the three models in question, there is still future potential to achieve phenomenological similarity, as in the case of the abovementioned BCI that produces an illusion of bodily ownership or some prototypes for neuromotor prostheses that provide sensory (and even nociceptive) feedback.[51]

PE, instead, seems the most difficult criterion to satisfy, as none of the three BCIs (nor other current BCIs) seem to pass the ergonomics test. In other words, given a choice and assuming equally successful performance under similar physical conditions, it does not seem likely anyone would prefer to use a BCI. Granted, BCIs may be fundamental for re-establishing lost connections, in cases where, for example, people suffer motor disabilities, but no healthy person would prefer (except temporarily, out of curiosity): to extend their communicative ability by using a BCI instead of their own voice and gestures; to walk and interact with their environment wearing an exoskeleton instead of doing so normally; to drive a car or a drone with motor imagery instead of actual hands and feet. This is because the use of BCIs is not so simple, immediate, and well-incorporated that it becomes preferable to normal bodily actions or mental processing. In this sense, BCIs remain unlike other common objects: I prefer to perform the calculation 438x561 by means of pen and paper (or a calculator) to doing it in my head (which I could also accomplish, but only with much more time and energy). Hence, I believe that, at the moment, PE is the biggest obstacle to BCIs moving beyond clinical and experimental contexts to become everyday examples of human-tool integration. See Table 3 for a review of the criteria set out here in relation to the selected BCIs.

4.5 Limits and potentialities of BCI

Above, I first analysed the different versions of EMT and discussed the relevant approaches (e.g. embeddedness and embodiment) and pragmatic principles. Then, I presented three BCI models, indicating which criteria they did or did not meet. I used EMT and, more generally, 4E theories to interpret BCI technology as a tool for cognitive and bodily extension and to answer the following questions: Can BCIs extend our mental processes and to what degree? What EMT criteria should be considered in assessing this technology? What is the role of the body in the process of integrating the user and computer? What are the limits that prevent complete cognitive and bodily extension through BCIs?

BCI technology could become a useful tool for extending mental processes, in par-

BCIs	**Criteria**						
	PP	*Integration*	*Transparency*	*Incorporation*	*Mediation*	*EBA*	*PE*
SSVEP BCI	Yes	Yes	Yes	No*	Yes*	No	No
P300 BCI	Yes	Yes	Yes	No*	Yes*	No	No
MI BCI	No	No**	No	No*	Yes*	No	No

* Room for improvement
** Integration in specific cases, such as MI BCI used to move a human-like robot
PP: Parity Principle; EBA: Extended Bodily Awareness; PE: Principle of Ergonomics

Table 3. All the criteria for human-device coupling applied to SSVEP BCI, P300 BCI, and MI BCI

ticular, where these are limited by disabilities and pathologies. It could also improve integration with the digital systems that already surround us in our daily lives. As a result of the previous analysis, I argue that, in principle, brain-computer interfaces have the potential to be considered cognitive artefacts that contribute to the extension of mental processes beyond the head. In this regard, every single BCI differs in the type and degree of mental extension it manages to support, depending on context (e.g. a disabled patient or healthy person), paradigm, and model. For this reason, instead of establishing in advance the validity of one criterion over another (for example, preferring the parity principle to cognitive integration), I have suggested taking all the various criteria and approaches into account and using them as different lenses to interpret specific BCIs. This pluralistic approach allows one to identify the theory that most efficiently interprets the role of a specific artefact in relation to a specific mental process.

At the same time, while the theoretical analysis should maintain a broad and pluralistic approach, the target of the analysis should be as local and specific as possible. As it is not possible to effectively apply a single criterion to all the examples of BCIs presented here, it is also not possible to analyse BCI technologies as if they were uniform, with no significant differences between models. Therefore, a local approach recommends focusing one by one on specific BCE models, since the different technologies and paradigms used (mental imagery, P300 classification, visual tracking, etc.) produce different effects – hence different interpretations – as shown above.[52]

As for the relationship between the body and BCIs, I have shown that all three selected BCI models have particular difficulty meeting the criteria related to corporeality (in particular, incorporation, extended bodily awareness, and the principle of ergonomics). This could prevent effective interaction between a user and a BCI, as the technological tool may produce poor results, be cumbersome, and hard to use. According to 4E cognition, mental processes are not merely instantiated internally by the brain; rather, the whole body mediates information processing. Therefore it is likely that the more ergonomic and incorporated an object becomes, the easier, more automatic and efficient interaction will be. If the aim is to achieve efficient and multidimensional human-device integration (not only in the cognitive but also in the bodily domain), I advocate that special attention be paid to the interaction between bodily abilities, bodily awareness, and BCI technologies. This would be extremely useful for clinical applications and rehabilitation,[53] but also in experimental and entertainment contexts (see Introduction and Section 3).

5 Conclusions

At first sight, brain-computer interfaces seem to offer a perfect example to explain how the mind extends beyond the brain and the body towards the environment; however, a deeper look reveals different criteria that must be met before considering BCIs as tools that can contribute to mental extension. The Extended Mind Theory is a wide-ranging conceptual framework that can be used to investigate specific human-tool couplings. In this paper, I put the brain-computer interface under the lenses of EMT and, more generally, 4E cognition order to understand whether these tools actually contribute to extending mental processes. Since it is not always clear how to satisfy the requirements of the parity principle, which also does not in itself determine the presence of an integrated system, the analysis has been also based on concepts from the second-wave of extended mind theory. While respecting – at least partially – parity and integrative principles, I suggested other supplementary criteria and pragmatic principles that have helped us understand which of the various BCIs investigated here can contribute to extending our cognitive and bodily processes in combination.

I have argued that the BCIs presented here may be interpreted as potential tools of cognitive extension according to the extended and embedded theories of mind, at different layers and to different degrees. In particular, I have highlighted that most of the current BCIs lack transparency, incorporation, phenomenological extension, and ergonomics, preventing effective integration with the user. Thus, I have advocated for greater focus on the connection between body and tool in the development of high-performance integrated systems, primarily for clinical and rehabilitation purposes, but also to meet future daily needs. There is still a lot of work to be done but BCI is a relatively young and promising technology with excellent potential.

Notes

[1] Cf. A. NEWEN, L. DE BRUIN, S. GALLAGHER (eds.), *The Oxford handbook of 4E cognition*, Oxford University Press, Oxford 2018.

[2] Cf. S. GALLAGHER, *Decentering the brain: Embodied cognition and the critique of neurocentrism and narrow-minded philosophy of mind*, in: «Constructivist Foundations», vol. XIV, n. 1, 2018, pp. 8-21; T. FUCHS, *Ecology of the brain. The phenomenology and biology of the embodied mind*, Oxford University Press, Oxford 2018; T. FUCHS, *The brain – A mediating organ*, in: «Journal of Consciousness Studies», vol. XVIII, n. 7-8, 2011, pp. 196-221.

[3] Cf. E. DI PAOLO, E. THOMPSON, *The enactive approach*, in: L. SHAPIRO (ed.), *The Routledge handbook of embodied cognition*, Routledge, London/New York 2014, pp. 68-78; A. NOË, *Action in perception*, MIT Press, Cambridge (MA) 2004; A. NOË, *Out of our heads: Why you are not your brain, and other lessons from the biology of consciousness*, Hill & Wang, New York 2009; J.K. O'REGAN, A. NOË, *A sensorimotor account of vision and visual consciousness*, in: «Behavioral & Brain Sciences», vol. XXIV, n. 5, 2001, pp. 939-973.

[4] D.D. HUTTO, E. MYIN, *Radicalizing enactivism: Basic minds without content*, MIT Press, Cambridge (MA) 2012; D.D. HUTTO, E. MYIN, *Evolving enactivism: Basic minds meet content*, MIT Press, Cambridge (MA) 2017.

[5] G. THEINER, *The extended mind*, in: B. TURNER (ed.), *The Wiley-Blackwell encyclopedia of social theory*, Wiley-Blackwell, London/New York; R.A. WILSON, *Embodied cognition*, in: E.N. ZALTA (ed.), *The Stanford encyclopedia of philosophy*, 2017, Spring Edition.

[6] A. CLARK, D. CHALMERS, *The extended mind*, in: «Analysis», vol. LVIII, n. 1, 1998, pp. 7-19.

[7] R. HEERSMINK, *A taxonomy of cognitive artifacts: Function, information, and categories*, in: «Review of Philosophy & Psychology», vol. IV, n. 3, 2013, pp. 465-481.

[8] G. YOUNG, *Locked-in syndrome*, in: R. DAROFF, M.J. AMINOFF, *Encyclopedia of the neurological sciences*, Academic Press, New York 2014, p. 916.

[9] A. MINKYU, L. MIJIN, C. JINYOUNG, J. SUNG CHAN, *A review of brain-computer interface games and an opinion survey from researchers, developers and users*, in: «Sensors», vol. XIV, n. 8, 2014. pp. 14601-14633.

[10] M. ROWLANDS, *Externalism: Putting mind and world back together again*, McGill-Queen's University Press, 2003, p. 13.

[11] R.D. RUPERT, *Challenges to the hypothesis of extended cognition*, in: «The Journal of Philosophy», vol. CI, n. 8, 2004, pp. 389-428.

[12] This is more related to content externalism. H. PUTNAM, *The meaning of "meaning"* (1974), in: H. PUTNAM, *Philosophical papers, Vol. II: Mind, language, and reality*, Cambridge University Press, Cambridge 1975, pp. 215-271; J.A. CARTER, J. KALLESTRUP, S.O. PALERMOS, D. PRITCHARD, *Varieties of externalism*, in: «Philosophical Issues», vol. XXIV, n. 1, 2014, pp. 63-109.

[13] The example of the stick for the blind is particularly widespread and used by various authors to explain how not only cognitive processes but also perceptual and experiential processes can be extended through elements external to the brain and the body. The blind person and the stick form a single perceptual system, in which the stick is not a boundary but a pathway through which the person can discover and make sense of the external environment. This example has been used by many authors, including Descartes, Bateson, Polanyi, Merleau-Ponty, and Noë. «Think of the way the stick shapes the mind of the blind man. It is not simply a matter of expanding the boundaries of his "peripersonal space" (that is, the space surrounding the body). Neither is it simply a matter of delimiting a new range of action possibilities, dependencies, or sensory hierarchies (for example, substituting vision for touch). The stick does more than that. It be-

comes an interface of a peculiar transformative sort – what might be called a brain-artifact interface». L. MALAFOURIS, *How things shape the mind. A theory of material engagement*, MIT Press, Cambridge (MA) 2013, p. 244.

[14] A. CLARK, D. CHALMERS, *The extended mind*, cit., p. 8. Clark and Chalmers mention specific examples where the parity principle seems to work well, for instance, using mental rotation to play Tetris, physically rotating the image on the screen by pressing a button, or using a hypothetical neural implant that directly rotates the image. Another famous example involves Inga and Otto. Inga remembers where New York's Museum of Modern Art is located perfectly, while Otto, suffering from Alzheimer's disease, cannot find it without consulting the directions written in his notebook. In this case, under certain circumstances (e.g. if the notebook is directly available to Otto and he has already endorsed that information in the past), Otto's notebook functions like an intracranial belief about MoMA's location.

[15] F. ADAMS, K. AIZAWA, *The bounds of cognition*, in: «Philosophical Psychology», vol. XIV, n. 1, 2001, pp. 43-64; F. ADAMS, K. AIZAWA, *Defending the bounds of cognition*, in: R. MENARY (ed.), *The extended mind*, MIT Press, Cambridge (MA) 2010, pp. 67-80. For some replies, see A. CLARK, *Coupling, constitution, and the cognitive kind: A reply to Adams and Aizawa*, in: R. MENARY (ed), *The extended mind*, cit., pp. 81-99; A. CLARK, *Memento's revenge: The extended mind, extended*, in: R. MENARY (ed), *The extended mind*, cit., pp. 43-66. G. PIREDDA, *The mark of the cognitive and the coupling-constitution fallacy: A defense of the extended mind hypothesis*, in: «Frontiers in Psychology», vol. VIII, 2017, Art.Nr. 2061.

[16] J. SUTTON, *Exograms and interdisciplinarity: History, the extended mind, and the civilizing process*, in: R. MENARY (ed.), *The extended mind*, cit., pp. 189-226.

[17] For the Complementarity Principle, see J. SUTTON, *Exograms and Interdisciplinarity*, cit. For the Cognitive Integration, see R. MENARY, *Cognitive integration and the extended mind*, in: R. MENARY (ed), *The extended mind*, cit., pp. 227-244.

[18] The external process does not need to «mimic or replicate the formats, dynamics, or functions of inner states and processes»; J. SUTTON, *Exograms and interdisciplinarity*, cit. p. 194.

[19] M. FASOLI, *Substitutive, complementary and constitutive cognitive artifacts: Developing an interaction-centered approach*, in: «Review of Philosophy & Psychology», vol. IX, n. 3, 2018, pp. 671-687.

[20] M. HEIDEGGER, *Being and time* (1927), translated by J. MAQUARIE, E. ROBINSON, Harper New York 1962.

[21] R. HEERSMINK, *Embodied tools, cognitive tools and brain-computer interfaces*, in: «Neuroethics», vol. VI, n. 1, 2013, pp. 207-219.

[22] The body image «consists of a complex set of intentional states – perceptions, mental representations, beliefs, and attitudes – in which the intentional object of such states is one's own body. Thus, the body image involves reflective intentionality». The body schema «involves a system of motor capacities, abilities, and habits that enable movement and the maintenance of posture»; unlike the body image it operates «below the level of self-referential intentionality, although such functions can enter into and support intentional activity. The preconscious, subpersonal processes carried out by the body schema system are tacitly keyed into the environment and play a dynamic role in governing posture and movement». S. GALLAGHER, J. COLE, *Body schema and body image in a deafferented subject*, in: «Journal of Mind & Behavior», vol. XVI, n. 4, 1995, pp. 369-390.

[23] The lens metaphor is taken from A. FENTON, S. ALPERT, *Extending our view on using BCIs for Locked-in syndrome*, in: «Neuroethics», vol. I, n. 2, 2008, pp. 119-132; R. HIBBERT, *LIS and BCIs: A local, pluralist, and pragmatist approach to 4E cognition*, in: «Neuroethics», vol. IX, n. 2, 2016, pp. 187-198.

[24] R. HIBBERT, *LIS and BCIs*, cit.

[25] The use of the term "artefact" has a different meaning here than that used before. In this specific case, an artefact is a signal recorded by the EEG but not generated by the brain. As these artefacts could influence or ruin the classification of the data collected, they must be identified and removed.

[26] A. KÜBLER, *The history of BCI: From a vision for the future to real support for personhood in people with locked-in syndrome*, in: «Neuroethics», first online 29 May 2019; A. KÜBLER, *Brain-computer interfaces for communication in paralysed patients and implications for disorders of consciousness*, in: S. LAUREYS, G. TONONI (eds.), *The neurology of consciousness*, Elsevier, Amsterdam/New York 2009, pp. 217-233.

[27] D. LESENFANTS, C. CHATELLE, J. SAAB, S. LAUREYS, Q. NOIRHOMME, *Neurotechnological communication with patients with disorders of con-*

sciousness, in: M. FARISCO, K. EVERS (eds.), *Neurotechnology and direct brain communication. New insights and responsibilities concerning speechless but communicative subjects*, Routledge, London/New York 2016, pp. 85-99.

[28] A. KÜBLER, *The history of BCI*, cit.

[29] A.T. CHAN, J.C. QUIROZ, S. DASCALU, F.C. HARRIS JR., *An overview of brain computer interfaces*, in: «Proceedings of the 30th International Conference on Computers and Their Applications, CATA 2015», 2015, pp. 9-11. There is another quite similar – still not equivalent – distinction, between BCI based on exogenous paradigms and endogenous paradigms, where the former means that the user is engaged by external stimuli (e.g. P300-based BCI with a matrix of symbols to choose from, etc.), while the latter means that the device is based only on the generated brain pattern (e.g. SMP-based BCI activated by mu and beta rhythms; usually used only after several training sessions); *ibidem*. In this sense, endogenous paradigms are necessarily related to independent BCI, and exogenous ones to dependent BCI, nevertheless some exogenous paradigms, i.e. based on brain responses to external stimulus, can be either used in dependent or independent BCIs. For example, the SSVEP paradigm (therefore exogenous) is based on covert attention and is completely independent of neuromuscular functions, such as gaze control (therefore independent BCI); D. LESENFANTS, D. HABBAL, Z. LUGO, M. LEBEAU, P. HORKI, E. AMICO, C. POKORNY, F.GOMEZ, A. SODDU, G. MÜLLER-PUTZ, S. LAUREYS, Q. NOIRHOMME, *An independent SSVEP-based brain-computer interface in locked-in syndrome*, in: «Journal of Neural Engineering», vol. XI, n. 3, 2014, Art.Nr. 035002.

[30] J.J. VIDAL, *Toward direct brain-communication*, in: «Annual Review of Biophysics & Bioengineering», vol. II, 1973, pp. 157-180; see also A. K:UBLER, *The history of BCI*, cit.

[31] C. CAVALIERE, C. DI PERRI, S. LAUREYS, A. SODDU, *Instrumental assessment of residual consciousness in DOCs*, in: M. FARISCO, K. EVERS (eds.), *Neurotechnology and direct brain communication*, cit.; A. KÜBLER, *Brain-computer interfaces for communication in paralysed patients and implications for disorders of consciousness*, cit.

[32] Cases of misdiagnosis are not rare in patients with brain trauma resembling complete unresponsiveness, who instead have covert consciousness, as in cognitive motor dissociation (CMD), or even complete locked-in syndrome (CLIS). The rate of misdiagnosis failing to distinguish between a minimally conscious state (MCS) and unresponsive wakefulness syndrome (UWS) is still relevant: 37-43% in 2015. Cf. A. BENDER, R.J. JOX, E. GRILL, A. STRAUBE, D. LULÉ, *Persistent Vegetative State and Minimally Conscious State A systematic review and meta-analysis of diagnostic procedures*, in: «Deutsches Ärzteblatt International», vol. CXII, n. 14, 2015, pp. 235-242.

[33] In this respect, over the last 13 years, Owen and colleagues have modelled and refined a method for assessing residual consciousness through mental imagery in patients with brain trauma: «In 2006, we put a young woman who had been diagnosed as being in a vegetative state into a functional magnetic resonance imaging (fMRI) scanner and asked her to imagine she was playing a game of tennis [...] We had seen this pattern many times in studies of healthy participants, who we had also asked to imagine playing tennis in the scanner. We then asked the patient to imagine moving from room to room in her house and a very different pattern of fMRI activity emerged. [...] Again, this pattern of fMRI activity was indistinguishable from that seen in healthy participants. On the basis of these fMRI findings, we concluded that our patient was not vegetative at all, but conscious and aware, despite the fact that she had been entirely physically non-responsive for more than 5 months at that point». A.M., OWEN, *The search for consciousness*, in: «Neuron», vol. CII, n. 3, 2019, pp. 526-528, here p. 256. See also A.M. OWEN, M.R. COLEMAN, M. BOLY, M.H. DAVIS, S. LAUREYS, J.D. PICKARD, *Detecting awareness in the vegetative state*, in: «Science», vol. CCCXIII, n. 5792, 2006, pp. 1402.

[34] L. CHENG, D. CORTESE, M.M. MONTI, F. WANG, F. RIGANELLO, F. ARCURI, H. DI, C. SCHNAKERS, *Do sensory stimulation programs have an impact on consciousness recovery?*, in: «Frontiers in Neurology», vol. IX, 2018, Art.Nr. 826; D. MORLET, P. RUBY, N. ANDRÉ-OBADIA, C. FISCHER, *The auditory oddball paradigm revised to improve bedside detection of consciousness in behaviorally unresponsive patients*, in: «Psychophysiology», vol. LIV, n. 11, 2017, pp. 1644-1662.

[35] L. MALAFOURIS, *How things shape the mind*, cit., p. 244.

[36] Cf. A. FENTON, S. ALPERT, *Extending our view on using BCIs for Locked-in syndrome*, cit.; S. WALTER, *Locked-in syndrome, BCI, and a confusion about embodied, embedded, extended, and en-*

acted cognition, in: «Neuroethics», vol. III, n. 1, 2010, pp. 61-72; M. KYSELO, *Locked-in syndrome and BCI – Towards an enactive approach to the self*, in: «Neuroethics», vol. VI, n. 3, 2013, pp. 579-591. R. HEERSMINK, *Embodied tools, cognitive tools and brain-computer interfaces*, cit.; R. HIBBERT, *LIS and BCIs*, cit.

[37] For an overview of non-medical BCI applications (present and future), see J.B.F. VAN ERP, F. LOTTE, M. TANGERMANN, *Brain-computer interfaces: Beyond medical applications*, in: «Computer - IEEE Computer Society», vol. XLV, n. 4, 2012, pp. 26-34.

[38] The P300 wave is a positive deflection in the EEG about 300 milliseconds after presentation of rare target stimuli within a stream of frequent standard stimuli.

[39] Some examples of SSVEP BCI: X. XING, Y. WANG, W. PEI, X. GUO, Z. LIU, F. WANG, G. MING, H. ZHAO, Q. GUI, H. CHEN, *A high-speed SSVEP-based BCI using dry EEG electrodes*, in: «Scientific Reports», vol. VIII, n. 1, 2018, Art.Nr. 14708; Z. İŞCAN, V.V. NIKULIN, *Steady state visual evoked potential (SSVEP) based brain-computer interface (BCI) performance under different perturbations*, in: «PLoS ONE», vol. XIII, n. 1, 2018, Art.Nr. e0191673.

[40] Some examples of P300 BCI: H. HWANG, V.Y. FERREIRIA, D. ULROCH, T. KILIC, X. CHATZILIADIS, B. BLANKERTZ, M. TREDER, *A gaze independent brain-computer interface based on visual stimulation through closed eyelids*, in: «Scientific Reports», vol. V, 2015, Art.Nr. 15890; E. YIN, T. ZEYL, R. SAAB, D. HU, Z. ZHOU, T. CHAU, *An auditory-tactile visual saccade-independent P300 brain-computer interface*, in: «International Journal of Neural Systems», vol. XXVI, n. 1, 2016, Art.Nr. 1650001.

[41] P. WIERZGALA, D. ZAPALA, G.M. WOJCIK, J. MASIAK, *Most popular signal processing methods in motor-imagery BCI: A review and meta-analysis*, in: «Frontiers in Neuroinformatics», vol. XXI, 2018, Art.Nr. 78.

[42] Some examples of MI BCI: N. PADFIELD, J. ZABALZA, H. ZHAO, V. MASERO, J. REN, *EEG-based brain-computer interfaces using motor-imagery: Techniques and challenges*, in: «Sensors», vol. XIX, n. 6, 2019, Art.Nr. 1423.

[43] J.I. MÜNßINGER, S. HALDER, S.C. KLEIH, A. FURDEA, V. RACO, A. HÖSLE, A. KÜBLER, *Brain painting: First evaluation of a new brain-computer interface application with ALS-patients and healthy volunteers*, in: «Frontiers in Neuroscience», vol. IV, 2010, Art.Nr. 182; A. PINEGGER, H. HIEBEL, S.C. WRIESSNEGGER, G.R. MÜLLER-PUTZ, *Composing only by thought: Novel application of the P300 brain-computer interface*, in: «PLoS ONE», vol. XII, n. 9, 2017, Art.Nr. e0181584.

[44] «Painting does not solely happen in the head, in the sense that the painter thinks of an image and then just puts it out there. It involves bodily movement and checking back constantly with the result on canvas» (M. KYSELO, *Locked-in Syndrome and BCI*, cit., p. 581).

[45] According to the enactivist position, cognitive processes can be understood as a dynamic interaction between the embodied subject and various affordances offered by the environment. The mind is a specific modality of the structural coupling between organism and environment. Cf. D. WARD, D. SILVERMAN, M. VILLALOBOS, *Introduction: The varieties of enactivism*, in: «Topoi», vol. XXXVI, n. 3, 2017, pp. 365-375.

[46] M. ALIMARDANI, S. NISHIO, H. ISHIGURO, *BCI-teleoperated androids: A study of embodiment and its effect on motor imagery learning*, in: «2015 IEEE 19th International Conference on Intelligent Engineering Systems (INES), IEEE», 2015, pp. 347-352; M. ALIMARDANI, S. NISHIO, H. ISHIGYURO, *Removal of proprioception by BCI raises a stronger body ownership illusion in control of a humanlike robot*, in: «Scientific Reports», vol. VI, 2016, Art.Nr. 33514.

[47] Some might say that cases where MI BCI moves a robot are merely instances of bodily extension, where the cognitive process remains in the head, e.g. A. Fenton, S. Alpert, *Extending our view on using BCIs for Locked-in syndrome*, cit. Using a pragmatist perspective, I believe that it is not always possible to make a clear-cut distinction between cognitive and bodily extensions, as some bodily processes may count as cognitive (e.g. mental rotation and gestures), while some cognitive activities (e.g. language, complex mathematical calculations, memory, etc.) are often also constituted by bodily processes. Cf. M. KYSELO, *Locked-in syndrome and BCI*, cit.

[48] R. HEERSMINK, *Embodied tools, cognitive tools and brain-computer interfaces,* cit.

[49] G. GRÜBLER, A. AL-KHODAIRY, R. LEEB, I. PUSOTTA, A. RICCIO, M. RÖHM, E. HILDT, *Psychosocial and ethical aspects in non-invasive EEG-based BCI research – A survey among BCI users*

and BCI professionals, in: «Neuroethics», vol. VII, n. 1, 2014, pp. 29-41.

[50] *Ibidem*.

[51] Cf. P. SVENSSON, U. WIJK, A. BJÖRKMAN, C. ANTFOLK, *A review of invasive and non-invasive sensory feedback in upper limb prostheses*, in: «Expert Review of Medical Devices», vol. XIV, n. 6, 2017, pp. 439-447; L.E. OSBORN, A. DRAGOMIR, J.L. BETTHAUSER, C.L. HUNT, H.H. NGUYEN, R.R. KALIKI, N.V. THAKOR, *Prosthesis with neuromorphic multilayered e-dermis perceives touch and pain*, in: «Science Robotics», vol. III, n. 19, 2018.

[52] Cf. R. HIBBERT, *LIS and BCIs*: *A local, pluralist, and pragmatist approach to 4E cognition*, cit.

[53] See, for example, *recoveriX*, a brain-computer interface specifically developed for the rehabilitation of hand and arm movements after a stroke. The BCI paradigm comprises a combination of EEG classification during mental imagination of the paralyzed hand, muscle stimulation that recreates the imagined movement, and visual feedback from the virtual simulation of the imagined limb on the screen or with a first-person perspective 3D avatar. The combination of virtual simulation and actual stimulation of the body allow for the restoration of a link between imaginary and real body action. Cf. D.C. IRIMIA, R. ORTNER, M.S. POBORONIUC, B.E. IGNAT, C. GUGER, *High classification accuracy of a motor imagery based brain-computer interface for stroke rehabilitation training*, in: «Frontiers in Robotics & Artificial Intelligence», vol. V, 2018, Art.Nr. 130.

References

ADAMS, F., AIZAWA, K. (2001). *The bounds of cognition*. In: «Philosophical Psychology», vol. XIV, n. 1, pp. 43-64.

ADAMS, F., AIZAWA, K. (2010). *Defending the bounds of cognition*. In: R. MENARY (ed.), *The extended mind*, MIT Press, Cambridge (MA), pp. 67-80.

ALIMARDANI, M., NISHIO, S., ISHIGURO, H. (2015). *BCI-teleoperated androids: A study of embodiment and its effect on motor imagery learning*. In: «2015 IEEE 19th International Conference on Intelligent Engineering Systems (INES), IEEE», pp. 347-35.

ALIMARDANI, M., NISHIO, S., ISHIGYURO, H. (2016). *Removal of proprioception by BCI raises a stronger body ownership illusion in control of a humanlike robot*. In: «Scientific Reports», vol. VI, Art.Nr. 33514 - doi: 10.1038/srep33514.

BENDER, A., JOX, R.J., GRILL, E., STRAUBE, A., LULÉ, D. (2015). *Persistent Vegetative State and Minimally Conscious State A systematic review and meta-analysis of diagnostic procedures*. In: «Deutsches Ärzteblatt International», vol. CXII, n. 14, pp. 235-242.

CARTER, J.A., KALLESTRUP, J., PALERMOS, S.O., PRITCHARD, D. (2014). *Varieties of externalism*. In: «Philosophical Issues», vol. XXIV, n. 1, pp. 63-109.

CHAN, A.T., QUIROZ, J.C., DASCALU, S., HARRIS. F.C. JR. (2015). *An overview of brain computer interfaces*. In: «Proceedings of the 30th International Conference on Computers and Their Applications, CATA 2015», pp. 9-11.

CHENG, L., CORTESE, D., MONTI, M.M., WANG, F., RIGANELLO, F., ARCURI, F., DI, H., SCHNAKERS, C. (2018). *Do sensory stimulation programs have an impact on consciousness recovery?*. In: «Frontiers in Neurology», vol. IX, Art.Nr. 826 – doi: 10.3389/fneur.2018.00826.

CLARK, A. (2010). *Coupling, constitution, and the cognitive kind: A reply to Adams and Aizawa*. In: R. MENARY (ed.), *The extended mind*, MIT Press, Cambridge (MA), pp. 81-99.

CLARK, A. (2010). *Memento's revenge: The extended mind, extended*, in: R. MENARY (ed.), *The extended mind*, MIT Press, Cambridge (MA), pp. 43-66.

CLARK, A., CHALMERS, D. (1998). *The extended mind*. In: «Analysis», vol. LVIII, n. 1, pp. 7-19.

DI PAOLO, E., THOMPSON, E. (2014). *The enactive approach*. In: L. SHAPIRO (ed.), *The Routledge handbook of embodied cognition*, Routledge, London/New York, pp. 68-78.

FASOLI, M. (2018). *Substitutive, complementary and constitutive cognitive artifacts: Developing an interaction-centered approach*. In: «Review of Philosophy & Psychology», vol. IX, n. 3, pp. 671-687.

FENTON, A., ALPERT, S. (2008). *Extending our view on using BCIs for Locked-in syndrome*. In: «Neuroethics», vol. I, n. 2, pp. 119-132.

FUCHS, T. (2011). *The brain – A mediating organ*. In: «Journal of Consciousness Studies», vol. XVIII, n. 7-8, pp. 196-221.

FUCHS, T. (2018). *Ecology of the brain. The phenomenology and biology of the embodied mind*, Oxford University Press, Oxford.

GALLAGHER, S. (2018). *Decentering the brain: Embodied cognition and the critique of neurocentrism and narrow-minded philosophy of mind*. In: «Constructivist Foundations», vol. XIV, n. 1, pp. 8-21.

GALLAGHER, S., COLE, J. (1995). *Body schema and body image in a deafferented subject*. In: «Journal of Mind & Behavior», vol. XVI, n. 4, pp. 369-390.

GRÜBLER, G., AL-KHODAIRY, A., LEEB, R., PUSOTTA, I., RICCIO, A., RÖHM, M., HILDT, E. (2014). *Psychosocial and ethical aspects in non-invasive EEG-based BCI research – A survey among BCI users and BCI professionals*. In: «Neuroethics», vol. VII, n. 1, pp. 29-41.

HEERSMINK, R. (2013). *A taxonomy of cognitive artifacts: Function, information, and categories*. In: «Review of Philosophy & Psychology», vol. IV, n. 3, pp. 465-481.

HEERSMINK, R. (2013). *Embodied tools, cognitive tools and brain-computer interfaces*. In: «Neuroethics», vol. VI, n. 1, pp. 207-219.

HEIDEGGER, M. (1962). *Being and time* (1927), translated by J. MAQUARIE, E. ROBINSON, Harper, New York.

HIBBERT, R. (2016). *LIS and BCIs: A local, pluralist, and pragmatist approach to 4E* *cognition*. In: «Neuroethics», vol. IX, n. 2, pp. 187-198.

HUTTO, D.D., MYIN, E. (2012). *Radicalizing enactivism: Basic minds without content*, MIT Press, Cambridge (MA).

HUTTO, D.D., MYIN, E. (2017). *Evolving enactivism: Basic minds meet content*, MIT Press, Cambridge (MA).

HWANG, H., FERREIRIA, V.Y., ULROCH, D., KILIC, T., CHATZILIADIS, X., BLANKERTZ, B., TREDER, M. (2015). *A gaze independent brain-computer interface based on visual stimulation through closed eyelids.* In: «Scientific Reports», vol. V, Art.Nr. 15890 - doi: 10.1038/srep15890.

IRIMIA, D.C., ORTNER, R., POBORONIUC, M.S., IGNAT, B.E., GUGER, C. (2018). *High classification accuracy of a motor imagery based brain-computer interface for stroke rehabilitation training.* In: «Frontiers in Robotics & Artificial Intelligence», vol. V, Art.Nr. 130 - doi: 10.3389/frobt.2018.00130.

İŞCAN, Z., NIKULIN, V.V. (2018). *Steady state visual evoked potential (SSVEP) based brain-computer interface (BCI) performance under different perturbations.* In: «PLoS ONE», vol. XIII, n. 1, Art. Nr. e0191673 – doi: 10.1371/journal.pone.0191673.

KÜBLER, A. (2009). *Brain-computer interfaces for communication in paralysed patients and implications for disorders of consciousness*. In: S. LAUREYS, G. TONONI (eds.), *The neurology of consciousness*, Elsevier, Amsterdam/New York, pp. 217-233.

KÜBLER, A. (2019). *The history of BCI: From a vision for the future to real support for personhood in people with locked-in syndrome.* In: «Neuroethics», first online 29 May 2019 - doi: 10.1007/s12152-019-09409-4.

KYSELO, M. (2013). *Locked-in syndrome and BCI. Towards an enactive approach to the self.* In: «Neuroethics», vol. VI, n. 3, pp. 579-591.

LESENFANTS, D., CHATELLE, C., SAAB, J., LAUREYS, S., NOIRHOMME, Q. (2016). *Neurotechnological communication with patients with disorders of consciousness*. In: M. FARISCO, K. EVERS (eds.), *Neurotechnology and direct brain communication. New insights and responsibilities concerning speechless but communicative subjects*, Routledge, London/New York, pp. 85-99.

LESENFANTS, D., HABBAL, D., LUGO, Z., LEBEAU, M., HORKI, P., AMICO, E., POKORNY, C., GOMEZ, F., SODDU, A., MÜLLER-PUTZ, G., LAUREYS, S., NOIRHOMME, Q. (2014). *An independent SSVEP-based brain-computer interface in locked-in syndrome.* In: «Journal of Neural Engineering», vol. XI, n. 3, Art.Nr. 035002 - doi: 10.1088/1741-2560/11/3/035002.

MALAFOURIS, L. (2013). *How things shape the mind. A theory of material engagement*, MIT Press, Cambridge (MA).

MENARY, R. (2010). *Cognitive integration and the extended mind*, in: R. MENARY (ed.), *The extended mind*, MIT Press, Cambridge (MA), pp. 227-244.

MINKYU, A., MIJIN, L., JINYOUNG, C., SUNG CHAN, J. (2014). *A review of brain-computer interface games and an opinion survey from researchers, developers and users.* In: «Sensors», vol. XIV, n. 8, pp. 14601-14633.

MORLET, D., RUBY, P., ANDRÉ-OBADIA, N., FISCHER, C. (2017). *The auditory oddball paradigm revised to improve bedside detection of consciousness in behaviorally unresponsive patients.* In: «Psychophysiology», vol. LIV, n. 11, pp. 1644-1662.

MÜNßINGER, J.I., HALDER, S., KLEIH, S.C., FURDEA, A., RACO, V., HÖSLE, A., KÜBLER, A. (2010). *Brain painting: First evaluation of a new brain-computer interface application with ALS-patients and healthy volunteeers*. In: «Frontiers in Neuroscience», vol. IV, Art.Nr. 182 – doi: 10.3389/fnins.2010.00182.

NEWEN, A., DE BRUIN, L., GALLAGHER, S. (eds.) (2018). *The Oxford handbook of 4E cognition*, Oxford University Press, Oxford.

NOË, A. (2004). *Action in perception*, MIT Press, Cambridge (MA).

NOË, A. (2009). *Out of our heads: Why you are not your brain, and other lessons from the biology of consciousness*, Hill & Wang, New York.

O'REGAN, K.J., NOË, A. (2001). *A sensorimotor account of vision and visual consciousness*. In: «Behavioral & Brain Sciences», vol. XXIV, n. 5, pp. 939-973.

OSBORN, L.E., DRAGOMIR, A., BETTHAUSER, J.L., HUNT, C.L., NGUYEN, H.H., KALIKI, R.R., THAKOR, N.V. (2018). *Prosthesis with neuromorphic multilayered e-dermis perceives touch and pain.* In: «Science Robotics», vol. III, n. 19 - doi: 10.1126/scirobotics.aat3818.

OWEN, A.M. (2019). *The search for consciousness.* In: «Neuron», vol. CII, n. 3, pp. 526-528.

OWEN, A.M., COLEMAN, M.R., BOLY, M., DAVIS, M.H., LAUREYS, S., PICKARD, J.D. (2006). *Detecting awareness in the vegetative state.* In: «Science», vol. CCCXIII, n. 5792, pp. 1402.

PADFIELD, N., ZABALZA, J., ZHAO, H., MASERO, V., REN, J. (2019). *EEG-based brain-computer interfaces using motor-imagery: Techniques and challenges.* In: «Sensors», vol. XIX, n. 6, Art.Nr. 1423 – doi: 10.3390/s19061423.

PINEGGER, A., HIEBEL, A., WRIESSNEGGER, S.C., MÜLLER-PUTZ, G.R. (2017). *Composing only by thought: Novel application of the P300 brain-computer interface.* In: «PLoS ONE», vol. XII, n. 9, Art. Nr. e0181584 – doi: 10.1371/journal.pone.0181584.

PIREDDA, G. (2017). *The mark of the cognitive and the coupling-constitution fallacy: A defense of the extended mind hypothesis.* In: «Frontiers in Psychology», vol. VIII, Art.Nr. 2061 – doi: 10.3389/fpsyg.2017.02061.

PUTNAM, H. (1975). *The meaning of "meaning"* (1974). In: H. PUTNAM, *Philosophical papers, Vol. II: Mind, language, and reality*, Cambridge University Press, Cambridge, pp. 215-271.

ROWLANDS, M. (2003). *Externalism: Putting mind and world back together again*, McGill-Queen's University Press.

RUPERT, R.D. (2004). *Challenges to the hypothesis of extended cognition.* In: «The Journal of Philosophy», vol. CI, n. 8, pp. 389-428.

SUTTON, J. (2010). *Exograms and interdisciplinarity: History, the extended mind, and the civilizing process.* In: R. MENARY (ed.), *The extended mind*, MIT Press, Cambridge (MA), pp. 189-226.

SVENSSON, P., WIJK, U., BJÖRKMAN, A., ANTFOLK, C. (2017). *A review of invasive and non-invasive sensory feedback in upper limb prostheses.* In: «Expert Review of Medical Devices», vol. XIV, n. 6, pp. 439-447.

THEINER, G. (2017). *The extended mind.* In: B. TURNER (ed.), *The Wiley-Blackwell encyclopedia of social theory*, Wiley-Blackwell, London/New York – doi: 10.1002/9781118430873.est0859.

VAN ERP, J.B.F., LOTTE, F., TANGERMANN, M. (2012). *Brain-computer interfaces: Beyond medical applications.* In: «Computer - IEEE Computer Society», vol. XLV, n. 4, pp. 26-34.

VIDAL, J.J. (1973). *Toward direct brain-communication.* In: «Annual Review of Biophysics & Bioengineering», vol. II, pp. 157-180.

WALTER, S. (2010). *Locked-in syndrome, BCI, and a confusion about embodied, embedded, extended, and enacted cognition.* In: «Neuroethics», vol. III, n. 1, pp. 61-72.

WARD, D., SILVERMAN, D. (2017). M. VILLALOBOS, *Introduction: The varieties of enactivism.* In: «Topoi», vol. XXXVI, n. 3, pp. 365-375.

WIERZGALA, P., ZAPALA, D., WOJCIK, G.M., MASIAK, J. (2018). *Most popular signal processing methods in motor-imagery BCI: A review and meta-analysis.* In: «Frontiers in Neuroinformatics», vol. XXI, Art. Nr. 78 - doi: 10.3389/fninf.2018.00078.

WILSON, R.A. (2017). *Embodied cognition.* In: E.N. ZALTA (ed.), *The Stanford encyclopedia of philosophy*, Spring Edition – URL: https://plato.stanford.edu/entries/embodied-cognition/.

XING, X., WANG, Y., PEI, W., GUO, X., LIU, Z., WANG, F., MING, G., ZHAO, H., GUI, Q., CHEN, H. (2018). *A high-speed SSVEP-based BCI using dry EEG electrodes.* In: «Scientific Reports», vol. VIII, n. 1, Art.Nr. 14708 - doi: 10.1038/s41598-018-32283-8.

YIN, E., ZEYL, T., SAAB, R., HU, D., ZHOU, Z., CHAU, T. (2016). *An auditory-tactile visual saccade-independent P300 brain-computer interface.* In: «International Journal of Neural Systems», vol. XXVI, n. 1, Art.Nr. 1650001 - doi: 10.1142/S0129065716500015.

YOUNG, G. (2014). *Locked-in syndrome.* In: R. DAROFF, M.J. AMINOFF, *Encyclopedia of the neurological sciences*, Academic Press, New York, p. 916.