Human Brainwaves Synchronization: An Hypothesis of Sympateia

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Abstract

Starting from the considerations that new generations communicate and manage social relationships in a different way, thanks to the use of new media, especially Internet, we wanted to study the effects of this communication mode on a neuro-cognitive level. Many studies, especially in sociological and psychological research fields, state that traditional communication among young people is decreasing and that the excessive use of social networking and mobile devices represents a limitation to the development of communication abilities.

In this chapter, we present our concept of "sympateia" and show the results of our early-stage experiments addressing our research. Progresses in Neuroscience and current Brain-Computer Interface (BCI) devices enable NeuroInformatics to deeper experiment new Human-machine communication methods and technology. Our aim is to address research efforts in finding new technologies and new IT paradigms to explore the possibility of a direct Human-Human communication mediated by technology.

The chapter consists of six sections: in section one, a theoretical background of the cognitive approach to communication and empathy will be defined. In section two, it will be traced the state-of-the-art in Information Technology and Neuroscience studies in human-computer interaction. In section three IT paradigms will be presented to individuate the well-suited ones, with particular attention to AI and learning machine methods. Section four will trace the scenario and the direction of the research, while section five will present some preliminary experiments performed. Finally, in section six will discuss some final considerations and future works.

Introduction

Our research originates from considerations based on the observation of new generations' behaviour. Many studies, especially in psychological and sociological research fields, state that traditional communication among young people is decreasing and that the excessive use of social networking and mobile devices represents a limitation to the development of communication abilities. It is a fact that new digital-natives do not communicate in a traditional way, but they choose different means and ways. It is not a surprising conclusion that a large part of digital-natives consider obsolete both Web sites' structure and Internet navigation modes, learning instruments and paradigms and communication tools, choosing, instead, fast and immediate media like mobile phone communication, social networking and so on (Croitoru et al. 2011). Actually, they communicate each other much more than ever done, using not only the verbal language, but also images, videos, sounds, and especially emotions. In this paper, we named this phenomenon telepatheia or, better, sympateia, that means that they seem to keep in contact independently by the mean. Of course, on our intention, this does not mean that we are observing a new organic evolution, but surely a kind of evolution can be traced: an era in which human and machines are evolving influencing one each other, determining a specific kind of communication strongly influenced and related to technology.

According with Dyson Freeman (Freeman 2010), we can assume that new progresses concern radio-telepathy, which is the way to realize a technology-driven communication joining human and technology, using brain and technological tools to communicate.

This future is not so far, considering the application of Brain Computer Interface in neurology. Furthermore, neuro-cognitive studies and the machine learning models of automatic learning, provide a great opportunity to explore the potentiality in communication mechanisms in humans. The aim of this paper is to explore possible models and trace new directions in research of a co-evolutionary model of human-computer bidirectional interaction.

On one side, in fact, the Computer Science enlarged the potentiality in biological systems analysis influencing the interaction mechanisms among biological macrosystems (humans), on the other side it has been influenced by them. The boundaries are very close, so this means that it is possible to imagine a future co-evolution of Computers and Humans, not only in robotics progress and prosthesis, but also in communication. Later, in the document, we will come back to this point. For now, we limit to give the focal point of our research position, which faces the challenge of a new co-evolutionary man-machine model starting from the study of the brain (Fogel, 1994). In fact, progresses of neuroscience concerning human brain structure and related functional dynamics generated the development of a paradigm proposing a new era, both for interfaces and for humans: the era of control and interaction through cerebral impulses.

This second point represents the focus of our position: we have to face the challenge of a new co-evolutionary man-machine model.

Psychology of communication

To understand how people interact each other in different contexts, at least five general domains should be considered. The first about the nature of cognition, the second about the nature of motivation, the third about the nature of media, the fourth about the nature of time, and the fifth about the nature of communication:

- First, people are assumed to be limited capacity information processors (Basil, 1994; Schneider, Dumais, & Shiffrin, 1984; Shiffrin & Schneider, 1977). We have limited cognitive resources to allocate on a task, such as perceiving, encoding, understanding, and remembering the world clues. When there are insufficient resources available, processing suffers.
- Second, people have two underlying motivational systems, the appetitive (or approaching) system and the aversive (or avoidance) system (Bradley, 1994; Cacioppo & Gardner, 1999; P. J. Lang, Bradley, & Cuthbert, 1997). These systems activate automatically in response to motivationally relevant stimuli in the environment and influence ongoing cognitive processing.
- Third, media are made up of variably redundant streams of information presented through multiple sensory channels (eyes, ears, touch) and formats (words, text, still pictures, moving pictures, etc.; Reeves, Thorson, & Schleuder, 1986; Reeves et al., 1985; Thorson, Reeves, & Schleuder, 1986).
- Fourth, all human behaviors occur over time and is constantly changing from one second to the next. Human behavior, and therefore human cognition, is a dynamic process (Thelen & Smith, 1994).
- Fifth, communication is an overtime process that implies the interplay between the information processing system and the message (Geiger & Reeves, 1993; Lang, 2000). This interaction is continuous. Aspects of the message influence the motivational and cognitive systems and aspects of those systems influence how the message is perceived, encoded, stored, and eventually retrieved. In other words, communication is a continuous, interactive, dynamic, embodied process.

When humans search for, process and share information these five domains should be taken in consideration in order to analyze cognitive, emotional and motivational aspects of communication as well as the related effects on knowledge structuring and sharing.
Knowledge is personalized information related to facts, procedures, concepts, interpretations, ideas, observations, and judgments. Knowledge may be defined as a set of personal beliefs that increases an individual’s capacity to take effective actions. Knowledge management is the collection of processes that governs the creation, dissemination, and utilization of knowledge (Norman, 1982).

Thus from a cognitive perspective, we need to systematically organize the process of acquiring information, communicating tacit and explicit knowledge, following the subsequent phases: knowledge creation, knowledge accumulation, knowledge dissemination, knowledge sharing, and knowledge use.

Knowledge is organized and managed by the use of two different thinking modes: an analytical or logical-scientific thinking and a narrative one (Bruner, 2003).

- The logical-scientific allow a categorization of reality with the aim to simplify the number of variables present and to organize the large amount of data available. It is the kind of thinking that we adopt for scientific aims, to pursue an explanatory formalized knowledge of the world. It may be considered a vertical thinking mode, since it is necessary to relate a single case with general categories according to a vertical process of sub-ordination and of super-ordination. This thinking modality is also nomothetic (facing with general laws and being context-independent) and paradigmatic (i.e., its propositions are connected each other by associations based on equivalences). The logical thinking is guided by the principle of non-contradiction and by ambiguity intolerance. Finally, it is an extensional modality, since it is based on general propositions valid for many occurrences and situations.
- The narrative thinking is dedicated to communication and interpretation of experience by building stories that provide an understanding of intentions, actions and human affairs. These stories might be either self-centered or others-centered. The narrative mode is typical active in everyday reasoning and applies mainly to the understanding and management of the social world. The stories produced by the narrative mind are generally plausible and reasonable, although not necessarily true, with the function of shaping the experience along spatial and temporal dimensions. The narrative thinking is ideographic (i.e., it is associated with the imagery and figures) and syntagmatic (i.e., its propositions are linked by contiguity in space and time). In knowledge based on the narrative thinking, mode utterances are closely dependent on the environment and are made by a collection of ideas rather than of a systematic structure of concepts and abstract categories. The narrative thinking has its foundation in the internal coherence of the story rather. It is intensional in nature, as it tries to build a complete picture of an individual case to grasp the originality of the subject. In summary, narrative thinking is a universal mode, present in all people, to organize, to give sense of and communicate experiences. However, it is strongly based on individual and cultural characteristics, depending on specific system of beliefs, values and discursive practices.

When we communicate by the use of a specific medium, we generally use a narrative format. However, this implies that a shared cultural and communication background is shared. We argue that the web-based communication system strongly contributed in accelerating this sharing, since the Web acts a big underlying knowledge structure able to shape communications as well as thoughts.

Actually, the use of web-based sources may enhance the spread of information, the sharing of a common knowledge and the individual trust. In fact, individuals tend to view virtual communities as a repository for the public goal, with the intent to benefit the collective, rather than the individual. The online content may provide accurate data through an easy-to-use format. The web-based content may encourage use, participation and share with others knowledge. In addition, the cognitive load should be taken into account together with emotional impact, to understand how people use communication media in order to interact, create communities and give rise to a shared cognition. Do all these aspects favor the raising of a rapid communication link and/or of minds synchronization?

Communication synchrony

As described above, communication is a dynamic process that occurs in a given context, by the use of a motivated cognitive system in order to structure and share knowledge and information. Hence, communication is a form of interaction that gives rise to a joint product by mutual participation. During a communicative interaction, participants are on the same level and share the same communication responsibility. Indeed, when people communicate, they must adapt their styles with each other and this lead to a mutual adaptation within a conversation, in which synchronization naturally occurs with regard to shift timing and rhythms. The sequence of exchanges can take two directions:

- Convergence, when the communication styles of both parties become more similar and assume a uniform modality;
- Divergence, when the differences become progressively larger and create distance between participants.

The emergence of patterns of synchronization and adaptation is crucial in ensuring effective communication and comprehensibility.

Synchronization is particularly important when communication becomes a tool for the management of relationships, i.e. when communicators act as players of an interactive game (e.g. seduction). In this communication game, meanings become shared as well as intentions and positions on a virtual communication chessboard. In this sense, communication implies much then information exchanges; hence, in order to understand the psychological value of a communication act is fundamental to understand the whole context of the interaction. The communication medium, the cognitive and emotional distance/vicinity of communicators and the shared knowledge background are then the essential parameters to consider. We argue that in computer-mediated communication, and in particular, in social network messaging and sharing, people, most of all implicitly, interact in such a way to enhance the effect of messages on cognitive and emotional systems. This implies that communicators give for grant that a large amount of tacit knowledge is already shared. Furthermore, it also implies that communicator implicitly share a common view of the pragmatic effects of communication, i.e. the power of messages to change emotions, cognition and motivation of others. This is probably the secret of new media messaging systems efficacy, but also that is a basic brittleness.

The concept of Empathy

The issue of the others' mind understanding has been one of the core points of human studies of the last decades. Indeed, all disciplines aimed to the exploration of human thought and behavior required an epistemological analysis of that issue in order to define their scientific background (Gallese, 2007). Humans have developed the ability to consider and comphrend other people as thinking creatures, so to identify their state of mind and to give sense to and to predict their behaviour. Humans are also able to understand if others behave in a certain way due to their moods or to the effects of other factors (e.g. the presence of other people or for some environmental influence). Hence, we are able, as human beings, to find out a motivation driver behind an explicit, and then observable, behaviour. This attitude to apprehend other people's mind must be considered the psychological foundation of our "social animals" standing, which allowed us to shape large and solid human societies (Gallese, 2007). In fact, being unable to understand others' mind might instead be a net disadvantage in pursuing individual interests in social contexts within which the success of our actions largely depends on interaction and cooperation. Even more significantly, difficulties in others' mind understanding (e.g. in autistic disorder), diminish our ability to pursue individual interests and imply a severely restricted ability to give rise to elementary social ties, also compromising learning practices and the development of basic cognitive abilities (Stueber, 2010). By a theoretical perspective, the German psychologist and philosopher Theodore Lipps (1851 - 1914) defined empathy as a substantially innate process that enable humans to identify others individuals of the same species as a subject with its own identity, by the use of imitation and projection. In Lipps' thought, empathy seems to be aimed not only to top off a hypothetical original unity between individuals, but also to allow, shape and regulate human relations. The work of Lipps popularized empathy as a fundamental category for other minds' understanding.

Edmund Husserl and his student Edith Stein exploited and further developed the category of empathy as a key concept in their explanation of inter-subjectivity. In this view, empathy not only allows approaching the issues of other minds' understanding and the appraising of other people as a thinking creature; empathy also allows developing ourselves as reflective and self-critical individuals (Gallese, 2003).

Inter-subjectivity may also be viewed within the perspective of so-called cognition naturalization approach, in which the concept of social intelligence acquires a wide scope and a relevant place in the cognitive theory. In this approach, consisting in the understanding of the neural processes that regulate interpersonal relations, social cognition is considered as a set of capabilities that allows an individual to build mental models of the relationship between him/herself and others; these abilities allow people using their representations to explore and to effectively move in their social environment. In this way, an individual becomes able to understand the mechanisms that take people into communication, with aim to convey wishes, beliefs, intentions and, simultaneously, to understand what others do and why (Ladavas, 2009).

Hence, the neuro-cognitive approach to psychology aims to shed light on the link between brain mechanisms and our cognitive and social skills; consequently, we argue this approach to empathy by be the most adequate, since empathy is complex domain where emotion, cognition and inter-subjectivity meet.

Indeed, aesthetics, philosophy, anthropology, psychology, psychopathology and psychoanalysis are all disciplines that have investigated empathy, but the debate about the nature and levels of empathy has received an extraordinary impetus by the recent discoveries in the field of neuroscience (Gallese, 2003; 2007).

As we've said before, empathy presupposes the differentiation between self and other, and the acquisition of object permanence (Adenzato & Enrici, 2005). The ability to understand and possibly share the emotional state of another person implies the individual to develop the awareness that others are different from themselves, that they have their stability and continuity over time, and that they experience their own emotions and feelings. These emotions are expressed in various ways and consequently an empathic individual should be able to adequately discriminate between the different ways people use to display emotions, and to take the perspective of others.

According to the evolutionary theory of emotional expressions, the ability to recognize and express emotions is regulated by a complex system of biological feedback, which is innate, species-specific and phylogenetically hereditary (Rizzolatti & Vozza, 2008; Adenzato & Enrici, 2005). According to this perspective, from birth, a biological mechanism for the detection and the transmission of emotional signals is active. An important corollary of this model is that emotions must have some basic properties: they are innate, universally spread and culturally independent.

Specifically, the universal character of emotional expressions, particularly mimics, if on the one hand does not exclude the role played by learning in their concrete display, however, is based on the assumption that there is a constant and an invariable correspondence between an emotional state and its mimic expression. This correspondence seems to be determined by the biological evolution, since some studies have shown a relative continuity of mimic in primates and humans (Gallese, 2003).

The opposite position holds that children learn how to recognize and respond to others' emotions through cultural experiences and language within a given social context (LeDoux, 1998). It is likely that the truth lies in the middle. Indeed, since the capability to share and to understand emotions is surely universal, it develops during life. Furthermore, we learn how to use this capability in different context and we optimize this process so to become emotionally experts. For instance, we cannot state that humans were provided with a mind mechanism to share emotions at-distance by the use of interconnected computers or smartphones. Still we are now able to transmit short and fast messages emotionally reach, though their lack all that features that were present in traditional in-presence messages. We learned how to use new media, both to send messages and to create (and to preserve) at-distance relationships with a human touch.

State-of-the-art in Information Technology and Neuroscience studies in human-computer interface

NeuroInformatics is an emerging field in neuroscience aiming to transfer basic research in the elaboration of information by the human brain to the development of tools helping people to recover functions lost because of diseases or traumas. Other applications concern Human-Computer interaction, with particular attention to gaming, entertainment and Virtual reality environment, allowing freedom from unnatural interface devices. Brain computing, and particularly the study of BCI (Brain Computer Interface) devices, represent the state-of-the-art in this field. In fact, currently Neuroinformatics is aiming mainly to create an input device from brain to computer, concerning both HCI (Human Computer Interaction) and movement devices control.

Many experiments are related to the development of control systems through brain activity faster and more accurate than a computer cursor, as in the case of text entry through a BCI device. For example, Anna Rose Childress from the University of Pennsylvania (Childress et al., 2010) proposes a system which feedback is given in “real time” by the patient’s brain activity and which can become an enlargement of treatment options for people with cerebral disease and syndromes limiting communication abilities. Other applications, in neuroscience, concern the brain stimulation to restore the use of paralyzed limbs in people recovering from a stroke, to increase motion in affected limbs (Keganemaru, 2010).

Researchers at the Graz University of Technology and the University College London’s virtual reality laboratory experimented the brain control of a wheelchair by tetraplegic subjects along a virtual street (Leeb et al., 2006; Pfurtscheller & Neuper, 2001) with a notable success after a few months period of training.

At the University of Tokyo, several experiments have been conducted using SSVEP (Steady-State Visual Evoked Potentials) brain signals, with the aim to navigate 3D immersive Virtual Environment, reaching a success rate of about 70-80 percent.

Other experiments concern the use of videogames to explore the potentiality of BCI to interact with virtual worlds. This is the case of researches done at University College Dublin and MediaLabEurope (Fogel, 1994), while in Gjovik University College researchers use BCI and EEG to measure and analyse attention and flow in videogames or use EEG waves to control the robot (Fagerjord, 2010).

The greatest increment in knowledge about brain influenced new way to interact with computers and machines, and, aided by technological advances in molecular biology and genetics, brain imaging and especially EEG and BCI allow easier and not-invasive techniques to collect data and interact with systems.

NeuroInformatics is a novel science, needing multidisciplinary knowledge and in early stage on many open issues. Logical directions in new researches are represented by Artificial Cognitive Systems (Reitman & Olson, 1990) and Brain Engineering. In these applications, approaches consist in a mixed knowledge of measurements, computational models and Human brain and cognitive functions.

Two important projects are currently in challenge in Korea (Lee, 2010): Artificial Cognitive Systems (ACS) and Brain NeuroInformatics and Brain Engineering (BNIBE) aiming, respectively, the first to develop a Proactive Knowledge Development and Self-Identity model to build functional modules for Knowledge Representation and the second to identify computational models for cognitive functions and its applications.

A large part of experiments is related to the human-computer interaction, particularly using game scenarios and BCI (Brain Computer Interface; Mason et al., 2003) as a test bench to analyse brain signals simulating specific environments and situations.

Except for ACS and BNIBE projects, many research works does not focus on bilateral-interactive man-machine interface (MMI), but instead in producing input mechanisms to facilitate human-computer interaction. ACS and BNIBE are in an early stage that is the recognition of human intentions and brain functions with EEG, EOG (ElectroOculoGraphy), EMG (ElectroMioGraphy) and audio-visual data, with the final scope to understand human behaviour and its application to real-time MMI.

Another promising field of application in Neuroinformatics is the rehabilitation of patients involved in stroke or affected by brain diseases. Rehabilitation is related either to esoscheleton development and to cognitive functions training and recover (Pineda et al., 2003). In addition, experiment for the control through BCI of a Wheelchair in Virtual Environments have been successfully performed (Leeb et al. 2007).

We also wish to recall the study in the field of invasive BCI, thanks to which the new BCI devices have been developed. Neurosurgery have done important progresses in using deep brain stimulation through electrodes implants, in many psychiatric and movement disorders (Kern & Kumar, 2007; Mayberg et al. 2003; Abosch & Lozano, 2003; Vidailhet et al., 2005) and especially for Parkinson disease (Komotar et al., 2010; Lucchiari et al., 2009; Fumagalli et al., 2011; Rosa et al. 2013).

The studies and the application of deep brain stimulation allowed to deeper understand brain signals through the interpretation of the EEG rhythms, accelerating the development of non-invasive BCI systems (Fumagalli et al., 2014).

Overview of IT paradigms adopted in NeuroInformatics.

The great interest born around NeuroInformatics generated an incredible number of research groups working on highly focused projects around the World and an increasing amount of data needed to be analyzed, integrated and managed. Another characteristic of data collected in NeuroInformatics experiments is the complexity of data that, compared to sequence ones, have more complexity levels, including the genomic one.

Of course, due to the complexity of data classification and interpretation and to the need of real time computation, the most suited computational methods are those typical of Artificial Intelligence field and, particularly, machine learning ones. Among all, the most used are the feature selection methods, the artificial neural networks and the Support Vector Machines, especially when the brain signal analysis is performed using real time BCI devices. BCI components, in fact, are constituted by an acquisition system, a module for signal preprocessing followed by a module for signal analysis and a controller that is an actuator performing the final scope of BCI applications.

Therefore, the four parts (schematically analogical signal acquisition, digitizing, feature extraction and transforming algorithms) largely involve advanced machine learning algorithms. Roughly speaking, a BCI device provides means to measure brain neural signal, methods and algorithms to decode cerebral states and intentions related to acquire signals, methodologies and algorithms to map the decoded cerebral activity into aptitudes or movement intentions.

The non-stationary property of EEG signals makes traditional analysis methods not very affordable. Also in EEG, signal classical classification methods fail for the great number of features to be considered and for the need to exclude artifacts and noise. Therefore, at each stage of the process, we can individuate more efficient A.I. algorithms both for analysis and for classification, such as, for example, Support Vector Machine.

Among all, Machine Learning methods have the peculiarity to allow computers to evolve on the base of empirical data, such as sensor data or features databases. Machine learning research focus on automatic learning to individuate complex patterns starting from examples (training data).

As the mixture of EEG and artifact is nonlinear, separation of the artifact from the actual signal is very difficult. Various methods have been investigated to eliminate artifacts or to classify EEG signals (Garrett et al., 2003). Due to the non-linear problem, SVMs are particularly suited for classification of EEG signals (Lotte et al., 2007), taking advantage of the specific properties of SVMs, such as the “optimal” margin of separation, the robustness of the solutions (Folgieri, 2009) and the large numbers of tools available for computation.

We wish to recall the general aspects of AI, making this discipline the most near to neuroscience and brain studies scopes. The commonly accepted definition of AI is that provided by Charniak and McDermott, stating, “Artificial intelligence is the study of mental faculties through the use of computational models” (Charniak & McDermott, 1985). Therefore, AI represents a key factor in NeuroInformatics and in BCI-related studies because it provides a large number of cognitive models to represent users and a variety of means to test the models. Additionally, AI offers the possibilities to elaborate intelligent systems that might adapt to the needs of users, as we will explore deeply in next paragraphs.

Scenario and direction of the research

As shown in previous sections, the mix of Neuroscience and Information Technology opens new scenarios in Research. Moreover, new interaction devices, such as BCIs, enable novel applications and enlarge the possibility of studying human brain potentiality.

If we start from the Artificial Intelligence point of view, we can start from the beginning, that is, from the Alan Turing's paper in 1950, in which he addressed the question: "Can machines think?" The main question we want to answer with our researches is, instead: "can Humans think through machines?" This mainly means, in a long term planning, to concentrate efforts in finding means to realize bi-directional brain communication between Humans and machines and brain communication among Humans, assisted by technology.

Let us initially concentrate on the bi-directionality cognitive problem. Before any other consideration, let us have a glance on efforts made by researchers in exploring potentiality of new possibilities offered by EEG and especially by BCI devices. BCI represents a great test bench for Neuroscience and for Information Technology Science. Due to the common vision of Information Technology as a serving discipline, many efforts are oriented to solve neurological, rehabilitation, cognitive problems, so main experiments performed with BCI devices are oriented to train the machine to interpret brain signals and transform them into events, and consequently to find the way to accelerate the training time. While performing some experiments concerning the use of BCI in human-computer interaction, we realized that the major difficulty in training is not on the machine side, but it is difficult for Humans to understand their own thought. In fact, all the subjects tend to feel tired after a while due to the difficulty in individuating where and how a specific though (for example "move on the right" or "concentrate") born in the brain and direct efforts in a specific brain region. It is true that there is still a lot of work to do in understanding the whole process of interacting with machines, but at the same time central issues in cognitive research concern how people move from skilled performance to problem solving, how a person learns, manages errors, interprets visual stimuli, and communicates. Changing the point of view, that is starting from stimuli and machine to enable Humans to empower their understanding of their own brain mechanism, will allow as first to reduce user's fatigue, individual differences or mental workload and, as a second issue, to empower communication among Humans enabled by technological devices, allowing brain-to-brain communication through devices, facilitating reciprocal understanding without the mediation of words, images or sound. Of course, this could seem futuristic but, considering the first results obtained by some experiments we performed, our point of view is not so far from brain-to-brain communication.

New generations are truly lazy or interactions among individuals are greatly event-driven or, better, stimuli-driven? Based on our observation, the emerging idea is that young people do not

communicate neither using words nor through images. We could state that they are “connected” and “react” in an instinctive way to communication needs or to problems.
The idea to orient our research to brain computing born from more considerations, derived by research experience and matured within didactic experiences.
BCIs (Vidal, 1973) allow using brain generated signals without the need of muscular activation. Till today BCIs covered particular importance in interaction with the external world for people affected by disabilities and in game field, but, since neurophysiology demonstrated that various processes, located in sensorimotor cortex area, can be acquired and used to express the intention of movement through a BCI, why do not use this technology in a more extensive way to create evolved learning models (Bassett et al., 2011) and to design new information technology systems?
Interacting by a BCI does not mean to read the thought, but means to be able to detect a spontaneous communication will. Impulses can be registered, catalogued and linked to specific brain areas, whose functions are known. Exploring this field means to become able to dispose a change by the cognitive point of view, because Humans will have to acquire a complete ownership of the relationship between cerebral stimulus and sensorial perception and a strong consciousness of the relationship between the thought and the external world.
The study, through BCIs, of the different perception modalities and of the different learning mechanisms not only will have practical applications (for example, in didactic and in medical and neurological applications), but will give the possibility to create new models using AI and Machine learning to design new paradigms for Information Technology systems design. For example, we could have a new machine model able to make bi-univocal, in real time, the adjustment mechanism of a machine for a user and vice versa. The IT systems could be designed to adapt to individual biology.
Today we have the Information Technology competence to create these models and we are in the era of the non-muscular control. Currently we can create a sophisticated environment characterized by multimodality ad multithreading input stimuli. Information Technology devices tend to not have the aspect of peripherals, but they are becoming mobile and “wearable”. Systems are evolving by a peripheral to a pervasive connotation, in which humans and sensors are in a stronger relationship. Intelligent systems might adapt to the needs of the user, intelligently helping users to understand the system, and systems might tutor the users in an educational setting. Think, for example, to the great advantages for people affected by dyslexia of by attentive diseases.

This is only the first step of our research and an example of practical applications of results. The main direction concern what we call Sympateia (ancient Greek *Σψμπατηια*: “to be on the same wavelength”).

We want to explore the communication mechanisms of telepathy (in the ancient Greek assumption of τελεπατηια that is τελε[tele]=”distance” and πατηια [pateia]=”emotion, feeling”) through BCI devices. This does not mean that we are trying to make humans telepathic, but we aim to deeply understand communication mechanisms among humans through human-computer interaction realized by BCI devices to create supports realizing communication means based on brain waves mediated by technology. This is not an impossible and futuristic aims, since it has been hypothesized also by the great scientists Dyson Freeman (2007), calling it radio-telepathy, but it means to change the point of view of brain and Information Technology researches, stressing the point of view of self-understanding of own brain.

To do this, we are performing some experiments, described below, to find a sort of sympateia revealed by brain rhythms detection among users submitted to the same experiments. Obtained results encouraged us to follow this direction.

Some preliminary experiments performed

To explore the context of sympateia, same experiments have been performed to analyse, in this early stage, the applicability of the concept of brain rhythms synchronization, as a first manifestation of our concept of sympateia.

We decided to start from a neuro-aesthetics point of view (Marini et al., 2012; Banzi & Folgieri, 2012). In fact, the primary need was that to setup a simple experiment in which brain rhythms alignment among users could have a preeminent importance. Neuroaesthetics is a recent sub-discipline of empirical aesthetics that assumes a scientific approach to the perception of art and music, as in the works of Semir Zeki, such as (Zeki, 2002; Ishizu & Zeki, 2011).

Current BCI devices consider a variety of different EEG signals, including VEP (Visual Evoked Potential), SCP (Slow Cortical Potentials), P300 potentials, and mu or beta rhythms. Alpha rhythms are also used for environmental control systems (ECS). We was looking for an experimental environment involving more EEG signals and not only those recalled by visual stimuli or movement intention, so we decided to use the evocative power of music with two main aims:

1. detect the presence of a waves alignment among different users hearing the same melody;
2. verify if a wave described by a melody could coincide, in shape, with those individuated analysing users’ brain rhythms.

The use of music has been suggested by the simple observation of mass phenomena during a concert, for which, after a while, the public seems to be “on the same wavelength” that is having the same perceptions/feelings/emotional and cognitive status.

The results of the experiments has been published in a specific paper (Folgieri & Zichella, 2014) and in a book chapter (Folgieri, Bergomi & Castellani, 2014). Here we will limit to underline main evidence.

- Results are independent of the genre of music. We performed experiments using both classic and pop music, each revealing similar effects on brain waves of different subjects.
- Results are independent by the age of subjects. We selected a sample of six persons: two in the age range 14-24, two in the range 25-35, two in the range 36-46.
- Experiments show that, after a relatively low time, brain waves, especially those corresponding to beta values, of different users align each other showing similar frequency and amplitudes, with insignificant differences. The same result is obtained if the comparison is done among persons’ brain waves and melody waves, obtained rescaling (that is normalizing) the sound signal to the same scale of users’ ones.

The following figure 1 graphically shows this phenomenon, comparing mu waves registered by different subjects hearing the same melody. To this aim, we played the 9th symphony of Beethoven and registered the brain rhythms using the Neurosky Mindwave headset and a specific procedure written in C++. Data have been after elaborated using Matlab procedures.

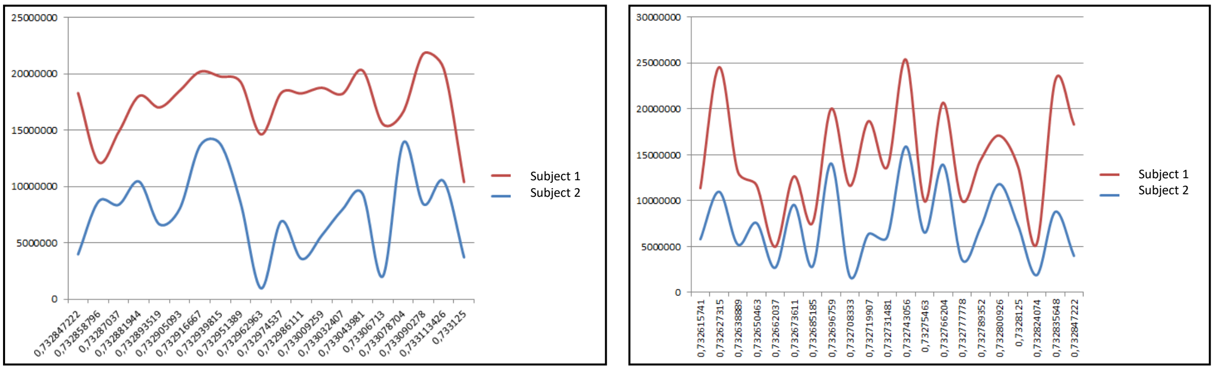


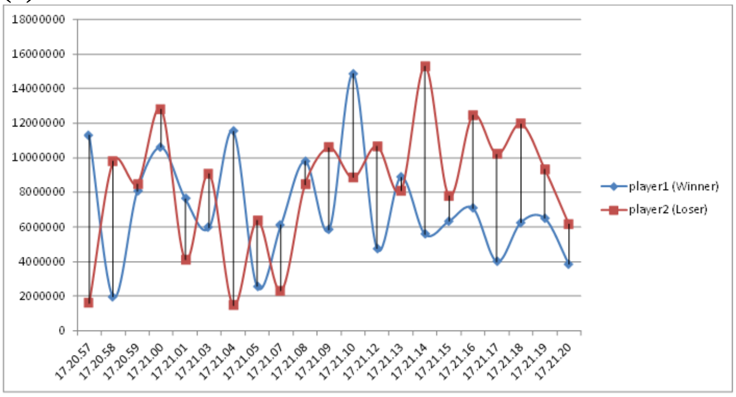
Figure 1 Initial (left) and final (right) status of beta brainwaves in two subjects hearing the same melody

The NeuroSky Mindwave is a simplified version of the traditional medical EEG technology. It monitors electrical potential between the sensing dry electrode, positioned on the forehead, and the reference electrodes, positioned on the left earlobe. Through this device, the measuring phase becomes less complex and more comfortable for the subject. The Mindwave does not require any initial training. Even if there the single point electrode does not make possible to register changes in brainwave activity in different parts of the brain, the volume conduction allows monitoring a significant part of the entire brain’s activity.

To record data, we wrote a specific procedure in C++, using the APIs at disposition for research and development purposes. The application returns the raw frequency data for the different brainwaves types as a six dimensional vector. We used Matlab to make 2D graphs and 3D scatter plots.
We performed the same experiments also using the Emotiv Epoch headset, provided by 14 wet electrodes, requiring more effort by users in the initial training phase. In addition, in this case we used specifically written procedures and Matlab to elaborate graphically the results.

We recall that the signal transmitted by the devices is already filtered to remove the 50 Hz frequency band related to electric power equipment. Moreover, Neurosky detects eye blinks, thus avoiding a specific filtering work. The Emotiv Epoc also detect some myographic signals, thus avoiding, also in this case, a specific filtering work. Other motion related activities should be detected with ad hoc signal analysis, that it has not been considered, since from a visual inspection the signal in general did not show these typical features.
Data have been divided into epochs. Epoched data were preliminary filtered in the interval 1-80 Hz. Subsequently, we performed the band decomposition and we visually inspected delta, theta, alpha, beta and gamma rhythms. The synchronization occurs particularly in the brain rhythms beta, thus revealing the performance of cognitive processes.
We performed also an experiment registering brain rhythms of two players during a chess play, using the Neurosky Mindwave. Our aim was to verify if the players involved in a complex challenge show brainwaves similar in amplitude and shape "synchronizing" their brains, showing a sort of sympateia.
Effectively, after a while and independently by the ability of the players, beta brain signals showed a very close amplitude and shape. The chess game has been, in this case the mean to realize the sympateia, as shown in figure 2, as an example, for beta rhythms related to two of the players participating to the experiment.

(a)



(b)

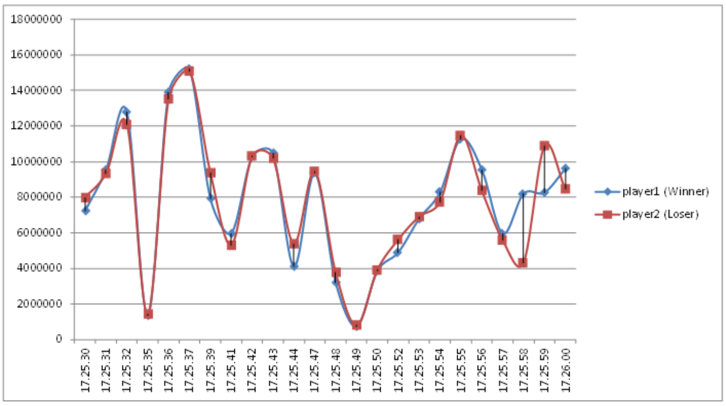


Figure 2 Initial (a) and final (b) state of beta brainwaves in two players in a chess game

As you can see in figure 2, in the initial phase of the game, the players are not synchronized, while as the game proceed, the brain rhythms tend to synchronize. The same result has been obtained for eight couples on ten participating in the experiment, independently from the ability of the player (beginner or expert). In this experiment, we also calculated a synchronization index. Considering a single electrode side, the phase coherence time can be easily revealed by inspecting the analytic phase. In fact, irregularity in analytic phase plots reveal the so-called *phase slips*, occurring when the phase is “reset”. Phase coherence time lapse can last 100ms ~ up to a few seconds, and then new phase locked oscillations arise. Around a stimulus onset (for example the decision to move a chess piece), the phase coherence interval is shorter. This phenomenon can be observed by computing the analytic phase of single filtered bands. To perform the phase analysis, we applied the Hilbert transform of the EEG signal collected by the single electrode. In this work, we are interested in calculating the synchronization index between two individuals. Given phase’s $\phi^1(t)$ and $\phi^2(t)$ of two individuals’ signal’s frequency bands, we get the phase difference $\phi^2(t)-\phi^1(t) = \phi^{1,2}(t)$ and a synchronization index, as in the following formula:

$$g_{12}^2 = \left\langle \cos(f^{1,2}(t)) \right\rangle^2 + \left\langle \sin(f^{1,2}(t)) \right\rangle^2 \qquad (1)$$

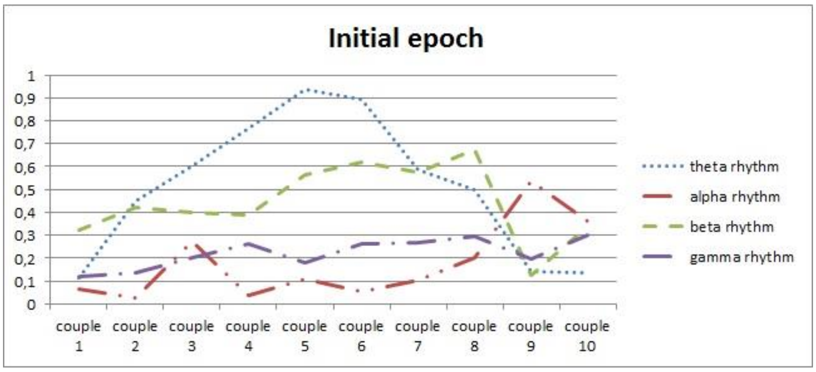
Where brackets < > denote the average of the computed cos and sine values. The index g_{12} ranges in [0,1], where 1 represents the perfect phase synchronization and 0 stays for the absence of phase synchronization. The presence of phase synchronization in cortical activity of the two individuals in the same epochs reveals similar neurons firing in-phase, corresponding to a similar (in the two individuals) neurons co-operation for perceptual or cognitive tasks (Brainard, 2001). In our experimental setup we collected one signal from a specific topographic position so we could explore phase synchronization index between wave bands from different individuals, revealing the same kind of functional activity of the brain. As already said, the phase synchronization index gives us an indication on neurons co-operation for perceptual or cognitive tasks, so we chose to compute this index to verify its value in correspondence of the different epochs into which we divided the chess play (initial, intermediate, final) and to verify if in different individuals we could find a similar result, thus revealing a synchronization between the two participants to the experiment.

	Synchronization Index among participant 1 and participant 2			
Epoch	theta rhythm	alpha rhythm	**beta rhythm**	gamma rhythm
initial	0,116	0,067	**0,325**	0,122
intermediate	0,866	0,210	**0,981**	0,744
final	0,901	0,462	**0,935**	0,678

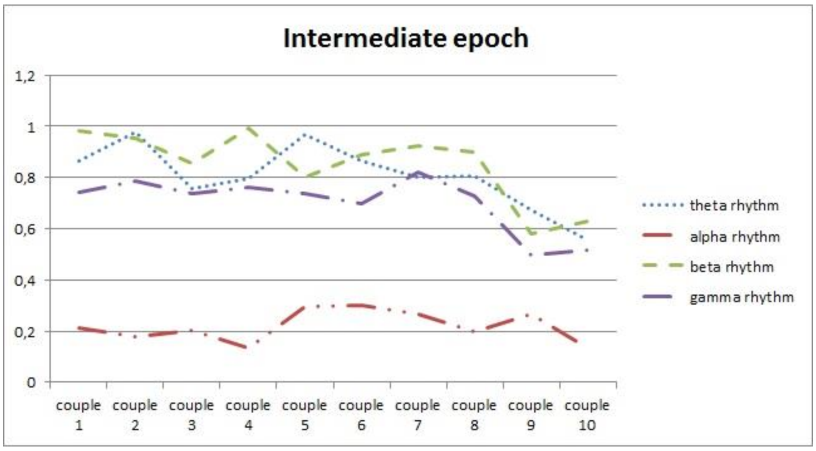
Table 1: An example of synchronization index computed on two chess players during different epochs of the play

Also in this case the brain rhythm greater influenced by the synchronization phenomena is the beta rhythm, but also gamma (revealing higher cognitive processes) and theta (related to stress) show significant synchronization indices.

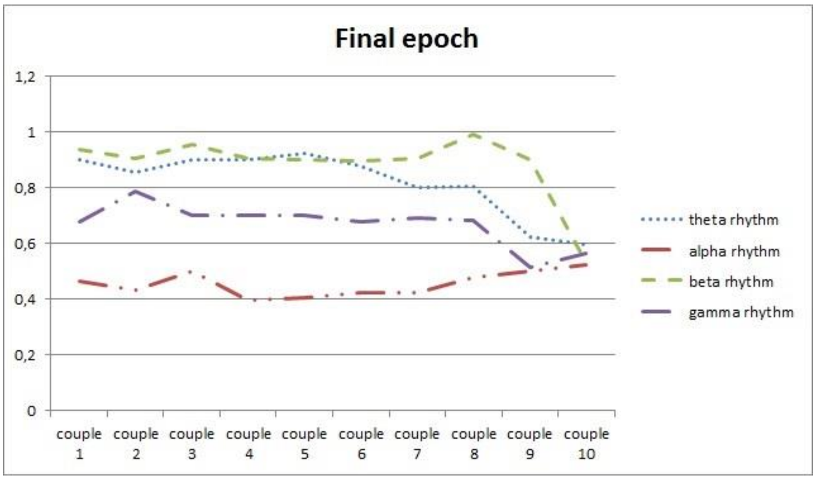
The graphics in next figure 3 show the trend of the synchronization indices for the theta, alpha, beta and gamma rhythms for all the 10 couples of players participating in the experiment.



(a)



(b)



(c)

Figure 3 Initial (a), intermediate and final (b) trends of theta, alpha, beta and gamma rhythms for all the couples of players

We are performing other experiments involving educational environments. In these experiments, as in previous ones, our aims is to establish if there is a specific range, independent of the considered individuals, corresponding to specific answers to the given stimuli, so that we could isolate such signals and use them, in future, to realize a machine-Human or Human-Human communication mediated by technological devices.

Conclusions and future works.

Starting with the idea that the communication medium used shapes both communications and thoughts, we were aiming at analysing if in specific conditions communication do modulate cognitive processes so to give rise to a sort of synchronization or computer mediated telepathy. Our hypothesis was that when people cooperate or participated in a shared task using an at-distance linking device culturally connoted human brain are able to find a way to connect each other, that is to work together, jointly, without the intervention of a conscious mechanism. If so, we would have found a kind of brain synchronization, that a brain correlate of the psychological mechanisms of empathy or telepathy, the process to connect minds each other at a distance. Isn’t this a specific, intended or not, face of computer mediated communication?

We performed some experiments with the aim of finding a kind of alignment in brain rhythms among users, using BCIs, subjected to the same audio stimuli or playing chess game. Positive results encourage our research in designing and developing means allowing Humans to communicate each other using brain mediated by technological devices.

Immediate and practical applications of this research issue are, moreover:

– the definition of new Information Technology systems implementing adaptation mechanisms to users behavior;

- the creation of even more “natural” man-machine interface devices, based on EEG signals, both for healthy and for non-healthy people (Pineda et al., 2003).

We are searching for a kind of “sympateia” among users’ brains that is to verify if, submitted to the same stimulus, different users show similar brain rhythms response putting them “on the same wavelength”.

Other experiments are in early stage and will be performed to verify conclusions in different environments, in this case using Virtual Reality and different stimuli. In fact, VR provides a motivating, safe and controlled environment to investigate brain responses to specific stimuli and neural processes involved in experiments (Robillard et al., 2003; Friedman et al., 2007; Touyama, Aotsuka & Hirose, 2008).

In our case, we will use VR to study methods to improve individual brain self-knowledge. Yet many experiments, in fact, demonstrated that VR shorten BCI learning and users’ performance.

Of course, future research directions will cover the possibility to exchange simple, atomic, messages from brain to brain, not only in experimental environment, but also especially in “real life” situations and extending the experiment to multiple users and multiple systems.

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