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Editorial correspondence: Llorenç Pagés-Casas <pages@ati.es>
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Farewell Edition

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CEPIS NEWS

IT for Health

Neuroscience and ICT: Current and Future Scenarios

Gianluca Zaffiro and Fabio Babiloni

This paper was first published, in its original Italian version, under the title "*Neuroscienze e ICT: Una Panoramica*", by ***Mondo Digitale*** (issue no. 2-3, June-September 2011, pp. 5-14, available at <http://www.mondodigitale.net/>). ***Mondo Digitale***, a founding member of **UP**ENET, is the digital journal of the CEPIS Italian society AICA (*Associazione Italiana per l'Informatica ed il Calcolo Automatico,* <http://www.aicanet.it/>.)

In the last couple of decades the study of human brain has made great advancements thanks to the powerful neuroimaging devices such as the high resolution electroencephalography (hrEEG) or the functional magnetic resonance imaging (fMRI). Such advancements have increased our understanding of basic cerebral mechanisms related to memory and sensory processes. Recently, neuroscience results have attracted the attention of several researchers from the Information and Communication Technologies (ICT) domain in order to generate new devices and services for disabled as well as normal people. This paper reviews briefly the applications of Neuroscience in the ICT domain, based on the research actually funded by the European Union in this field.

1 New Brain Imaging Tools allow the Study of the Cerebral Activity *in vivo* in Human Beings

In the history of science the development of new analysis tools has often allowed the exploration of new scientific horizons and the overcoming of old boundaries of knowledge. In the last 20 years the scientific research has generated a set of powerful tools to measure and analyze the cerebral activity in human beings in a completely "non-invasive" way. It means that they could be employed to gather data in awake subjects causing no harm to their skin. Such tools provide images of the brain cerebral activity of the subject while s/he is performing a given task. These could be then presented by means of colors on real images of the cerebral structure. In such a way neuroscientists could observe, like on a geographic map, the cerebral areas more active (more colored) during a particular experimental task. The high resolution electroencephalography (hrEEG) is a brain imaging tool that gathers the cerebral activity of human beings "in vivo" by measuring the electrical potential on the head surface [1, 2]. The hrEEG returns images of the

Authors

Fabio Babiloni holds a PhD in Computational Engineering from the Helsinki University of Technology, Finland. He is currently Professor of Physiology at the Faculty of Medicine of the *Università di Roma La Sapienza*, Italy. Professor Babiloni is author of more than 185 papers on bioengineering and neurophysiological topics on international peer-reviewed scientific journals, and more than 250 contributions to conferences and books chapters. His total impact factor is more than 350 and his H-index is 37 (Google Scholar). Currents interests are in the field of estimation of cortical connectivity from EEG data and the area of BCI. Professor Babiloni is currently grant reviewer for the National Science Foundation (NSF) USA, the European Union through the FP6 and FP7 research programs and other European agencies. He is an Associate Editor of four scientific Journals: "IEEE Trans. On Neural System and Rehabilitation Engineering", "Frontiers in Neuroprosthesis", "International Journal of Bioelectromagnetism" and "Computational Intelligence and Neuroscience". <fabio.babiloni@uniroma1.it>

Gianluca Zaffiro graduated in Electronic Engineering from the *Politecnico di Torino*, Italy, and joined the Italian company Telecom in 1994. He has participated in international research projects funded by the EU and MIUR, occupying various positions of responsibility. He has participated in activities in IEC standards in telecommunications. Currently he holds a position as senior strategy advisor in the Telecom Italia Future Centre, where he is in charge of conducting analysis of technological innovation, defines scenarios for the evolution of ICT and its impact on telecommunications services. He is the author of numerous articles in journals and conferences. <gianluca.zaffiro@telecomitalia.it>

"This paper reviews briefly the applications of Neuroscience in the ICT domain"

> “There are tools that provide images of the brain cerebral activity of a subject while s/he is performing a given task”

cerebral activity with a high temporal resolution (a millisecond or less), and a moderate spatial resolution (on the order of fractions of centimeters). Figure 1 presents images of the cerebral activity some milliseconds after performing a sensorial stimulation on the right wrist of a healthy subject. The tridimensional head model, on the left side of the picture, is employed for the estimation of the cerebral activity. The cerebral cortex, *dura mater* (the meningeal membrane that envelopes the brain), the skull and the head surface are represented. The spheres show the position of the electrodes employed for the recording of the hrEEG. In the same picture, in the upper row we can observe the sequence of the distribution of the cerebral activity during an electrical stimulation on the wrist, coded with a color scale ranging from purple to red. In the second row we present the cortical activity, related to the same temporal instants represented in the previous line, that is to say the superficial part of the brain (the cortex) which plays a key role in complex mental mechanisms such as memory, concentration, thought, and language.

In the last decades, the use of modern tools of brain imaging has allowed to clarify the main cerebral structures involved in cognitive and motor processes of the human being. These techniques have highlighted the key role of particular cerebral areas, such as the ones located just on the back of forehead and near the sockets (prefrontal and orbitofrontal areas), in the planning and generation of voluntary actions, as well as in the short and medium term memorization of concepts and images [3]. In the last years "signs" of the cerebral activity related to variation of memorization, attention and emotion, in tasks always more similar to everyday life conditions, have been measured and recognized.

2 Brain-computer Interfaces' Working Principle

In the last years researchers have observed, by means of hrEEG techniques, how, in human beings, the act of evoking motion activities occurs in the same cerebral areas related to the control of the real movement of the limbs. This important experimental evidence is at the basis of a technology, known as "brain computer interface" (BCI), which aims at controlling electronic and mechanical devices only by means of the modulation of people's cerebral activity. Figure 2 presents the scheme of a typical BCI system: on the left side a user is represented that with his/her own mental effort produces a change of the electrical brain activity

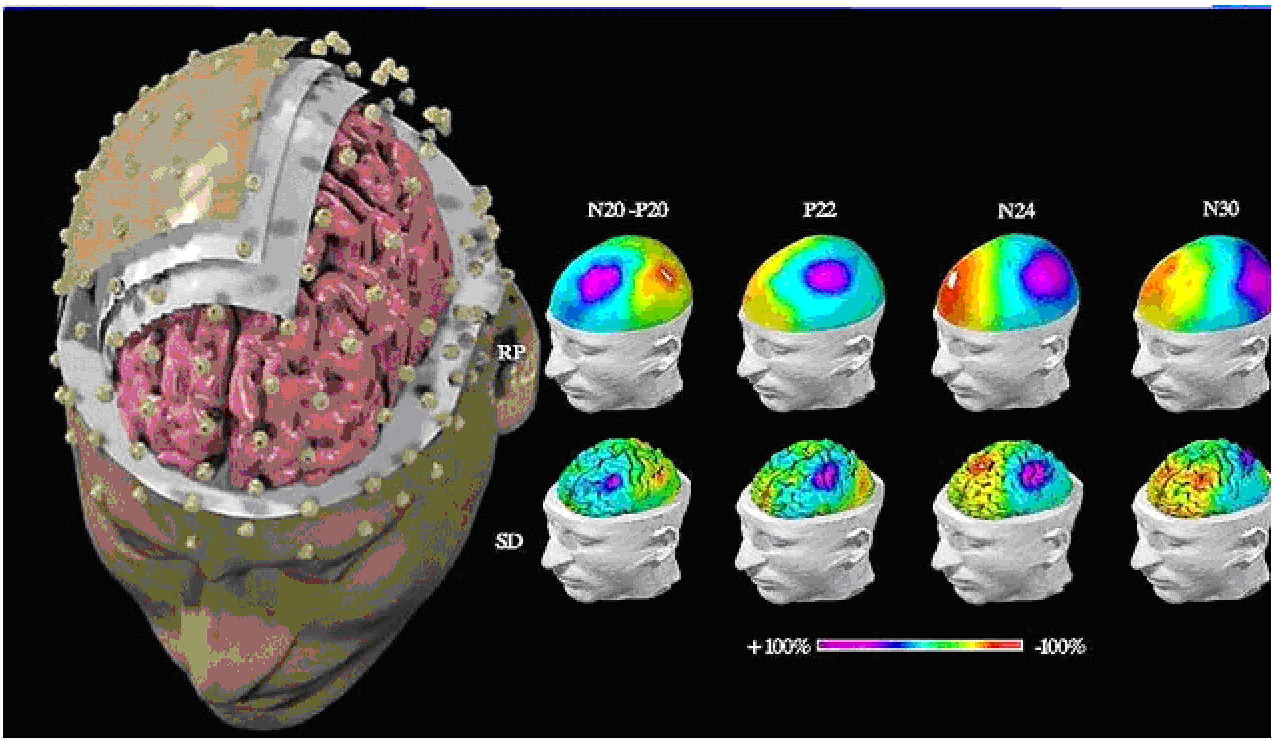

Figure 1: Images of the Cerebral Activity some Milliseconds after a Sensorial Stimulation.

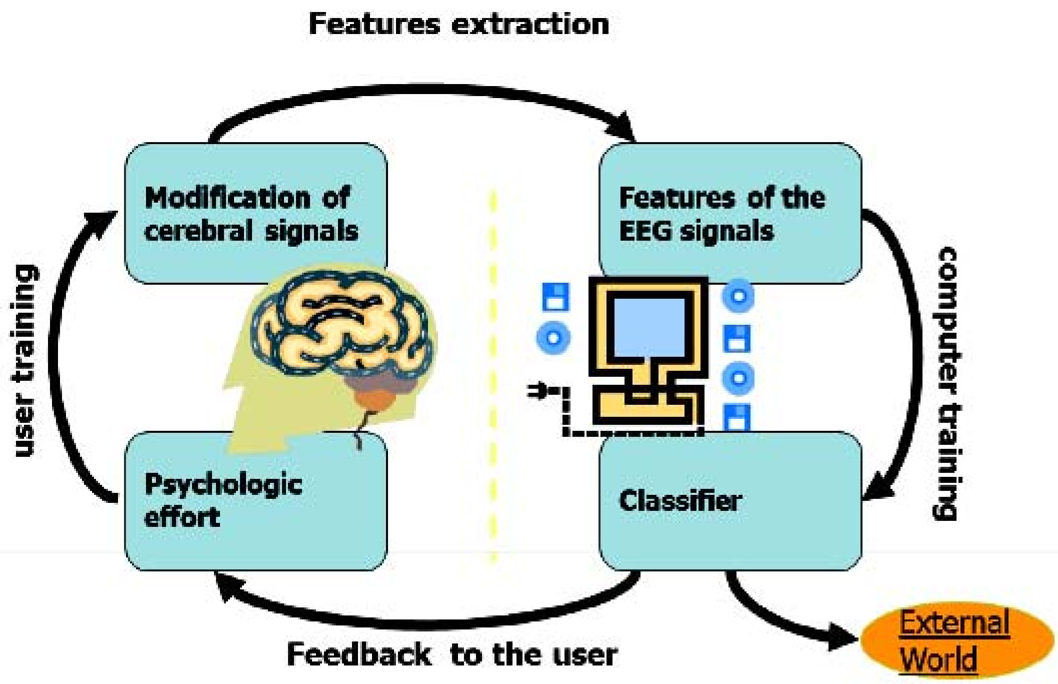

Figure 2: Logical Scheme of a BCI System.

which can be detected by means of recording devices and analysis of the EEG signals. If such activity is generated periodically, an automatic system can recognize the generation of such mental states by means of proper classification routines. Then, the system can generate actions in the outside world and give feedback to the user.

In particular, it can be observed experimentally that a subject can learn to autonomously modify the frequency pattern of his/her own EEG signals, without the need to recur to some external stimuli. The so called mu-rhythm, which is a particular EEG wave, can be recorded from the scalp by means of superficial electrodes located near the top of one's head and in posterior direction (central-parietal areas). It is known like such a rhythm is subjected to a strong diminution of its amplitude of oscillation (around 8-12 Hz) during limb movements. Such phenomenon is known in literature as desynchronization of the alpha rhythm. Through training, a subject can learn how to achieve such a de-synchronization of the EEG rhythm in absence of a visible movement, simply by evoking the movement of the same limb. In such a way it is possible to achieve the user's voluntary control of a component of the own cerebral activity which can be detected in a particular EEG frequency band (8-12 Hz), preferentially on electrodes overtop particular cortical areas (sensory-motor areas). As already explained, the simple evocation of motion acts generates patterns of cerebral activity which are basically stable and repeatable in time whenever the subject performs such an evocation [4, 5]. It is not obvious nor simple for automatic systems to recognize voluntary modification of the EEG trace with low error rates such to safely drive mechanical and electronic devices. The main difficulties addressed in the recognizing of the induced potential modification on the scalp are of manifold nature. First, a proper learning technique is required to let the subject control a specific pattern of his/her own EEG. Such a technique requires the use of appropriate instrumentation that analyzes in real time the EEG signals

"These techniques have highlighted the key role of particular cerebral areas in the planning and generation of voluntary actions"

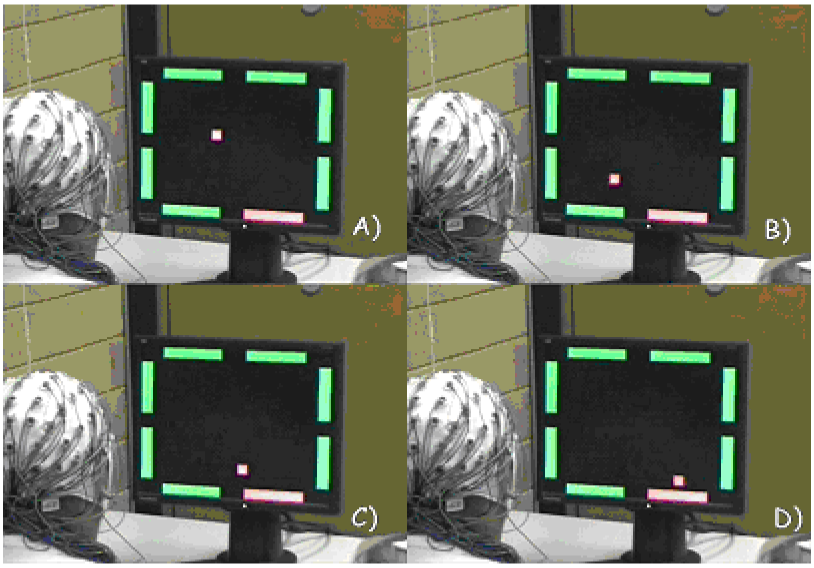

Figure 3: The subject generates a cortical activity recognizable by a computer by varying his/her own mental state. This phenomenon moves the cursor (red point on the screen) towards one of possible targets (red bar on the edge of the screen).

and send instantaneous feedback to the subject, the availability of a proper methodology such that the subject is not frustrated by common temporary failures during the training session and, at last, proper knowledge for using the training software in such a way that the operator can efficiently correct specific BCI parameters to facilitate the control for each subject. The second difficulty in recognizing the mental activity by EEG analysis comes from the low signal-to-noise ratio, which is a typical feature of the EEG itself. In fact, in still sate this signal is characterized by an oscillatory behavior which normally makes the variation of the mu-rhythm amplitude difficult to detect. In order to properly address this issue, specific techniques of signal processing must be adopted to extract the most relevant EEG features by employing adequate automatic routines of classification, known as classifiers. Like fingerprints are compared in a police database to recognize people, in the same way the EEG features are compared with those obtained by the subject during the training period. The extraction of the EEG features is often done by means of an estimate of the power spectral density of the signal itself in a frequency range of 8-16 Hz. Later, the recognition of these features as belonging to a specific user's mental state generated during the training period is performed by classifiers implementing mechanisms relying on artificial neural networks. Once such classifiers make a decision related to the user's motor evocation state, a control action is performed by an elec-

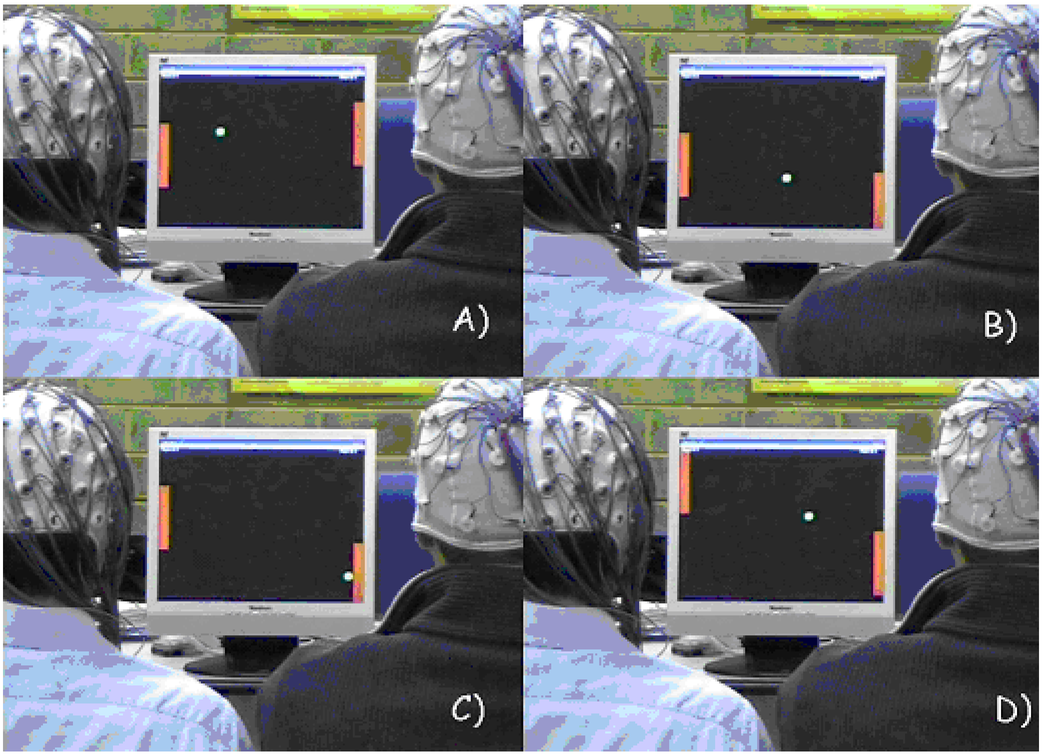

Figure 4: Two subjects playing electronic ping-pong without moving muscles, by means of a brain-computer interface installed at *Fondazione Santa Lucia* in Rome, Italy. (Panels run from A) to D).)

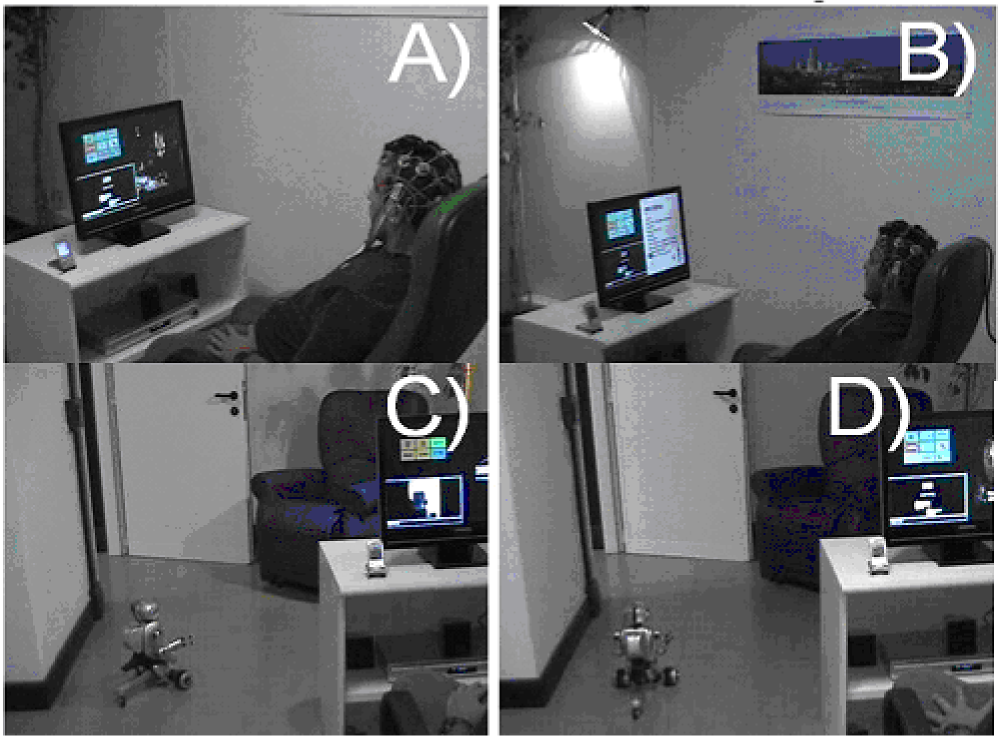

Figure 5: The Figure presents several moments related to the control of some electronic devices in a room by using the modulation of the cerebral activity. (Experiments performed in the laboratories of Prof. Babiloni at *Fondazione Santa Lucia*, Rome, Italy.)

tronic or mechanical device in the surrounding environment. This physical action is therefore an answer to a purely mental event generated by the user, acquired by the hrEEG device and later classified by the BCI software. In Figure 3 it is shown like a user can directly move a cursor in two dimensions by recognition of mental states. The command that triggers the movement to the right corresponds to evoking the right hand movement, and vice versa for evoking the left hand. The evocation of right and left foot movements slides the cursor towards upper or lower positions. All the experiments have been performed at IRCCS *Fondazione Santa Lucia* in collaboration with the Physiology and Pharmacology Department of *Università di Roma La Sapienza*, Italy.

In Figure 4 the image of two subjects playing ping-pong by means of a BCI is shown. In such a case the modulation of the mental activity translates into the movement of a cursor on the screen towards upper and lower positions for both subjects.

3 Examples of Use of the BCI Technology in the ICT Domains of Robotic and Device Control

In Figure 5 some existing functionalities available for the control of simple electronic devices in a room are presented. In frames A and B it can be noticed how the subject switches a light on through the selection of an appropriate icon on the screen just by using mental activity. In the C and D frames of the same figure it can be observed how the same user can control the movement of a simple robot by using the modulation of cerebral activity. The possibility of controlling the robot, equipped with a camera on its head, allows the disabled user to showing his/her presence in other parts of the home instead of having to use ubiquitous videocameras in every room, which harm the privacy of the caregivers.

In the area of assisted living there are companies working at the creation of a prototype of a motorized wheelchair controlled by using the brain computer interface technology. A possible example of such device is shown in Figure 7, as recently demonstrated by Toyota [6]

Figure 6 presents how a robotic device is controlled by using cerebral activity that could be used also in contexts beyond tele-presence or domotics, for example in entertainment applications.

> “The ‘brain computer interface’ (BCI) aims at controlling electronic and mechanical devices only by means of the modulation of people’s cerebral activity”

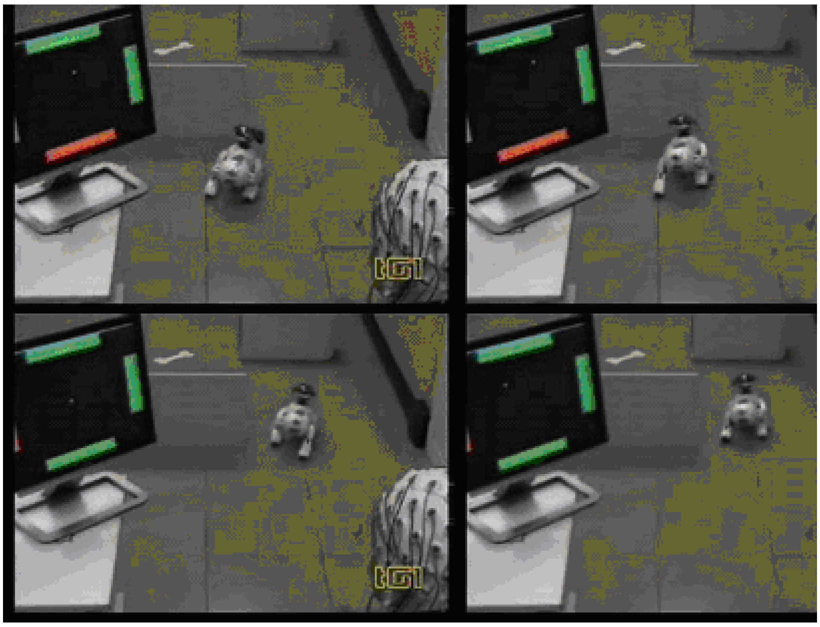

Figure 6: Robotic device (Aibo from Sony) driven by the modulation of EEG brainwaves as gathered by the EEG cap visible in some frames at the bottom right corner (frames have to be read from left to right and from the upper to the lower part). These pictures show the possibility of sending mental commands via wireless technology to the Sony Aibo robot.

4 About the Use of BCI Systems in the Next Future

BCI systems are studied currently to improve the quality of life of patients affected by severe motor disabilities, in order to provide them with some degree of autonomous movement autonomy or decision. The next step for such systems it is to make those systems available to non disabled people, in normal daily life situations. For instance, a videogame could be controlled just by thoughts (see Section 5) or messages could be sent to other users that could be constantly connected to us by modulating our mental activity. Such activity will be gathered by few subtle, invisible sensors disposed on the scalp, and the computational unit will be not greater than a watch and easily wearable. Although such kind of scenario seems taken from a science-fiction book or movie, a description like this about our future comes from a study from the European Union about new life styles in 2030, fruit of several days of debate between scientists in different disciplines, including ICT and health [7].

Figure 7: Motorized Wheelchair driven by BCI Technology, from Toyota.

5 Neuroscience and BCIs are already used in Entertainment and Cognitive Training Market Fields

Several examples of commercial solutions based on BCIs are reported in this section to demonstrate that these technologies are present also outside research labs. In most cases those solutions, such as gaming, healthcare,

> “A subject can learn to autonomously modify the frequency pattern of his/her own EEG signals, without the need to recur to some external stimuli”

Figure 8: Game Controller developed by Emotiv, a California based Company.

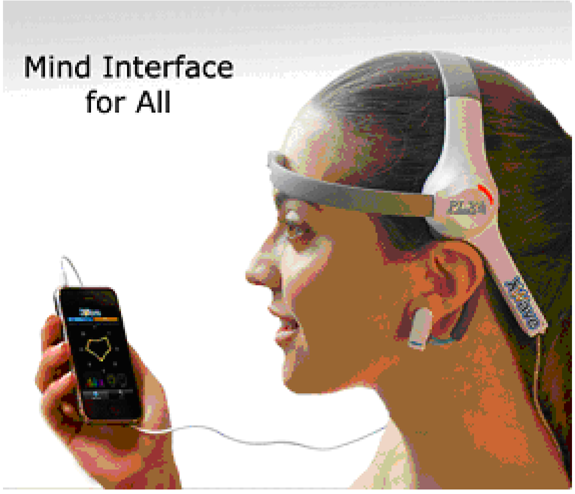

Figure 9: XWAVE plays by using Cerebral brainwaves on iPhone.

coaching or training, are sold in the range of ten to thousand dollars. Some companies address controller market for PC videogames: for example, two American companies, Emotiv and OCZ Technologies, are providing BCIs that interpret both the muscle movements and electrical cortical signals. Their devices consist of a headband or helmet equipped with special electrodes, which sell for $100-300. The Emotiv controller, shown in Figure 8, comes with a set of classic arcade games such as the Ping Pong and Tetris "brain-controlled" versions.

Other companies are offering these game controllers for smartphones or tablets, such as Xwave or MindSet. Mindset is a BCI developed by American NeuroSky which allows you to play BrainMaze with a Nokia N97, driving a ball with your mind in a labyrinth [8]. Xwave, a PLX Devices creation (Figure 9), is a device connected to your iPhone or iPad which allows you to compete in games or train your mind [9]. BCIs have also made inroads in toys: big companies like Mattel and UncleMilton are producing two similar toys, respectively Mind Flex (Figure 10) and the Star Wars Science Force Trainer. These toys are available for about $100. Both of them are based on a brainwave controlled fan used to levitate a foam ball, which in turn has to be moved around to a given position. In the United Stated of America (USA) alone the market of "cognitive training" has increased from 2 million dollars in 2005 to 80 million of 2009 [10]. Much attention has been raised by neurofeedback, a technique aimed at training to control your own brainwaves through their graphical display. This procedure is used both in

> “There are companies working at the creation of a prototype of a motorized wheelchair controlled by using the brain computer interface technology”

Figure 10: Mattel’s Toy based on BCI.

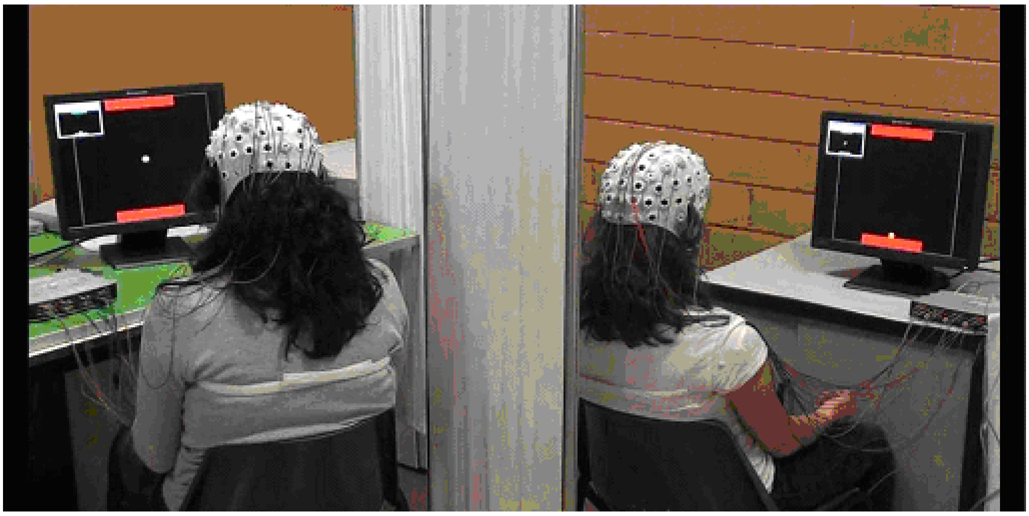

Figure 11: An experimental setup related to an experiment of synthetic telepathy at the laboratory of the *Fondazione Santa Lucia* and the *Università di Roma La Sapienza*, Italy, led by Prof. Babiloni. The two subjects are exchanging simple information bits (the cursor is moving up or down) just by modulating their cerebral activity through a brain computer interface system linking them.

medicine as a treatment for disorders such as ADD (Attention Deficit Disorder), and in training of professionals, students, and athletes as to improve their concentration, attention and learning performances.

At CES 2011, the most important exhibition for consumer electronics worldwide, a BCI-based prototype system for ADD treatment, BrainPal, has been unveiled [11]. In Sweden, Mindball, a therapeutic toy used to train the brain to relax or concentrate, is available from ProductLine Interactive. Some top level soccer teams like AC Milan and Chelsea have been undertaking neurofeedback training.

6 Applied Neuroscience can support Marketing and Advertising of Products and Services

Business people are looking into neuroscience in order to understand and predict the human buying mechanisms. Neuromarketing is a discipline born from the combination of these two scientific fields, aiming at knowing why a buyer chooses a product or service. Much attention is now directed to the analysis of advertising, notoriously one of the most effective stimuli for purchases.

Traditional marketing assesses people's reactions to advertising stimuli with indirect techniques (observation, interviews and questionnaires) whilst Neuromarketing investigates the direct physiological response caused by advertising stimuli (electrical response of the brain) and from this it infers the cognitive implications (levels of attention, memory and pleasure).

Neuromarketing does not assess behaviors but tries to find out how advertising stimuli "leave their mark" in the brain of people. Two approaches based on cortical EEG measures have mainly been adopted in the market. One is the scientific approach, which starts from the neuroscience evidence to infer the effectiveness of a given stimulus by measuring with a high density EEG (>60 electrodes) the cortical electrical activity in all the areas of the brain. This approach can be simplified by limiting the area of the neural signal measurements to the frontal lobes, on which a minimun of 10 electrodes should be applied, that are sufficient to acquire indicators for levels of attention, memory and emotion.

The obvious advantage with this approach is that the results can be directly related to scientific evidence, but there are limits to the practicality and scalability of the test since often measurement devices are required that are uncomfortable to wear and time-consuming in terms of the subject's preparation.

The other approach is the heuristic one, which has its strength in the use of proprietary EEG equipments that have a reduced number of electrodes (it could be just an electrode centrally positioned on top of the head or two on the frontal lobes) with which you measure the parameters of interest in neuromarketing. The simplified arrangements encourage portability by reducing discomfort and preparation

> "Neuromarketing is a discipline born from the combination of these two scientific fields, Neuroscience and Marketing"

Focus on Neuromarketing

In this section we report the application areas that neuromarketing companies are addressing today, associated with some examples of studies promoted by well-known international companies.

- **Advertising:** Neuromarketing is widely used to measure the effectiveness of print ads or videos (commercials) and their enhancement as a function of communication campaigns. Case Studies: we report an analysis produced by BrainSigns, spin-off of "La Sapienza" University of Rome. Figure A in this box presents two diagrams obtained for a population of viewers watching a TV commercial. The spot featured a flirt scene (a girl's message immediately interrupted) that literally "catalysed" the attention of the viewers and the memorization at the expense of attention and memorization of the brand advertised and its message. The viewers liked the spot, but they did not get the intended message from it. As a second example, Coca-Cola commissioned EmSense [13] to perform a study using neuromarketing techniques to choose, between several possibilities, the most effective commercial to air on television during the Superbowl, the final game of the USA National Footnall League . Finally on Google's behalf, NeuroFocus used neuromarketing techniques [14] to assess the impact on users of the introduction on Youtube of Invideo Ads, which are semitransparent banner ads superimposed on YouTube videos streamed over the Internet.
- **Multimedia:** Neuromarketing can evaluate a movie trailer, an entire movie or a television show with the aim of understanding how the engagement level of the audience changes in time and identify the points of a movie where, for example, there are high levels of suspense or surprise in the audience. Case Studies: 20-th Century Fox has commissioned Innerscope [15] to evaluate the movie trailers for the films "28Weeks Later" and "Live Free or Die Hard". NBC has commissioned Innerscope as well [15] to study the viewers' perception of advertising during the fast forward of a recorded TV content.
- **Ergonomics:** Neuroscience can improve the design process of device interfaces and improve the user experience, assessing the cognitive workload that is required to learn how to use the device, and the engagement, satisfaction or stress levels generated by its use. Case study: in 2006 Microsoft [16] decided to apply EEG to experimentally investigate how to perform a user task classification using a low-cost electroencephalograph.
- **Packaging:** Neuromarketing can be used to obtain a more appealing package design, so that, for example, a customer can recognize the product more easily on a shelf in a supermarket, chosen among others like it.
- **Videogames:** Neuromarketing can evaluate the players' engagement, identify the most interesting features of the games and optimize their details. During all phases of the game, the difficulty level can be calibrated properly so that a game is challenging, but not excessively difficult. Case Study: EmSense conducted a study [17] on the "first person shooting" genre of videogames in which, during the game, they evaluated the levels of positive emotion, engagement and cognitive activation of the players in function of time.
- **Product Placement:** Neuromarketing studies can support the identification of the best positioning of a product on the shelf of a supermarket and the optimal placement of advertising for a product or a brand in a scene during a TV show.
- **Politics:** Neuromarketing techniques can be applied to carry out studies in the political sphere, for example by measuring the reactions of voters to candidates at rallies and speeches. Case Study: during the elections of the UK Prime Minister in 2010 [18] NeuroFocus conducted and published a study about the measured prospective voters' neurological reactions, highlighting the subconscious scores evoked by the candidates on a sample of subjects.

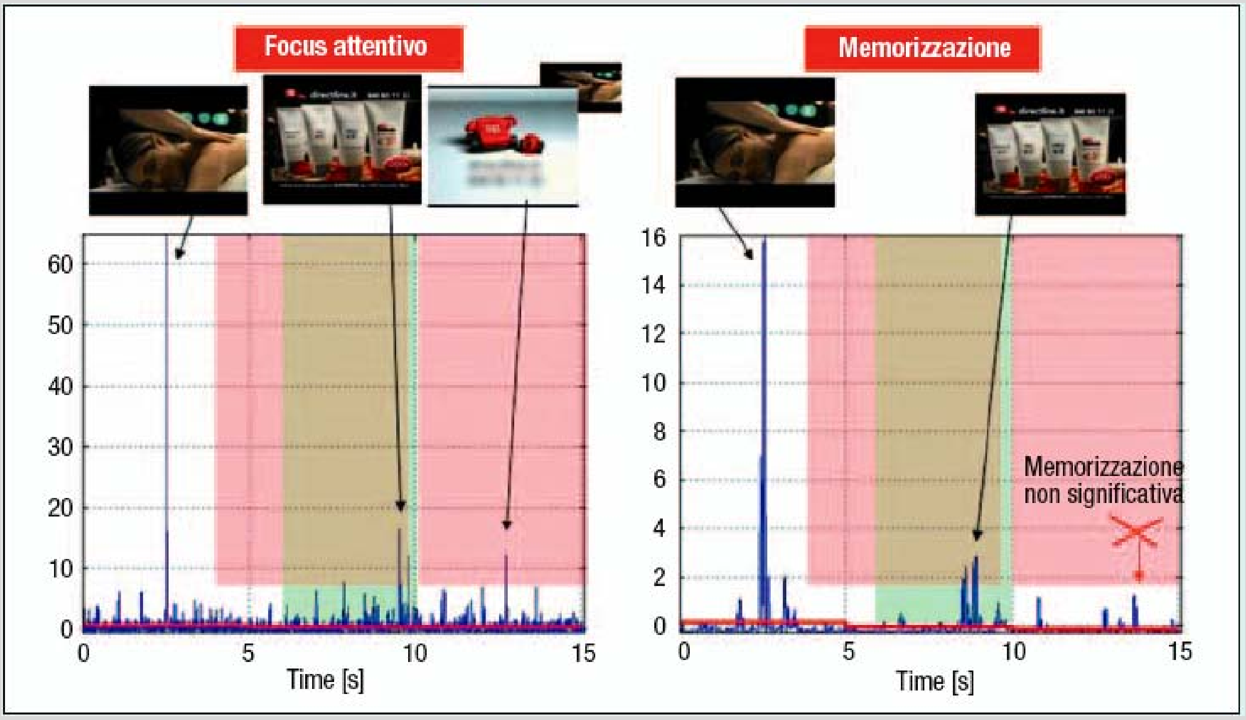

Figure A: Mean changes of attention (left) and memorization (right) of a given audience while watching a commercial. The higher the signal, the more active processes of attention and memory toward the spot. (Courtesy BrainSigns Ltd.)

"Neuromarketing is extremely suitable for supporting the design of advertising spots"

time, with the aim of make the testing process as equivalent as possible to the actual experience of the subject. However today it is not possible to compare the obtained results with the scientific literature.

Neuromarketing is extremely suitable for supporting the design of advertising spots, and it allows to increase the ability to stimulate attention and memory retention, and placing the advertisement in a manner consistent with the brand. In the TV spot post-creative phase, it is useful to measure comparative efficacy and to select and optimize the existing spots, reducing their time format. Finally, in the spot programming phase it allows to optimize the frequency in a given broadcasting timeframe, checking in lab how long subjects have to be exposed for the commercial to be memorized.

Today, most companies operating in neuromarketing are located in the USA where they were founded in the last five years. Many of these employ devices for neurophysiological measures (EEG and sensors) developed in-house, while others adopt technological solutions from third parties (see the box section "Focus on Neuromarketing").

7 What is going on in Research about ICT and Neuroscience

During the years 2007-2011 the European Union has supported with more than 30 million of Euros research projects linked to the use of BCI systems for the control of videogames, domestic appliances, and mechanotronic prosthesis for hands and limbs. In addition, EU funding has been directed also for the evaluation of the mental state of passengers of aircrafts during transoceanic flights, in order to provide them with board services in agreement with their emotional feels. Another interesting area of research in which EU supported scientific studies is the on-line monitoring of the cerebral workload of drivers of public vehicles, such as aircrafts, or trains as well as cars.

Recently a research line related to the field of the so called "synthetic telepathy" is being developed in the USA, where the capability of two common persons to exchange information between them just by using the modulation of their cerebral activity is being tested. This is made possible by using the concepts developed in the field of the BCI. In particular, Figure 11 presents an experimental setup of "synthetic telepathy" developed at the joint laboratories of the *Fondazione Santa Lucia* and the *Università di Roma La Sapienza*, Italy. In the picture two subjects are exchanging information about the position of an electronic cursor on the screen that they are able to move by using a modulation of their cerebral activity.

Although in this moment the speed transmission is really limited to few bits per minute, the proof of concept of such devices has been already demonstrated.

8 Conclusions

In this paper it has the main research streams involving both neuroscience and ICT have been described briefly. There is an increasing interest from the ICT area for the results offered by neuroscience in terms of a new generation of ICT devices and tools "powered" by the ability of being guided by mental activity. Although the state of the art is still far from everyday technological implementations like those shown in the modern science-fiction movies, there are thousands of researchers that are nowadays engaged in the area of brain computer interfaces researching about next generation electronic devices, while 10 years ago there were very few. As the eminent neuroscientist Martha Farah said recently [12] the question is not "if" but rather "when" and "how" our future will be shaped by neuroscience. At that time it will be better to be ready to ride the "neuro-ICT revolution".

"The capability of two common persons to exchange information between them just by using the modulation of their cerebral activity is being tested"

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