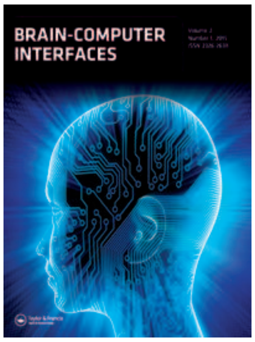

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Clemens Brunner[a]*, Niels Birbaumer[b], Benjamin Blankertz[c], Christoph Guger[d], Andrea Kübler[e], Donatella Mattia[f], José del R. Millán[g], Felip Miralles[h], Anton Nijholt[i], Eloy Opisso[j], Nick Ramsey[k], Patric Salomon[l] and Gernot R. Müller-Putz[a]

[a]*Institute for Knowledge Discovery, Graz University of Technology, Graz, Austria;* [b]*Institute of Medical Psychology and Behavioral Neurobiology, Eberhard-Karls University Tübingen, Germany;* [c]*Chair for Neurotechnology, Technische Universität Berlin, Germany;* [d]*g.tec Guger Technologies, Schiedelberg, Austria;* [e]*Institute of Psychology, Biological Psychology, Clinical Psychology and Psychotherapy, University of Würzburg, Germany;* [f]*Neuroelectrical Imaging and BCI Lab, Fondazione Santa Lucia, Rome, Italy;* [g]*Defitech Chair in Non-Invasive Brain-Machine Interfaces, École Polytechnique Fédérale de Lausanne, Switzerland;* [h]*Barcelona Digital Technology Centre, eHealth R&D, Barcelona, Spain;* [i]*Department EWI, Research Group Human Media Interaction, University of Twente, The Netherlands;* [j]*Institut de Neurorehabilitació Guttmann, Barcelona Spain;* [k]*University Medical Center Utrecht, The Netherlands;* [l]*enablingMNT GmbH, Berlin, Germany*

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The brain-computer interface (BCI) field has grown dramatically over the past few years, but there are still no coordinated efforts to ensure efficient communication and collaboration among key stakeholders. The European Commission (EC) has recently renewed their efforts to establish such a coordination effort by funding a coordination and support action for the BCI community called 'BNCI Horizon 2020' after the 'Future BNCI' project. Major goals of this new project include developing a roadmap for the next decade and beyond, encouraging discussion and collaboration within the BCI community, fostering communication with the general public, and the foundation of an international BCI Society. We present a short overview of current and past EU-funded BCI projects and provide evidence of a growing research and industrial community. Efficient communication also entails the establishment of clear terminology, which is a major goal of BNCI Horizon 2020. To this end, we give a brief overview of current BCI-related terms and definitions. A major networking activity in the project was the BNCI Horizon 2020 Retreat in Hallstatt, Austria. Over 60 experts participated in this event to discuss the future of the BCI field in a series of plenary talks, targeted discussions, and parallel focus sessions. A follow-up event was the EU BCI Day at the 6th International Brain-Computer Interface Conference in Graz, Austria. This networking event included plenary talks by eight companies and representatives from all seven ongoing EU research projects, poster presentations, demos, and discussions. Another goal of BNCI Horizon 2020 is the foundation of an official BCI Society. In this article, we summarize the current status of this process. Finally, we present visions for future BCI applications developed within BNCI Horizon 2020 using input from external BCI experts as well. We identify common themes and conclude with six exemplary use cases.

Keywords: BCI; coordination; collaboration; society

Introduction

In November 2013, the European Commission (EC) launched a coordination and support action with the title 'BNCI Horizon 2020: The Future of Brain/Neural Computer Interaction' (http://bnci-horizon-2020.eu/). This project, led by Graz University of Technology, consists of 12 European partners with extensive background in the field of brain-computer interfaces (BCIs). The ambitious goal of this project is to develop a roadmap for the field and sketch the future of BCIs within the next decade and beyond.

The EC has already funded several BCI-related research projects within their previous framework programs FP6 and FP7. Major past and ongoing EC-funded research projects are listed in Table 1. Among these projects, Future BNCI was the first coordination and support action dedicated to fostering collaboration in the BCI community. This project also developed a detailed roadmap, which contained recommendations on several key issues (including scientific and technical research, coordination and support, and funding instruments) specifically targeted towards funding agencies and policy-makers. In a nutshell, the major findings of Future BNCI were as follows: (1) invasive and non-invasive BCIs could provide different solutions for different users; (2) the formation of a BCI Society and publicly available web-based resources are recommended to encourage interaction and dissemination; (3) online resources such as software platforms, BCI data, documentation, and databases of references and events will facilitate development. Future BNCI was only the first step towards addressing these issues (it provided a roadmap for five years only).

*Corresponding author. Email: clemens.brunner@tugraz.at

Table 1. Overview of current and past BCI-related EU projects (in alphabetical order). The project names link to their official project description page.

Project name	Project ID	Budget (million €)	Project start	Project end
ABC	287774	2.5	11/2011	01/2015
AsTeRICS	247730	2.7	01/2010	12/2012
BackHome	288566	3.1	01/2012	06/2015
BETTER	247935	3.3	02/2010	01/2013
BNCI Horizon 2020	609593	0.9	11/2013	04/2015
BRAIN	224156	2.7	09/2008	08/2011
BrainAble	247447	2.3	01/2010	12/2012
CONTRAST	287320	3.2	11/2011	10/2014
DECODER	247919	2.8	02/2010	04/2013
Future BNCI	248320	0.5	01/2010	12/2011
MindSee	611570	3.0	10/2013	09/2016
MINDWALKER	247959	2.8	01/2010	05/2013
MUNDUS	248326	3.4	03/2010	02/2013
NEBIAS	611687	3.5	11/2013	10/2017
TOBI	224631	9.1	11/2008	01/2013
TREMOR	224051	2.5	09/2008	04/2010
WAY	288551	2.3	10/2011	09/2014

Therefore, BNCI Horizon 2020 was launched as its direct successor to continue networking and roadmapping efforts and to develop a roadmap for the next decade and beyond.

The main goal of BNCI Horizon 2020 is a new roadmap, which of course builds upon the results developed in Future BNCI, TOBI (which was a large-scale integrated project in FP7 with dedicated roadmapping activities), and other projects. Specifically, this updated roadmap will provide suggestions for future funding priorities within the current EU research framework program Horizon 2020. In contrast to previous framework programs, transfer of technology from research to companies has become a major focus and requirement. This means that the BCI field needs to evolve from a purely research-driven effort to a more applied field with commercial products entering the market. BNCI Horizon 2020 has the unique opportunity to sketch the necessary work ahead and lay out the required timeframe for this process in a roadmap for the BCI field.

Project partners

The 12 partners in BNCI Horizon 2020 include the following eight BCI research groups: Graz University of Technology (Graz, Austria); Barcelona Digital Centre Tecnològic (Barcelona, Spain); Eberhard-Karls-Universität Tübingen (Tübingen, Germany); École Polytechnique Fédérale de Lausanne (Lausanne, Switzerland); Julius-Maximilians-Universität Würzburg (Würzburg, Germany); Technische Universität Berlin (Berlin, Germany); Universitair Medisch Centrum Utrecht (Utrecht, The Netherlands); and Universiteit Twente (Twente, The Netherlands). Furthermore, the project includes Fondazione Santa Lucia (Rome, Italy) and Institut de Neurorehabilitació Guttmann (Barcelona, Spain) as clinical partners (of which Fondazione Santa Lucia is also a research group). Finally, enablingMNT GmbH (Berlin, Germany) and Guger Technologies OG (Schiedelberg, Austria) represent two companies in the project.

What is a BCI?

A brain-computer interface (BCI) is a device that enables communication without movement.[1] Therefore, a BCI may be the only communication system possible for severely disabled users who cannot speak or use keyboards, mice, or other traditional interfaces. In the most commonly adopted definition,[2] any BCI must

(1) rely on direct measures of brain activity,
(2) provide feedback to the user,
(3) operate online, and
(4) rely on intentional control (that is, users must choose to perform a mental task to send a message or command each time they want to use the BCI).

A more recent definition describes a BCI as follows [3]: 'A BCI is a system that measures central nervous system (CNS) activity and converts it into artificial output that replaces, restores, enhances, supplements, or improves natural CNS output and thereby changes the ongoing interactions between the CNS and its external or internal environment.' This definition includes BCIs that do not require intentional control, which are sometimes also referred to as passive BCIs.[4] Figure 1 illustrates the basic principle of a BCI according to this definition.

BCIs can be used in the following six application scenarios (adapted from [3]):

(1) BCIs can **replace** natural CNS output that has been lost as a result of injury or disease. Examples include communication (through a spelling system and voice synthesis) and motorized wheelchair control.
(2) BCIs can **restore** lost natural CNS output. Examples include functional electrical stimulation of muscles in a paralyzed person and stimulation of peripheral nerves to restore bladder function.
(3) BCIs can **enhance** natural CNS output. Examples include monitoring brain activity during prolonged demanding tasks such as driving a car and detecting lapses of attention, which alerts the person and restores attention.

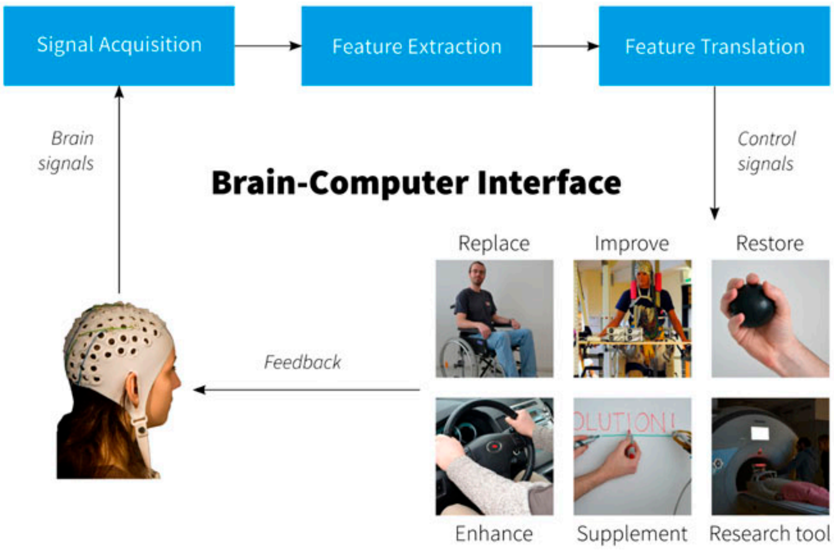

Figure 1. (Color online) Principle of a brain-computer interface including possible application scenarios (adapted from [3]).

(4) BCIs can **supplement** natural CNS output. Examples include providing a third (robotic) arm to a person and providing a selection function for people using a joystick.
(5) BCIs can **improve** natural CNS output. Examples include using a BCI in stroke rehabilitation that detects and enhances signals from a damaged cortical area to stimulate arm muscles or an orthosis to improve arm movements.
(6) BCIs can be used as a **research tool** to investigate CNS functions in clinical and non-clinical research studies.

The term brain/neuronal computer interaction (BNCI) was introduced in the call texts of the previous European research framework FP7 without a clear definition at the beginning. However, the BCI community has adopted the convention that a BNCI differs from a BCI only in the signals used. Specifically, a BNCI does not only rely on direct measurement of brain activity, but also includes signals from other (neuro-)physiological activity such as eye movement, muscle activity, or heart rate. Finally, a device that combines a BCI with another input device (which also includes another BCI) is known as a hybrid BCI [2,5,6] or a multimodal BCI.[7]

BCI research field

Research on BCIs began in 1973, when J. J. Vidal introduced the concept of a brain-computer interface to the scientific community.[8] It took well over a decade before a dedicated BCI research field really started to gain momentum, and at present the number of scientific publications is steadily increasing (see Figure 2). Another measure of progress is the attendance at international conferences. For example, the six Graz BCI conferences in 2002, 2004, 2006, 2008, 2011, and 2014 were attended by 32, 52, 95, 116, 169, and 189 participants, respectively. The International BCI Meeting series in 1999, 2002, 2005, 2010, and 2013 attracted 50, 90, 160, 283, and 301 participants, respectively.

While BCI research traditionally focused almost exclusively on replacing and restoring lost functions for patients,[9,10] the other four application scenarios (improve, enhance, supplement, and research) have received increased attention lately. For instance, BCIs might be used as valuable tools for rehabilitation of stroke patients to improve motor output.[11–13] Many potential applications can be found in the enhance scenario, which includes passive BCIs that assess covert aspects of the user's state and adapt the environment accordingly. Examples include systems that adapt to a user's current workload in driving tasks,[14] avoid dangerous situations in industrial workplaces,[15] or improve human-computer interaction by measuring implicit information encoded in perceptual and cognitive processes.[4]

Numerous companies are now active in the BCI field. The roadmap developed in the Future BNCI project in 2011 lists 39 companies producing BCIs or related devices for different market sectors such as health and neurofeedback, assistive technology, education, safety and security, entertainment and performance, research, and financial and marketing.[16] Within BNCI Horizon 2020, we have already identified more than 100 companies[1] either directly developing BCIs or related devices, or aiming to integrate BCI-based technology into their product portfolio or upcoming market applications.

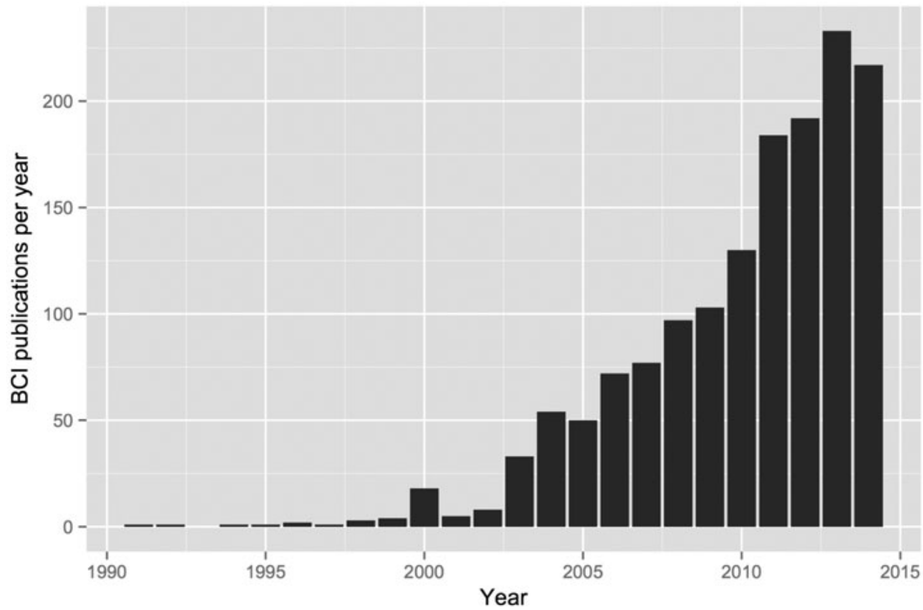

Figure 2. Number of BCI publications per year. Data were obtained with a PubMed query for the term 'brain-computer interface' on 23 October 2014. Note that data for 2014 are still incomplete. The peak in the year 2000 corresponds to articles resulting from the First International BCI Meeting 1999 in Rensselaerville, NY, USA.

Current challenges

The BCI field is rapidly expanding, but it currently faces the following four organizational challenges.

First, there are no major coordination efforts in place to ensure efficient coordination and collaboration among key stakeholders. Specifically, the BCI field is not represented by an official group or society to coordinate and foster communication with policy-makers, the media, the general public, and other groups.

Second, the BCI community has not agreed upon a common terminology.[17] Even fundamental questions like 'What is a BCI?' have no clear answers. There are no gold standards on how to objectively evaluate BCI performance or which key facts should be reported in scientific publications,[18] and there are no guidelines on how to properly deal with ethical, legal, and societal issues. In addition, comparing signal processing and machine learning algorithms across different groups is practically impossible, because there is no central open database with curated benchmark data sets.

Third, there is inadequate communication with people outside the BCI community. This leads to false beliefs and unrealistic views on what a BCI is and which problems BCIs can solve. Often, people working in other fields such as assistive technologies do not even know that BCIs exist and that they might be relevant for their fields. Conversely, the BCI community might not be fully aware of relevant work in other fields.

Fourth, the most promising future directions for BCIs have not been identified yet.

These four challenges cannot be addressed without an effective coordination effort. It seems unlikely that any project can align constituencies and prepare future joint research and roadmaps when the relevant disciplines and stakeholders are not even clearly identified. The principal vision of BNCI Horizon 2020 is to address these challenges by establishing and supporting a thriving, efficient, and well-connected BCI community. Ultimately, these efforts might lead to the formation of an international BCI Society, which is also an explicit goal of BNCI Horizon 2020.

Goals of BNCI Horizon 2020

BNCI Horizon 2020 continues coordination efforts that were initiated by Future BNCI to ensure that progress is not impeded by a lack of infrastructure, lack of communication between key stakeholders, ambiguous terminology, or an unclear roadmap of the research field.

The main achievement of BNCI Horizon 2020 will be a roadmap for the BCI field. This roadmap will serve as a guideline for future activities that will be supported by the EU research framework program Horizon 2020.

In addition, BNCI Horizon 2020 will encourage discussion and collaboration among and within the BCI community. The project will also foster communication with the media, the general public, and other groups.

Finally, BNCI Horizon will actively support the foundation of an official BCI Society. Three members of BNCI Horizon 2020 are part of an international committee working towards this goal (see below for the current status of the BCI Society).

Our main communication and dissemination channel is the official project website, which includes news items, job offers, an event calendar, constantly updated lists of BCI research groups and companies, related projects, and more. The BNCI Horizon 2020 Retreat in Hallstatt was the main opportunity for the project to interact and communicate face to face with external experts in the BCI field. The BNCI Horizon 2020 website aims to be more than just a project website. Our goal is to provide accessible information about BCIs, community news, a list of BCI-related events, a list of research groups and companies in the BCI field, guidelines, job offers, and a publicly accessible database with real BCI data sets, among other things. Ultimately, contents produced within the BNCI Horizon 2020 project will be used on the BCI Society website after the project has ended.

BNCI Horizon 2020 Retreat

A major activity to address the challenges described above was the BNCI Horizon 2020 Retreat held on 24–26 March 2014, in Hallstatt, Austria. This meeting brought together over 60 BCI experts from 13 different countries. Among the participants, about 60% were researchers, 30% worked in companies, and 10% worked with end users or end-user associations (for example in rehabilitation clinics). A full list of participants is available on our project website. Registration fees for the three-day retreat were below €80 to attract people to this event. In addition, we waived this fee for company representatives to maximize the number of industrial participants. Since the number of total participants was limited, we first invited key stakeholders to participate in this retreat, and then accepted registrations on our project website until all available places were filled.

The main goal of this meeting was to involve and integrate key stakeholders in the BCI field in BNCI Horizon 2020, specifically to discuss ideas and get feedback for our planned roadmap. The retreat style of this event in a relatively secluded location ensured that all participants could focus on and actively participate in the official meeting, but it also offered many opportunities for more informal and personal exchanges of ideas.

The meeting was set on two half days and one full day. The agenda included plenary talks, targeted discussions, and parallel focus sessions. BNCI Horizon 2020 is centered on the six application scenarios described above, and so these elements were also important items on the retreat agenda. On the first day of the event, participants split up into three parallel sessions dealing with the replace, restore, and enhance application scenarios. On the next day, people could choose between the parallel sessions focusing on the improve, supplement, and research scenarios. The goal of the workshops was to brainstorm ideas for future applications within an application scenario and to identify bottlenecks and promising future directions.

Focus sessions

The parallel session on the first day consisted of workshops on restore, replace, and enhance scenarios. José del R. Millán (École Polytechnique Fédérale de Lausanne) led the session on applications which **restore** lost CNS functions. Examples in this scenario include control of neuroprostheses and bladder control. An important point in this scenario was shared control, which means that the BCI user issues high-level commands to execute a task instead of controlling the individual low-level functions required to complete the task. Another important topic in this session pertained to suitable feedback for BCI users. In particular, haptic feedback might be relevant for the restore scenario, which would enable users to feel their movements again. A point that came up in several discussions was whether results from studies with healthy people can be readily transferred to patient populations. Since this is still an open issue (not just in the restore scenario), more large-scale trials with patient end users are required to address this question. BCIs restoring sensory input were also considered, but people agreed that such devices can only be referred to as BCIs if they include a feedback loop, for example cochlear implants that measure brain activity to automatically optimize their parameters in real time.

Andrea Kübler (Julius-Maximilians-Universität Würzburg) chaired the session on **replace** applications. This scenario contains most traditional BCI use cases, for example wheelchair control and spelling applications; most BCIs to date have explored examples within this scenario. Therefore, people feel that such applications are ready to go beyond research prototypes to be used by real end users at home. This paradigm shift raises new questions such as which evaluation metrics should be used to assess and compare the performance of BCIs. Also, ethical issues are now becoming relevant. However, it is not clear if the target market of such BCI applications is large enough to warrant expensive product development and maintenance. A possible solution might be to develop components that can be reused in other applications with more potential users (such as the gaming or telemedicine sectors). Another key issue in product development is to focus on end users' needs by employing a user-centered design approach standardized in ISO-9241-210.[19]

Benjamin Blankertz (Technische Universität Berlin) led the **enhance** session. Examples in this application scenario include most passive BCIs, for example workload estimation in the workplace and predicting emergency braking during driving. This application scenario has attracted a lot of attention and interest lately, with new passive BCI applications appearing in the scientific literature. The discussions focused on novel ideas for BCI applications to enhance natural CNS output, which participants grouped into five categories according to their intended usage. Although there might be some overlap with other application scenarios, these groups were: BCIs for control (such as multiplayer games and neuro-gaming), BCIs exploiting the user's mental state (for instance cognitive load adjustment), medical tools (such as adjusting hearing aids or improving medical diagnosis), feedback of mental states (for instance to improve wellness or manage stress), and BCIs for enhanced product development (neuro-usability). Applications within the enhance scenario will benefit from mobile comfortable (wireless) EEG systems and robust hardware and software.

The parallel session on the second day consisted of workshops on improve, supplement, and research scenarios. Donatella Mattia (Fondazione Santa Lucia) chaired the session on **improve** applications. Rehabilitation is an important target area for such applications. For example, a typical use case is a BCI for improving hand motor function in stroke patients, which could be used in addition to existing state-of-the-art rehabilitation therapy. Other examples include neurofeedback training for attention deficit hyperactivity disorder (ADHD) and neurofeedback training to reduce cortical excitation in epilepsy patients. Several issues need to be addressed to realize these applications, such as a definition of 'normal' brain activity, the role of instructions, and development of objective outcome measures to fine-tune training procedures. Most importantly, there is a need for randomized controlled trials to prove the efficacy of therapeutic BCI applications. If such an effect can be demonstrated, the number of people who could benefit from such BCIs is relatively large (in contrast to BCIs in the replace application scenario for example).

Christoph Guger (Guger Technologies OG) led the session on BCIs that **supplement** natural CNS output, for instance a third robotic arm controlled by a BCI. The major part of this workshop was devoted to identifying novel BCI use cases in this scenario. Participants were grouped into fields of expertise, such as signal processing and machine learning, assistive technology, target markets, patients, and other potential end users. After a first round of brainstorming, the workshop participants came up with a list of possible BCI use cases in the supplement scenario. These use cases were subsequently ranked by the different expertise groups, and, due to time constraints, the group evaluated only the third-arm use case (which was on top of the list) in more detail. Participants identified possible use cases for a robotic arm and rated them according to different criteria such as associated risk, time to market, cost, number of potential users, and usability. The most promising target group for such a BCI-controlled third arm could be stroke patients, who could use this device to assist them in their daily lives.

Nick Ramsey (University Medical Center Utrecht) chaired the session on BCIs as a **research tool**. This means that BCIs can be used to conduct research in other fields where single-trial analysis and online feedback are important. Examples include all applications where brain responses need to be detected on a single-trial basis and, based on these responses, the environment is adapted accordingly. Many basic neuroscientific questions could benefit from such a BCI-supported analysis, because traditional averaging approaches could be replaced by more natural environments. This also implies that such studies could be performed much faster if the stimuli are adapted to the current brain response and optimized to the specific research question. Furthermore, brain responses can be much more accurate than behavioral responses, which are often highly subjective. In addition, subconscious processes or covert aspects of the user state can often not be assessed at all with behavioral correlates. Importantly, BCIs in research also allow investigators to study the immediate and long-term impact of online feedback on the brain.

Special session at the Graz BCI Conference

As a follow-up event of the BNCI Horizon 2020 Retreat, we organized a special session on the first day of the Graz BCI Conference. On this so-called 'EU BCI Day', we offered companies and research project leaders the opportunity to present their work on BCIs in the form of plenary talks in front of the conference audience. In total, eight companies (three of which also participated in the retreat and two from outside the EU) and seven EU project coordinators participated in this networking event.

Current status of the BCI Society

Currently, a small group of international BCI experts are working together to form the BCI Society. The initiative for a society was launched at the Fifth International BCI Meeting 2013 (Pacific Grove, CA, USA). From the steering committee associated with that meeting, a small group was formed to prepare the foundation of the society. This committee consist of the following people (in alphabetical order):

- Brendan Z. Allison
- Emanuel Donchin
- Shangkai Gao
- Christoph Guger (member of BNCI Horizon 2020 consortium)

- Jane Huggins
- Andrea Kübler (member of BNCI Horizon 2020 consortium)
- José del R. Millán (member of BNCI Horizon 2020 consortium)
- Nick Ramsey (chair, member of BNCI Horizon 2020 consortium)
- Eric W. Sellers
- Jonathan R. Wolpaw

The aim of an official BCI Society will be to make sure that the BCI field has a strong unified voice, for example to inform the general public, interact with the media, promote BCI research, work with other societies, and lobby funding agencies. Other goals include managing finances for meetings; maintaining a website; educating people about BCIs; and creating/publishing guidelines, standards, and recommendations. These goals are very much in line with the goals of BNCI Horizon 2020, thus we think that BNCI Horizon 2020 can contribute substantially towards the foundation of the society.

The foundation committee is currently working on the bylaws. It has already determined the mission statement, rules for membership and organization of the board, and the rotation of officers. The main purpose of the BCI Society will be *'to foster research leading to technologies that enable people to interact with the world through brain signals'*. In forming the society, special attention is paid to attracting people from multiple disciplines who work with different approaches (non-invasive, implants, induction of sensory feedback, functional electrical stimulation, stroke rehabilitation, and so on). The board aims to encourage other (emerging) BCI organizations to collaborate and join forces in organizing meetings when possible. An official society is important for future developments of BCI research and applications. The society is expected to be established in early 2015, at which time there will also be a website available. BNCI Horizon 2020 is closely collaborating in this process, for instance by streamlining the integration of the two website back ends.

BCI visions

Before and after the BNCI Horizon 2020 Retreat, we asked all participants to share their visions of BCIs with us. We received more than 30 ideas for future BCI applications. Although these visions are inevitably very subjective, we can still distil the following four common themes from the responses:

(1) Patients will use invasive BCIs to compensate for movement disorders. This is a new finding which was not envisioned in the previous Future BNCI project (except for a more general statement that invasive and non-invasive BCIs will both have their merits for different target groups).
(2) Passive BCIs will enrich human-computer interaction, for example through personalization. This vision is compatible with the Future BNCI roadmap, and the increasing interest in passive BCIs is further evidence for this new application field.[4]
(3) BCIs will be commonly used as tools for basic research. This vision has also been described in the previous Future BNCI roadmap.
(4) Albeit still controversial, the use of BCI technology for rehabilitation (for example to improve and maintain motor and cognitive functions that are impaired due to stroke, traumatic brain injury, and other neurological acquired disorders) is a very exciting area.[20] Provided that well-controlled studies demonstrate a tangible improvement in rehabilitation outcome, this area of BCI application will increase the number of potential BCI users exponentially. Once again, this vision is in line with the Future BNCI roadmap.

Selected individual visions are listed in the appendix.

BCI use cases

Inspired by the discussions during the retreat, recommendations by our advisory board, and more specifically by the various visionary applications of BCI experts, we started to devise numerous use cases for each of the six application scenarios. From over 50 candidate use cases, we selected a number of representative use cases that will be included in the final roadmap. These examples will make our envisioned BCI applications tangible for people outside the field, which will be important to identify the most promising areas within the BCI field.

For illustrative purposes, we present six future use cases in more detail below, one for each application scenario. A more detailed description of use cases will be available in the roadmap (see http://bnci-horizon-2020.eu/roadmap for the latest version of this document).

Unlocking the completely locked-in (replace)

This use case describes a BCI used for people in a complete locked-in state. Such a system will be used for communication and control, such as spelling systems and ambient assistive living applications. Depending on the individual situation, the BCI will be either non-invasive or implanted.

BCI-controlled neuroprosthesis (restore)

People with spinal cord injury who cannot move their upper extremities will use invasive BCIs to restore arm function. This will enable the users to carry out activities in their daily lives that were otherwise impossible before (for example, autonomously grasping a glass of water or painting on a canvas).

Enhanced user experience in computer games (enhance)

Computer games will be enriched by information about the current state of the gamer. For example, immersion could be maximized by presenting a scary scene at the exact moment when the person least expects it. Additionally, the difficulty level could be continuously adapted to a gamer's current state.

Brain glass (supplement)

Augmented reality glasses will become popular devices, but currently they have to be controlled either via voice commands or with gestures. BCIs will create a covert way to control such glasses to make selections, start applications, or take pictures by using mental commands.

Upper limb rehabilitation after stroke (improve)

Stroke rehabilitation will be supported by BCIs. By measuring brain and muscle activity, suitable feedback is provided only if the patient performs correct movement attempts. This approach will drastically shorten and improve the rehabilitation process compared to traditional therapies.

Cognitive neurosciences (research tool)

Since BCIs can be used to decode brain activity and deliver feedback in real time, neuroscientists will apply BCIs as a tool to study various brain functions. BCIs for research will be modular devices that can be connected to a variety of existing tools such as EEG amplifiers or MRI scanners. This will open up new possibilities in neuroscientific studies.

Summary and outlook

In summary, we introduced the BNCI Horizon 2020 project as a direct successor to the previous EU-funded project Future BNCI. We provided an overview on the current definition(s) of a BCI (and various derived terms) and explained the need for coordination of the BCI field. We then summarized a key event of the project, the BNCI Horizon 2020 Retreat, and the follow-up EU BCI Day event at the Graz BCI Conference. Furthermore, we outlined the current status of the planned BCI Society. Finally, we concluded with future BCI visions and short descriptions of novel use cases.

With over 60 participants, the BNCI Horizon 2020 Retreat brought together experts from all over the world. By structuring the retreat according to the five application scenarios that replace, restore, enhance, supplement, and improve natural CNS output and the sixth scenario on BCIs as research tools, we strengthened awareness of this definition introduced by Wolpaw and Wolpaw [3] in the BCI community, which is an important step toward a common terminology. Almost a third of the retreat participants represented companies active and/or interested in the BCI field. Connecting researchers with the industry is an important step towards more efficient knowledge transfer and ultimately BCI products, which will help us maintain an adequate representation of industrial interests in our roadmap.

The parallel workshops led to future BCI visions and use cases, some of which we presented in this article. Many of these visions have already been touched upon in the previous Future BNCI roadmap, with the notable exception of the vision that invasive BCIs will be predominantly used to compensate for movement disorders. It is also worth noting that classic BCI applications for communication and control seem to play only a minor part in the future. In contrast, BCIs that enhance natural CNS output will be the most prolific area of BCI applications with the largest target group and market size. One reason for this shift towards passive BCIs might be that BCIs can estimate abstract constructs such as workload or lapses in attention more easily than other competing technologies.

This shift is also reflected in the future visions and use cases presented here. Although the replace use case describes the application of existing BCI technology in locked-in patients to re-establish communication, the other five scenarios contain applications that have not yet been explored by the BCI community in such depth.

We are aware that including external opinions is crucial for the success of our project. To avoid biasing the roadmap towards a certain direction dictated by the BNCI Horizon 2020 project members, we encourage input from people outside the consortium. For example, our advisory board, which consists of seven people mainly from companies and end user associations, validates and approves our methodologies, deliverables, and results. The very reason why we organized the BNCI Horizon 2020 Retreat was to obtain input from key stakeholders outside the project. Our website at http://bnci-horizon-2020.eu/ encourages readers to contribute contents by submitting news, events, job offers, or other comments to us via email. Finally, we will publish the first draft of the roadmap on our website and explicitly ask for comments from everyone interested in contributing.

The upcoming BCI Society will directly benefit from all contributions of BNCI Horizon 2020, which is an important factor to motivate people to contribute to our project. We hope to convey a very clear message here, namely that BNCI Horizon 2020 is not just another BCI-related project. In contrast, it will pave the way for increased collaboration and create sustainable contents such as the website, which will ultimately culminate in the formation of the BCI Society.

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Note

1. We provide a continuously updated list of BCI-related companies on our website at http://bnci-horizon-2020.eu/index.php/community/companies.

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Appendix

Selected individual visions on the future of BCIs include the following statements below. We grouped similar statements into four broad application categories.

Entertainment, human-computer interaction

- BCIs will be valuable tools to assess cognitive and emotional user states in various applications, something that cannot be achieved easily with other technologies.
- Technical enthusiasts will use BCIs at home for gaming.
- There will be a flourishing use of BCIs in entertainment applications.
- BCIs that detect emotions will enrich our (joined) experience of books, music, and interactive arts.
- BCIs will monitor the cognitive state to optimize human-computer interaction.
- BCIs will be the most commonly used tool to personalize existing products.

Rehabilitation

- The main application of BCIs will be in rehabilitation and as a research tool.
- BCIs will be common devices to enhance current rehabilitation therapies.
- BCI technology will be used for treatment and rehabilitation.
- BCIs will not be used in clinical stroke rehabilitation due to missing evidence of superiority and applicability.
- BCIs will be used to improve both cognitive and motor rehabilitation outcomes.

Medical/therapeutic applications

- Disabled persons will use customized BCI solutions to compensate for lost functions.
- Invasive BCIs will be a first-line medical solution for functional movement compensation and treatment of brain injuries and neurological disorders.
- ECoG-based BCIs will be widely used for medical applications such as severe motor handicap compensation, presurgical epilepsy evaluation, and post-stroke rehabilitation.
- BCIs will be used to assess awareness in disorders of consciousness, basic communication for the severely impaired, and alternative game interfaces for physically impaired and healthy users.
- Invasive BCIs will be common solutions for individuals with movement disorders caused by spinal cord injury, stroke, and neurological disorders.
- Invasive ECoG-based BCIs will be used for movement functional compensation with multiple degrees of freedom.

Research

- BCI technology will open a new era of fundamental and applied psychophysiological research.
- BCIs will be unobtrusive with tiny sensors, and smart phones will be used for data processing.