BNCI Horizon 2020

The Future of Brain/Neural Computer Interaction: Horizon 2020

Appendix B Industry

BNCI Horizon 2020 (FP7-ICT-2013-10 609593) was funded by the
European Commission within the 7th Framework Programme.
Project runtime: Nov 2013–Apr 2015

This appendix and the corresponding main document can be downloaded from
http://bnci-horizon-2020.eu/

B Industry

B.1 Sources

To analyse the BCI industry ecosystem and the potential relationships with related sectors, different strategies based on market research methods were used. We acquired and qualitatively categorized relevant data from the main industry stakeholders in the BCI and related sectors. The whole process relied on links to industry, academia and end users coming from the consortium, as well as from our advisory board and the BCI Society.

B.1.1 Market research methodology

We followed market research methodology based on a five-phase approach summarized in Figure 1.

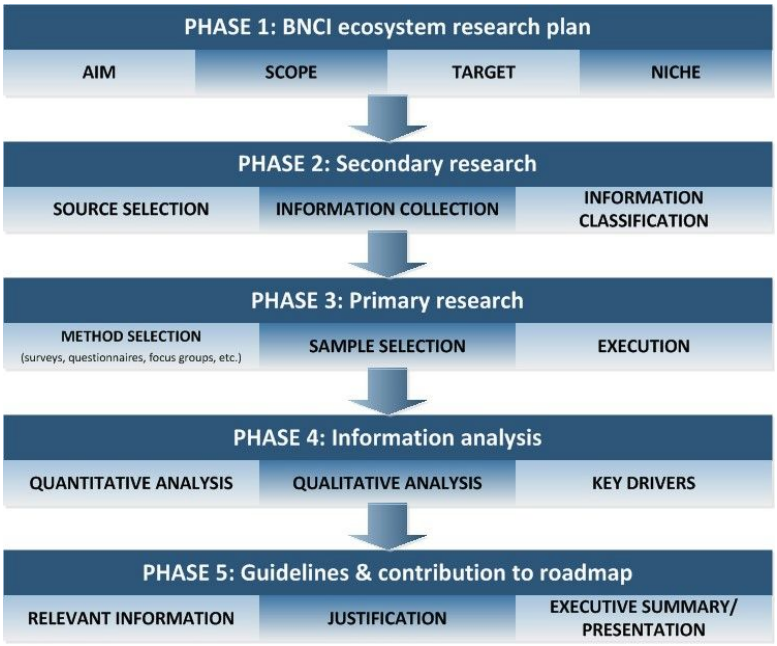

Figure 1. BNCI Horizon 2020 market research methodology.

- In phase 1, we defined a plan in conjunction with the whole consortium to establish common mechanisms for the posterior i) identification; ii) classification; iii) contacting; and, iv) collection of information, from the different BCI industry stakeholders and those in related sectors. We specified our scope and target markets.
- During phase 2, we mainly dealt with secondary research data (i.e. currently published or in electronic form). Following the identification of the principal industry stakeholders, we collected and classified BCI-related input data, mainly extracted from official company websites or BCI-related conferences. These efforts led to the characterisation of the BNCI industry ecosystem database, which was thereafter validated by the industry questionnaire sent to the industry stakeholders in the database. We also identified and classified success stories from previous EU-funded projects that derived into BCI market products or prototypes (see section B.1.4).
- Within phase 3, we aimed at gathering primary research data, which, unlike secondary research data, cannot be found elsewhere. Primary data was obtained by means of open-ended questions in the industry questionnaire and by several surveys in business-oriented social networking activities devoted to the BCI application scenarios (Wolpaw and Wolpaw, 2012).
- Phase 4 was devoted to quantitative and qualitative market research analysis from the data contained in the industry database and the responses from the retreat surveys.
- Finally, phase 5 gave rise to actionable recommendations, guidelines and the overall main contribution to the industry roadmap.

B.1.2 Industry ecosystem database

The BNCI industry ecosystem database contains a sample of 148 industrial stakeholders. For a general picture of the BCI sector and related domains, we identified, classified and analysed current BCI and potential BCI-related industry stakeholders from all over the world, with special emphasis on European and North American companies (Figure 2).

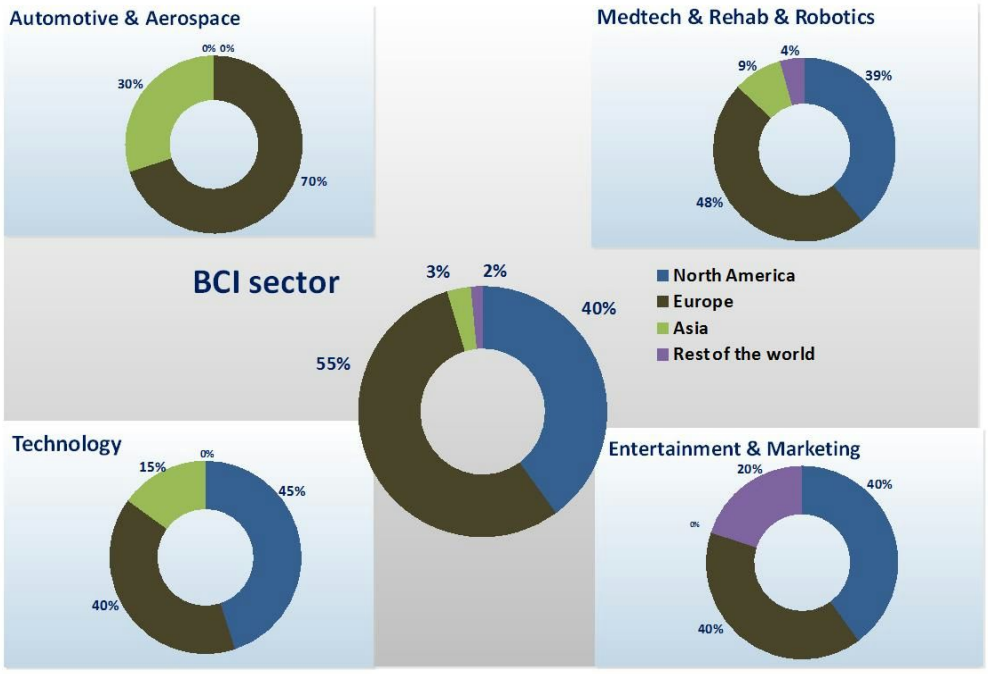

Figure 2. BCI and BCI-related industry stakeholders rearranged per group sectors. Percentage of companies classified by geographical location: North America; Europe; Asia; and Rest of the world.

The corresponding data was classified into 15 extra categories to allow quantitative and qualitative market research analysis.

B.1.3 Industry questionnaire and surveys

The industry questionnaire consisted of 23 questions: 16 multiple-choice questions for our database validation (i.e. secondary input data), and 7 open-ended questions for acquiring primary data that addressed relevant issues in relation to end users' involvement, key market applications, potential bottlenecks and major technology breakthroughs. Additionally, answers from the specific surveys helped us to validate our vision assessing the market impact. All contacted industry stakeholders were informed on the potential role of this roadmap to influence the European Commission in their funding decisions for the new framework program Horizon 2020. The gathered information was used to qualitatively estimate the market impact, and to develop the guidelines and recommendations towards technology transfer.

B.1.4 Success stories and business cases

We identified and classified relevant success stories and derived business cases in relation to BCI systems that are currently on the market and are the result from previous and current EU-funded R&D projects. We used a classification that is in line with the BCI application scenarios.

B.1.4.1 Replace scenario

Lessons learned in PRESENCCIA[1] stimulated the development of the first worldwide commercially available BCI system intendiX[2] - a P3-based device that enables the user to sequentially select characters from a keyboard-like matrix on the screen just by paying attention to the target for several seconds. Additional features of intendiX were further implemented and adapted to specific end users tasks and environments conjointly in other EU-funded projects like BRAINABLE[3], BACKHOME[4] and VERE[5]. Those projects shared in common the development of new means to empower people with functional deficits to mitigate their own barriers of everyday life, and to generally improve their quality of life (QoL) - therefore enabling autonomy and social inclusion. intendiX became a BCI system for communication, designed to be installed and operated by caregivers or the patient's family at home.

Nowadays, intendiX is sold worldwide. However, the targeted market size, mainly in the replace scenario, is small (see section B.3.1.1) and, generally difficult to reach. New means and efforts are required to efficiently access those minorities who may profit most from this sort of BCI technologies.

B.1.4.2 Restore scenario

TOBI[6] demonstrated how a functional electric stimulation (FES) hand orthosis could be developed for long term use. The BCI controls electrical stimulation, which moves the according muscles of the upper limb to perform grasping movements. MUNDUS[7] investigated multimodal neuroprostheses for daily upper limb support. WAY[8] developed a BCI system that controls a hand exoskeleton restoring the ability of a paralyzed hand to manipulate different objects in daily-life environments.

A major challenge in commercialization of such BCI-based systems is to provide individually tailored effectors and reliable BCI systems requiring minimum maintenance (see B.3.2). None of the TOBI, MUNDUS, and WAY prototypes have directly been licensed as a market product

[1] http://www.presenccia.org/
[2] http://www.intendix.com/
[3] http://www.brainable.org/
[4] http://www.backhome-fp7.eu/
[5] http://www.vereproject.eu/
[6] http://www.tobi-project.org/
[7] http://www.mundus-project.eu/
[8] http://www.wayproject.eu/

or are commercialised at this point of time. However, their efforts are influencing R&D and technology transfer in several BCI application scenarios[9].

B.1.4.3 Improve scenario

Apart from TOBI and WAY, there are other examples in the improve scenario.

BETTER[10] aimed at improving physical gait rehabilitation by introducing real time BCI feedback to the patient. DECODER[11] targeted cognitive assessment and rehabilitation. In relation to BETTER and DECODER, two exemplary BCI products can already be found on the market: recoveriX[12] designed for upper limb stroke neurorehabilitation, and mindBEAGLE[13] designed for consciousness assessment and communication.

CONTRAST[14] aimed at contributing to new medical and practical knowledge for guiding and improving intervention for daily life functioning after stroke. Efforts from CONTRAST led to COALA: an auto-adaptive tool for in-patient and home-based rehabilitation after stroke. The included semi-dry EEG headset is already marketed by MindMedia B.V. (Herten, Netherlands).

Further research is required to confirm the clinical efficacy and the longer-term effects of BCI based neurorehabilitation (see B.3.2).

B.1.4.4 Enhance scenario

SENSATION[15] explored a wide range of micro and nano sensor technologies, with the aim to improve real-time detection and prediction of human physiological states (e.g. wakefulness, fatigue and stress). SENSATION inspired the current market product Enobio[16]- now designed for a wider range of market applications. Other projects improving features in the design and development of the current Enobio are BEAMING[17], HC(2)[18] and ASTERICS[19].

MINDSEE[20] aims to develop an information seeking application which combines modern BCI technology with real-world human-computer interaction (HCI). It will develop a prototype for a cutting-edge information retrieval system that improves upon state-of-the-art tools with respect to performance of information seeking in realistic tasks.

More market research and user acceptability studies are required to be able to guarantee the success of this and other similar BCI-related products in different market niches (see B.3.2). These products are mainly sold as research tools, although their potential is large in a wide range of market applications, such as entertainment and gaming (see B.3.1).

[9] Here, we have highlighted relevant examples in the restore scenario.
[10] http://cordis.europa.eu/project/rcn/93258_en.html
[11] http://www.decoderproject.eu/
[12] http://www.recoverix.at/
[13] http://www.mindbeagle.com/
[14] http://www.contrast-project.eu/
[15] http://www.sensation-eu.org/
[16] http://www.neuroelectrics.com/enobio
[17] http://beaming-eu.org/
[18] http://hcsquared.eu/
[19] http://www.asterics.eu/
[20] http://www.mindsee.eu/

B.1.4.5 Research scenario

BRAIN[21] aimed at developing BCIs into practical assistive and ICT tools to enhance social inclusion for a wide range of different users with functional deficits. BRAIN led to the development of a completely new water-based EEG sensor (i.e. easier to handle, quick to apply, and comfortable to wear and yet maintain an excellent signal quality). This gel-free wireless EEG system is now distributed by TMSI[22] and is used by a variety of research groups around the world, normally in combination with Mobita[23] amplifiers.

CSI[24] achieved substantial advances in state-of-the-art medical 3D-imaging platforms and focused on the diagnosis and therapy of serious diseases of the central nervous system. Brain mapping techniques are key important for some neurological research topics. cortiQ[25] is one licensed product that uses BCI technology for brain mapping research purposes. Findings from CSI and also VERE influenced the development of cortiQ and may lead to further improvements of the product.

Most SMEs in the BCI market target the research scenario, which in fact may cover all the aforementioned scenarios in a more preliminary stage - i.e. when the application is still not the focus, but exploring the brain instead.

B.2 Summary of state-of-the-art

Here, we provide a general summary of different analyses carried out with the data in the industry ecosystem database, and the responses from our questionnaires and surveys.

B.2.1 The BCI Sector

From our analysis, 65 industry stakeholders were directly associated to the BCI sector. Figure 3 shows the distribution of sensors and signals that are used and offered by the identified industry stakeholders. The names describe the raw signal without any feature extraction. For example, with the ECG one extracts the heart rate, or with EEG band power features. Many stakeholders offer or use more than one signal type, but EEG is the most preferred one. EMG and ECG are robust, cheap, and non-invasive, which could be the reason why they are found on second and third place. Invasive electrical signal acquisition of the brain comprises electrocorticogram (ECoG), local field potentials, multi-unit recordings, and single-unit recordings. The invasive nature, and thus practical problems if used, might be the reason why only 6% of stakeholders use invasive signals. Other potential BCI-related signals, such as near infrared spectroscopy (NIRS) and respiration rate (for hybrid BCIs) have about the same share as invasive electrocorticography. The remaining analyzed BCI-related signals sum up all other signals that are used, like fMRI or galvanic skin response.

[21] http://www.brain-project.org/
[22] http://www.tmsi.com/products/accessories/item/water-based-eeg-electrodes
[23] http://www.tmsi.com/products/item/mobita
[24] http://www.eniac-csi.org/CSI/
[25] http://www.cortiq.eu

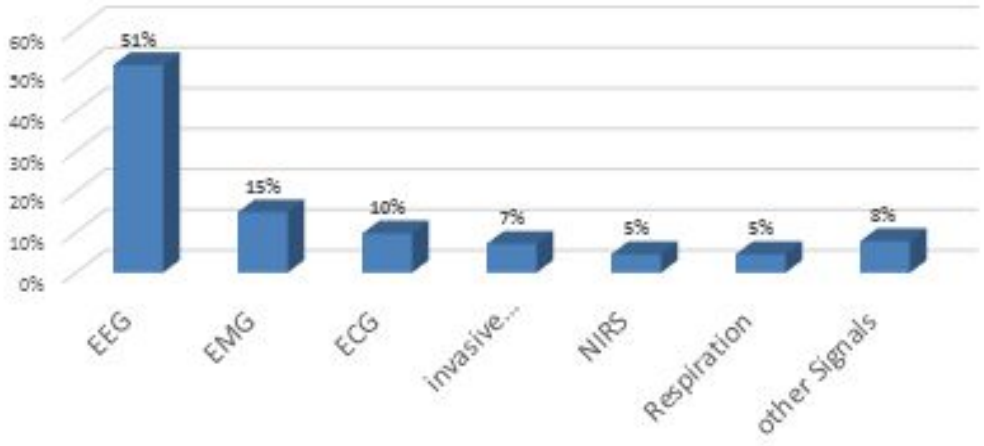

Figure 3. Distribution of used sensors and signals by the stakeholders working in the area of BCIs.

Although there are promising synergies among other identified industry stakeholders and the ones in the BCI field, many of the following applications mentioned in the following section B.2.2 (especially those for entertainment and gaming) are based on basic scalp recording systems. Their alleged ability to actually record neural signals still needs to be verified.

B.2.2 BCI-related industry stakeholders and potential interrelationships

We classified the 148 identified BCI-related industry stakeholders into the following sectors (or synergy fields):

- the **BCI sector** with 65 companies;
- the **automotive and aerospace sectors** altogether consisting of 7 BCI-related industry stakeholders;
- the **medtech, rehabilitation and robotics sectors** altogether consisting of 46 BCI-related stakeholders;
- the **entertainment and marketing sectors** altogether consisting of 10 BCI-related industry stakeholders; and
- the **technology sector** comprising 20 BCI-related industry stakeholders.

For each BCI-related industry group sector, Figure 4 shows the proportion of companies classified by company size, depending whether the stakeholder is a large enterprise[26], an SME[27] , a public entity (non-profit) or a startup[28].

[26] mostly multinational companies

[27] independent small to medium company with less than 250 employees, an annual turnover less or equal to 50 million €, and balance sheet less or equal to 43 million €.

[28] independent small company founded less than 4 years ago (i.e. 2010)

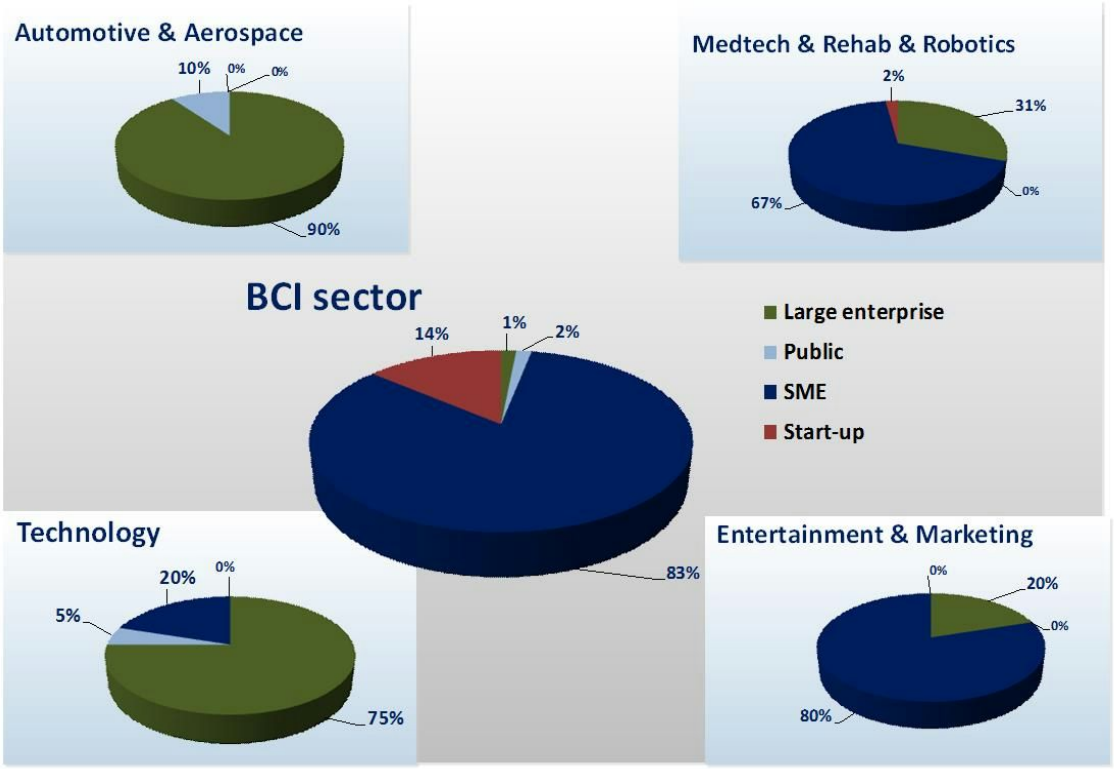

Figure 4. Company size of the BCI and BCI-related industry stakeholders arranged by group sectors. Percentage of companies classified by company size: large enterprise; public (non-profit); small to medium companies (SME); and start-ups.

The results obtained from analysing the company size in the industry database show that the BCI sector, the entertainment and marketing sectors, and the medtech, rehabilitation and robotics sectors are mainly comprised by SMEs. The largest proportion of startups (14%) can be found in the BCI sector, and the largest percentage of large enterprises is in the automotive and aerospace sectors, followed by the technology sector. Public or non-profit industry institutions are mainly found in the aerospace sector, the technology sector, and the BCI sector.

When it comes to evaluate the interrelationships with the synergy fields (or sectors), we assessed on-going efforts and exemplary business cases. The EU-funded project Brainflight showed new opportunities within the **aerospace** sector by an ambitious project investigating the feasibility of flying a brain-controlled aircraft, which might reduce the workload of pilots and increase safety. Likewise, synergies between the **automotive** industry and the BCI sector led to the development of cars that can be geared, steered or provide feedback by using brain-controlled systems like BrainDriver.

Examples of potential opportunities that could most benefit the **health care** or **medtech** industry are brain-controlled bionic legs and arms, or computerized bladders. BCIs may also be used in neurorehab treatment of neurodegenerative diseases in an attempt to recover lost cerebral functions. In 2009, the FDA approved a second clinical trial to implant the BrainGate technology into severely disabled patients. Within this sector, there are several examples of success stories and business cases, described in section B.1.4, in relation to the *restore* and *improve* scenarios.

Following the same line, synergies between BCIs and **assistive technologies (AT)** are progressing rapidly as shown by the brain-controlled DARPA prosthetic arm. We recently saw the success of the EU-funded projects in the restore and replace scenarios, like TOBI and WAY (but also Mind Walker and WalkAgain), or BrainAble and BackHome.
Remarkably, BCI devices have a number of growing opportunities in the **entertainment** sector. The field of **education** is one of the major targets for open source (Puzzlebox Orbit) or commercial (MindWave Education) brain-controlled devices. These games claim to monitor attention levels of students performing a task. Other companies in the **entertainment** sector are developing BCI-based games, which let you manipulate targets just by concentrating on them (NeuroBoy, Mindflex, and the Star Wars Force Trainer). Games like Focus Pocus can be played on a PC simultaneously by multiple players. Further, the **music** industry is working on a device called Neuro Turntable (by Neurowear), which plays music only when the user is concentrated. Another related project explores a collaborative system to generate music supported by a hybrid BCI (b-Reactable). The **wellness** industry may also benefit from BCI tools by devices like MUSE (InteraXon), which guides you to relax or focus before or after you perform a mentally challenging task, and which could be used for meditation. Additionally, BCIs may allow the **marketing** sector to tailor individual-target advertising, based on mood, emotional state, and cognitive analysis. If successful, this could be incorporated in any device that allows for neurofeedback, including brain-controlled games and mobiles headsets of companies such as Personal Neuro Devices, Neurosky, and Nielsen.
In relation to the latter, large multinational companies in the **technology** sector are likely to form joint ventures with those BCI stakeholders offering the most promising BCI solutions. Apparel and accessory companies are releasing brain-controlled clothing and gadgets, such as Neurowear's Necomimi and Shippo, which are supposed to communicate individual moods. Other industry stakeholders in the BCI sector have produced systems (Epoc, IntendiX, Brainfingers, BrainGate) for brain control of laptops and PCs that may be beneficial for the **computer** industry. Potential synergies with the **telecommunication** industry are exemplified by Neurosky's MindWave mobile headset compatible with Apple iOS products and Android smartphones and tablets.
Please note that despite the claims of most companies to market these products as BCIs, for some of these systems, it is not clear if control is based on neural (EEG) or muscle (EMG) activity.

B.2.3 Key BCI market applications in synergy fields

Based on the BCI definition from Wolpaw and Wolpaw (2012) and the related BCI application scenarios, we aim at introducing a tentative match among these application scenarios and new emerging opportunities in synergy fields. Potential key BCI market applications in relation to these identified synergy fields and industry sectors are illustrated in Table 1.

Table 1. Key BCI market applications in relation to application scenarios, synergy fields and industry sectors.

Application scenario	Market application groups	Key BCI-related market applications
replace enhance	communication & control	affective computing, interface to smartphones, multimodal PC interaction, apparel and accessories (**technology sector**)*
restore improve enhance	health & neurofeedback	prevention, diagnosis, therapy, monitoring, cognitive and motor rehabilitation , addiction disorders, wellness, nutrition (**medtech & rehab & robotic sector)***
replace enhance	AT & smart home control	ambience intelligence, domotics, elderly care, geriatric hospices (**technology sector**)*
enhance	safety & security	public transport (**automotive and aerospace sectors**)*, fire brigade, police, process controls, banking security, agriculture
enhance	entertainment & gaming	educational games, serious games, cinema, art, sports, meditation techniques (e.g. yoga, tai chi) (**entertainment sector**)*
enhance	neuromarketing & finance	market research, decision-making studies and support (**marketing sector**)*, neuroeconomics, stockbrokers
research	R & D	real-time analysis, signal acquisition, signal processing, output devices, BCI-hybrid interfaces, artificial intelligence & machine learning

*Relates to identified synergy fields and industry stakeholders in potential BCI-related sectors

In this sense, the ***replace*** application scenario includes communication & control, and also AT & smart home control market applications, where mainly the **technology** sector with apparel and accessories industry stakeholders joining the computer and telecommunication industry may play a fundamental role. For this aim, a BCI device ***replaces*** the natural output that has been lost as a result of injury or disease (e.g. communication, motorized wheelchair control, in-house light control, and bed position control). Health & neurofeedback applications overlap also the ***replace*** scenario, e.g. BCI applications specifically addressed to communicate with in-hospital patients in a locked-in state. Nevertheless, health & neurofeedback market applications most directly relate to both the ***restore*** and ***improve*** application scenarios. In the former, a BCI ***restores*** lost natural output (e.g. a person using a BCI to stimulate a paralyzed muscle via electrodes to move the limbs). In the latter, a BCI device aims to ***improve*** natural CNS output. (e.g. a person using a BCI to detect and enhance signals from a damaged cortical area in order

to improve functions that have been impaired). In this sense, future key BCI market applications may influence the **medtech**, **rehabilitation**, and **robotics** sectors.
The widest scope within the identified key BCI market applications can be found in the ***enhance*** application scenario, where a BCI device ***enhances*** natural CNS output (e.g. a person using a BCI to monitor attention level during a demanding task). Here, nearly all identified application groups in Table 1 could be considered. BCIs applied for safety & security in the **automotive** and **aerospace** sector will mostly benefit from this sort of BCI synergies. Similarly, BCIs applied for entertainment & gaming and also neuromarketing & finance may influence the **entertainment** and **marketing sectors.**
Finally, using a BCI as a ***research*** tool can give rise to more novel market applications not identified so far.

B.3 Future outlook

We estimated the relative market growth and relative market value of a set of identified key BCI market applications by 2020, which may enable future opportunities for interfacing with industry stakeholders, target end users, potential competitors, collaborators, and potentiate their interrelations. Further, we intended to develop general guidelines and support actionable recommendations in relation to the selected use cases, as a tool mainly to SMEs and policy makers, to promote industry innovation.

B.3.1 Future opportunities and estimated market impact

The impact of BCIs on our society is expected to increase in the near future thanks to new emerging opportunities in identified synergy fields. Expanding into new markets offers even more growth opportunities than expanding into related markets. The further a company departs from its current markets, the greater the number of opportunities. However, it is also true that the further a company travels from what it knows, the greater the risk. The difference between a related and an unrelated new market can be a matter of perspective, though.
In relation to the selected use cases, this section provides a general analysis of the industry-related questions that we have been addressing to guide future exploration avenues and business plans for the European market. We evaluated:

1. the market size (according to each target group/niche)
2. the payer (who pays?)
3. the incentive for industry (why should industry be interested?)
4. the market impact (estimated relative qualitative analysis)

B.3.1.1 The market size

We defined the target group as a group of people (or niche) who could potentially benefit from a BCI product or market application. The market size was derived from the target group, and is characterized by the estimated number of European users per year that may benefit from the corresponding BCI solution in their market niche. We classified the market size for the European market as small, medium, large or very large:

- small (< 50,000 European users);
- medium (50,000 to 1 million European users);

- large (1 to 10 million European users); and
- very large (> 10 million European users).

Market size in the replace scenario

Target groups from the different use cases in the replace scenario range from people in a completely locked-in state to survivors of a spinal cord injury (SCI) or other potential users with severe motor impairments (e.g. amyotrophic lateral sclerosis (ALS), primary-progressive multiple sclerosis (PPMS), etc.). The **market size** considering each of these user groups can be classified as **small**. However, the expected impact of BCI technologies on the QoL of each individual within these niches is very high.

Market size in the restore scenario

According to Lee et al. (2014), the incident rate for SCI in Western Europe is 16 per million, which results in about 8200 people per year suffering a SCI within the EU. Detailed data about life expectancy does not exist, but the ten year mortality is about 10% to 20%. Based on these data, we can estimate the **market size** for BCI-based neuroprostheses and equivalent implanted technologies to be **small**. Again, here the expected impact of BCI technologies on the QoL of each individual within these niches is very high. However, there are other market niches that can benefit from BCIs in the restore scenario. For example, 70,000 individuals have received cochlear implants in the United States[29], and based on this figure we estimate about 110,000 persons in the EU. Considering this specific niche of people with hearing impairments and deafness, its market size could be defined as **medium**.

Market size in the improve scenario

According to WHO estimates, the number of stroke events in EU countries, Iceland, Norway and Switzerland is likely to increase from 1.1 million per year in 2000 to more than 1.5 million per year in 2025 solely because of the demographic changes (Truelsen et al., 2006). Further, 70% of stroke survivors have deficits in arm movement and 40% are unable to use one arm in the long term[30]. The **market size** for stroke rehab is potentially **large**, i.e. > 1 million upper limb rehabs due to stroke. Additionally, as the population ages, the frequency of dementia is expected to double by 2030 and triple by 2050[31]. Recent epidemiological surveys report that North America and Western Europe have at age 60 the highest prevalence of dementia (6.4% and 5.4% of the population at age 60)[32]. The **market size** for BCI applications targeting neurorehab within this niche is also **large** and progressively growing with the aging population.

Another different example in the improve scenario is the epilepsy niche. Two thirds of all epilepsy patients can be treated with drugs and around 8% with surgery. That leaves around one third of all cases to be potential candidates for stimulation treatment (i.e. vagal nerve stimulation, non-invasive stimulation, invasive stimulation), where BCI technologies may play a synergic role. The **market size** of the epilepsy niche is also quite **large**.

[29] http://www.asha.org/public/hearing/Cochlear-Implant-Frequently-Asked-Questions/
[30] http://www.stroke.org/
[31] http://www.who.int/mental_health/publications/dementia_report_2012/en/
[32] http://www.who.int/medicines/areas/priority_medicines/BP6_11Alzheimer.pdf

Market size in the enhance scenario

In Europe, there are more than 100 million students. All of them could benefit from optimized BCI-based learning environments. However, one cannot expect that everyone will use a BCI device to enhance his or her learning skills. Still, we consider the **market size** in this niche to be **large**.

From 2005 to 2014, Microsoft sold more than 80 million units of its Xbox 360 gaming console and more than 24 million of the Kinect, which is an additional motion sensing device used as an additional input channel for gamers. Sony sold eight million units of it's Playstation Move controller in the time between September 2010 until April 2011. A BCI-based gaming device that is supported by the manufacturer of the console and by some game developer could probably reach similar selling numbers as the Kinect or the Playstation Move. The **market size** for BCI experiences in gaming applications is **very large**, the largest indeed. However, BCI technology should be affordable for each family to guarantee product success and mass penetration.

Market size in the research scenario

The **market size** in the research scenario may vary considerably from **small** to **medium**, since there exist multiple fields where a BCIs can be used to further explore the brain.

B.3.1.2 The payer (who pays?)

When it comes to analysing the payer, we could generally differentiate between BCI medical and BCI non-medical devices. In Europe, it is expected that the public healthcare system or private (health) insurance companies will finance or co-finance BCI medical devices, as those derived from the replace, restore or improve scenarios. Charity entities could also be an option, if no legal claim exists. Overall, non-medical devices, like those in the enhance scenario, will be paid by the user himself (or relatives), or by a private company, who may obtain some benefit by the use of the device. Research tools are expected to be paid by governmental entities or private companies that may profit from future derived market products.

B.3.1.3 The incentive for industry (why should industry be interested?)

For large and very large market sizes, numbers may speak by themselves. However, from the estimated small market size in the replace scenario, it cannot be expected that many companies target this market. The expected high price in those derived products and the corresponding reimbursement from private or public healthcare insurance companies may make it still interesting for SMEs or even for larger companies, if they manage to cover the whole market or a large portion of it. Similarly, the BCI solutions addressed in the restore scenario are not thought for large markets, although they could be adopted from a considerable number of users, if cost effectiveness is achieved or governmental funds are used to compensate return of investment. BCI-controlled prostheses represent a cutting edge technology with high visibility and high social impact.

B.3.1.4 The market impact (estimated relative qualitative analysis)

BCIs have already been used for restoring communication and mobility of persons with functional deficits through applications such as spellers and web browsers (Gürkök & Nijholt, 2012). In parallel to advances in computational intelligence and the introduction of consumer BCI products, BCIs have recently started to be considered as alternative modalities in human-computer interaction (HCI). A popular topic in HCI is multimodal interaction, which deals with combining multiple modalities to provide powerful, flexible, adaptable, and natural interfaces. With the emergence of portable signal acquisition hardware as well as robust data processing and artifact removal techniques, BCIs have started to be considered as an HCI modality for healthy users as well. Some potential non-medical BCI applications include games, attention monitors, and interfaces to smart mobile devices. One of the visions behind the investment in gaming applications is that the potential shortcomings of BCIs can be turned into challenges. Figure 5 illustrates the results of our qualitative market analysis estimating the relative market growth and relative market value of the identified key BCI market applications by 2020 (see section B.2.3. - Table 1). This is an approach to qualitatively assess potential future market opportunities for SMEs and other industry stakeholders in the BCI and related emerging markets.

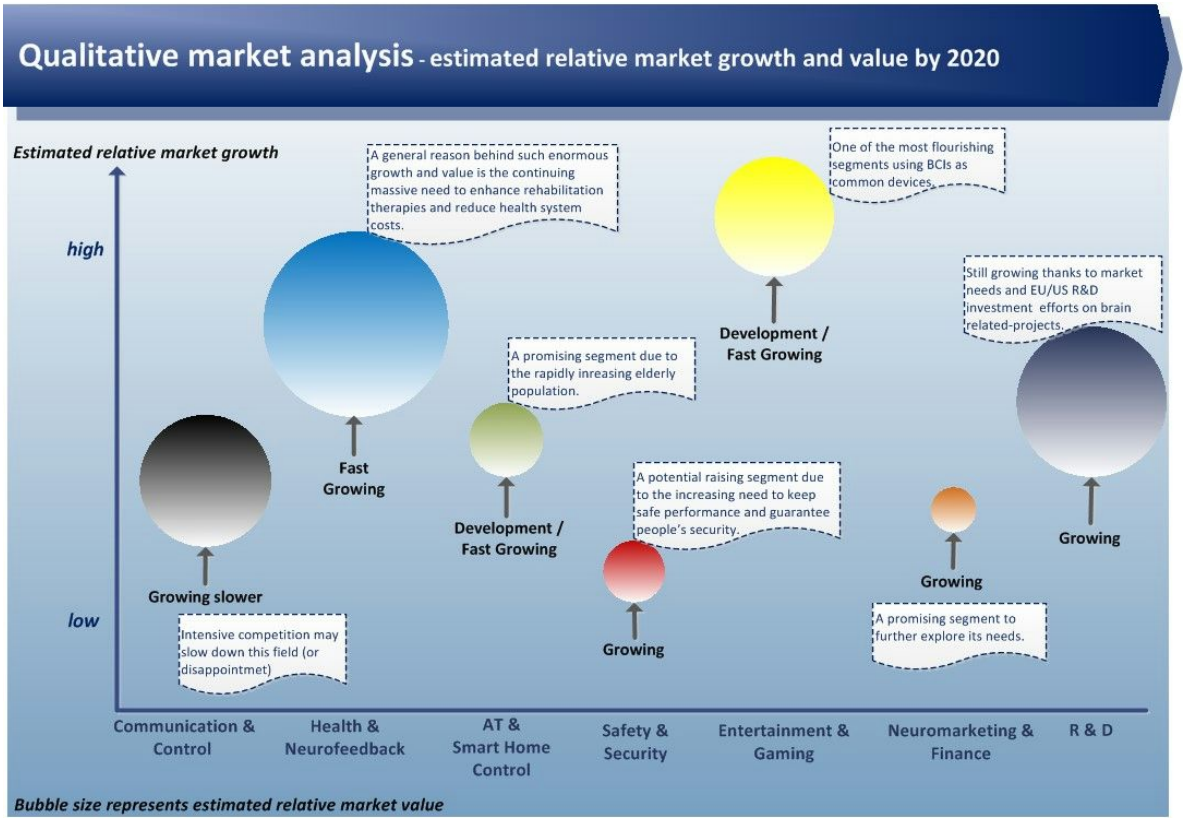

Figure 5. Qualitative market analysis on estimated relative market growth and relative market value by 2020 from the identified key BCI market applications groups.

The intensive competition in communication & control technologies, such as eye-tracking and enabling software, may slow down the growth of this conventional and most specific BCI field - but just relative to other new emerging applications groups, as illustrated in Figure 5. A general reason behind the enormous growth in health & neurofeedback market applications is the major need to enhance rehabilitation therapies and preventive practices (e.g. to delay cognitive impairment) in an effort to reduce overall healthcare system's costs. The increase in life expectancy in emerging market countries, and the rapidly growing elderly population in our society will give rise to larger market opportunities in related fields in the upcoming years. This demographic framework makes health system policies having to face several challenges concerning care for the elderly and co-morbidities associated with old age. In the same line, new BCI solutions can emerge as AT & smart home control applications, thus growing faster and in parallel with health & neurofeedback related applications. This assumption is based on the idea that rehabilitation does not need to restrict itself to the hospital, but could also take place at the patient's home. Of course, BCIs for rehabilitation and BCIs for AT are two different approaches. However, if end users get used to BCI devices "for rehab at home", this can open a window to use the same BCI device as a new way to generally access the environment.
Furthermore, safety & security applications are now a real segment due to the increasing need to guarantee people's security and safety in diverse settings. Clearly, entertainment & gaming applications are among the most flourishing segments using BCIs as common devices. For its success, it is essential to find a trade-off among high-tech and affordable cost. This is the reason why its estimated relative market value may be smaller in comparison to other BCI market applications. However, entertainment & gaming applications may turn BCI shortcomings into challenges finding potential new users and become an incentive for future industry investments that may lead to the highest estimated relative market growth (see Figure 5). Likewise, but not yet with such a growth, neuromarketing & finance applications may be quite promising. BCIs may help to further explore consumer needs and even influence (IT) finance as a whole. Finally, R & D investment efforts are still required to try to answer basic science questions aiming to improve real-time processing methods and self-learning algorithms, to increase throughput rates, and to achieve higher accuracy and reliability.

B.3.2 Guidelines for technology transfer

We present a list of BCI requirements, which can be used as general guidelines for BCI exploitation and technology transfer. These guidelines are derived from the consortium's experience and the work on the specific use cases, and were also capitalized from previously established networking activities in BCI-related congresses and with other external industry stakeholders. This section highlights major milestones for industry stakeholders, the BCI community and policy makers towards BCI commercialization, product success, and general acceptability.

→ For industry stakeholders

Type A: End user, customer & commercialization requirements

A.1: Market research analysis

- **A.1.1**: competitors and SWOT[33] analysis to discover new opportunities
- **A.1.2**: identify how the customer perceives an improvement or novelty versus existing BCI solutions on the market (or in the research field)
- **A.1.3**: identify how the customer perceives novelty versus existing alternative competitors on the market (or in the research field)
- **A.1.4:** identify specific end-user and customer needs coming from different synergy fields (e.g. medical devices, robotics, gaming, ICT, marketing, safety...)
- **A.1.5:** plan and target at cost-effective solutions adapted to the specific field, use case and technology that is being addressed/used

A.2: Usability studies & testing

- **A.2.1:** early and continuous involvement of potential end-users, understanding of user/customer requirements and the whole user experience
- **A.2.2**: undergo usability studies addressed to the user, and his/her task and environment in each specific field (effectiveness, efficiency and user satisfaction)
- **A.2.3:** recognise different training needs
- **A.2.4:** conduct acceptability studies

A.3: Licensing & certification

- **A.3.1**: develop and use standards for BCI hard- and software
- **A.3.2:** obtain CE and (if required) medical certification
- **A.3.3:** (if required) conduct clinical trials (safety, feasibility and clinical efficacy)

A.4: Advertising

- **A.4.1:** improve knowledge of the access and availability of BCI systems for potential users (e.g. specific groups of people with functional deficits, their relatives, care-giving institutions and the general public)
- **A.4.2:** establish specific target campaigns for BCI solutions (e.g. targeting people with functional deficits, especially in the replace scenario where retailers/intermediaries may filter the access to end-users)
- **A.4.3:** extend dissemination mechanisms

Type B: Technology non-functional requirements *(product quality levels)*

B.1: Invasive BCI solutions

- **B.1.1:** very high resolution implantable sensor systems (e.g. ECoG grids or Utah arrays)
- **B.1.2**: fully-implantable multiple-channel amplifiers
- **B.1.3**: advanced real time signal processing techniques for high resolution data

[33] Evaluation of the strengths, weaknesses, opportunities and threats

- **B.1.4:** reliable sensory feedback mechanisms to the sensory cortex
- **B.1.5:** very low power consumption
- **B.1.6:** highly reliable wireless power techniques to charge micro-implants via near-field wave technology
- **B.1.7:** feasibility approval for long-term implant system durability (i.e. implants are required to provide long-term good signal quality and to last for > 10 years)
- **B.1.8:** safety approval for long-term implant systems (i.e guarantee safety and minimise related secondary adverse events).
- **B.1.9:** (derived from A.3.3) clinical studies (including risk-benefit and cost-benefit studies) to demonstrate clinical efficacy and gather the "standardised" required implant certification - (if required) learn from other implant fields (e.g. pacemakers, defibrillators, SC neuro stimulators, DBS)

B.2: Non-invasive BCI solutions

- **B.2.1:** robust and reliable biosignals decoding and against interference
- **B.2.2:** robust continuous classification and adaptive learning algorithms, allowing data fusion of several streams
- **B.2.3:** user-friendly and comfortable BCI hardware (sensor technology and setup time) allowing long-term use at different settings (e.g home use, on the street - outside the lab)
- **B.2.4:** minimal or no calibration
- **B.2.5:** fast user-initiated action selection
- **B.2.6:** (for specific use cases) relieve BCI control platforms
- **B.2.7:** low-power and wireless solutions
- **B.2.8:** non-visible or aesthetically pleasing (e.g in-ear sensors or integrated in a cap)
- **B.2.9:** feasibility studies for system durability and especially system performance in home (outside lab) environment
- **B.2.10:** (if required; derived from A.3.3) clinical studies (including risk-benefit and cost-benefit studies) to demonstrate clinical efficacy and gather medical certification

→ For BCI community and policy-makers

Type C: Ethical & social requirements

- **C.1:** support initiatives in relation to ethical approval
- **C.2:** encourage proactive attitude towards BCI solutions, especially towards invasive BCI solutions
- **C.3:** strengthen the dialog between end-user groups and BCI research community
- **C.4:** establish feedback mechanisms from opinions leaders and decision makers to assure that appropriate guidelines are received

Type D: Finance & funding requirements

- **D.1:** increase research funding for BCI initiatives relevant to society and encourage feedback mechanisms from academia to industry and vice versa
- **D.2:** invest directly into SMEs that support BCI initiatives relevant to society

- **D.3:** support market research studies to analyse and promote commercialization of BCI-related products
- **D.4:** support standardisation bodies that promote commercialization of BCI-related products
- **D.5:** strengthen collaboration & private funding in identified synergy fields (e.g. robotics, HCI, medical devices, automotive, ICT)
- **D.6:** (if required) support proof-of-concept studies necessary to improve safety and standard technical specifications (e.g. sensitivity, power consumption, usability, robustness, reliability) getting towards a functional device
- **D.7:** (if required) support co-sponsorship of pre-clinical and clinical trials (safety, feasibility and clinical efficacy) in relevant fields for society
- **D.8**: (if required) support device approval and assist investors towards commercialization

B.3.3 Conclusions

Overall, from the industry perspective, we can summarise the following concepts:

- Nowadays, most BCI-related products are made for research and development purposes.
- Based on current market research, a shift towards more specific end user products can be expected in the following years caused by a larger market demand.
- Health-oriented market applications in the medtech, rehab, and robotics sectors (but also in synergy with the automotive, aerospace and technology sectors) are likely to be among the most promising opportunities for specific BCI applications to enter the market.
- Notwithstanding, the entertainment and gaming sectors may uncover flourishing market potentials through the enormous number of still latent future customers (probably the largest market size among all possible BCI applications). This will lead to significant investments in further (low-cost) technology and fabrication development, which is expected to have a stimulating influence back into the health-related market opportunities.
- From the BCI application scenarios' view, the highest industry impact within the next years is expected to be in the improve scenario, especially for neurological rehabilitation. BCI-based systems in such a field may potentially reach the highest market value, i.e. good margin and a rising number of end users due to the ageing population.
- BCI application scenarios with a smaller number of potential end users (i.e. small market size) may offer a dramatic enhancement in quality of life for specific niches. However, these specific solutions will require more funding opportunities in order to create customised and high quality products.

B.4 References

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