Brain-Computer Interaction: Can Multimodality Help?

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ABSTRACT
This paper is a short introduction to a special ICMI session on brain-computer interaction. During this paper, we first discuss problems, solutions, and a five-year view for brain-computer interaction. We then talk further about unique issues with multimodal and hybrid brain-computer interfaces, which could help address many current challenges. This paper presents some potentially controversial views, which will hopefully inspire discussion about the different views on brain-computer interfacing, how to embed brain-computer interfacing in a multimodal and multi-party context, and, more generally, how to look at brain-computer interfacing from an ambient intelligence point of view.

Categories and Subject Descriptors
H. Information Systems, H.5 INFORMATION INTERFACES AND PRESENTATION (I.7), H.5.2 User Interfaces (D.2.2, H.1.2, I.3.6). Subjects: Input devices and strategies (e.g., mouse, touchscreen); Evaluation/methodology.

General Terms
Algorithms, Measurement, Performance, Design, Reliability, Experimentation, Human Factors.

Keywords
Brain-computer interaction, hybrid BCIs, multimodal interaction, bandwidth.

1. INTRODUCTION
In the last years, there has been considerable enthusiasm about Brain-Computer Interface (or Brain-Computer Interaction) (BCI) research, BCI technology and applications and BCI commercialization. New applications have proven successful, simple BCI games have been sold to over a million healthy users, media attention is growing, and the word "revolutionary" has been used many times (e.g. [1]) Clearly, such excitement can – and often should – elicit criticism and cynicism about previous 'hypes' and promises in the past. For example, there was once tremendous enthusiasm for scientific progress in neurofeedback, cold fusion, or Artificial Intelligence (AI), which led to a backlash when these fields did not deliver on unrealistically high expectations.

This paper is an introduction to a special ICMI session on BCI. During this paper, we first discuss problems, solutions, and a five-year view for BCIs. We then talk further about unique issues with multimodal and hybrid BCIs, which could help address many current challenges. This paper presents some potentially controversial views, which will hopefully inspire discussion about the different views on brain-computer interfacing (BCI), how to embed brain-computer interfacing in a multimodal and multi-party context, and, more generally, how to look at BCI from an ambient intelligence point of view.

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2. PROBLEMS AND CHALLENGES
This section briefly overviews the top ten problems that impede wider BCI adoption. The top seven are problems with BCIs themselves, whereas the last three are more general challenges for the BCI community.

Reliability: Once ready, BCIs should be usable in any environment, any time of day or night, with minimal preparation, maintenance, discomfort, embarrassment, inconvenience, and cleaning. In real world settings, particularly with patients, BCIs may be unreliable because of fatigue, changes in the user's brain within or across days, background activity that produces electrical noise, or activity the user cannot control that produces noise, such as fasciculations, spasms, or other movements.

Proficiency: There has not been any BCI approach that works for all users. That is, for any given BCI approach (P300, SSVEP, ERD), at least a few percent of users cannot attain any control whatsoever [2], [3].

Bandwidth: BCIs have attained ITRs above 60 bits per minute, and more recently 100 [4], [5], [6]. However, this remains far slower than other communication means, and reflects laboratory performance with elite subjects. Many real world BCIs still allow about 10-25 bits per minute, which is unchanged in almost 10 years [7].

Convenience: An assistive device or other communication tool should be available on-demand. Most BCIs instead require at least 20 minutes of preparation before each usage, and the hair and cap must be washed after each session. It should only function when needed, supporting asynchronous operation and a standby mode.

Support: Very few people can use BCIs. A typical end user today needs help to identify, buy, setup, configure, maintain, repair and upgrade the BCI [8], [9].

Training: Some BCIs require weeks or months of training. BCI training can be boring and repetitive, with no clear progress during early training [10].

Utility: Most BCIs can do only one thing, such as spell. An ideal BCI can allow users to easily choose any application desired with minimal delay or hassle [11].

Image: People are less likely to buy a device if they do not know about it or think it is ineffective, dangerous, nerdy, over-hyped, or ugly. BCIs are usually portrayed inaccurately and negatively in the popular media, which may lead to unreasonable fears or concerns [1].

Standards: The BCI community needs numerous standardized elements, including standard file formats, data interchange protocols, ethical procedures, media reporting guidelines, bit rate reporting guidelines, and terminological clarifications [3].

Infrastructure: The community needs improved resources that could lower the barriers to entry and development, such as better software tools that are freely available, improved documentation and help, downloadable (anonymous) data and processing tools, and a central repository of IP, articles, and other information.

3. SOLUTIONS AND TRENDS

The ten problems described above are generally recognized by BCI researchers. There are many research trends that could help address these problems.

Reliability: Improved sensors (including practical electrodes), high impedance amplifiers, and noise reduction software can help make BCIs work in more environments. Wireless BCIs are becoming more common. There also needs to be more attention to numerous aspects of clinical validation and integrating BCI hardware and software with existing devices.

Proficiency: Improved signal processing can reduce but not eliminate "BCI illiteracy". Switching to an alternate input signal is an increasingly popular research direction [3], [9], [12].

Bandwidth: Improved signal processing, new stimuli and tasks, and improved interfaces and environments will continue to increase bandwidth [13]. Hybrid BCIs can provide an additional control signal, increased accuracy, and/or reduce selection time. Shared control, context awareness, and error correction improve effective bandwidth.

Convenience: Practical electrodes could considerably reduce the time needed to mount the cap, and washing the hair or electrodes is no longer necessary [14], [15], [16]. Improved electrodes might be better integrated with head mounted devices or clothing, and wireless transmission also improves convenience. Invasive BCIs are always available.

Support: Numerous research efforts, largely funded by the EC, are focusing on developing free tools to reduce the need for expert help. Practical electrodes require considerable less support, since the user could don the sensor system without any help, and cleaning is not needed.

Training: This is an area of substantial progress. The BCI approach that requires such extensive training is no longer used. Numerous groups reduce training time, not only through improved signal processing, but also immersive environments and an effective reward structure. If BCIs gain attention for functional rehabilitation, training time for them will emerge as a new challenge.

Utility: Ongoing research is identifying new BCI applications, and producing tools to help people switch between them [11].

Image: As more companies and groups solve the technical problems associated with robust high quality signal capture, focus will move to design and ergonomics, with greater focus on design-centered approaches. We need to produce and/or encourage professional, fair, and positive media about BCIs, such as interviews, documentaries, and news programs. Media guidelines could help, although they cannot be enforced. Public demonstrations at expositions or other events can help inform and engage the public.

Standards and infrastructure: Developing the backbone of a more integrated BCI community. requires intensive and often polemic interactions among key stakeholders. One recommendation is a "BCI Society" or steering board that consists of highly respected established researchers and thus has the authority to propose and develop various standards, guidelines, tools, and resources.

4. FIVE YEAR VIEW

We expect the following changes over the next five years.

Reliability and Proficiency: The underlying problem of "BCI illiteracy" will probably not be solved. That is, in five or even ten years, it is unlikely that a specific BCI approach will be proven to work for 99.9% of users. However, it will become easier to find the right BCI for each user, and switch between BCIs or other systems, which will considerably improve reliability and reduce illiteracy.

Bandwidth: The 100 bit per minute barrier was just broken [6], and (especially with invasive systems) there is hope for BCIs with much higher bandwidth or vocabulary. However, these developments will have little impact on home users within five years. Bandwidth will see modest to good progress within five years, due more to existing trends like identifying the right BCI and parameters for each user.

Convenience: BCIs will become considerably more convenient. In particular, driven largely by corporate funds, new headwear will be developed that can provide information about brain activity less obtrusively than modern headwear. Practical electrodes that are better integrated with head-mounted devices will become prevalent. However, BCIs will remain far from transparent devices.

Support: We have mixed anticipations. On the bright side, there will be substantial improvements in various tools to help reduce demand for experts. These will include introductory materials, online and printed documents and manuals, troubleshooting and problem solving guides, tele-monitoring tools. But, these will only reduce the demand for expert help. In five years, many end users without technical backgrounds who want a BCI will still need some help, excluding most simple games.

Training: Two trends will continue. First, BCI flexibility will improve, making it easier to choose a BCI that requires no training. Second, due to improved signal processing and experimentation, BCIs that do require training will require less training.

Utility: This is an area of considerable uncertainty. It will be easier to switch between BCI applications and adapt to new applications. However, it is too early to say whether BCIs for functional improvement will gain traction, which would greatly increase utility

Image: We are very concerned about how people will view BCIs in five years. There is no “check” on inaccurate and negative portrayals in science fiction and news media. Also, there is considerable risk that the “bubble will burst” – that is, that the unrealistic expectations that many people have will not be fulfilled and lead to a backlash against BCIs akin to the neurofeedback backlash.

Standards: We anticipate modest progress in the next five years. At least, numerous technical standards will be established, including reporting guidelines. Ethical guidelines will probably also proceed well. We think the disagreement over the exact definition of a BCI will only grow, and cannot be stopped with any reasonable amount of funding. We are helping form a BCI Society.

Infrastructure: We also anticipate modest progress. Many software tools will improve, and improved online support will advise people on the best systems and walk people through setup and troubleshooting. Infrastructure development depends heavily on outside funding.

5. MULTIMODAL AND/OR HYBRID BCIs

BCI means measuring and interpreting brain activity. Activity in various regions of the brain allows different interpretations of this activity because of different functions of brain regions. Hence, we can, for example, distinguish brain activity related to different kinds of movements (measured in the motor cortex) from brain activity related to visual, auditory or haptic perception, or activity that tells us about a more global mental or affective state of the user.

This has been the traditional view on BCI in medical, rehabilitation and research environments. Research focused on brain research and BCI applications of this brain research. Or research focused on patients with a particular disability and how knowledge of brain activity could overcome this disability. This is a quite different approach from multimodal research in human computer interaction, where information that can be obtained from a particular modality is just one of the many sources that can be obtained from the ‘user’, his or her context, the domain application and the ‘history’ of the user (background, interests, preferences, previous interactions, etc.). HCI researchers look at BCI as embedding information obtained from measuring brain activity as just one added modality to modalities that receive much attention at this moment (such as speech recognition, gesture recognition, facial expression recognition, affect recognition, physiological measurements, etc.) and to more direct traditional mouse, keyboard, touch pad and joy-stick input modalities.

Today, most BCIs are “simple” systems that only rely on one type of input. The BCI community has started looking at hybrid BCIs, where initially the interest remained at looking at brain activity, but activity that can be detected from different regions and functions of the brain and using different BCI modalities. This is a research shift made possible because of increasing knowledge of brain functions and how to exploit the associated activity, and also because of a growing interest BCI research for applications not necessarily related to the medical domain.

From this point of view hybrid BCIs can combine a device that relies on brain signals with another tool to send information. The additional tool might be another BCI, a device based on other physiological signals, or a conventional input such as a keyboard or joystick. There are many different types of multimodal signal combinations, and many ways that hybrid BCIs could capitalize on different indicators of users’ mental states. Hybrid BCIs have already shown promise in improving reliability, proficiency, bandwidth, convenience, and utility [12], [17], [18], [19]. The typical point of view is how can we intelligently design BCIs so that any additional signals provide useful information for the particular application?

From the HCI and multimodal interaction point of view it is rather the other way around. From the HCI point of view BCI is an area that is rather unexploited [20]. Clearly, measuring EEG activity has already been considered to be useful for investigating new interface designs. How can we measure workload and design interfaces that require less mental workload? But presently, from a multimodal interaction point of view, the main question, assuming interesting applications, is how information available from measuring brain activity (and that is what BCI is about) can be embedded with information on other human activity that can be detected, measured, and interpreted [21]. EEG or other methods of measuring brain activity can be combined with other methods of detecting human activity. For example, sensors might collect physiological information that can help identify the mental state of the user. Other intelligent sensors (using cameras and microphones) can look at human activity and try to interpret, predict and anticipate human activities, decisions and preferences. Other sensors could know about each user’s position relative to other people or objects, and provide information about other users, such as whether they are in the same physical location or somewhere else. Rather than having BCI as starting point and giving BCI priority above other modalities, in multimodal BCI research we look at embedding information from the BCI modality in a multimodal, artificial intelligence, social intelligence, and computer science context.

Brain activity, skin conductivity and heart rate variations provide us with information of the cognitive state of a human performing individual, interaction and collaboration activities (interacting with the environment, other humans, virtual humans, social robots), but so does information collected from cameras, microphones, and other sensors. These other sensors provide us with other information about the mood and emotional state of the user and in particular, when available, from keyboard, mouse and speech recognition, more explicit information about what the user wants the computer (virtual human, social robot, environment) to do.

Information obtained from brain activity must be fused with information obtained from other modalities while collecting information about the user, to be used in a pro-active and reactive way, and while interacting with a user. From a human-computer interaction point of view, brain activity could be used in much the same way as other sources of information. Hence, similar challenges arise. How can brain-based information enhance human-computer interaction? What information is available, how can it be correlated with the user’s actions and desires, and how can the system act on this information, both in real-time and non-real-time? How can brain-based information best be fused with other information about the user in a smart and supportive environment using multimodal and multi-party context information?

There are several problems when we want to consider embedding the brain activity modality in a multimodal and multi-party context, or, more generally, an ambient intelligence context.

However, does looking at and including this brain activity recognition modality really differ from including a speech recognition, a gesture recognition, or an emotion recognition modality in getting a complete view of the user's need of support?

We should mention that decades of research have passed before we saw applications of speech recognition and identification, facial expression recognition or human behaviour and activity classification. However, none of the technologies that resulted from this research can be considered as reliable or robust. Speech recognition can be looked at as an example. Distinguishing between ‘yes’ and ‘no’ was already an achievement in the early years. And, probably, being able to make binary decisions, opened the way to speculate about all kinds of applications where interaction choices and decision making could be expressed as a series of binary decisions. Currently, the possibilities of speech recognition technology allow domain-dependent applications where not only hundreds of words can be recognized, but we can also recognize these words in their linguistic context, allowing us to assign meaning to sequences of words, that is, to sentences, using linguistic knowledge. This knowledge makes it possible to design useful applications in rather controlled contexts. In this case, ‘controlled’ means that the user operates in a context in which it is ‘unnatural’ to behave outside of the domain of the particular application.

Similar observations can be made when looking at recognizing, interpreting, and using information obtained from facial expressions. Or, information that can be obtained from nonverbal features of speech signals or whatever signals that can be detected and measured using physiological sensors, cameras, microphones, pressure sensors, proximity sensors, et cetera. From a multimodal point of view there is no reason to look at BCI in a different way than at these other modalities.

6. A ROADMAP FOR FUTURE BCI RESEARCH

From the previous sections, it should be clear that BCI research is increasing. And, it should also be clear that there is considerable interest for applications for users without physical disabilities [22]. Practical electrodes and increasing commercial interest could make previously impractical technologies much more feasible for everyday field use. On the other hand, many possible directions might initially seem clever but would provide little or no benefit over simpler interfaces. Here, we briefly discuss some possible directions for BCI applications that might have been impractical only a few years ago.

First, passively recorded information might become much more common in future BCI systems. This refers to information that is recorded without any active effort from the user, such as changes that occur when a user becomes tired or frustrated. “Affective” BCI systems could adapt interfaces and interaction possibilities in many ways according to user state changes.

Second, multimodal and hybrid BCIs could help address many current problems with BCI systems, notably reliability, performance, and usability. Eventually, most complete BCI systems will be hybrid BCIs, meaning that users can effect control via whichever mental tasks and associated brain signals are easiest and most effective for them. This may not occur within five years, but will eventually be the norm.

Third, BCIs might be used not just for communication, control, and monitoring, but also for neuromodulation. That is, people might use BCIs because they want to produce changes in their brains, particularly chronic changes that reduce or eliminate an unwanted condition. For example, BCIs might help people with autism or stroke by producing long-term changes that counteract unwanted effects of these conditions [23], [24], [25]. Of course, a portable home system that could treat major disorders could dwarf other BCI applications, particularly if these disorders remain resistant to other forms of treatment. However, this direction requires substantial clinical validation before mainstream use, which is unlikely within five years.

Of course, technical progress is only one facet of developing and successfully launching a new product. More generally, a future roadmap of BCI research should take into account marketability of current and future BCI applications by looking at emerging markets and commercial opportunities. The future Brain/Neuronal Computer Interaction project (fBNCI; http://future-bnci.org/ aims to develop such a roadmap by drawing on the expertise of BCI researchers, as well as many other stakeholder groups, including companies, end users, patient organizations, policy makers, and the general public. In the context of this project BCI researchers were surveyed on the marketability of BCIs at the 4th International BCI Meeting, which took place at the Asilomar conference centre in June 2010 [26], and a BCI expert meeting was organized in Graz in September 2010 where various short- and long-term scenarios for BCI research and applications were designed and elaborated.

These workshops, and other events and discussions, have underscored the complexities inherent in analyzing future directions. As noted, different user groups, and different types of applications, are emerging, and often cannot be lumped together within a single coherent analysis. For example, the most commonly sold BCI system today is a very simple game that allows very limited control, with questionable reliability, that costs less than $100. For such BCIs, users probably would not be inclined to pay substantially more. Consider another example: an EEG system that can be used in the home, or even on an outpatient basis, that can substantially alleviate the motor problems resulting from stroke. Users might easily pay tens of thousands of dollars for such a system.

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