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論文題名

Brain-Computer Interface–A Glimpse of the Revolution Yet to Come－

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論 文 要 旨

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Brain-Computer Interface–A Glimpse of the Revolution Yet to Come-

This paper seeks to introduce to the general crowd and business investors over the emerging technology of brain-computer interface (BCI) and the important roles and business chances that BCI may deliver in the future. While the fields of neuroscience and brain imaging has long been introduced, it is not until recent years that technology advancements finally allow for a better understanding of the human brain and the mechanics of our sensory systems, at a less prohibitive cost for many different research parties. Although BCI technologies and commercialization efforts are still at their infancy, there has already been numerous research projects throughout institutes in the world in using BCI as a revolutionary form of medication, or new IT startups trying to build upon BCI technologies for personal consumption such as novelty toys. Large corporate efforts, on the other hand, seems to remain fairly under involved, and the majority of the general crowd are unaware of this area of research. The purpose of this paper is to generalize as much about BCI as possible, by combining some of the current BCI research trends, to form up a plausible roadmap of what is expected to come in the future, in hopes of helping current and future investors or business leaders to leverage on the technologies that can hopefully secure a reasonable amount of fortune, while ultimately granting the human race a better life.

This paper is largely written in English. However, in hopes of having a broader audiences, a shorter, Japanese summary is provided at the end of each chapter.
本論文は英語で執筆されているが、より多くの方に読んでもらうべく日本語版の短編サマリーを各章に収録してある。

Keywords: Brain-computer interface (BCI), prosthetics, invasive / non-invasive BCI, electroencephalography (EEG), prosthetics, neuroprosthetics, neurofeedback, neuromarketing, neurogaming, natural user interface (NUI), virtual / simulated reality, immersive experience / presence, entrepreneurship, incremental innovation, radical innovation, skunkworks, crowdfunding, dominant design

Brain-Computer Interface

–A Glimpse of the Revolution Yet to Come−

Abstract

This paper seeks to introduce to the general crowd and business investors over the emerging technology of brain-computer interface (BCI) and the important roles and business chances that BCI may deliver in the future. While the fields of neuroscience and brain imaging has long been introduced, it is not until recent years that technology advancements finally allow for a better understanding of the human brain and the mechanics of our sensory systems, at a less prohibitive cost for many different research parties. Although BCI technologies and commercialization efforts are still at their infancy, there has already been numerous research projects throughout institutes in the world in using BCI as a revolutionary form of medication, or new IT startups trying to build upon BCI technologies for personal consumption such as novelty toys. Large corporate efforts, on the other hand, seems to remain fairly under involved, and the majority of the general crowd are unaware of this area of research. The purpose of this paper is to generalize as much about BCI as possible, by combining some of the current BCI research trends, to form up a plausible roadmap of what is expected to come in the future, in hopes of helping current and future investors or business leaders to leverage on the technologies that can hopefully secure a reasonable amount of fortune, while ultimately granting the human race a better life.

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1. Introduction / はじめに

When Anakin Skywalker lost his arm during his duel against Count Dooku, the technologies in Star Wars allowed him to easily replace it with an artificial one that works exactly like his organic counterpart. While most of us probably just enjoyed it as a simple science fiction moment, scientists and engineers sit back with their eyes filled with flaming jealousy. Indeed, the current commercially available prosthetics that we have in reality is nothing like those science fiction movies. Despite huge technological breakthroughs in numerous areas such as material engineering and kinesiology that allow for far better designs and functions in prosthetics designs than the early days, it is general knowledge that most of them are slow and cumbersome. They only partially restore a patient's normal daily life, and are not aesthetically pleasing either.

Switching channels, we arrive at the world of The Matrix series, a tragic era when humanity is unknowingly enslaved inside a gigantic, indistinguishable simulated world known as "The Matrix", by The Machines who cultivates and harvests mankind's bioelectricity. Of those humans who do wake up, they have little choice but to learn about the mechanics of the Matrix and alter some of its code to perform superhuman capabilities, to combat The Machines who impersonate as human governmental agents to eliminate them. Now, violence and warfare aside, consider a day when many of the real world luxuries, unique services, or superhuman strength would become available in a virtual, fully interactive environment which is much more accessible, affordable, and entertaining for all groups of people. Indeed, as technologies progress, human beings are increasingly being given the capabilities of "playing God", to achieve an incredible amount of feats that may easily translate into business profit.

映画スター・ウォーズのアナキン・スカイウォーカーがドゥークー伯爵との決闘にて腕を失ってしまったものの、後に義肢で代用され、正常の生活を取り戻している。一方、映画マトリックスでは、模擬現実に等しい仮想の世界にて人間は超人的な身体能力を入手し、人間を支配しようとするマシーンと壮絶な戦いを繰り返している。どちらもＳＦのみの作り話であったが、「ブレイン・コンピューター・インターフェイス」、または BCI（日本では、ブレイン・マシン・インターフェイスとして知られる）、という技術の発展により、それが実現しつつある。暴力のテーマはさておき、BCI 技術の様々な応用は、巨大なビジネスチャンスに繋がる可能性を秘めていると言っても過言ではない。

1.1 Lack of Large Corporate Efforts, Despite the Potential / 問題意識：注目度の低さ

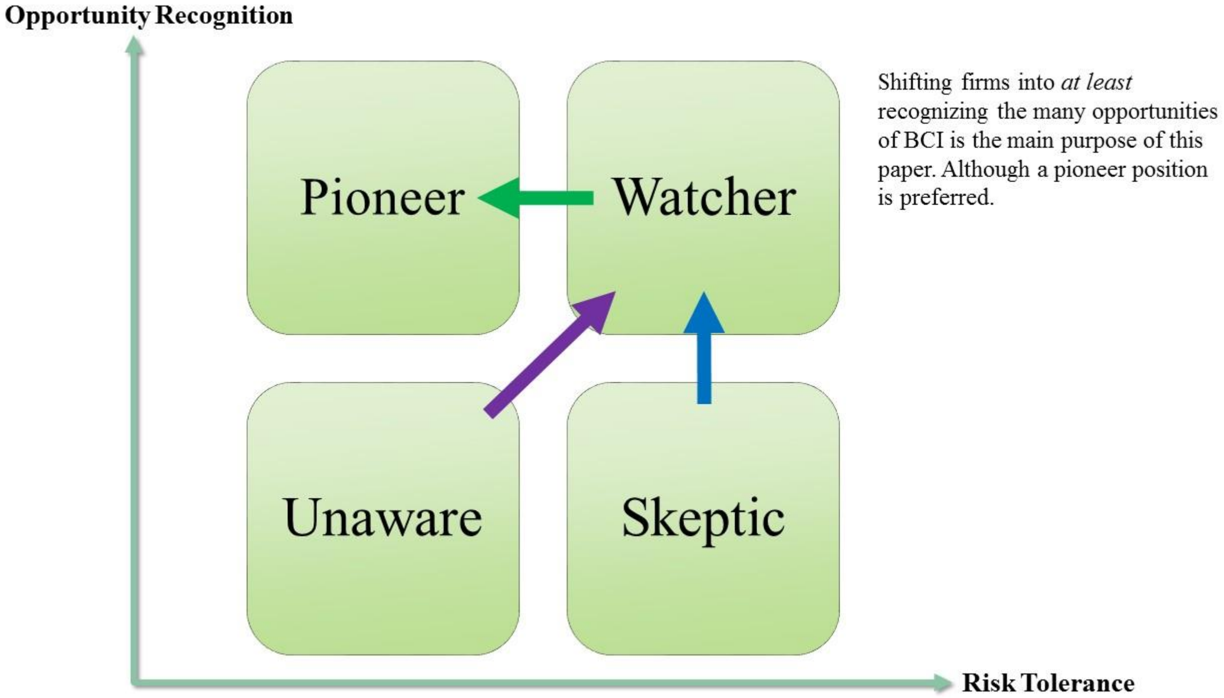
Those sci-fi movie plots previously mentioned, could potentially be made possible with brain-computer interface (BCI) technologies, pending future R&D and commercialization efforts. However, just as was how only a handful of visionaries such as Bill Gates or Steve Jobs recognized the importance of personal computers and consumer electronics, which lead to them founding their own companies that would ultimately grow into IT empires, commercially available BCI technologies today also largely remain as venture efforts, with large corporates either silently watching or even completely unaware of them, despite their large amount of resources at hand. While at the same time worldwide institutional researches, SMEs (small and medium sized enterprises), or individual enthusiasts surge forward steadily every single day with new theories, discoveries, or innovative ideas.

BCI 技術の高い潜在性に関わらず、一部の中小、ベンチャー企業を除き、現状では、大手 IT 企業が積極的に BCI 技術のノウハウを取り組もうとするのはそう多くはない。後述する BCI 技術の多様な応用幅を考慮すると、BCI 技術に注力している中小企業は、80 年代のまだ中小企業だったマイクロソフトやアップルに類似している。BCI は世間では大幅な認知を得られていないものの、水面下ではすでに、研究機関やベンチャー企業による新理論やイノベーションが雨後の筍のように日々溢れていると言える。

1.2 The Goal of this Paper / 目的

By examining at the many potentials of BCI, it is likely that most will ultimately arrive at the conclusion of how these technologies may trigger a new era of business revolution that will likely translate into a substantial amount of profit across many different business sectors. While at the same time, they will propel the lifestyle and welfare of humanity further forward towards a healthier, more convenient, and more equal society.

However, save for a few, the commercialization efforts of BCI currently remain dominantly at SME level. Thus, the main goal of this paper is to bridge the gap between technology and business that can hopefully help BCI gain more awareness among audiences of any age groups or backgrounds. The goal of this paper is to encourage and accelerate BCI R&D and commercialization efforts in hopes of turning science fiction into reality and prosper together as a race.



本論文の最大の目的は、BCI のあらゆる応用可能性を整理し、投資家や企業家にその背後に隠されているビジネスチャンスや人間社会に対する有意性を促し、直接投資に達しなくても関心を呼び起こし、BCI 技術の商用実現化を加速させることである。

1.3 Format and Study Method / フォーマット及び研究手法

This paper will be split into two chapters: Part I is more descriptive and explores the basic background of BCI and the many promising applications of it. Most of which will be based on readily available scholar papers, consumer electronics news, and secondary market analysis data for different applications of BCI. Part II involves a deeper observation of the *current* BCI market, venture efforts and research trends to devise a plausible future roadmap. Part II also postulate on why large corporates may choose to stay out of it at this time, and what can be learnt from BCI venture leaders, based on established scholarly researches and professional opinions. We will also propose some possible strategies for firms to become pioneers in this technology.

Due to BCI industry being largely at its infancy, the fact that most large corporates' choose to be mere observers, that venture companies are mostly private and rarely report their detailed financial performances publicly, only a handful of fragmented business information can be retrieved and utilized. For this reason, the study methods will be limited to a purely inductive, qualitative study with a minor abductive twist, by collecting science news journals and conducting expert interviews and analyze the situation, to arrive at the possible root cause of the problem mentioned in section 1.1.

Technical information, such as mathematical equations, overly detailed neuroscience, or computer science aspects of BCI are far beyond the scope and relevance of this paper and will be deliberately kept as brief and short as possible.

本論文は二部に分かれている。第一部は、BCI の大まかな定義、種類、利用幅等を整理・解説した。第二部は、今現在の商用 BCI 業界の現状やトレンドを整理し、投資家や経営者に対して有力な投資分野や早期に取り組めると思われるいくつかの戦略オプションを提示することを目的としている。

現在の BCI 業界の有力企業はほぼ非上場の中小ベンチャー企業が占めており、財務諸表による定量分析は困難を極めるため、本論文は定性分析に限定することとなった。なお、専門性の高い用語や計算式は本論文の研究目的や範疇に含まれないため、詳細は割愛した。

Part I
Introduction and Application of Brain-Computer Interface

“What is real? How do you define 'real'? If you're talking about what you can feel, what you can smell, what you can taste and see, then 'real' is simply electrical signals interpreted by your brain.” (Morpheus, The Matrix, 1999)

2. Definition of Brain-Computer Interface / ブレイン・コンピューター・インターフェイスとは

BCI is short for “brain-computer interface”, which refers to any technology that connect the human brain with computers devices or machines, eliminating the need to use an external input device or physical contact to control it. This is achieved by measuring changes in brain activities, process them into digital signals, and interpret them into command inputs that computers understand, and also the exact converse in a more distant future to download information into our brain. BCI is a combination of traditional electronics engineering and neuroscience. It is an emerging research field that has only recently come to attention by a handful of technology pioneers, with several novel toys or wearable devices being released or planned. Depending on the context of what the brain is being connected to, there can be many different names for BCI, such as brain-machine interface (BMI), cerebral interface, neural interfaces, direct-control interface, etc. However, whatever the name, what they seek to achieve are all similar — connecting the human brain to some artificial devices to achieve some otherwise previously impossible feats. (Wolpaw JR, et al., 2000) For simplicity, this paper will refer to all of them as BCI in this article.

BCI とは「ブレイン・コンピューター・インターフェイス」の略称であり、コンピューターを始め、人間の脳をあらゆる電子機器に繋ぎ、他の入力デバイスを使わずに制御するのが目的である。日本では「ブレイン・マシン・インターフェイス」(BMI) とされることは多いが、多くの機械で演算ユニットを内蔵している近年では、同様の物だと考えて差し支えない。本論文は、こういった電子機器を BCI として統一して称することとしたい。

2.1 Basic Neuroscience and Electroencephalography (EEG) / 神経学及び脳波とは

Our brains process information by a type of cells called “neurons”. We can think of it as a computer connected on the internet, where it receives information from many other computers, processes them, and then outputs it out to other devices for further processing. One thing worth noting, however, is that connections between neurons are "*plastic",* meaning that it allows our brain networks to adapt to new inputs and changing circumstances (e.g. something artificial), as opposed to real computers which are less flexible and rely on serial computations (e.g. a device driver program must be installed before new changes to the system can be understood). When sufficiently strong inputs occur, there is a rapid change in the level of K+ and Na+ ions. This rise or fall in ion activities produce electrical pulses that are called "action potentials" or "spikes", the main methods of communication between neurons. Each spike transfer little to no information, and is not unlike the 0 and 1 based binary systems of an ordinary computer. It is generally agreed that information is carried in the form of "how fast spikes occur in one second" and "the timing of the spikes". Measuring these spikes directly via electrodes form the basis of electroencephalography, or EEG, one of the oldest, but the most used methods of measuring brain activities. (Rao, 2013)

Other than electrical changes, there are also other ways of imaging for brain activities, such as minor changes of blood flow, magnetic fields generated by electrical activities of the brain. These imaging methods form the basis of other techniques. (Rao, 2013)

人間の脳は、意識の有無に関わらず、どんなに微小であれ体のあらゆる部分を動かす際に必ず「ニューロン」と呼ばれる神経細胞を介して情報を伝達する。この際、電気パルスが発生し、それを「脳波」と呼ぶ。脳波の電気パルスを探知するための技術を EEG（脳波計）と言い、現時点では最も古いと同時に、最も多用される手法である。EEG の他にも、血流、電磁気など多様な探知方法があり、どれも一長一短であり明確に優れている手法がないとされている。

2.2 Invasive and Non-Invasive BCI / BCI の種類

To properly monitor and process brain activities, the measuring devices need to be in close proximity to the human brain. To achieve this, there are two main categories of BCI: invasive and non-invasive. Different categories and measurement techniques of BCI offer varying degrees of spatial and temporal resolution. Spatial resolution can be described as the clarity of the images or information retrieved, while temporal resolution refers to how accurate a measurement is in respect to time. (Rao, 2013)

脳活動を正確に計測するためには、センサーは脳の付近に設置される。このため、BCI には二種類のカテゴリがあり、侵襲的（invasive）と非侵襲

的（non-invasive）と分かれる。あらゆる計測手法はそれぞれの得意分野があり、主に空間分解能（spatial resolution）と時間分解能（temporal resolution）で評価される。簡単に言えば、空間分解能は取得した情報の精度や有意性、時間分解能は計測の時間的精度である。

2.2.1 Invasive BCI / 侵襲的 BCI

Like its name literally suggests, invasive BCI involves surgically opening the skull and planting sensor devices either deep into the brain or onto the surface of the brain. To this date, invasive BCI will always be able to obtain the most accurate and clear readings of brain-activities compared to non-invasive alternatives. (Rao, 2013) Quite obviously, invasive BCI is most likely only suitable for research or medical purposes such as for treating amputees or brain diseases. Its feasibility of being marketed towards the able-bodied mass market is very slim, considering the risks and fear factors of requiring a foreign objects inserted into our brain.

Currently, many electronics devices need non-organic components to protect it from damage. Thus, in the event of a successful approval from regulatory agencies and / or commercialization attempt of a certain invasive BCI device, two important design considerations will be whether the sensors are biocompatible and / or biodegradable. Biocompatibility refers to whether cells would grow and encase the largely non-organic implant, and insulate it over time as a part of our body’s natural defensive mechanism against a foreign project. This will eventually compromise its effectiveness, resulting the BCI system to fail and may cause potential irritation or tissue damage. (Rao, 2013) On the other hand, biodegradability refers to whether if the sensors can eventually “melt away” in our body. There are several reasons for considering this: such as to simply ignore the device when it is no longer used, to have more flexibility, to eliminate the number of brain surgeries needed for removing the implants in case of malfunction or maintenance. Or ultimately, to effortlessly handle and deliver a large device that contains nanometer-sized electrical circuits deep inside the brain that are too small to cause rejection or harm, while the rest, unneeded parts decays away (Rao, 2013) (Litt B., Roger J., et al., 2010) (MIT Technology Review, 2009).

侵襲的 BCI は文字通り、頭蓋骨を開け、電極センサーを脳組織の表面に直接付けるか、脳内に埋め込む手法である。手術を必要とし、且つリスクを伴っているため、医療用以外の商業化には不向きである。しかし一方、情報の精度や探知の速度に優れており、後述の非侵襲的 BCI をはるかに凌駕している。侵襲的 BCI を商業化するためには、デバイスを構成する物質の「生物的適

応性」（biocompatibility）や「生物的分解性」（biodegradability）は重要なポイントとなる。前者は安全性を考慮し、体の防衛機能に拒絶されない物質を指し、後者は自然的に体に吸収されることを指す。分解性は、不要になったセンサーを手術することなく自然廃棄する際、または近未来、微小すぎて拒絶反応が起こらないナノマシンをより簡易に埋め込む際に有用だとされている。

2.2.2 Non-Invasive BCI / 非侵襲的 BCI

Non-invasive BCI require no surgeries. These are devices or techniques that are placed in proximity to, or on the scalp to measure brain activities. While much more suitable for being marketed towards the general crowd, the existence of the human skull greatly interferes with the accuracy of the readings. Depending on the techniques used, there is often a tradeoff between either spatial or temporal resolution, portability, or cost, making different techniques only suitable for a certain purpose at this stage (Rao, 2013). Despite the shortcomings, many simple and interesting tasks and applications have already been developed at numerous institutes or some companies. Firms other than those who are directly involved in neuroscience and the biomedical industry will likely focus more on the non-invasive category of BCI in favour of a bigger audience.

There are several types of non-invasive brain imaging techniques for BCI. Each with their pros and cons*[1]:

	EEG	MEG	fMRI	fNIRS	Functional Ultrasound
Spatial Resolution	Bad. Lots of noise. Surface only	Good	Very Good	Worse than EEG. But better skull penetration.	Higher than EEG. But also lots of noise.
Temporal Resolution	High	High	Low	Low	Moderate
Portability	Portable and compact	Institute-grade, Cumbersome. Need shielding to prevent interference	Institute-Grade, Cumbersome	Portable, but prone to environmental interference	Ultrasound devices are usually portable
Cost	Low	High	High	Low	Low

1 Organized based on information from *Brain Computer Interfacing: An Introduction* by Rajesh Rao, 2013 and *A Brain-Computer Interface Based on Bilateral Transcranial Doppler Ultrasound*, by Tom Chau, et al., 2011. Edited and verified with the assistance of Associate Professor Yasue Mitsukura, Department of System Design, Faculty of Engineering, Keio University.

Electroencephalography, or **EEG**, is one of the oldest, but also the lighter, and cheaper methods for brain imaging. As was mentioned earlier, EEG detects brainwaves by placing electrodes on the scalp to measure and interpret the fluctuations in electrical currents as brain activities change. BCI sensors that are commercially available today are almost exclusively EEG due to its cost, portability, high temporal resolution, and relative ease of use. However, it cannot penetrate deep into the skull nor the brain tissue, making measurements largely superficial. EEG also pick up a significant amount of potentially unwanted signals – known as artifacts (or noises), which must be filtered out to obtain a more precise measurement. These drawbacks contribute to EEG's poor spatial resolution of information, which require extensive R&D work in techniques such as signal processing to filter out any irrelevant data. (Rao, 2013).

Magnetoencephalography, or **MEG**, measures brain activities via magnetic fields generated by electrical currents in the brain. MEG offers both favourable spatial and excellent temporal resolution when compared to other imaging techniques. However, it is very cumbersome and expensive. MEG is also prone to interference from magnetic fields of any sort, including Earth's own magnetic field, requiring a heavy shielding. These drawbacks currently limit MEG's use at institutional environments (Rao, 2013). However, there have been research efforts such as the United States National Institute of Standards and Technology (NIST) who are attempting to miniaturize MEG sensors into portable sizes, at an affordable cost. If successful, it may potentially open up a new chapter in commercial BCI devices (NIST Tech Beat, 2012) (Exhibit 3).

Functional magnetic resonance imaging, abbreviated as **fMRI**, measures brain activity via detecting changes in blood flow. When neuron activity intensifies, more oxygen will be required, thus triggering a blood flow towards a particular area of the brain which is picked up and interpreted by fMRI. fMRI currently offers unrivaled spatial resolution compared to any other imaging methods. Like MEG, fMRI is also very big and expensive. Subjects must also lie down for scanning procedures to be conducted and the uncomfortable experience may affect thinking patterns, further adding its impracticality to be sold as a consumer device. (Rao, 2013).

Functional near infrared imaging, shortened as **fNIR**, is an optical technique for also measuring the changes in blood flow, by emitting infrared light into the brain and measuring how much infrared light reflects back to the device due the oxygen level in the blood affecting infrared light absorbance. fNIR's spatial and temporal resolution are both unfavourable, even compared to EEG. However, the unique nature of infrared lights allow for a few centimeters deeper penetration into the human skull and brain tissue, and are less prone to artifacts, allowing for the retrieval of information that is not available from EEG. fNIR is also portable and light (Rao, 2013). fNIR is a newer addition to BCI. For this reason, no commercial consumer product has been released yet to this date. However, some of fNIR's unique properties have already caught the eyes of many researchers. There are already research projects underway attempting to integrate EEG and fNIR into a hybrid system so that they could offset the disadvantages of each other. (Gillespie B., Shewokis P., et al., 2011)

Functional ultrasound, or **fUS**, is the latest addition to non-invasive brain imaging, by emitting sound waves into the brain and measuring the time it takes to be reflected back to the sensor. While also picking up quite a substantial amount of artifacts like EEG, sound waves easily penetrates the skull or brain tissues, generating much more information (but also more artifacts) that are otherwise unobtainable. fUS is said to offer spatial resolution better than EEG while maintaining a moderate temporal resolution. Ultrasound devices are also fairly portable, making the potential developments behind fUS a very interesting topic to observe. (Chou T., et al., 2011) (Tanter, M., et al., 2011)

手術を必要としない非侵襲的 BCI は、より商業化に適しているのは言うまでもない。しかし、頭蓋骨や脳組織の干渉により、脳活動計測時の情報の精度や有意性を低下させてしまう。また、手法によって大量のノイズも探知してしまい、それを消去するためには、信号処理など高度な技術や労力を要するが、近年ではようやくその仕組みを解明されつつある。非侵襲的 BCI の計測手法は多様で、分解能、コスト、利便性などの面において、それぞれの長所と短所があるとされている。

前述の **EEG**（electroencephalography、脳波計）は、情報の有用性や精度である空間分解能が低いものの、時間分解能に優れており、大量の情報が得られるとされている。さらに、コストや携帯性も傑出しており、現時点で BCI デバイスが用いたセンサーのほとんどは EEG がメインとなっている。

MEG（magnetoencephalography）とは脳磁計である。電気パルスが生じる際、自然の物理現象として磁気も生じるため、それを測るのが MEG である。磁気は頭蓋骨に影響されることが少なく、精度は非常に高いものの、コストが高く、大型で携帯性に問題があり、干渉に弱いため磁気シールドを要し、消費者向けに商業化するのは非常に難しいと思われている。しかし、アメリカ国立標準技術研究所では MEG を小型化するための研究を進めており、もし成功すれば BCI 技術に大きな進展をもたらすと言われている。

fMRI（functional magnetic resonance imaging）とは、磁気共鳴機能画像

法である。MEG と同じく磁気を用いた計測手法であるが、電気パルスではなく脳活動による脳内血流の変化を測るのが最大の違いである。空間分解能の精度は突出しているが、時間分解能の精度は低いとされる。また MEG と同じく大型機器で高価なため、消費者向けに商業化するのは不向きとされている。さらにほとんどの場合、ユーザーは横たわる必要もあるため、BCI に取り組むにはやや使いづらさがあるという側面もある。

fNIRS（functional near-infrared spectroscopy）とは、近赤外脳機能計測法であり、fMRI と同じく脳の血流を測る技術であるが、磁気ではなく赤外線が用いられている。fNIRS の精度は高くないものの、赤外線は電気パルスよりも頭蓋骨に対する貫通力が高いため、EEG では探知しにくい情報を探るのに有用だとされている。fNIRS は携帯性とコスト面でも優れており、消費者向けの BCI としては有力技術の一つだとされ、近年脚光を浴びている。

fUS（funtional ultrasound）とは機能超音波画像法であり、非侵襲的イメージング手法として比較的歴史の浅い手法である。fMRI や fNIRS と同じように血流を測る手法であるが、超音波を用いるため頭蓋骨の干渉を受けづらく、かつ中程度の空間分解能を持つとされている。超音波技術も比較的携帯性に優れているため、今後の発展や応用は見逃せないであろう。

2.3 Brain Stimulation and Bidirectional BCI / 脳への刺激と双方向 BCI

So far, we have introduced many imaging methods for obtaining brain data that can be interpreted into information or command inputs for computers. However, the reverse is also possible, and a BCI system that is able to accomplish both is called a bidirectional BCI. By stimulating various areas of the brain via techniques such as magnetic fields, electric pulses, or ultrasound, it is also possible to either enhance brain performance or even create imaginary sensory feedbacks, such as simulating the senses of touch, taste and smell. Given the fact that every brain is unique and that we still have yet to fully understand the various areas of this vital command centre of our body, it is extremely challenging for brain stimulation to be done with pinpoint accuracy, and even more so for non-invasive BCI. However, it is far from impossible, as there are already implants and prosthetics that have successfully partially replicated tactile, visual, or auditory senses (Rao, 2013). In a recent brain-to- brain experiments with non-invasive technologies, researchers have successfully transmitted simple greeting messages such as “Hola” across several thousands of kilometers of distance between 2 different brains (Ruffini G. et al., 2014). As experiment techniques become more complicated and mastered overtime, eventually we may be able to upload images or create fully traversable virtual environments, completely inside our own mind like a dream.

ここまで脳活動の探知をメインに紹介を行ったが、映画マトリックスのようにその逆も可能である。電子信号を電気パルスや超音波や磁気などに変え、脳を刺激することによって仮想的感覚や脳機能の強化も可能だと判明している。脳で機械を操作し、そして機械から脳にとって有意義な情報を受け取るのは双方向（bidirectional）BCI と呼ばれている。探知だけでも精一杯の現時点では商業化するための動きはまだ少ないが、今後の発展や応用には目が外せないところである。

3. Applications of BCI / BCI の応用

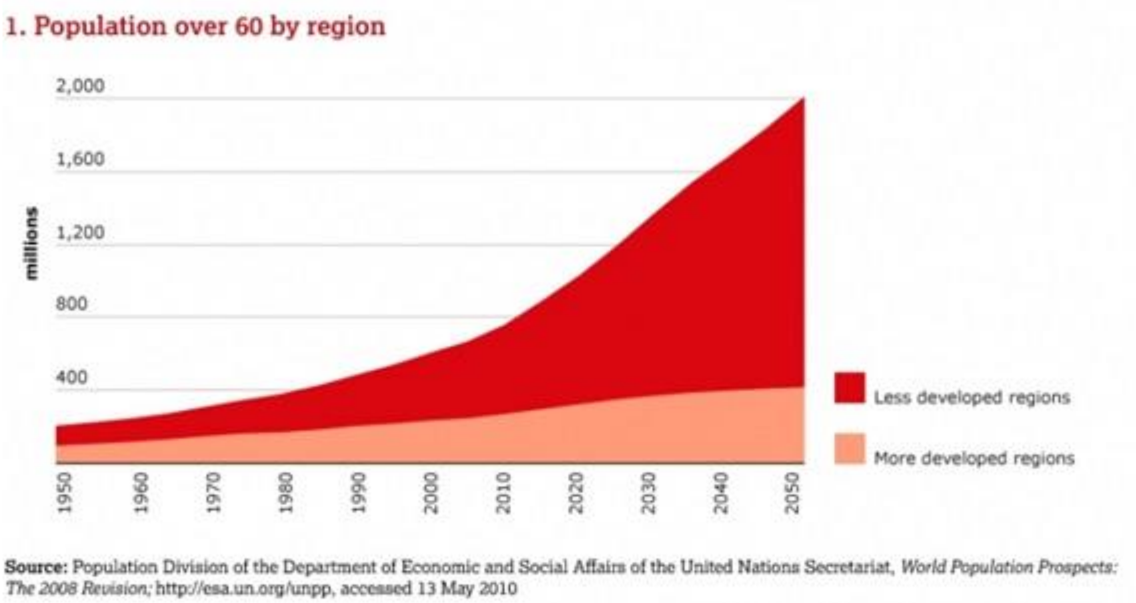
There are numerous applications for BCI technologies. Based on recent research journals, we will subjectively divide them by either near-future (5 years) or distant future (10 years more) in terms of feasibility. The former indicates applications that can be or are already achievable today, only pending on further commercialization efforts, while the latter still require extensive R&D efforts and funding, but otherwise also promising.

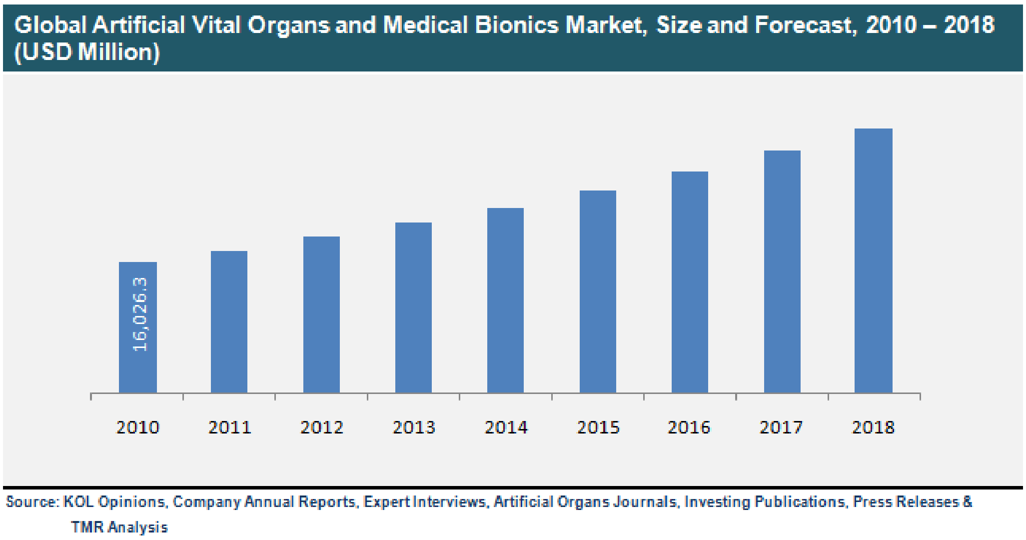
BCI のあらゆる応用をこの章にて紹介する。主観的ではあるが、それぞれの分野の商業化の実現可能性を「現在/近未来」と「遠い未来」に分けている。

3.1 (Near Future) Prosthetics and Bionics / 義肢装具

Prosthetics are artificial body parts that replaces the corresponding organic limbs or organs that are damaged through natural causes or accidents. This is an active area of research and is technologically feasible on the shorter term. Invasive BCI techniques can be used slightly more freely in this area, as most patients requiring prosthetics often volunteer to become test subjects, allowing for majors leaps in the technologies. However, it must be reminded that invasive devices will require governmental approval to be commercialized, as any slightest carelessness can cause mishap on the patient.

The world population is aging and the demand for prosthetics will likely be on the rise. As the world population grow older, many diseases start to surface and gradually one loses many normal body functions. This is one of the reasons why the forecasts for prosthetics have always been optimistic, as indicated in the following:





(Transparency Market Research) (Note: Detailed secondary data on market forecast for prosthetics is a paid service and unobtainable given the budget constraints)

Unless alternative biotechnologies to prosthetics advance fast enough that allow organs to be artificially regrown, most humans would unfortunately likely rely on a certain mechanical aid of some sort as our physical conditions deteriorate overtime, driving up demand for medical aids that are more intuitive to use.

日本のみならず、世界人口全体が高齢化しつつある。このため、正常な生活を助長するための義肢装具やバイオニクスの市場は成長するであろうと楽観的に予測されている。BCI はこれらのデバイスの使用をより簡単にするための可能性を秘めているが、安全第一のため、政府規制の動きなどにも注目す

る必要がある。

3.1.1 Thought-Controlled Limbs, Bionics, Robots and Exoskeletons / 脳で制御する義肢、ロボット、パワードスーツ

Ideally, a BCI enabled prosthesis should be comparable in performance to its organic counterpart with little input delay from the brain, and complete with all sensory feedbacks to make the mechanical part feel like a natural part of our body The Sci-Fi example seen from Star Wars may finally be achieved and restore many patients life almost, if not completely back to normal.

On the other hand, thought-controlled exoskeletons or wheelchairs may also become feasible and be able to augment many seniors' lives back to where they once were.

スター・ウォーズに登場した、本物と全く同じような義肢装具は、言うまでもなく多くの技術者や患者たちの夢であろう。また、体の一部のように直感的に制御できるロボット、車椅子なども可能であり、体が不自由だった人々の正常な生活を取り戻せると言っても過言ではない。BCI 技術の進展は、これらの実現をするためには不可欠である。

3.1.2 Neuroprosthetics / 脳チップや神経義肢

Another type of prosthetics that seek to restore damaged brain functions, which is only made possible by the use of BCI, is known as neuroprosthetics. Some of the patients suffering from neural diseases such as the Alzheimer's disease or Lou Gehrig's disease (ALS) have long craved for such a device that can cure them via activating a certain neural passage or bypassing the damaged links via microcomputers embedded inside a brain implant.

神経義肢とは、脳の病気などで身体の正常身体機能の喪失や認知障害などを治療するための研究分野である。例えば、天才物理学者スティーヴン・ホーキングが患っている筋萎縮性側索硬化症(ALS)や、年配の人々が起こしやすい老人性認知症など、神経的病気を治療できるとされている。

3.2 (Present - Near Future) Neurofeedback & Mental Health / ニューロ・フィードバック

Neurofeedback is a type of non-invasive brain training via the monitoring of brainwave patterns and voluntarily matching it against a certain pattern that is clinically observed to be more appropriate to deal with symptoms such as depression, anxiety or etc. It can also be used to enhance calmness or clarity of thought. Neurofeedback is growing to become a prominent industry, in part because of interests in using them as either a rehabilitation therapy or preventive measure for numerous mental impairment that many encounter in their daily life (BNCI Horizon 2020, 2013).

As of 2015, out of the many BCI applications, neurofeedback is one of the few ones that is commercially available to the general crowd, via EEG headbands provided by some venture companies such as NeuroSky, Emotiv, and InteraXon. While neurofeedback is clinically observed to have excellent effects on many test subjects under a clinical setting and equipments, there are some expert disputing over whether a simple commercial off-the-shelf BCI devices really are capable of true neurofeedback. They argue the possibility of placebo effects, when compared with the more expensive but also more powerful clinical grade EEG devices (Exhibit 3). Nevertheless, the demand from consumers is extremely strong, as is witnessed in some crowdfunding platforms; often overshooting the targeted funding by a large amount (Kickstarter, 2013).

ニューロ・フィードバックとは、脳パターンの可視化をし、ユーザーが自分の脳パターンを臨床実験で証明された、より好ましいとされるパターンに自力でマッチングすることを通して、脳機能の向上や訓練を図る手法である。あらゆる潜在性を持つ BCI が 2015 年現在、最初に商業化に成功しており、誰でも気軽に購入できるようになっている。その需要も実需に即しており、Kickstarter などのクラウドファンディングサイトでは常に集金目標を遥かに超えている現象も見られている。

3.3 (Present - Near Future) Neuromarketing / ニューロ・マーケティング

Neuromarketing is the use of non-invasive BCI devices, such as EEG or fMRI scans of different brain area to evaluate and interpret some of the emotional responses for a certain cue such as from advertisements, with the goal of achieving a more pinpoint targeting for marketing practices. Neuromarketing is not a new concept. There have already been attempts of using biometric data such as skin responses and heart rates on some test subjects to determine and predict possible customer reactions (Fukushima, Inoue, & Niwa, 2010). However, in the face of recent BCI technology advances and cost reductions of related neuroimaging hardware, some of these biometrical methods are nearly obsolete, or work better in conjunction with other non-invasive BCI detection methods (FCB, n.d.). Superficial measurements from other body parts alone are susceptible to external interferences such as room temperature and moisture.

While neuromarketing is a very interesting BCI application area that is readily doable, there are some skepticism to whether it really produces meaningful results and uncertainties over how exactly the data can be leveraged (Harvard Business School, 2012). There is also no generally agreed study methods or software available, meaning companies wishing to exploit neuromarketing may need to start from scratch or collaborate extensively with other firms or institutes to determine what works the best. Some methods such as fMRI scans are also extremely expensive and thus are prohibitive to many marketers (Fukushima, Inoue, & Niwa, 2010). Also, business ethics issues do exist, such as whether the detection of human emotions is really a breach of privacy, and if fully developed, the fear of one day we may involuntarily give away secret, or even confidential information (WBUR, 2014).

Despite the controversies and difficulties, it is a very interesting area worth investigating for marketers of all backgrounds and across any industries. Neuromarketing may make global marketing substantially easier by bypassing even cultural differences and open up a new era of globalization (Harvard Business School, 2012).

ニューロ・マーケティングとは、脳スキャンなどの手法により、人から感情や感性など抽象的なデータを抽出して評価をし、よりピンポイントに顧客をターゲットするために用いられる手法である。もっとも、調査方法やソフトウェアのデザイン、得られたデータをどう解釈すべきかはまだ不明点が多いものの、一旦判明されれば企業にとって大きな助力になるのに違いないであろう。

3.4 (Present - Near Future) Neurogaming & Entertainment / ニューロ・ゲーミング

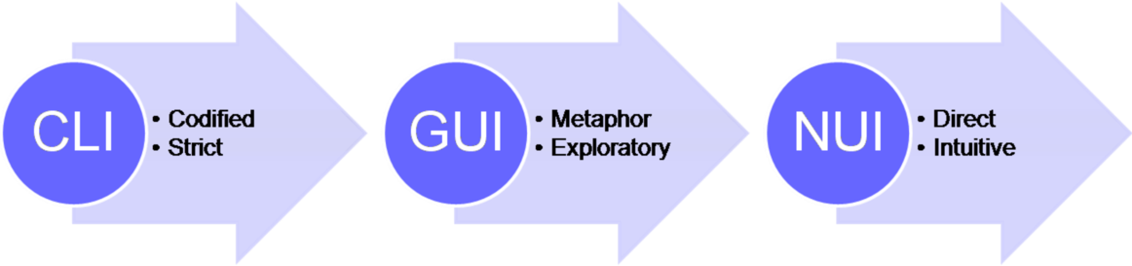
Neurogaming, like its name suggests, involves the use of a BCI device to play a certain videogame that is controlled by thoughts. This is a very promising area for growth because of the high willingness to pay nature of core gamers who are always looking for newer, and better interactions with computer characters. It will be a very exciting experience to achieve previously impossible tasks such as telekinesis or magic inside a game environment without the use of a controller.

Despite this, it is important to note that BCI devices have yet to be incorporated into the more mainstream videogame consoles, thus neurogaming’s future success is dependent on the success of a current commercial BCI device, and hence its market size should currently be viewed separately from the present videogame market. Fortunately, the huge demand in the neurofeedback market seem very promising, and hopefully more headbands can be sold, which in turn will also help the recognition and adoption of neurogaming by the general crowd. Ultimately, it may become an important gameplay element of photo realistic (known as AAA titles) hardcore videogame titles on the console market, where most videogame players have a high willingness-to-pay for new technologies for a completely new experience.

ニューロ・ゲーミングとは文字通り、思考を入力コマンドとして取り組むゲームデザインのことである。例えば、ゲーム内で超能力や魔法など、感覚的には人間の思考を必要とする行動だが、今まではコントローラーやキーボードなどアナログ的なもので操作することに違和感を持つプレイヤーは少なくないのである。ゲーマーは、こういった新たな体験のために新技術を取り組むことを厭わないのがほとんどのため、非常に有力な市場の一つだとされる。

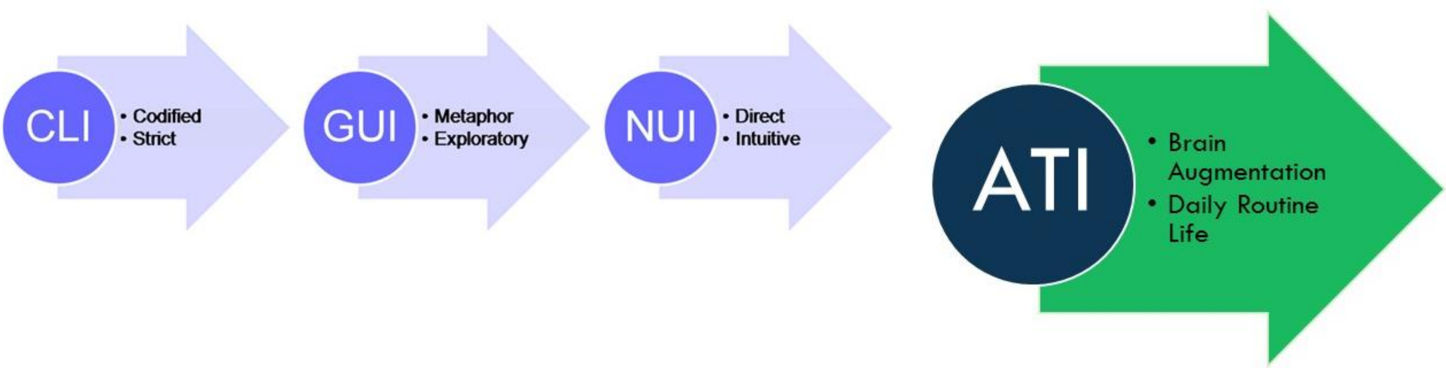
3.5 (Near & Distant Future) Natural User Interface and its Future Evolution / ナチュラル・ユーザーインターフェイス

When Microsoft launched its graphical user interface Windows 3.1 twenty years ago, it was a huge game changer. Before then, human computer interaction is limited to command-line interface, an era when computers had an extremely steep learning curve that only those who have majored in computer science could effectively use them. With the new era of graphical user interface (GUI), computers finally become accessible to the general crowd when any end user could more easily understand and make sense of the various computer commands, thus sparking the IT revolution. Similarly, the advent of touchscreen smartphones and voice recognition, often classified as natural user interface (NUI), allow users to directly interact with an object presented before them at without giving much thought or product switching cost. The trend towards further simplification of computer interaction apparently continues to evolve (de los Reyes, "Predicting the Past", 2008).



Theoretically, a NUI-based user interface design should be very intuitive to use and ultimately be able to reach a much broader range of consumers by significantly lowering the learning curve of a new device or software. However, in reality, NUI-based design has yet to replace its predecessor, like how GUI have almost completely replaced CLI for the end users of consumer electronics, as tasks become more complicated and cannot be simply displayed on a single touchscreen. Currently, the majority of the consumer electronics' designs are based on a combination of NUI and GUI, and still needs a certain degree of practice or familiarization of the product – a challenge that still exists among the elders. An adequately developed BCI interface can serve as the ultimate form of NUI, with minimal training or practice required, since no interface can be as intuitive as merely thinking about what one needs. Such a device may also eliminate the tricky situation when voice recognition cannot be used or if the user speaks with a thick accent that the device cannot understand. This can also greatly reduce the learning curve or training cost of a previously very sophisticated equipment such as an airplane, saving millions of dollars that are often required for labour training.

In the distant future, we may have advanced so far past NUI and that a certain type of machine or brain-enhancing device become essentially part of our daily life, augmenting our brain power and accomplishing something previously impossible. There is currently no term to describe such a new interface, in this paper we will invent a new term "Augmented Trans-human Interface" (ATI), for use in our roadmap in Part II.



パソコンの操作インターフェイスが、近年ではより直感的、よりシン

プルになっているトレンドは明白である。かつて、ユーザーが専門知識を要するコマンドライン・インターフェイスから始まり、より理解しやすいよう画像を多用するグラフィック・ユーザーインターフェイス（GUI）に進化し、そして今はタッチスクリーンや音声入力などによる直感的操作であるナチュラル・ユーザーインターフェイス（NUI）となっている。BCI も今後、究極の NUI になりうるだろう。なぜなら自身の思考より直感的なインターフェイスはないからである。特に、飛行機や複雑な機械の操縦をよりシンプル化でき、人員訓練などのコストを大幅に抑制できるのは言うまでもない。実際、一部の大学ではすでに脳波でフライトシミュレーターを操作するための実験に成功している。「人機一体」という時代はそう遠くはない。

遠い未来、ユーザーインターフェイスはもはや直感的だけでなく、もはや気づかれないまま我々の日常生活の一部となり、人間の体の制限を越えて我々のあらゆる仕事において支えてくれる時代も来るだろう。業界ではまだそれほど未来の用語は決められていないものの、本論文では後のロードマップ用のために「オグメンテッド・トランスヒューマン・インターフェイス」（ATI）と呼ぶ。

3.6 (Distant Future) Immersive Virtual Reality (VR) / バーチャルリアリティにおける応用

The concept of virtual reality via computer generated images is nothing new. Applications of virtual reality in numerous areas, especially in military hardware when pilots spent hundreds if not thousands of hours in simulators to familiarize themselves with the simulated counterpart of the equipment they will need to rely on the battlefield.

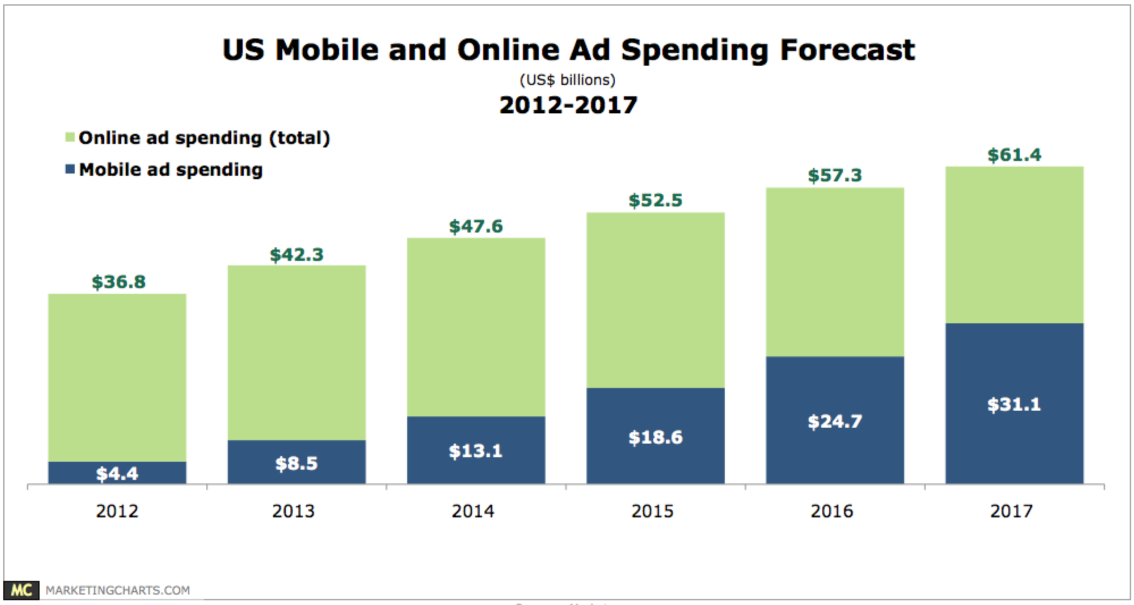
One important design aspect of VR is the concept of immersion, the sense of feeling “present” in an artificially generated world. Such a design makes it easier for us to connect the dots and make sense of, which has great potential for a satisfying and unforgettable experience (Max-Planck-Gesellschaft, 2015), which is beneficial for numerous applications such as advertising, entertainment, or education.

In the far future, when humans have finally mastered the technique of BCI and become capable of both motor and sensory control and stimulations, a Matrix-movie styled, fully immersive bidirectional BCI virtual reality may finally be realized.

遠い未来ではあるが、いずれ双方向 BCI の研究が進み、マトリックスのような現実世界とほぼ区別できなく、没入感を最大限にしたバーチャル・リアリティ（VR）がやってくるであろう。

3.6.1 VR as a Complement to Advertising / 広告活動の補完

Online advertising has seen tremendous growth over the recent decades. According to eMarketer, firms in the US alone spends roughly $36.8 billion on online and mobile ads combined, and is projected to rise to as high as $61.4 billion by 2017. However, if taken to a global scope, it is safe to say that even the most optimistic market projection is likely to be a humble estimate of the future's reality, when we take into considerations of how fast emerging countries industrialize themselves and the demand for IT products continues to grow.



Source: eMarketer

Conventional advertisings have their limitations. The most obvious barrier being that users can hardly try the products before they actually buy them, leading to significant challenges in advertising and design efforts in order to convince the targeted consumers of this asymmetrical information. To partially alleviate this, firms rely on sampling at physical stores to let buyers experience the products. But not everyone is fond of going outside just to try something they want to buy, not to mention that not everything is available for trial. Yet on the other hand, online shopping alone is risky to some, especially in places where refund and exchange policies are rather strict or limited. With a VR environment coupled with simulated senses, users will be able to shop through virtual malls and sample through everything before deciding on what to purchase.

アメリカにおけるネット広告市場は、今後も成長していくものと予測されている。しかし、世界でのスマートフォンやブロードバンドインターネットの普及速度を考慮すると、これも悲観的となりうる。

一方、インターネット広告や販売などにおける最大の問題は、やはり商品の写真と現実の差による不透明性のリスクである。しかし、毎度サンプルを顧客に送るという対応はコストもかかり、お互い時間のロスにもなる。そこで、BCI で仮想の触覚や味覚体験などをシミュレートできれば、これらの問題を簡単に解決できるであろう。

3.6.2 VR as Education / VR 教育

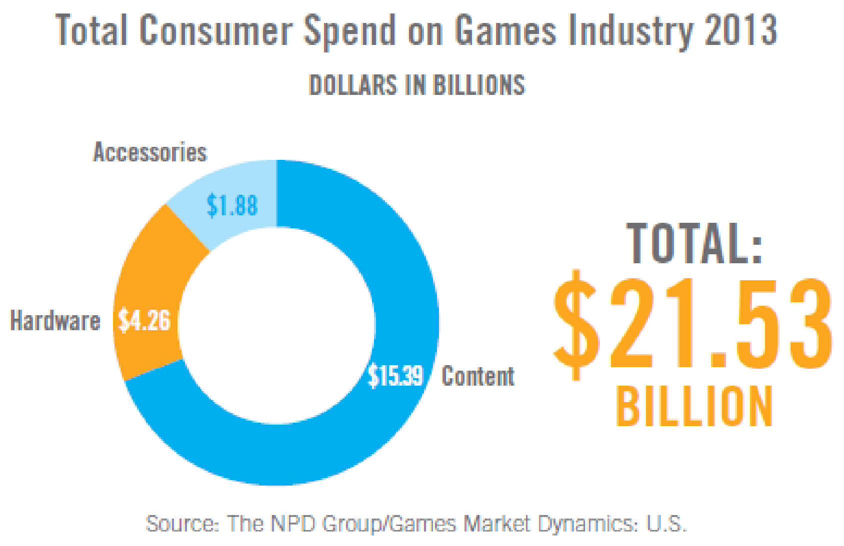
As was mentioned earlier, the earliest applications of VR stemmed from military applications such as flight simulators, it is quite obvious that it serves well in other educational purposes. In the case of an even higher degree of simulation only made possible by BCI, there is a potential to make teaching more efficient and entertaining. It is common knowledge that mere texts, drawings and photos alone are often inadequate to convey the entire picture and scope of the topic; not to mention how some students find it boring to learn from something lacking in interaction such as a textbook.

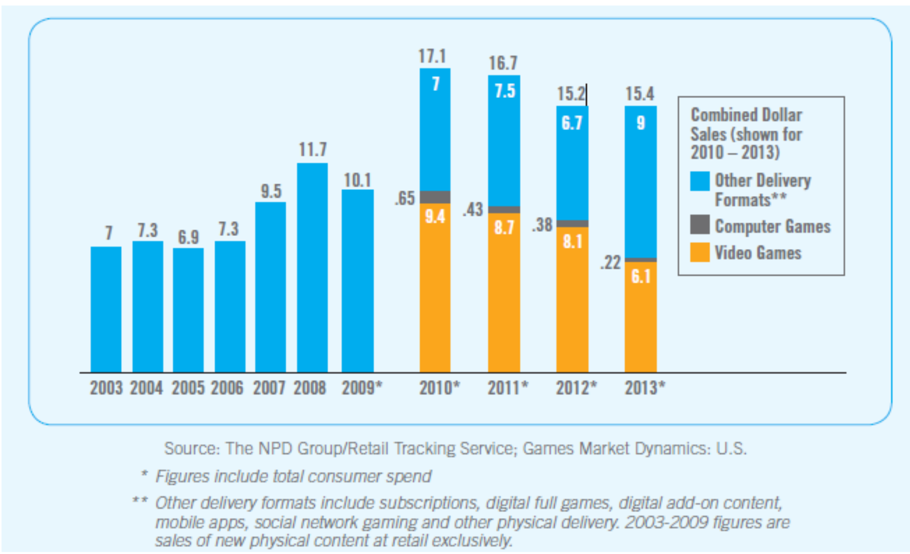
For example, consider students studying in a history class about the Renaissance era of Italy. With a traditional teaching approach, the professor can only assigns students with long texts and some drawings to the students in order to properly communicate the course materials. If he / she can bring students to a fully immersive and interactive virtual environment, complete with all sensory stimuli such as taste, smell, touch, and visual cues, it is not hard to imagine that this will likely arouse more curiosity and interest among them, motivating them further. (Max-Planck-Gesellschaft, 2015)

VR による仮想体験は、教育にも役立つであろう。事実として、文字や図表だけでは教え切れない重要な情報がたくさんあるのは言うまでもない。さらに、本のような双方的な伝達の無いモノから知識を得るのはつまらないと言う学生も少なくない。それゆえ、直接に学生たちに身をもって体験してもらうのがむしろ効率的であり、興味を湧かせるのに役立つと言われている。

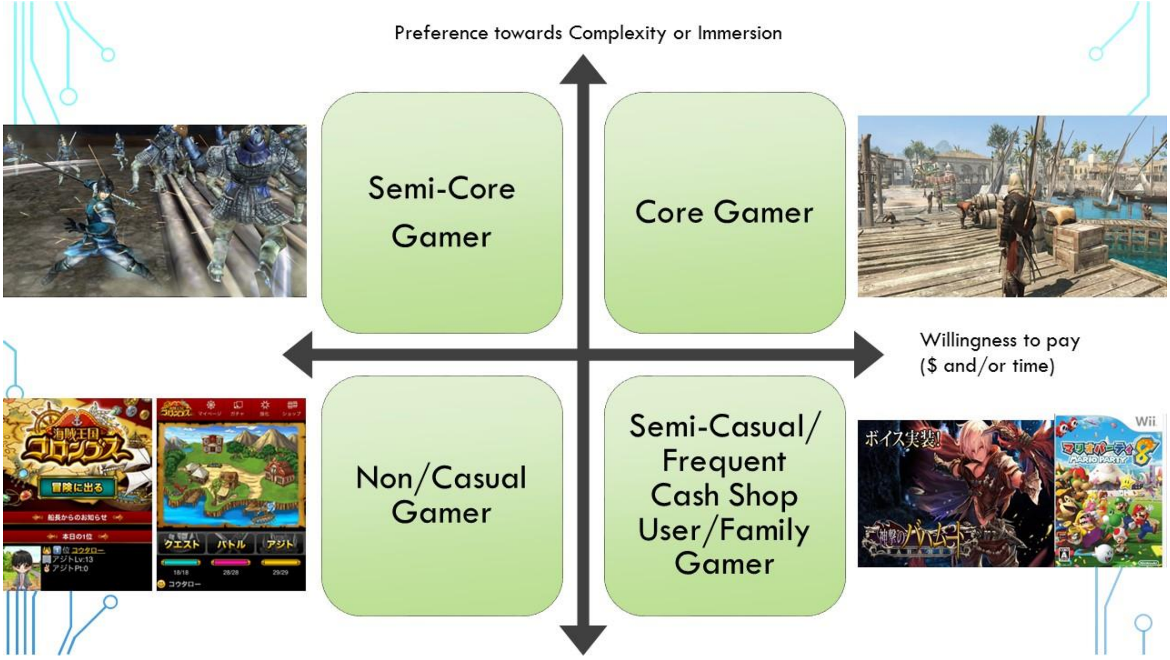
3.5.3 VR as Entertainment / VR エンタテインメント

Video games have always been the closest commercially available form of VR in an average household. Within only the recent 30 years, computer graphics have evolved from simple 8-bit pixel games into breathtaking, photorealistic 3D environment that can be traversed with an avatar via the use of a controller, and this trend is expected to continue. While the industry remains strong and profitable with a $21.5 billion market in the US alone, there has been a slight decline recently (NDP Group, 2014), which can be attributed to a variety of complicated reasons, such as players growing





tired of repetitive game designs, the anticipation for the release of new hardware, or declining in willingness to pay and embracing of free-to-play model. Nevertheless, it remains stable and player preferences can be split into 4 groups: casual gamer, semi-causal/family gamer, semi-core gamer, and core gamers, based on preference towards game complexity or immersion, versus the willingness to pay either money or time to playing, or learning to play them.



Ideally, a BCI-enabled game should provide the highest degree of simulation of something impossible in reality, yet complete with all sensory stimuli to make it seem real in a player's mind. For example, let us imagine that a player can fly and fight like Goku from Dragonball, where in the virtual world the player can "sense" that he/she moves much faster than an ordinary human can, while striking his/her opponent with special moves such as "Kamehame-ha" and "feel" the shockwave of launching such a chi-blast. If this ever comes true, the ultimate form of immersion, something core gamers seek the most, is enhanced to a revolutionary degree and will continue to engage many heavy gamers even in the far-future. On the other hand, the natural and intuitive experience of such a video game system may also convert some other consumer groups into preferring complexity or immersion, adding further longevity to the industry.

前述したゲームや娯楽が、双方向 BCI-VR となるとまた新たな楽しみ方もある。ゲーム、アニメ、映画などのファンであれば、誰もが超人的な能力を手に入れてみたい。例えば、ドラゴンボールの孫悟空のように「かめはめ波」を撃って、その衝撃波や感動といった体験を渇望したことはあるはずだ。これらの要望を実現するためには、BCI は唯一の道であろう。

4. Ethics, Risks and Impact of BCI / BCI の倫理問題やリスク

Like all great life-changing technologies such as the internet, BCI also has many of its own ethical considerations that may trigger an outcry for a stricter regulation, hampering its development.

One such risk, as was mentioned in neuromarketing, is the breach of privacy. Ever since entering the internet digital age, there has already been an endless of troubles and lawsuits surrounding privacy issues on websites such as social networks. With a mind-reading device such as BCI, one can easily argue that the likelihood of these issues will become even more complicated. This is especially true as the accuracy of the information or resolution of BCI devices continue to increase over time.

Also, the potential nature of a bidirectional BCI device may hint at the possibility of companies or a certain malevolent 3rd party to upload a certain unwanted information into our brains, achieving effects similar to mind control or forced advertisement. Also, the risk of being brain-hacked may also arise as a new form of cybercrime where valuable private information become stolen via BCI devices connected over the internet and targeted by hackers, with no way to protect them. (Rao, 2013).

In the distant future, if full immersive bidirectional VR is indeed achieved by BCI technologies, we then also have to revisit an age old fundamental philosophical question: what is reality? As technologies progress, the boundary between reality and fake may ultimately become shattered. It is possible that there would be a group of people who would prefer to stay inside a VR environment forever that provides more satisfaction via virtual goods or granting us superhuman abilities in another world. This could result in the rejection of one’s real-self for numerous reasons, such as the discrepancy of lives between the fake and the real.

Our understanding of neuroscience and BCI may progress so far in the future that choice and freewill become irrelevant because we are free to manipulate them at will; we will just “correct” those individuals who have radically different opinions that the norm consider “unwanted”, to create an “equal and harmonious” society. Even worse, we cannot rule out the possibility of a brain damaging “virus” or “hacks” that may cause harm to our nerve systems, similar to some sci-fi cybercrime movies. Also, the necessary evil of lying may also become impossible and cause huge social havocs.

Even if we are able to avoid all the immoral abuse of BCI, humanity’s crave for materialism, one of our source of creativity and drive behind our diligence, may vanish in a very devastating way with the advent of an increasingly indistinguishably VR environment. While the companies that produce the devices may remain profitable, retailers, for example, could particular be at danger as there may be less motivation for consumers to buy real world goods when everything can be modeled into VR objects and enjoyed in the virtual world.

Or does it? After all, what is available exactly in a VR environment are still be at the hands of the merchants. It is very unconvincing to assume that they will fail to see the risks of sharing everything virtually. They are still free to program the magnitude of simulation and perhaps could even exploit this to their advantage and promote how physical goods are even better than the “toned-down demo” in the VR world. Also, unlike Matrix, we will not be forced to live in a virtual world; as long as we are aware of the true world we live in, it is difficult to imagine that we would lose our materialism, given that virtual world does not give true satisfaction of ownership. While a fully immersive VR environment is difficult to imagine given today’s technologies, there has currently been few cases (if any) where digital data completely replaced physical goods. Although many firms indeed go out of business in the face of radical technological changes, the truly competitive and flexible firms tend to find ways to exploit both the new technologies and the resources readily available to provide new innovations or customer values. An example of this phenomena is the current shift of department stores into an omni-channel retailer, where the virtual and physical stores co-exist and encourage its loyal customers’ bilateral movement and usage.

All technologies can be immorally exploited, but the reason that have allowed humanity to dominate the world is our adaptability. Humans have undergone through too many difficulties and tragedies as new technologies emerge, yet humanity still stands and continues to thrive and continues to dream big. The pessimistic thought of one technology bringing doom to the entire race is arguably even more unrealistic.

当然、他の先端技術と同じように、BCI にも濫用や危険性を伴う使い方が多数考えられる。情報の読み取り能力や精度が上がるにつれ、真っ先に考えられるのはプライバシーの侵害であろう。さらに、双方向 BCI が実現される際、事情がさらに複雑になるのに違いはない。例えば、脳ウィルスや暗示などを植えつけられる可能性も否めない。また、人間の競争力の源の一つである、物質的欲望もリアルすぎる VR の登場によって崩壊してしまう可能性も考えられる。

しかし、人類の適応性というものは、あらゆる時代における困難や悲劇をも乗り越え、今日まで至った。寧ろいきなり一つの技術によって文明が崩壊するという恐れのほうが考えにくいであろう。

5. Summary / サマリー

So far, we have introduced and explored the some of the basic knowledge of BCI, and their potential applications and dangers. At this point, it is not difficult to notice how the possibilities of BCI is endless. Applications are only limited to individual imagination, public reaction, or governmental regulation. Companies that master BCI technologies likely will be able to dominate across various business sectors and grow into a new business empire, very similar to how Google, Apple and Microsoft winning a landslide world dominance in their products.

However, going back to section 1, it is observed that despite all of these potentially lucrative areas for exploitation, the current reality is that not many large corporations are known to be actively investing in BCI technologies, not even collaboration projects. Currently, most of the commercialization efforts remain dominantly at startup or SME companies. This is peculiar considering how much more resources large corporates have. And how we, as consumers and end users, often look up upon and ask large corporates to take responsibilities in leading humanity's quality of life into a new chapter, with state-of-the-art technologies and services. Yet, it is the poor who have taken the first initiatives, like how Steve Jobs and Bill Gates had done almost 30 years ago. Can we argue that maybe history is repeating itself? In Part II, we will investigate further on this matter.

今まで、我々は BCI のあらゆる可能性を見てきた。しかし、問題意識において提示したように、大企業が豊富な資源を持っているにも関わらず、BCI に対する注目度があまりに低く、中小ベンチャーが主体となっているのが現状である。歴史が、約 30 年前のマイクロソフトやアップルのように再び繰り返してしまうのか？

Part II
A Closer Observation of the Current BCI Market
Why is BCI currently dominated by venture startups?

"*The advantage of being a startup is the ability to take the high-risk/high-reward path without having to justify our actions to the public markets.*"
(InteraXon, personal e-mail interview, 2014, see Exhibit 2)

6. Research Background / 研究背景

The current BCI market is dominated by venture companies as opposed to large corporates. Going back to the original intent of this paper, this situation is not very favourable. Considering the amount of resources large corporates have at hand, and how BCI have a very high likelihood of benefiting across numerous business sectors, it makes little sense for large companies to stay out of BCI. To alleviate the situation, we will examine the current market closer, postulate some plausible reasons of why corporate efforts are lacking, and devise a plausible investing roadmap of BCI and suggestions to companies based on recent research trends and existing business frameworks.

BCI の未来の可能性を信じ、本論文の筆者は大手企業が BCI に対する注目度が低いことは好ましくないと考えている。第二部では、現在の BCI 研究と業界のトレンドを整理し、現存するビジネス理論を用いて現状を解釈し、提言及び可能なロードマップを作成するのを目的としている。

7. Data Collection, Global BCI Research Trends, and Case Study / データ、BCI 研究トレンド、ケーススタディ

Exhibit 4 shows a list of BCI related R&D journals that are collected from the websites ScienceDaily.com and Neurogadget.com, from 2005 to 2014. It is separated into 4 different categories of applications: neuroscience, prosthetics, neuroprosthetics, and other. The rationale behind this categorization is, despite the promising growth forecast of the prosthetics and neuroprosthetics industry, much of its applications are likely to be invasive and thus they may not form a knowledge base that is immediately usable by other non-biomedical equipment companies who are seeking for other novel applications of BCI to either accommodate existing products or to cause a radical innovation. Fortunately but also unsurprisingly, applications and different research ideas are scattered somewhat evenly and is not overly concentrated in invasive (neuro-)prosthetics industry, proving our point from Part I that BCI's applications are endless and every single day new discoveries and innovations are made. On the other hand, this categorization is also used to test whether BCI prosthetics is a research area that only a handful of countries are committed to, which is clearly false. This is important because, although unfeasible to the general crowd, an intuitive and aesthetically pleasing prosthesis make for an excellent visual impact to the mass and serve as a great advertisement for the whole BCI industry. With the entire globe pooling its talents to prosthetics and some even have working examples, it is safe to argue that an eventual BCI prosthesis is not far out of reach and likely will be available within only a few years, pending agency approval, and various countries may readily have the knowhow to quickly absorb the knowledge from elsewhere. This also hints a prelude to a fierce competition of BCI race in the future, once the general crowd become fully aware of BCI technologies.

It is clear that the United States dominates the whole world in every areas of research and commercial efforts, due to the Obama government's approval of the BRAIN Initiative in 2013. BRAIN is a 10 year project with a budget of $300 million per year that seeks to map every single area of the human brain (The New York Times, 2013). BRAIN's announcement apparently has a very strong promotional effect for various areas of neuroscience applications (Exhibit 1). Japan follows the United States in terms of total active BCI projects, but falls short on venture startup, with the 2nd and 3rd place of most venture projects taken away by Australia and Canada respectively. Furthermore, for ethical reasons, it is claimed that there exists a considerable amount of resistance in conducting invasive BCI researches in Japan (Exhibit 3), which explains the lack of BCI prosthetics research in the country.

One observation worth noting is the number of venture efforts in Australia and Canada. Together with the United States, the 3 countries all have English as a major or an official language. Considering the fact that the business model of IT venture capitals originated from the United States (Exhibit 2), and the fact that the United States have the most venture capitals of all in the world, English speaking countries having an edge on fundraising is not overly surprising. However, what must be reminded is the possibility of sample selection bias. Venture companies such as NeuroSky, Emotiv, and InteraXon have seen excellent successes in the recent years, and are extremely active and vocal to demonstrate who they are, possibly resulting in a more bloated media coverage over their partnership deals. It must be emphasized that the data presented in Exhibit 4 is not an indicator of how many venture companies there are, but rather how active venture efforts are. Nevertheless, the original core question remains unchanged, as there is only a disproportional amount of large firms pursuing BCI.

BNCI Horizon 2020, an EU funded research project by Graz University of Technology, is also seeking to bridge the gap between companies and BCI technologies. Their findings have also reached a very similar result over the inactivity of large firms, out of a selection of 148 BCI-related industry stakeholders from EU and North America (BNCI Horizon 2020, 2013):

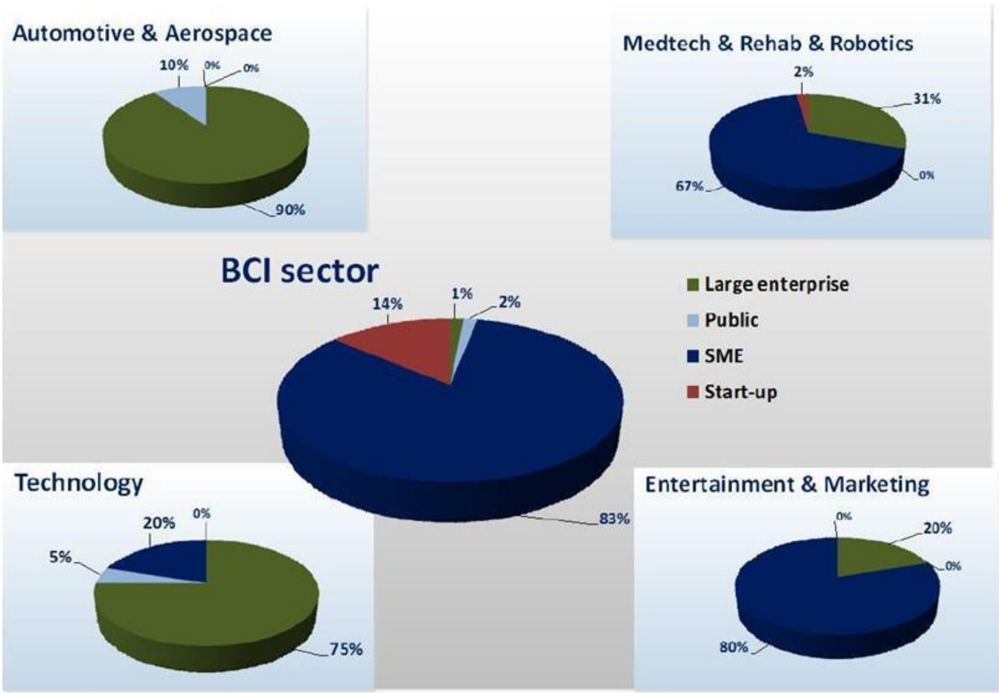


Figure 2: Company size of the BCI and BCI-related industry stakeholders arranged by group sectors. Percentage of companies classified by company size: large enterprise; public (non-profit); small to medium companies (SME); and startups.

- Retrieved from BCNI 2020.

"The final BNCI industry ecosystem database is composed by a sample size of 148 BCI related industry stakeholders. Following homogeneity criteria in terms of target users and market segments, we grouped these 148 BCI-related industry stakeholders into the following sectors:

*1. the **BCI sector** with 65 companies;*

*2. the **automotive and aerospace sectors** altogether composing 7 BCI-related industry stakeholders;*

*3. the **medtech, rehabilitation and robotics sectors** altogether composing 46 BCI related stakeholders;*

*4. the **entertainment and marketing sectors** altogether composing 10 BCI-related*

industry stakeholders; and

*5. the **technology sector** comprising 20 BCI-related industry stakeholders."*

Notice how the large firms in automobile and aerospace industry is comprised of almost 100% of the sample size. Considering that automobile and aerospace's high barrier to entry and that most of them are industrial giants, it is not too surprising why there are no SME or start-up firms engaging in BCI in the automobile & aerospace industry. On the other hand, this is consistent with the data collected from exhibit 4. Auto firms such as Honda, Ferrari, and Nissan / Infiniti, all have expressed interests in BCI for various applications into cars and are actively pursuing them (Exhibit 4).

While the technology sector seemingly have paid adequate attention to BCI based on BCNI 2020's findings at a quick glance, considering the sheer amount of existing technology enterprises and how rapid technologies and innovation becomes obsolete making new entries easy, a sample size of 20 for the technology sector seem far too low and may indicate that there is indeed still much misunderstanding or obliviousness towards BCI.

Now that we have studied the larger scope of the whole BCI market, it will be interesting to look at a smaller scope on how some of the successful BCI venture recognized and captured their own share of opportunities and decided to move earlier than anyone else. What do these leaders have in common, and what can corporates learn from them to better leverage on the sheer amount of possibilities that BCI can bring in the future?

BCI Venture Companies Case Study

As of 2014, there are already many startups trying to exploit BCI technologies. Some focus on toys, some develop neuro-videogames or smartphone apps, some try to provide neuromarketing solutions, while some focus on wearable technologies. The options are extremely varied. However, out of all the different applications and existing startups of BCI, 3 companies received the most attention from media coverage and investors — NeuroSky, Emotiv, and InteraXon, situated in the United States, Australia, and Canada, respectively.

NeuroSky

NeuroSky was founded by Stanley Yang in 2004, located in Silicon Valley, San Jose, California. NeuroSky is currently arguably the most famous due to its involvement in many interesting and successful novel toys using brainwave technologies.

Stanley's Background, Pre-NeuroSky

Stanley Yang was a Taiwanese-American who immigrated to the United States at a young age. Stanley is a fanatical Star Wars fan who admitted that he thought many of the movies' technologies and "The Force" were real in 1979 and was dismayed to know that they were special effects as he grew older. This however sparked his interest in IT technologies and he would later graduate from the University of Berkley with an engineering degree. Upon graduation, Stanley joined Xilinx, then a startup company by Bernie Vonderschmitt. Stanley quickly noticed that he was sort of lazy and did not suit an engineer job well.

Vonderschmitt one day called Stanley and told him he should become a manager of the engineering team. In 1997, Vonderschmitt felt Stanley's potential as a business leader and encouraged him to found his own company by providing him with 1 million USD. Stanley then founded Triscend, a company that focused on SOC (system-on-chip, a type of embedded systems) design, which would later be bought back into Xilinx in 2004.

After Triscend's acquisition, Stanley resigned from Xilinx and had the opportunity to meet an anonymous neuroscientist who worked on brainwave technologies. The professor introduced to him with an EEG helmet, wired with many electrodes, which could move a radio car by thoughts. He asked Stanley if it was possible to commercialize the device. Stanley responded that the helmet must be less cumbersome and simple to use to ever be commercially successful. This event, coupled with Stanley's dream about "The Force", was a tipping point for the founding of NeuroSky in the same year of 2004.

Stanley at NeuroSky

In 2006, the company received their first major funding. Stanley's previous involvement with 2 startup companies had blessed him with an edge in negotiating with shareholders and he was fully aware of their demands. Stanley quickly went to Star Wars director George Lucas and discussed ideas about a novel toy that uses BCI technologies. His strategy was obvious. He wished to affiliate BCI technology with something popular so anyone can quickly and intuitively understand its concept. Fortunately, Lucas adored the idea and gave him the permission to do so. In 2009, NeuroSky successfully released their first working product, the Star Wars Force Trainer under the partnership and brand of Uncle Milton Toys. Children wearing a simple, bundled BCI device can control a ball's motion by concentrating their thoughts to control the speed of a fan blowing underneath it. The toy was a major hit and successfully opened the very first chapter of BCI's commercialization to the mass market.

NeuroSky would later also partner up with toy maker Mattel to produce another successful toy, the MindFlex , under Mattel's brand. The product was well received and was named the Top 100 Most Influential Toys by the Time Magazine. NeuroSky also released the MindSet multimedia device and its SDK (software development kits) for other companies and academic institutes. NeuroSky also helped other companies integrating BCI into product prototypes, or help process the brainwave signals into computer commands, accelerating BCI's research and introduction. B2B and OEM activities currently form up the majority of the company's revenues. (數位時代 222 期, 2012) (MIT Media Lab, Diversity@ML, 2013)

NeuroSky's Recent Activities & Stanley's Visions

In 2011, the company released their first consumer product under its own name, the NeuroSky Mindwave, a direct successor to the Mindset, at a price of $79.99. Similar to its predecessor, the product also had its SDK released, allowing curious end-users, individual developers or low budget researchers to come up with their own ideas to further popularize BCI technologies.

In 2012, NeuroSky partnered with Neurowear, a Japanese project organization, to release arguably one of their most viral BCI product, the Necomimi. Necomimi was a type of wearable cat-ears that automatically moved according to the user's brainwave patterns or emotions for cosplay uses. The toy was a huge success, securing a sizable amount of revenue for NeuroSky.

Today, NeuroSky is very actively participating in many IT exhibits to communicate who they are and what they do. NeuroSky also partners with many other software or game companies and hosts a variety of both 1st and 3rd party apps and games for the MindWave in an e-shop accessible from NeuroSky's website.

Like its competitors, the company is currently especially interested in the field of neurofeedback, to improve the quality of life via the visualization of brainwave patterns.

Stanley Yang's long term vision for NeuroSky is simplicity and intuition of use. While jokingly claims it being because of his laziness, he firmly believes that many current IT products forces consumers to conform to machines rather than they conform to us, given the complexity of learning a new equipment. With BCI, Stanley has high hopes of someday making the usability of any devices as simple to use as possible, while also eventually open up new opportunities to achieve what was previously impossible. (MIT Media Lab, Diversity@ML, 2013) (Neurogadget, 2010-2014)

Emotiv (previously Emotiv Systems)

Emotiv was founded in 2003 at Sydney, Australia, by Tan Le, a Vietnamese-Australian who immigrated to Australia at the age of 4 as a refugee, along with co-founder Nam Do, a passionate Vietnamese information technology student turned expert who met Tan when he was fresh out university, and Professor Allan Snyder, a leading pioneer in fibre optics and neurobiology who was awarded the Marconi Prize in 2001, an honour next only to the Nobel Prize (Freedman D., Inc.com, 2008). Emotiv is the more "geeky" company of the 3. Emotiv EEG devices tend to feature the most EEG sensors compared to other commercially available EEG products. This in turn also makes it arguably the most powerful product available off-the-shelf, albeit at a higher price.

Tan's Background, Pre-Emotiv

CEO Tan Le's early days were very rocky. At the age of 4, her family and relatives secretly fled Vietnam in 1981. Running out of fuel and low on rations, their ship floated over South China Sea, awaiting the seemingly inevitable death. Yet by a sheer miracle, a British shipping tanker sailed past them and rescued Tan and her families, who later dropped them off at Malaysia and provided assistance in applying for immigration as refugees into Australia (Freedman D., Inc.com, 2008).

With the Racial Discrimination Act only recently passed by the Australian government in 1975, the general Australians were hardly very tolerant of foreigners during Tan's earlier years in Australia. In one of Tan's TED speeches in 2011, she mentioned seeing many graffiti paintings with unwelcoming messages such as "Asians Go Home", a luxury that Tan did not have. For this reason, Tan had stiffened herself and decided to eventually bypass all of them (Tan Le: My Immigration Story, 2011).

Tan was indeed an overachiever. At the age of 16, she entered Monash University, one of the most prestigious institutes in Australia, to practice business and law. In 1998, at the age of 20, Tan earned Young Australian of the Year from the Australian government, making her a public celebrity which opened up opportunities to meet many scientists and entrepreneurs, one of which included Allan Snyder, with whom Tan established contact with.

Upon graduating, she was hired by a very prestigious law firm in Australia, but only to find that those scientists and entrepreneurs she had met earlier greatly inspired her to be part of the revolutionaries, re-shaping the world as they see fit. She quit her job and later met Nam Do, with whom she would later co-found SASme International, and successfully stuck a licensing deal with Telco Systems for a mass text messaging software. The software was a success and secured a substantial amount of personal wealth for the duo. In 2003, Tan and Nam sold SASme to an anonymous company, dreaming of something even bigger (Freedman D., Inc.com, 2008).

The duo went to Professor Snyder's house for inspiration. Professor Snyder proudly demonstrated his latest works on non-invasive brain stimulations using magnetic fields, and numerous other BCI gadgets, claiming how the world of human-computer interaction failed to capture and leverage on human emotions — a driving force behind all the tasks humans do. The trio grew more and more inclined about bringing the technology to market. Along with the help of chip designer Neil Weste, a friend of Tan who had recently sold his company for billions to Cisco, the 4 partners have all decided to found a new company, Emotiv Systems, with the determination to bring emotion back into computers (Freedman D., Inc.com, 2008).

History of Emotiv

With 4 successful partners, there was no shortage of startup and operating capital for the new company. However, EEG sensors and software at the time simply were not designed to detect emotions or brain commands. They needed to start from scratch by deriving and solving the equations for the brain signals of human emotions. Emotiv hired numerous mathematicians, signal processing experts to decipher the daunting task at hand. To cut R&D costs, Emotiv also hired numerous university graduate volunteers, who happily joined Emotiv's cause in exchange for a resume entry that could claim that they have worked on cutting edge technologies.

By 2004, Emotiv finally have completed most of their work and quickly filed 25 patents for their accomplishments. The group successfully tested their creation for detecting the emotion of excitement while watching movies, and agreed that everything was worth the efforts. All Emotiv employees had confidence that they will succeed. The founders expanded their ambition and envisioned something marketed towards the mass market.

In 2008, the landslide success of the Nintendo Wii worked in favour of Emotiv's grand scheme for a consumer product. Videogame players were usually very early new-technology adopters with a high willingness to pay, making them an excellent target for gaining traction in the market. Having spent 4 years to hone the technology, Emotiv decided to unveil a prototype at the 2008 Game Developers Conference. Unfortunately, technical difficulties cut off the devices connection with the computer, and Emotiv lost its chance of giving gamers all over the world a great first impression. Nevertheless, of those individuals who eventually tried the prototype at Emotiv's booth were all convinced that the technology would someday be a hit, which greatly boosted Emotiv's confidence.

In 2009, Emotiv finally released their first EEG head set, the Emotiv EPOC. With 14 EEG channels, it was a much more powerful device compared to competitors. At a hefty price tag of $399.99, EPOC was arguably more intended for developers or low budget research uses. EPOC's sales have been favourable, with no less than 5,000 units pre-ordered by various curious parties. The company was also in financial good shape, having just raised $13.4 million in 2007 from 3 venture capitals and also governmental subsidy from the Australian government. Emotiv was more than ready to march into the 2010s (Freedman D., Inc.com, 2008).

Emotiv's Recent Activities & Tan's Visions

In 2011, the company apparently has changed its name from Emotiv Systems into simply Emotiv, as the founding year of the company currently shows 2011 on Emotiv's official website. No information behind this change has been available.

Recently in 2013, the company unveiled its new, 5 sensor EEG headset, the Emotiv Insight. With a sleeker and more stylish design in addition to better usability in mind, it will be priced competitively at $299, competing directly with the InteraXon Muse in the neurofeedback mental health care market. The company also launched a Kickstarter $100,000 campaign for Insight, promising to add additional features such as a gyroscope if they reach $1 million raised. The campaign ultimately raised a total of $1.6 million, way beyond its original target, indicating a very promising start (Kickstarter, 2013).

Like NeuroSky, Emotiv also releases SDK for their products and maintains an online e-store for third party apps or games.

In 2014, Accenture and Philips announced a partnership with Emotiv, intending to improve the lives of ALS (commonly known Lou Gehrig's disease) patients. The project will grant the patients more freedom, such as the ability to control tablet computers with eye movements, calling for assistance, and turning on TVs (Neurogadget, 2014).

Tan and her Emotiv colleagues envision a world where human beings finally can unleash the powers of our brain and fully utilize it for tasks that have not been possible previously. The recent IT world's fierce battle over wearable technologies present excellent opportunities for the company. To one day achieve their vision, Tan seeks to further democratize and decentralize brain research from clinical settings into individual environments, achieving mass recognition, and market penetration, to accelerate brain research for a better future (Foege A., JWT Intelligence, 2014).

InteraXon

InteraXon is a Canadian BCI company situated in Toronto, Canada. It was founded in 2007 by fashion designer and neuroscientist Ariel Garten, along with her best friends, entertainment industry expert Trevor Coleman, cool gadget designer Chris Aimone, and joined by her next door neighbour and EEG enthusiast James Fung, and finally Professor Steve Mann, widely known as the "father of wearable computing". It is a much smaller company compared to the others but has great potential. Out of the 3 BCI ventures, InteraXon's 4 EEG sensor $299 headset, Muse, is arguably the most unobtrusive of them all and clearly had been designed with daily life and prolonged use in mind from the very start. Despite InteraXon being a very young company compared to the others, it has gained extensive media attention and is very fast-growing.

Ariel's Background, pre-InteraXon

Ariel is the daughter of Vivian Reiss, a famous oil-on-canvas painting artist. Greatly influenced by her mother, Ariel is also highly interested in arts and fashion and a capable artist, albeit at a different twist — via the integration of multimedia technologies (The National Post, 2003).

Having studied and graduated with a degree in neuroscience, Ariel was no foreigner to EEG technologies and psychology, and was already fascinated by the technology very early on. (The Blueprint, 2013)

Upon graduating from University of Toronto in 2002, she founded her own clothing boutique, Flavour Hall, designing unique clothes that combined technology and psychology.

3 years later, Ariel could not forget about her interest in neurosciences. She closed down the boutique and partially worked as a psychotherapist, helping clients deal with anxiety.

In 2007, dreaming of working on something more cutting edge on neuroscience applications, she reunited with her friends, Trevor and Chris. Together with her next door neighbour, then EEG PhD student James, the group went to Professor Steve Mann for inspiration. The quintet soon arrived at the interesting idea of a wearable, quality of life enhancing EEG headband, giving birth to InteraXon in the same year. (The Blueprint, 2013)

History of InteraXon

In October 2009, InteraXon successfully entered talks with the Canadian government over a project that no one has ever tried — to control the Olympic lightings on the CN Tower, Niagara Falls, and the Canadian Parliament Buildings for the 2010 Vancouver Winter Olympics Games with people's minds, *from Vancouver*. The project was a huge success, securing a sizable amount of fame for the little company. Business talks and opportunities soon rushed in.

Eventually, the company decided it was time to move according to their original plan of a consumer BCI device. InteraXon successfully raised a crowdfunding campaign on Indiegogo.com in 2011 for the Muse, with an original goal of raising $150,000. InteraXon ultimately secured near double of that amount, receiving a very generous $287,000 fund from enthusiasts all over the world (The Blueprint, 2013) (CTV News, 2012).

InteraXon's recent activities and Ariel's Vision

The successful crowdfunding not only solidified Ariel and her colleagues' confidence levels; it also attracted the interest of many investors. In 2013, the company successfully received $6 million worth of capital from various venture capitals (Venture Beat, 2013). The company's outlook looks bright.

Like its rivals, InteraXon has been very actively attending numerous exhibits such as Consumer Electronics Show (CES), to showcase what the technology can do. Following a few delays, the Muse was released on 2014, complete with SDK.

Currently, the company does not seem to feature its own e-shop to host apps and games, as most of their applications are only found in established stores such as Google Play or iTunes App Store.

Consistent with her background as a psychotherapist, Ariel currently envisions BCI neurofeedback headbands becoming an integral part of our daily life, with people paring it with portable devices such as smartphones and bring it to work to increase productivity or stress relief.

However, it must not be forgotten that BCI's applications are not limited to neurofeedback. InteraXon has also demonstrated an array of miscellaneous gadgets controlled by thoughts, the future strategy of the company remains very interesting.

Others

While we have only introduced the 3 most prominent BCI venture companies, by no means they are the only ones. IMEC, a joint project team between Netherlands, Belgium plus numerous other EU countries, had also expressed interest in the consumer BCI market in 2011. (Neurogadget, 2011)

Also in Japan, interests in BCI technologies has also recently arisen, following the Japanese government's aggressive effort to rival the United States BRAIN Initiative in exploiting neurosciences. For instance, with direct funding and partnership with Digital Garage, the Japanese advertising giant Dentsu has reached Associate Professor Mitsukura of Keio University, the mastermind behind the Necomimi Project, to establish a subsidiary company called Science Jam (Internet Watch, 2013). Although not much information is known about Science Jam, one can speculate that Dentsu's ultimate goal is likely neuromarketing, for precision targeting of advertisement audiences, considering Dentsu's background.

Taking a closer look at the story behind Stanley, Tan, and Ariel, the following common characteristics can be found:

The 3 Venture Leaders

	Stanley Yang	Tan Le	Ariel Garten
Birth and youth background	Taiwan Immigrated to US at a very young age.	Vietnam Immigrated to Australia as a refugee Australia's 30 most successful women under 30 (2001)	Canada Daughter of oil-on-canvas artist Vivian Reiss Top 40 under 40 by UoT Magazine (2004)
Past start-up experiences	Xilinx. Inc (venture at that time. Worked as an engineer and manager) Triscend. Corp (founder & CEO)	SASme (Co-founder and manager)	Flavour Hall (founder & CEO)
Educational Background	Electrical Engineering	Law	Neuroscience Psychotherapy
Source of Passion & Vision	-Star Wars fanatic -Laziness turned into innovation -Electronics should learn to conform to us, not the other way around	-Do something radically different over standard Asian conformism. -Democratization of brain research from clinical to anyone -Unleash our brain power	-High tech media-art artist -Fashion designer -Enhancement of quality of life -Brain device becomes an integral part of our life

- All three have had extensive high tech startup experiences and may have accumulated some wealth already. It is especially obvious in the case of Emotiv's founders.
- All three have gone to and met a university professor of BCI for inspiration some time in their life.
- All three are very passionate leaders, with a firm and clear vision.
- All three speak English, and are from countries with a diversified ethnic composition.
- At least two of the companies have founders of diverse educational backgrounds.

Taking another closer look at the firm or product level, these common trends can be observed:

	NeuroSky	Emotiv	InteraXon
Year Founded	2004	2003	2007
CEO	Stanley Yang	Tan Le	Ariel Garten
Location	San Jose (Silicon Valley), United States	Sydney, Australia	Toronto, Canada
Business Model	B2B (BCI solutions) and B2C	B2B/C (EPOC) and B2C (Insight)	B2C
Flagship Devices & Price	NeuroSky MindWave ($79.99)	Emotiv EPOC ($399.99) Emotiv Insight ($299.00)	InteraXon Muse ($299)
Number of EEG Sensors	1	14 5	4
Market Positioning	Simple. Cheap. Novel toy & entertainment. Limited neurofeedback.	EPOC – Low-budget research / developer Insight – Consumer. Neurofeedback	Neurofeedback. Fashionable. Daily Use.
Software Development Kit	YES	YES	YES
Used Crowdfunding	No	No (EPOC) Yes (Insight)	Yes

- All three companies have released a software development kit (SDK) for their product(s).
- All three come in the form of a headband.
- All three have expressed interest and are actively pursuing the neurofeedback market.
- The price and specifications of BCI devices are more or less equal for 2 firms.
- Two firms have similar number of sensors for their consumer product.
- Emotiv and InteraXon both have successfully made use of crowdfunding.

With these common factors in mind, we will seek assistance from existing business frameworks to answer why corporate efforts in BCI is currently very limited.

付属資料４では、科学ニュースサイト、ScienceDaily 及び BCI ガジェットに特化した IT ニュースサイト Neurogadget にて載せてある 2005-2014 年までの BCI と関連する記事ピックアップし、カテゴライズ化したものである。結果だけを言うと、アメリカは脳科学及び BCI 技術を国家先進産業戦略とし、莫大の資金を投入した BRAIN Initiative を始動し、あらゆる研究分野、及び商業化

の動きの面において諸国を凌駕している。日本でも文部科学省や産総研などの努力により、近年 BCI 研究に注力しているものの、大手自動車メーカー以外、BCI の商業化を図る企業や起業家は少なく、オーストラリア及びカナダには及ばずにいる。

オーストリアのグラッツ大学は、EU のバックアップを得て本論文の目的と類似するプロジェクト「BNCI Horizon 2020」で BCI 研究と投資家や企業家のタイアップを目論み、付属資料 4 から得られる結論と概ね類似している。しかし、IT 業界において大手企業の BCI に対する注目度を 75%と示すが、148 社のサンプルサイズのなか、少なくとも数千社に及ぶ IT 企業のうち、僅か 20 社が選ばれているところは正確性に関しては少々疑問視すべきであろう。もっとも、BCI 技術のメジャープレイヤーの中に大手企業は少ないという点は合致している。

この章では、なぜベンチャー起業家達がリスクを恐れず、BCI のような新しい分野に真っ先に進出しているかという疑問を答えるために、近年でもっとも注目度の高い３社 NeuroSky、Emotiv、InteraXon のケーススタディを作成してある。しかし、ページ数の制限により、日本語サマリーでは類似点の要約という形で割愛したいと思う。

人的類似点：

- CEO の 3 人とも過去に IT ベンチャーを起業した経験があり、新事業のためにある程度の個人財産を持っていると思われる
- 3 人とも大学にて BCI を研究している教授にインスパイアされた経歴がある
- 3 人ともそれぞれ独特のビジョンや情熱を持ち、世界をより良くしたいという気持ちが強い
- Emotiv, InteraXon 両社の創設陣はいずれも工学部出身だけで構成するのではなく、様々の教育背景を持つ

会社と製品の類似点：

- 3 社とも自社製品の開発キット（SDK）をリリースしている
- 3 社の製品ともヘッドバンドの形をしている
- 2 社の製品は価格とセンサー数の面で類似している
- Emotiv と InteraXon は両社ともクラウドファンディング・キャンペーンにて話題性を巻き起こし、プロジェクトの集金に成功した経験があった。

これらの類似点を念頭に置き、現状を既存のビジネス理論の範疇での可能性を次章で分析していくこととする。

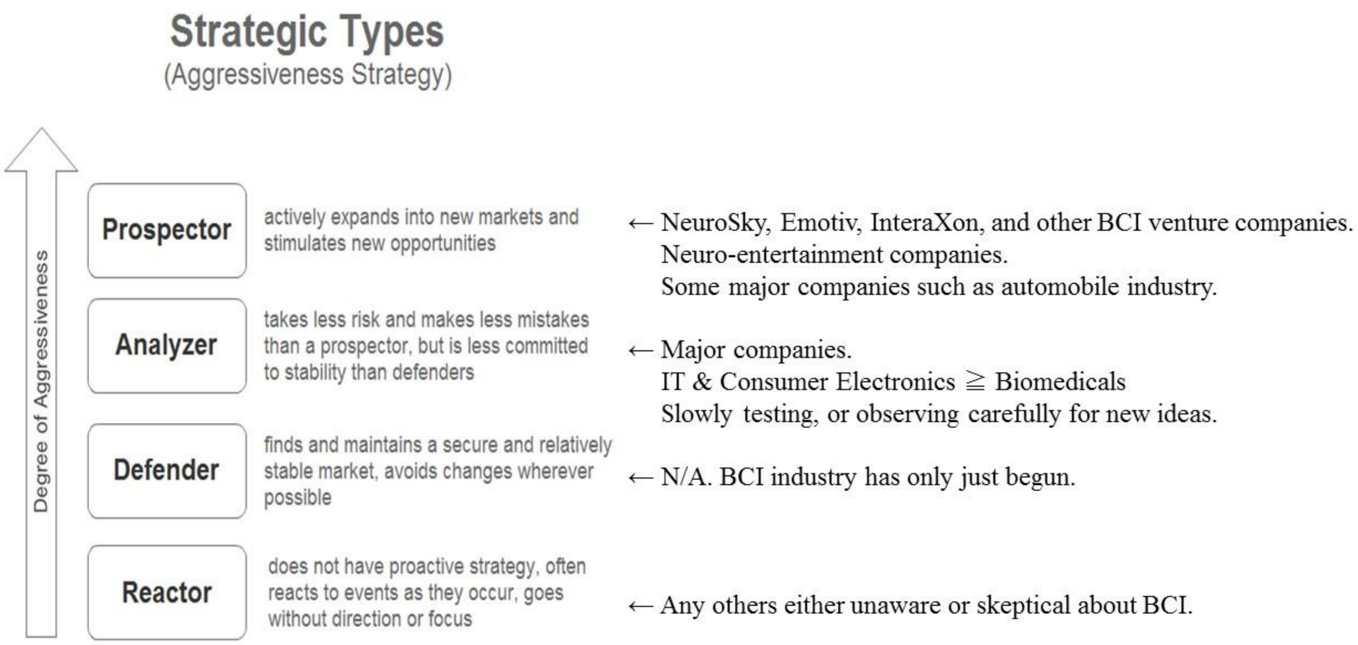
8. Preliminary Research and Frameworks Used to Explain the Situation / 既存理論による現状分析

With the environment identified and some common characteristics of BCI ventures jotted down, we are ready to move forwards and utilizing existing business administration frameworks to further investigate some of the plausible reasons of why large corporates are slower to move compared to venture and SMEs in the BCI market.

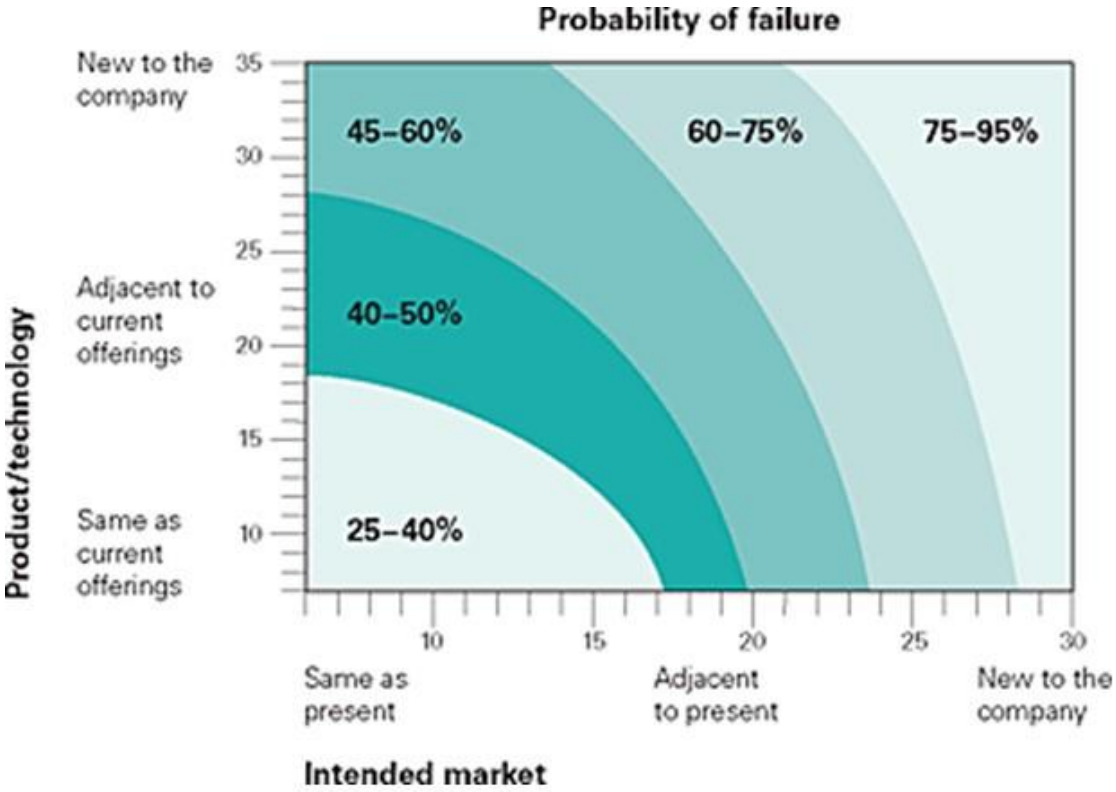
この章は、なぜ大手企業が中小ベンチャーよりも BCI に対して身動きを取らずにいるかの原因を推察する。

8.1 From Innovation Management Point of View / イノベーションマネジメントの観点から

The old, but still applicable corporate aggressiveness theory, pioneered by Miles and Snow in 1978, comes in handy in describing the current situation:

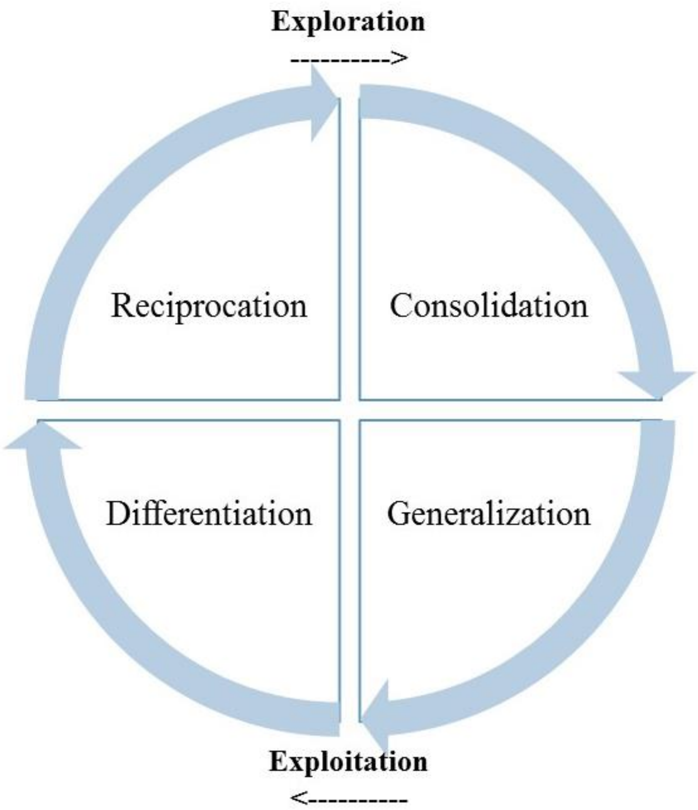


Most large corporate currently fall under the analyzer position in terms of BCI, despite how the recent rapid shifts of technologies today often calls for a more swift, flexible and risk taking corporate structure and culture. This is not too difficult to imagine, because save for a few exceptions, large enterprises structures are usually governed by tighter control via established rules and practices (Miles & Snow, 1978), or otherwise it is usually a communication and management nightmare across different hierarchies and departments. For this reason, new strategies or new opportunities may get turned down or get lost in this sea of rigid rules. Furthermore, a general perception that many managers often share over their jobs is to carefully control and direct with *exactly what they have at hand and what they already know*, such as the current strategies of the company (Miles & Snow, 1978), despite how the external opportunities continue to show signs of imminent revolutions. Only in a very rare occurrence will a tyrannically but influential visionary genius CEO such as Steve Jobs appear, and only then would all management teams start looking for new opportunities to impress the particular individual. Going back to BCI, due to the stiff structure, managers often think from only a narrowed point of view and ask themselves the wrong questions such as "how do we use this technology right now?" as opposed to "what potential *new business or products* can be done?". In a personal e-mail interview, NeuroSky comments that "*[Large] companies continue to monitor the technology while seeking out compelling use cases. Adding an extra hardware element to the application truly requires a very strong value proposition*" (Exhibit 1), hinting how existing firms generally only think in terms what is readily available and within their own comfort zones when evaluating new technologies and opportunities. The recent pace of technological leaps, especially in the IT industry, will only continue to challenge managers and leaders over the decision whether to embrace uncertainties and move early. However, on the other hand, we must not overly blame managers for failing to spot opportunities and leverage them to benefit the whole company. BCI is new and radical, but at the same time difficult, especially if the company is of a different business and simply lack the absorptive capacity to take advantage on them. In 2007, Day came up with a brilliant Risk Matrix and published it in the December release of Harvard Business Review, which is extremely useful to postulate what the large corporate managers may have in mind (Day, 2007):



Considering the novelty and complexity of BCI, no firms or individuals on this planet can confidently say they have mastered the technology. Even if the company has had some experience with EEG or other neuroimaging techniques, BCI will likely immediately register somewhere at least within the range of 25-35 on the y-axis, already giving a potential fail rate of no less than 50% no matter what the intend market is, which likely will immediately turn away an average manager who understandably prefers not to jeopardize his or her career or family wealth on something enigmatic and risky.

Then there is also Nooteboom's Knowledge of Cycle from 2000 (Nooteboom, 2000). The Knowledge of Cycle is a useful framework for us to categorize and plot where each of the currently achievable BCI application is. Based on numerous other scholar findings that also built upon Nooteboom's model, we can interpret and make sense of some of the reasons why BCI is not a mainstream favourite of large corporates yet:



There are 4 stages inside the cycle of knowledge: consolidation, generalization, differentiation and reciprocation. Consolidation and generalization is the exploration phase of knowledge or technology, this is the phase where a large amount of information is scattered across numerous parties, with firms or venture companies seeking opportunities, breeding trust between different parties, and fostering mutual understandings. Eventually, a certain dominant design emerges, and competitors all start releasing similar products near the very end of Generalization, and all players prepare themselves for exploitation. The market quickly turns to the differentiation phase with similar firms each fighting for dominance in the wake of competition; this is also when competitive advantages start to surface and the market gains more recognition. And finally, once a clear winner is selected by the market, new innovators (who may or may not be the designer of the original winning firm) who are unsatisfied with it will further build upon the previous dominant design by adding new elements in the phase known as reciprocation, and ultimately restarting the cycle (Nooteboom, 2000) (Gilsing, 2005).

One of the most important keywords presented in the above argument is dominant design. It is perhaps easier to think of a dominant design as a *de facto* standard, something that all competitors or new entrants must adhere to and be properly incorporated into the design of their products to successfully capture a meaningful amount of customers (Utterback, 1994). An example of dominant design would be cars. For almost 100 years, cars always have only one steering wheel, the same wiper and turn signal lever layout, and only 2 wheels out of 4 that can be turned. While numerous design innovations may be incorporated into newer cars, the basic layout remains unchanged among any manufacturer so that consumers can switch between brands without worrying about another learning curve. For this reason, many firms would prefer to wait for a dominant design to emerge before entering the market themselves (Utterback & Suarez, 1995), to avoid wasting R&D cost in the case that their design is not selected by the market.

Based on the data and current events of BCI we have at hand, we can organize various current BCI applications into graphs and diagrams. We will first examine whether if a dominant design has emerged for the currently technologically feasible applications of BCI, based on recent research breakthroughs organized in Exhibit 4:

Definition of Dominant Design for current BCI examples

Non-invasive QoL / NUI	Non-invasive Neuromarketing	Invasive Biomedical Applications
Optimal number of sensors	Optimal number of sensors (presumably more than consumer BCI if using EEG)	Local government approval (e.g. FDA in the US)
Sensitivity, and type of sensor (predominantly EEG)	Sensitivity, and type of sensor (MEG, fMRI, some EEG) (fMRI scan is not cheap)	Sensitivity, and type of sensor (Invasive sensors are very clear)
Optimal arrangement of sensor position(s) over the skull	Optimal arrangement of sensor position(s) over the skull (B2B EEG can have as many as they want)	Biocompatible and / or biodegradable sensor implants (see section 2.2.1)
Signal processing Noise filtration techniques	Signal processing Noise filtration techniques	Bidirectional BCI sensory feedback
Software development kit Online apps market	Database consolidation Meaningful interpretation of Data	Fail-safe designs
Compatible Platform (e.g. PC, smartphones)	Study method and setting	Maintenance procedures and/or service locations
Pricing	Feasibility at an uncontrolled, public setting	Equipment lifespan
Weight (wearables must be light)	Feasibility for any company without huge investment cost	Portable power source
Battery life (8+ hours)	Business ethics	Safe and painless operation

Design considerations that are reaching a dominant design

- Very clear
- Moderately clear
- Unclear
- More R&D / commercialization efforts required

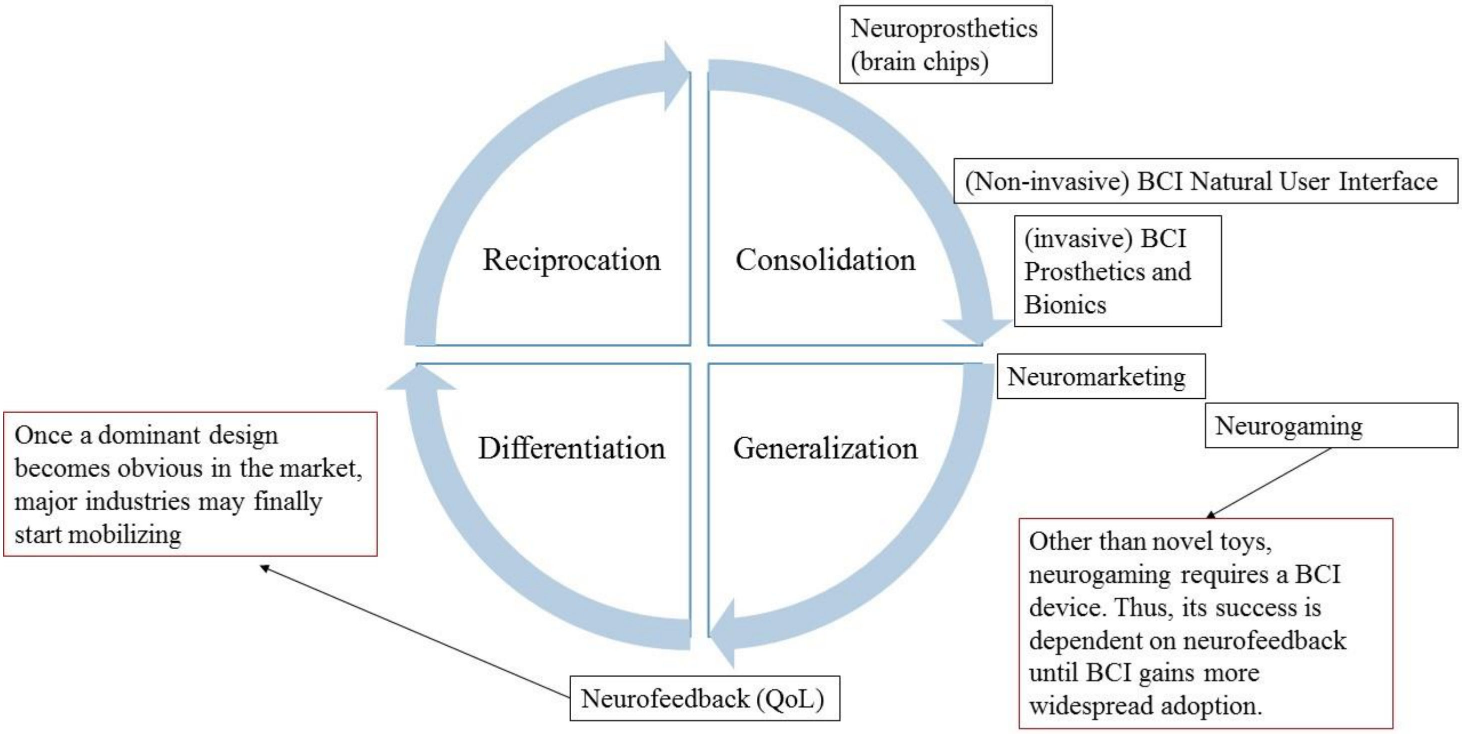
Since all 3 headsets have demonstrated some limited capabilities beyond neurofeedback, the quality of life and NUI is combined together in the dominant design graph for simplicity. Wearable technologies must be lightweight and easy to understand, hence the reason why all 3 venture companies have chosen the shape of a headband, instead of, say, a cap, that on paper can fit even more sensors and be more powerful. Also, similar to how smartphones have very much replaced traditional cell phones, the release of software development kits will allow individuals or other companies to develop applications to easily add more value to the device while saving up on in-house development costs.

For B2B neuromarketing uses, the options are more varied and simplicity may or not be as relevant. On the other hand, there have been little news of firms openly discussing how BCI neuromarketing has lead them to great success. Therefore many design aspects, such as study methods, software designs, database creation, sensor types, and business ethics, are rather unclear if there is already a dominant design at this stage. Work on better signal processing and noise filtration techniques for better information clarity and reduced EEG sensors on non-invasive BCIs are also never-ending.

On the invasive BCI side, numerous institute and universities have already demonstrated working examples of functional BCI prosthetics, some even complete with tactile feedbacks to simulate temperature and firmness of an object grasped. Unfortunately, one of the most important obstacles to invasive BCI commercialization is the obligation of waiting for a lengthy and expensive governmental approval, which in turn impedes further efforts on other important areas of designing and supporting such a product. However, taking into account of how the United States put brain research as a national priority, it is safe to expect the situation to change rapidly.

Having identified some of the dominant design factors, we are now free to plot the many applications of BCI onto the cycle of knowledge:

Applications of BCI Technology and Their Current Relative Position



Based on our analysis from dominant design point of view, it is safe to assume that most BCI applications have yet to go past the consolidation phase with the exception of neurofeedback. Referring back to the information we have retrieved from our case study, all three ventures have all of a sudden selected the wearable neurofeedback device market as an area of focus, when their previous products or activities often seem to have little to do with it. While this may seem like a mere coincidence, Gilsing is noted to have written in one of his textbooks, indicating that "*some first tentative, shared concepts and technical norms may also develop, reducing cognitive distance and improve mutual understanding […] After the emergence of a dominant design, networks no longer need to hide in seclusion and will tend to extend their market internationally*" (Gilsing, 2005), and it seems to be an accurate portrayal of the current situation. The 3 firms may be so eager to widen the market and gain recognition that they have decided to demonstrate something that may become a part of our daily life, as opposed to focusing only on some "mind-controlled cool gadgets". Thus, we can argue that neurofeedback is nearing the end of or have passed the phase of generalization and is heading into differentiation stage. Neurogaming is a more special case because it has to rely on a BCI devices. Thus, a mass market-winning design will be crucial to its success and emergence as a new industry, or as a new design element that can be absorbed by existing videogame companies.

Taking into account of the fact that neurofeedback is mostly likely not in line with most existing companies, it is possible that most firms are waiting for a more refined dominant design to emerge from the differentiation phase, and only then would they finally start mobilizing resources and enter the market, whether through mimicking, collaborating, or practicing M&A, to ultimately restarting the cycle.

近年のビジネス理論が、成長のためによりリスクを負うよう経営者や投資家たちに促すのは少なくないにも関わらず、そうしようとする企業が少ないのは誰もが知る事実である。これは、やはり従業員が多くなるにつれ、それをなるべく合理的に束ねるため大企業がよく持つ官僚主義やコミュニケーションの困難さによるものであろう。この際、いかに優れたアイデアであっても、コミュニケーションの問題で理解者が少なく、あるいは合理化しすぎて不確実なモノに資源を費やしたがらないという可能性が出来てしまい、チャンスを逃してしまう。しかし、経営陣や管理職を過度に責めるべきではない。彼らも人間であり、失敗の可能性が 5 割以上を超えるとされている新技術や事業のためにまで体を張る必要性などないと言っても誰もが頷くであろう。

一方、実際はドミナント・デザインという概念を待ち、後から漁夫の利を狙っている可能性も否めない。ドミナント・デザインとは、市場が明らかに好んだデザインに沿い、どんな会社にも関わらず似たような製品を出すことを指し、ユーザーのスイッチングコスト（新商品を買い換える際の理解しやすさ）を下げるための試みである。最も分かりやすい例は自動車の運転席のレイアウトであろう。約 90 年前、車にドミナント・デザインはなかった頃には様々なレイアウトがあり、車を買い替えるたびにまた一から新車の勉強し直すことを強いられ、煩わしい時代であった。現在の BCI 業界でも、ニューロ・フィードバックの QoL（クオリティ・オブ・ライフ）ビジネスや簡単な BCI 玩具以外の応用は、いずれもドミナント・デザインと呼べるものは現れておらず、まだ明確に確立されていないのである。見たことのない新技術を先に他人にやってもらって結果を側から評価するのは、実に楽であろう。もっとも、その思考は、果たして本当に企業の成長と持続性に貢献できるか、実に評価しづらい。

8.2 From a Leadership / Entrepreneurship Point of View / リーダーシップや企業家精神の観点から

In Kotter’s book “A Force for Change” from 1990, organizational behaviour pioneer Kotter examined some of the characteristics that differ between “true” managers from “true” leaders, which are two distinctive roles that often actually become fused into one individual in real world corporate practice. In short, the biggest difference between the two is that true leaders excel at the creation, communication, and execution of a certain vision among a group or inside a company, while managers excel at the monitoring, control, and allocation of resources (Kotter, 1990). Looking back at the 3 BCI venture CEOs, they all share a certain passion towards where they are at, and where they want to be. They have already convinced themselves of the success they will inevitably have. Leaders also need to communicate their vision to others to build a strong, efficient, and passionate team — which often only takes place in SMEs, where communications are much easier, resulting in a strong shared value. In large corporations, on the other hand, it is much more difficult to achieve this due to layers of hierarchies or bureaucracy. As was discussed in the previous sub-section, large corporate innovators may have all experienced the frustration of crashing into a brick wall of bureaucracy or mistrust from their managers, delaying not only potential business growth but also the chance to incubate individuals who truly can recognize opportunities and lead the company to great success some time.

But where does vision and passion come from? There cannot possibly be a definitive answer. However, Baron in 2006 proposed an interesting framework worth examining (Baron, 2006):

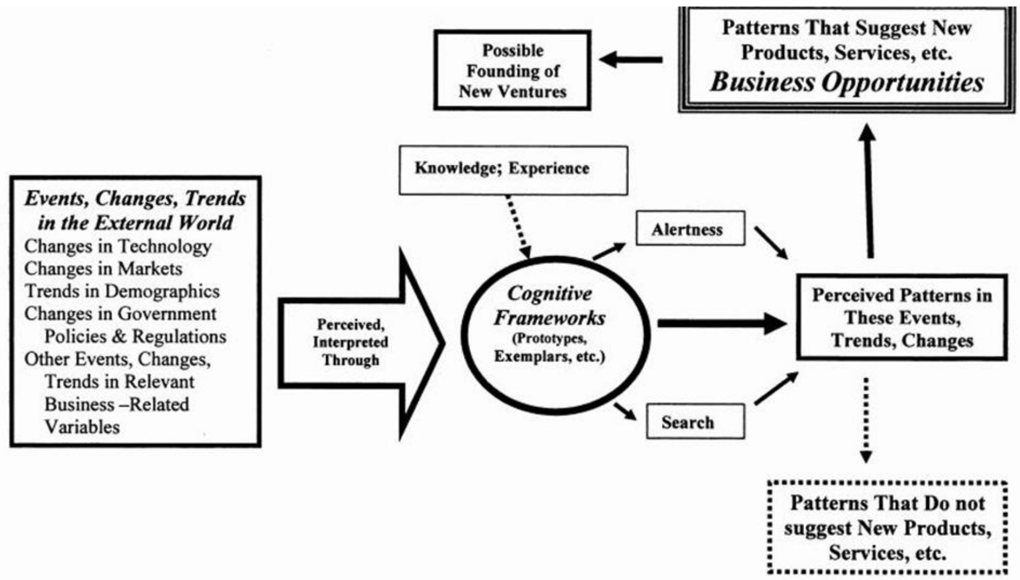


Figure 1
The Potential Role of Pattern Recognition in Opportunity Recognition

Baron, R.A. 2006. Opportunity Recognition as Pattern Recognition: How Entrepreneurs "Connect the Dots" to Identify New Business Opportunities. ***Academy of Management Perspectives***, 20(1): 104-119

Recalling from our case study, we know that all 3 leaders already have had previous experiences working with high tech and startups. These experience may have reduced their fear in starting up companies and they know how to properly negotiate with investors.

The “dots” for Stanley and Ariel are easier to connect. One wants to use “The Force”, while the other wants to improve our quality of life and reduce stress via brain power. Considering this, Tan Le is indeed especially interesting, because she does not have any educational background working with neither neuroscience nor high tech before founding SASme with Nam Do. In Tan’s TED talk mentioned earlier in the case, Tan said she was determined to be successful and dreamt big when she faced discrimination during her early days of immigration. This spirit, coupled with the fact that she had met many entrepreneurs of the same age as her, may be the reason she abandoned her comfort zone and pursued something unknown.

Other than NeuroSky, where not much information over its cofounders is available, both Emotiv and InteraXon’s founders came from a diverse educational background. It could be possible that, if a band of very different people are able to sit down and share a common vision, it may be an indication that they are already very open-minded people to begin with. Perhaps this open-mindedness is one of the keys in recognizing the changes and opportunities of the outside world, thus allowing them to pursue something radical earlier than anyone else? Further investigation is beyond the scope of this paper, but the correlation between such a mindset and entrepreneurship is definitely an area worth further research.

Lastly, it is important to note that all 3 leaders have met their own inspirational mentor of BCI sometime in their life from different universities. All 3 professors have had working examples of BCI technology prototypes, which may also be influential in their decisions in embracing a completely unknown market.

リーダーとマネジャーは、実際のビジネスの人事慣習ではよく同じ人物だとされるが、実は二つの異なる役割である。無論、両方を備えた逸材もいるだろうが、リーダーの資質が全部のマネジャーにあると断定されがちなのは実に好ましくない。リーダーは、コミュニケーション力、情熱、執行力など、新しいビジョンや物事を実現させるための力量や勇気が求められる。一方、マネジャーとは資源をうまくコントロールし、無駄やプロジェクトの暴走などを抑えるために存在する役割である。したがって、管理職の多い大企業では満足に身動きを取れないのも頷けるであろう。

では、ビジョンや情熱はどうすれば育てられるだろうか。無論、正解などはないが、ベンチャー3 人の CEO だけを見て、いずれも初心に戻って大学の教授にインスパイアされ、いずれも SF 映画や過去の経験を経て大きな夢を持つようになり、いずれも現在の世界に満足できずにいるのは明白だ。こういった精神が、彼らを誰よりも先に未知の道を歩ませたと言えるのではなかろうか。

9. A Plausible Roadmap of Promising Areas worth Investment / 有力な投資分野及びロードマップ作成

Assembling the pieces from our data and discussion, we can estimate a roadmap of what investors and business leaders should expect of BCI in the next upcoming decade and in the more distant future:

Promising Fields worth Investing

Categories	Short-term returns (less than 5 years)	Long-term returns (10+ years)
BCI Prosthetics and Bionics	Very promising. Prototypes already available. Pending commercialization efforts and government approval.	May further grow into exoskeletons, remote robots, etc, for able bodied consumer use.
Neuromarketing	Promising. Pioneers that make good use of neuromarketing may gain an advantage on marketing activities.	May become an industry standard, and no longer a competitive advantage.
Neurogaming	Promising. Many ventures are developing games for commercial BCI devices as we speak right now.	Very promising. AAA hardcore titles combining emotion-based interaction, and potentially bidirectional BCI communication will cater well to gamers who seek maximum immersion.
Natural User Interface / Augmented Trans-human Interface	Moderately promising. Projects such as BrainFlight demonstrate how it can be done. Simple thought-commands for smartphones, tabs, or wearables may be viable.	Very promising. This has the potential to significantly cut labour training costs for operating sophisticated machines.
Neurofeedback Quality of Life	Very promising. Passionate consumer support witnessed on crowdfunding platforms shows great growth potential.	Likely to become a commodity, with stable but no major returns

Possible Roadmap into the future

Present (2015)	1-3 Years	4-5 Years	6-10 Years	10-15 Years
• Release of development kits for indie/venture developers (OpenBCI, BrainWriter) • Commercial EEG devices for individuals / low budget researches • DARPA, major US universities get funding from BRAIN • Prototypes of thought controlled prosthetics / sensory feedback (invasive) • Some companies are trying BCI, but very little more is known • Neurofeedback brain training with commercial EEG sensors for the *curious ones*	• More venture/indie applications for commercial BCI devices, greatly boosting sales and recognition. • Thought controlled limbs commercially available at *a high price* • More neuroscience researches combining VR and BCI	• EEG cheap enough for mass consumers ($60~$99 USD). More indie/venture developers • Miniature MEG sensors available • Mass BCI neuromarketing among consumer goods firms • Video game consoles launch peripherals of BCI to enhance gameplay • Brain training devices become widespread and a part of household health device • First neuroprosthetics available but expensive	• Early bidirectional BCI with active brain enhancements or stimulations becomes commercially available • US BRAIN Initiative ends • New devices incorporating machines and BCI. Significantly lowering labour training costs • 2nd generation BCI-prosthetics cheap enough for any amputees	• *Matrix*-styled full bidirectional BCI. New internet businesses combining VR, Cloud, and BCI • NUI transition into ATI (Augmented Trans-Human Interface). Machines and exoskeletons become a part of routine life. • Huge controversies over the social impact and ethics of computers further interfering with our brains • Neuroprosthetics become cheap for anyone

* Edited and verified under the assistance of Associate Professor Yasue Mitsukura, Department of System Design, Faculty of Engineering, Keio University.

While it is impossible to truly tell whether this roadmap will indeed reflect the future, the message this paper wishes to convey is simple: BCI has too many applications that will likely cause a widespread revolution. In a rapidly changing business environment due to extreme-pace innovations, technology obsolescence occurs so fast that the chance to invest in a certain firm or R&D project to great profit is often very transient. Firms must start to investigate and evaluate new opportunities early on, while embracing risks to truly ensure the longevity of a company.

ここまでの資料や議論を踏まえて、BCI のあらゆる応用を、ロードマップ風にまとめた。ニューロ・フィードバックの最近の注目度を考慮し、将来の数年間は話題となり続けるであろう。加えて、既にプロトタイプがいくつかあった BCI 義肢が安全性を証明し、政府機関からの規制が解禁されて販売されれば、その視覚的インパクトの大きさも大きな話題となる。そして、ようやく BCI 技術を一般大衆にも注目され、多くの団体からの大量の資金注入に繋がる。その段階となると技術革新のペースが一気に加速し、発売されたばかりの商品に用いた技術が既に時代遅れとなり、投資のタイミングがますます複雑となってしまう。このため、まだ競争が白熱化していない今現在こそ、BCI を深く理解し、未来に備えるための時期だと言える。

10. Proposals to Large Companies / 大企業への提言

Now that we have examined a roadmap of "what" corporates should do facing BCI technologies to gain an edge early on, this paper would also like to make proposals of "how" to tap into this market.

The approach this paper would like to suggest is perhaps similar to the idea of ambidextrous organizations, by Tushman and O'Reilly in 1997. In an ambidextrous organization, firms are building tomorrow's future while still managing today's successes. At microscopic level, the company has fragmented cultures, but united together by one single, easy, but extremely firm vision. In such an organization, employees cherish the differences and are not afraid of the likelihood of another team forcing them out of business; because if the whole company misses an opportunity and goes out of business, they lose even more (Tushman & O'Reilly, 1997). Needless to say, achieving this need some serious tinkering of the corporate culture, with very open-minded managers, risk-taking culture, and a stern top management vision.

To achieve ambidexterity, top management should encourage internal venture teams such as Skunkworks. A 2014 survey conducted by Accenture in the United States may indeed indicate a demand for this. 69% of the employees in the United States report that they believe companies are not doing enough to encourage innovation to stay competitive in an increasingly volatile global business environment. But on the opposite end, 85% of the top managers or corporate leaders report that many innovations are focused on internal improvements rather than external ones. In addition, while 52% of the 800 employees surveyed claim that they pursue an entrepreneurial idea, only 20% say there is enough support from their employers (USA Today, 2014). The discrepancy between the 2 parties hint some serious misunderstandings. To avoid this, companies should practice internal entrepreneurship and establish project teams that are free from the constraints of the core company's culture and rules. This is different from how many companies have already established separate large scale remote research centres outside the company. It is inevitable that a large entity will ultimately always develop a stiffened approach in order to properly communicate between large groups of workers. In contrast, Skunkworks teams should be fairly small and be treated like a venture startup company, with only minimally adequate resources but a selection of the most capable, passionate, brave individuals from the company. The standard corporate R&D centre should retain its roles of incremental innovation that are aligned to the company's present core businesses, and only grant full support to any new invention or innovation that successfully stemmed from the Skunkworks teams. The rationale behind an internal venture startup is so that the teams face a certain "pressure" to at least demonstrate a proof-of-concept working prototype to the "investors" (employer or a manager over watching the team with minimal interference). If a prototype cannot be completed within a pre-determined timeframe and there is no good reason to justify it, the project can be deemed as lacking in a firm vision and is sacked. This is consistent with the currently popular saying of "start small, fail early, fail small, dream big" and is an excellent way to explore new business and test a certain new technology. On the other hand, if a project is successful and worth further investigating, it is the manager's job to find ways to re-integrate it back to the company, which is often easier said than done, but absolutely necessary to retain a stream of innovation.

Another strategy worth consideration when facing something radically new is open innovation. As was seen in section 9.1, most of BCI's current knowledge are extremely scattered between the hands of numerous startups and research institutes. To foster quick understanding of a potentially revolutionary technology, firms must learn to tear down pride and bravado and embrace the sheer amount of opportunities existing outside the corporate barrier, and avoid the tempting thought of developing everything in house and use patents to set up a barrier to entry. In fact, it may be even riskier in today's environment, because the complexity of new technologies often does not give firms the chance to slowly learn and evaluate something foreign completely by itself. Furthermore, contracting to or directly investing in university projects may potentially cut R&D costs, as was witnessed in how Tan Le brilliantly assembled a group of volunteers from universities to write the software code for emotion-recognition of raw EEG data. Also, having a university professor bearing allegiance to the company may help "eavesdrop" on some insider information about the most up-to-date research trends and where to look for further innovation opportunities. However, this is not to say that firms should just leave R&D to outsiders, because incremental innovation capacity is sometimes needed to understand or truly leverage the opportunities found outside, not to mention it is also an important element of an ambidextrous organization. Furthermore, no company could possibly survive without a certain competitive advantage. Managers and CEOs must be able to identify what information can be shared to foster greater growth, and what not to be shared to sustain the current competitive technological advantage against competitors.

The third is perhaps relatively new — the exploitation of crowdfunding. To date, the use of crowdfunding is predominantly at venture or SME levels for no obvious reasons that have been agreed upon. Crowdfunding is a fairly powerful tool to show market traction (Exhibit 2) and how consumers respond to a certain new line of products. This in turn, gives the company enough evidence of success even before a product has been actually produced, greatly negating some of the risks of a failed product due to a weak value proposition. Furthermore, projects listed on crowdfunding sites often require close monitoring of questions, doubts or suggestions that must be cleared and answered one by one, to win a consumer's trust (The Blueprint, 2013). In return, this grants an unprecedentedly close interaction with consumers to fix any shortcomings and truly build a dream product that everyone desires. Although some companies may be afraid of giving away the details of a "killer product" too prematurely, proponents encouraging large companies to use crowdfunding argue that it usually is not the idea that matters. It is the execution of the idea that truly matters, which is almost never asked in details by any consumers (The Globe and Mail, 2014). The logic being that ideas can be copied pretty quickly, but the execution, and the original innovative mindset or culture that gave birth to the idea in the first place, cannot be duplicated, at least never exactly. Also, a mere copycat would be barred from the valuable experience and information gained from the close interaction with consumers, making its ability to maintain incremental improvements and innovation questionable. A recent example of large corporate using crowdfunding is Sony. Recently, Sony has been found using a Japanese crowdfunding site to crowdfund its smartwatch e-Ink, under the disguised name Fashion Entertainment, raising 3.5 million yen, 175% more than the targeted 2.0 million. While a Sony spokesperson later commented the reason for the campaign is to learn more about the demand (Wall Street Journal, 2014), the rationale behind the disguising of the company's name remains vague. Nevertheless, it is apparent that large enterprises are starting to exploit crowdfunding as a tool to alleviate some risks of product innovation.

Our last suggestion is the ultimate decision of whether companies really should wait for a BCI dominant design. Although intuitively we may think that by waiting for a dominant design, firms may avoid the painful disappointment and waste of money in the case their design is not selected by the market, as was discussed in section 9.1. However, the findings by Utterback and Suarez in 1995 suggests otherwise: firms that engaged in pre-dominant design are actually more likely to survive even if their design fails to win the market. An easy explanation is the first mover patent advantage that the company may incorporate into the rival's design and eventually bounce back. But also, there is the possibility that by engaging in pre-dominant design R&D, firms have an ample amount of time to evaluate and test the market demand, while at the same time assess internally the missing links necessary to leverage on the new technologies, and acquire any relevant collateral asset to strengthen future R&D efforts (Utterback & Suarez, "Dominant Designs and the Survival of Firms", 1995). Furthermore, as was previously mentioned, the recent advent of crowdfunding can be exploited to reduce some of the risks during pre-dominant design phase. Based on these arguments, this paper suggests that companies who are interested BCI and who have the absorptive capacity to do so should not wait or be overly reactive to truly dominate a radically new industry.

BCI のような複雑で全く新しい領域に踏み入れるために、本論文でも幾つかの提言を挙げたい。

まずは、社員の中から最も有能で、最も新技術に対して情熱を持つ少数精鋭を選抜し、普段の勤務先と企業文化から切り離して、社内ベンチャーのような少人数のプロジェクトチームを作る。予算と納期もベンチャーらしくギリギリまでに設定し、期日までに必ず上層部という「投資家」達に示すよう命じる。これが、P-38 や SR-71 や F-35 などの奇抜な飛行機デザインで名を知られたロッキード社（現ロッキード・マーティン）が立案し、そして今でも採用されている破壊的イノベーション戦略の一つ、「スカンクワークス」である。ポイントは、少数精鋭チームと資源の少なさであり、多くの大手企業がすでに持った大型研究センターとはまた違う。これは、文化、官僚主義、行き過ぎた合理性などに縛らせないためであり、ベンチャー企業のようなカオスな状態を突破し、うまくまとめ上げられたモノも相当にポテンシャルが秘めているはずだとされたためである。実際、第二次世界大戦のとき、ロッキード社がこの方法で、たった 180 日でジェットエンジンのノウハウを持たなかったアメリカが初のジェット戦闘機を作り上げたことは有名である。これは決して、大型研究センターが悪いという意味ではない。大型研究センターは企業の持続的イノベーションを維持する面でも重要な役割を持ち、企業現在のビジネスを支えることやスカンクワークスで得られた新技術や発想の全面的バックアップにおいては非常に重要である。

次は、オープンイノベーションである。あらゆる産業や技術分野が次々に交わるようになってきた現代では、何もかもを自社開発に拘っているとキリがなく、寧ろプロジェクトが度々に先延ばしとなってチャンスを逃してしまい、組織が不必要に膨張してしまう可能性に繋がるのは言える。あらゆる研究機関や中小企業と連携し、自社に不足や対応しきれないところを取り組むか補うか、そして他社とシェアできる情報を開示し、共に新しいイノベーションを生み出すほうが、より身動きが取りやすくなる。最も、自社の競争優位性だと判明されているものは、容易に開示すべきではない。

もう一つは大手企業にとってはまだ新しいコンセプトであろう。それはクラウドファンディングの利用である。クラウドファンディングというコンセプト自体の歴史はまだ 10 年も経っていないにも関わらず、既に様々な中小企業や起業家の助力となっている。無論、クラウドファンディングは中小限定という制限は一切無く、それを使わずにいる大手企業が顧客との近距離接触を拒むように見えるという不思議な現状がある。確かに、「キラー商品」を未熟なタイミ

ングで情報をリリースして他社にコピーされてしまうことを恐れる企業もあるだろう。しかしクラウドファンディング推進派は、そのキラー商品が必ず売れるという保証は無いため、クラウドファンディングによる顧客との交流を行うことで、より「キラー的」な商品に仕上げられることや、ただコピーだけをした企業は顧客との交流情報を持たないという利点をあげている。そして、アイデアだけが頼りとなる商品はコピーされるのはほぼ当然であり、むしろその執行やそのアイデアを生み出せた文化やマインドセットのほうが重要だと反論している。

最後に、ドミナント・デザインを待つのは、果たして賢明な判断であろうか？市場に受け入れられず、他社に負けたデザインは一見、無駄な金銭ロスに見えなくもないが、多くの経営学者は異議を唱えている。早期に取り掛かるほうが、時間的に余裕を持って業界分析や自社の不足なところを調査して補える。また、例え最初の勝負に負けたとしても、いち早く現ドミナント・デザインの不足点を理解でき、別のところからイノベーションを図って再びシェアを取り戻せ、企業が生き永らえるのに繋がると言われている。

11. Conclusion / 結論

In this paper, we have explored many different applications of BCI, and how the technology may cause an eventual worldwide revolution on almost all aspects of our life. We also looked into why large enterprises, despite their ample amount of resources at hand, would rather become mere observers when current business administration theories often screech for a style more dauntless to gain an advantage. Fully convinced of the opportunities and in line with today's business administrative theories trend, the author of this paper also tries to encourage large firms to more actively explore the unknown, to accelerate BCI research and commercialization to further better the lives of mankind.

However, due to time and budget constraints and the closed nature of current BCI industry in terms of corporate information such as financial performances, this paper acknowledges many of the shortcomings in its arguments and data collection. Many parts of this paper may require more quantitative validation for a more persuasive argument over innovation strategies. On the other hand, it must be emphasized that the goal of this paper is not to prove a business administration hypothesis, but serves a more promotional purpose for BCI technologies, and hopefully some of the logics are also usable on other areas of innovation management in the future.

When facing a potentially game changing technology such as BCI, it is very important for firms to open up and recognize the opportunities and threats that the new technology may eventually deliver. Even if today a certain technology does not seem to align to a company's current core business, and that the company does not have the absorptive capacity to leverage it, it is never wise to think of it as a sort of distraction and completely ignore about it. Many industries ultimately do emerge, as is witnessed from the Internet Age, and the recent wireless Smartphone Age. The world often changes quickly without warning and by the time one notices it, it is already too late.

本論文では、BCI の種々の応用分野を紹介し、今後の人間社会のために大きな革命をもたらす可能性を提示している。一方、これほど大きなチャンスがあるにもかかわらず、資源が豊富な大手企業が積極的でない現状の原因や、なぜ資源を持たないベンチャーのほうが活発になっているかを推察した。

断片的な情報しか得られない現在の BCI 産業事情や金銭資源の制限により、本論文は検証面においてはやや甘いという側面は否めない。しかし、それは本論文の本来の目的ではないということを理解してもらいたい。本論文の不足点は、BCI 技術に興味を持った今後の有志者による補完を期待したい。

技術革新によって産業融合が進むなか、新技術を「我が社の事業分野とは関係ない」と軽く一蹴する判断は、決して容易くやるべきものではない。特に BCI ほど多くの潜在性を持つ技術と直面するときは尚更である。現代のビジネス環境は、新技術の普及により一瞬で変化してしまうというリスクは常にあり、「時既に遅し」という事態は、20 世紀以降、多くの人々が嫌なほど見てきたのではなかろうか。

Exhibit 1
E-mail Interview with NeuroSky

Industrial Side

1. <u>Current trend, and investor preferences:</u>
   Is there a certain area of concentration on BCI research among the different countries? For example, one country excel at using BCI for medication while the other intends to use BCI for the mass-market? Is the United States a major source of innovation and breakthrough on BCI research compared to the other countries?

   Yes, certain countries tend to focus the technology into certain use cases based on market need fulfillment. For example, the U.S. is more interested in entertainment uses whereas Asian countries see the technology as a platform for educational advancement.

2. <u>Possible reasons for lack of active involvement from big companies:</u>
   Have the major IT giants (e.g. Google, Apple, Microsoft, IBM, etc.) and prosthetics/bionics manufacturers been actively funding BCI projects to your knowledge? Or are most researches still mostly being done at the researchers' own interests and passion, funded by public agencies? If the major companies indeed have been largely inactive, what are some of the reasons you can think of?
   I cannot tell you our own relationship with major companies. Yet, in general, major companies continue to monitor the technology while seeking out compelling use cases. Adding an extra hardware element to the application truly requires a very strong value proposition.

3.
   Please tell me a bit more about NeuroSky. From what I have gathered, you were founded as early as 2004. How did the founders get involved in BCI technologies, and how did they overcome the risks and fear of investing in something that was arguably enigmatic back then? How did they manage to persuade the investors? Can NeuroSky's experience and success provide an insight for future investors or entrepreneurs who may be interested in BCI?
   While as you say the technology was "enigmatic back then," it also had an incredible "wow factor" that drew a lot of attention from just about everyone. People did not understand what information could be gathered from their minds by a piece of hardware that no one had seen outside of a hospital. Many drew their own conclusions and hyped

up their own expectations about what information the technology could actually capture and interpret. This led ultimately to a period of deflated expectations. Nevertheless, the technology continues to make important advancements that are being tracked today.

4. The labour market:

   Currently, I am assuming that in order to work on BCI technologies, one must have adequate understandings of both neuroscience and computer science. Has there been difficulties in attracting new talents or experts who are knowledgeable in BCI to foster further growth? Similarly, should creditors also start hiring people of relative expertise to better assess the potential value of a project?

   There are plenty of worldwide schools producing neuroscience talent. Some go into research. Some go into medicine. Others go into industry. It is amazing how many go into industry and the pool of talent is growing as BCI goes commercial.

5. The US Government's national strategies:

   Does the BRAIN Initiative help NeuroSky and any other companies focusing on brain sensors *in anyways?*

   From a PR point of view, yes, it helps all BCI companies.

6. Japan? :

   I see that NeuroSky has a representative office in Japan already, probably ahead of any other companies. It would be interesting to know about *NeuroSky's perspective* of Japan. Generally speaking, are Japanese companies or investors expressing any more interests in "brain-machine-interface" (as how they refer to BCI) than their Western counterparts? Has the Japanese government done enough, when compared to the West, in promoting and subsidizing its research?

   There are a lot of R&D investigations on both sides of the Pacific.

7. Competitors…? :

   NeuroSky, Emotiv, InteraXon seem to be the major players in the current commercial BCI devices market. How does NeuroSky differ from the other two in approach, target, and vision?
   Simplicity and value.

Technical

8. Just a funding problem?
   What are the main obstacles of BCI devices today for mass commercialization? Is it something that simply attracting more funds can solve, or is it much more complicated than that?

   Funding certainly helps to solve problems, overcome challenges and make new discoveries.

9. Mental Fatigue:
   Part of my paper's argument seeks to use BCI as the ultimate evolution of *natural user interface* and *human computer interaction* design, where devices or machines will become extremely intuitive to use, further bridging the gap between the experts & novices, the young & old, and the virtual & real. However, today's BCI largely requires very concentrated attention from the user and may induce mental fatigue. Can this be alleviated within the next decade?

   BCI applications don't always have to be about demands on the user's conscious control of a mental state or emotion. Simply monitoring a user's mental activity without their awareness is how the technology will find a permanency in the mass market.

10. Computer-brain communication and safety:
    There has been announcements by numerous universities around the world that invasive prosthetics have been able to successfully simulate tactile senses for amputees. Can the same be done with current non-invasive BCI technologies (regardless of cost) to pave way for BCI's potential use in virtual reality? If not, is the future looking bright in solving those issues?

    I don't see that particular use case happening with a $99 technology, but certainly other VR uses are possible. Since VR is not my field, I'd have to leave that answer to them.

11.

    Current BCI technologies are mostly limited to one-direction communication. While there have been some researches seeking to achieve sensory feedback or brain-to-brain communication via outside stimulations such as light electrical shocks, has there been enough research over the safety of prolonged exposure to such stimulations? Furthermore, is this safety issue the most major obstacles for a more active research into full-bidirectional communication? If indeed bidirectional BCI becomes a reality, will it have to go through the expensive and lengthy FDA approval?

NeuroSky is a passive sensor company. We do not do research into using our technology to stimulate the brain in any way and we don't track other companies that do.

12. <u>Is it worth it investing in new detection methods?:</u>
    My understanding is that current commercial BCI technology is predominantly EEG in favour of its portability and price, while MEG and fMRI are more reserved for research due to their bulky and expensive nature. However, I have read that EEG offers poorer spatial resolution when compared with the other methods, ultimately limiting their uses somewhat. Are we close to the absolute limitation of EEG, or are there still many rooms for improvements?

    EEG will not match up to MEG and fMRI, but the cost and inconvenience of those other technologies are very prohibitive. It's all about use cases where one technologies advantages will fit a given use case while another's advantages will fit to a different use case. EEG certainly has room to improve its noise filtering, signal detection capabilities and algorithmic interpretations, so there is still room to grow.

13. Related to 5, fNIRS and ultrasound has recently came to light as new scanning methods, both of which can be extremely compact and portable if I understood them correctly. In what ways are they superior or inferior to EEG? Will it be necessary to ultimately consolidate numerous sensors into one device to achieve both optimal spatial and temporal resolution?
    I have not studied these other technologies by comparison. You may want to Google some research papers.

14. <u>Exploiting BCI for greyer activities:</u>
    Let us talk about a grey area. Can current BCI devices be exploited for neuromarketing? For example, conducting a survey with random volunteers and monitor their mental states and emotions when they are presented a certain new products, to help determine whether to release the product. Similarly, can current BCI "accidentally" pick up information that an unsuspecting user may not want to share, such as privacy?

Neuromarketing is certainly a real market for current BCI devices. I am not sure how BCI could "accidently" pick up information about a user if the user has made the choice of putting a headset on their head. I think that the privacy concern is really blown out of proportion. There are many much more intrusive technologies that yield far greater information about who we are to very intimate details. Search engines are the biggest violators of our privacy. Social networks are second. Anything that gathers data on an individual has the potential to be misused in some way.

15. Vision and Dreams:

What are some of the possible major breakthroughs of BCI, or other relevant technologies to BCI or neuroscience, within the 10 years that you can think of, or would like to see? Are they more likely to be developed by firms or research institutes?

I see BCI data as only a piece of a bigger set of data that can be aggregated, sorted and analyzed. It provides data on a user's mental and emotional states that other technologies can only indirectly claim to gather through other feedback mechanisms. Building a bigger picture of the individual through a combination of different modalities can yield huge benefits not only the individual, but to societies as a whole. It's all about big data over the next 10 years and it will be a combined effort by firms and research institutes.

Please describe NeuroSky's long term vision, and some comments for business investors or leaders about BCI.

NeuroSky is the leader in Body and Mind biosensor solutions. Our vision is to enable our users to build the most advanced, state-of-the-art wearable devices that provide individual users with important insights about themselves in order to enhance their lifestyles. We provide a turn-key shop of biosensors and interpretative algorithms that our partners leverage to add value to their applications and products.

Exhibit 2
E-mail Interview with InteraXon

What makes InteraXon different?

1. While I am aware that Muse is currently the only BCI headband for daily use, it is not difficult to imagine that competitors would soon arise (especially with the announcement of Emotiv Insight). What inimitable unique value does InteraXon have that are different from your competitiors, especially NeuroSky and Emotiv? (anything)

- Ours is the only one that actually does something of value for the average person
- We are the leaders in user experience development for BCI (award winning)
- Our headband is easy to put on and comfortable to wear

Ms. Garten's entrepreneurship. Crowd funding's effectiveness.

2. I notice that Ms. Garten is a talented artist and had founded a clothing design company before. Was it closed down purely because of her passion for neurotechnology?

- Ariel's not in the office this week, but you can find lots about her profile online.

With the recent advent of crowd funding, has the process and the ease of funding for a company or a project significantly changed when compared with Ms. Garten's previous experiences?

- Crowdfunding is a great way to show traction in the market, but it hasn't replaced traditional financing. Crowdfunding only represents about 3% of the money raised by Interaxon.

Language matters?

3. InteraXon, Emotiv, and NeuroSky, the 3 most successful BCI ventures are all from English speaking countries. Is this a coincidence, or are there some other potential factors at play?

- The tech startup world has been overwhelmingly english for a long time, mostly because the whole tech startup / venture capital model was invented (or at least refined in its current form) in California in the years following WWII.

Fortunately, it's changing, and more and more startups are able to get funding in countries around the world, in many different languages.

fNIRS, ultrasound, and (maybe portable in the future) MEG

4. Is there a reason why other portable scanning methods other than EEG has not been truly exploited for commercialization?

- Form factor: fNIRS is portable now but requires a lot of power and big hardware. Same with Ultrasound. MEG will not be portable in the foreseeable future, if ever: most MEG manufacturers have gone bankrupt or scaled back, and the limits of the technology (liquid Helium containment) can only be overcome by new discoveries in the physics of superconductivity.

Scarcity of large corporate efforts in BCI

5. Save for a few, many major companies seem to be either unaware of, or prefer not to directly involve in BCI despite all its potentials and the sheer amount of resources they have at hand. Are there any reasons for this?

- In general large companies wait for a market to be proven before launching a product. We've met with several large companies who have teams actively investigating EEG as a potential avenue for new product development. They are looking to companies like us to solve the technical and user experience hurdles, and to prove that there is a market for these types of products before jumping in. The advantage of being a startup is the ability to take the high-risk/high-reward path without having to justify our actions to the public markets.

B2C only?

6. Is InteraXon currently purely B2C with the Muse?

- The product is packaged as a B2C product, but fundamentally Muse is a platform and can enable a wide variety of applications. We are in discussions with a number of partners about potential B2B applications

Difficulty in finding new talents?

7. Considering BCI spans across neuroscience and computer science, I presume that one must be sufficiently knowledgeable in both to work in the field, making it difficult to find the right talents and limits the industry's growth. Am I overly pessimistic?

- Not at all. We hire neuroscientists to do the neuroscience and computer scientists to do the computer science. The vast majority of the work at any company is not so specialized. Our marketing people, for instance, have studied neither neuroscience nor computer science. Certainly someone who had a background in both would be a very attractive hire, but anyone who is an expert in either computer science or neuroscience should be able to learn enough about the other field to be useful.

Future of an active brain stimulation device?

8. Current commercial BCI devices are more on the passive sensor side. When I think of BCI I also dream of a day when we may eventually get Matrix-like virtual experiences, which presumably require devices that can stimulate our brain and directly put information into it. What is InteraXon's view for this potentially more risky yet exciting part of BCI?

- That kind of experience will most likely only be possible with implants, and I think we're a long way off from "elective brain surgery" becoming a thing.

Exhibit 3

Personal Interview with Associate Professor Yasue Mitsukura, of Keio University

1. Compared to other countries, is Japanese BCI technology any inferior?

   Technology wise not at all. However, in Japan ethical problems and outcries can easily arise, which makes invasive BCI experiments extremely difficult to be carried out. In that sense, we may be at a disadvantage in invasive BCI knowhow.

2. The US government has just announced the BRAIN last year (2013), to place neuroscience and its related applications into top priority as a national competitiveness strategy, with a funding of $300 million per year over a 10 year span. Has the Japanese government done something similar?

   The Japanese government announced a budget of 10 billion yen, but there is no clear span.

3. Is Keio in sort of a pioneer position in BCI research in Japan? Are there any other universities or institutes?

   Indeed Keio is a leader. Other famous places are institutes such as Riken, and Sansouken (AIST). Other than that, there is not many universities pursuing BCI in Japan.

4. I see that Mitsukura Sensei has just recently founded a company called Science Jam, via funding from Dentsu and Digital Garage. Is it a holding company? Also, is it difficult in Japan for high tech startups to go fully independent similar to companies such as NeuroSky or Emotiv? Is it rare to have professors to found companies in Japan?

   Yes, it's a shareholding company with Dentsu owing 60% of the shares and Digital Garage the rest. In Japan, venture capitals are not as abundant as in the United States, plus we are more of a risk averse culture, it is very difficult to acquire the funds needed for an independent company. Especially if it's a novel high tech business, where very few actually understand what you are trying to do. As for the last question, yes, I would say it is indeed quite rare for professors in Japan to found companies outside, while still teaching.

5. Compared to the western countries, are project collaborations between corporates and research institutes as common in Japan? Are there any obstacles preventing a direct

funding of a university project from corporates?

There is very little collaboration. Most corporates basically do not even invest a penny in university projects. Many interesting ideas just die down without anyone noticing, which is a real shame.

6. Generally speaking, how interested are Japanese firms about BCI?

   Not too bad. Especially from the automobile industry.

7. Does neuromarketing really work? If we really know what emotion customers have, can we call it the Holy Grail of marketing?

   It's not that omnipotent as of now, just another new variable worth considering. However, just that one extra variable can hugely impact the process of decision making in marketing.

8. I got interested in BCI via reading popular science journal sites such as Nature and Science Daily, which are abundant in the United States. Is Japan really lacking communities that try to popularize science to foster curiosity?

   You are absolutely correct. In fact, I think it's safe to say that the majority of the Japanese pay little to no attention to science and engineering topics. I really wish the government can do something about it.

9. Due to the human skull, EEG's resolution just can't seem to improve. Is it feasible to combine EEG with other scanning techniques to improve information clarity?

   Of course. However, mind you that the US NIST is researching ways to miniaturize MEG sensors that will be portable and affordable. I am also personally involved in some parts of the project, and if successful BCI research will really start leaping upwards.

10. Recently ventures such as NeuroSky and InteraXon are pursuing the vision of improving QoL via neurofeedback. Is there any risks of everyone become sort of brainwashed and have the same mindset?

    No, neurofeedback does not do that and it is not a concern. Also, I must emphasize that while neurofeedback is clinically proven, those commercial sensors you see simply are not powerful enough to achieve the same results. I suspect there is a bit of a placebo effect going on.

11. Can a bidirectional BCI system like The Matrix be achieved with non-invasive technologies?

    Yes. And not very long. There are already many related researches out there and I think just within 15 years we may see a working example.

Exhibit 4
BCI Research Journals and Trend Analysis

News	Country	Invasive?	Government / Universities / Institutes / NPO	Indie / Venture / SME	Large Corporate	Neuro-science	Pros-thetics	Neuro-prosthetics	Non-Prosthetics / Personal Consumption
University Of Pittsburgh - Brain Controls Robot Arm In Monkey (2005)	USA	○	○				○		
Duke University - Monkeys Adapt Robot Arm As Their Own (2005)	USA	○	○				○		
Dartmouth College - Dartmouth Study Finds How The Brain Interprets The Intent Of Others (2006)	USA	○	○			○			
Queen's University - Study Of Hand-brain Function Offers Insight Into Recovery For Stroke Survivors (2006)	CAN		○			○		○	
Elhuyar Fundazioa - An Adaptive Interface For Controlling The Computer By Thought (2006)	ESP		○				○		○
University of Manchester - Scientists Build Brain Box Computer (2006)	GBR		○						○
Multi-institutional; published by University of Chicago - Brain-computer Link Lets Paralyzed Patients Convert Thoughts Into Actions (2006)	USA		○				○	○	
University of Colorado - Human Brain Region Functions Like Digital Computer (2006)	USA		○			○			
University of Washington- Electronic Chip, Interacting With The Brain, Modifies Pathways For Controlling Movement (2006)	USA		○				○	○	○

University of Pennsylvania - New Ideas On Developing Thought-Controlled Artificial Limbs (2007)	USA		○				○		
Max Planck Society - Revealing Secret Intentions In The Brain (2007)	DEU		○			○			
University of Michigan - Robotic Exoskeleton Replaces Muscle Work (2007)	USA		○				○		
Hebrew University of Jerusalem - Brain Input Aids Devices That Move Injured Or Artificial Limbs (2007)	ISR	○	○				○	○	
University of Leicester - Researchers Can Read Thoughts To Decipher What A Person Is Actually Seeing (2007)	GBR		○			○		○	
University of Leicester - Nature Of Consciousness: How Activity Of Single Neurons In Human Brain Reflect Conscious Perception (2008)	GBR		○			○		○	
University of Pittsburgh - Monkey Feeds Itself Using Its Brain (2008)	USA	○	○				○		
Heidelberg University - How The Brain Separates Audio Signals From Noise (2008)	GER		○			○			
University of Florida - Neural Implant That Learns With The Brain May Help Paralyzed Patients (2008)	USA	○	○				○	○	
University of Reading - New Research Provides Insights Into How The Brain Works (2008)	GBR		○			○			○
National Institutes of Health - Movement Restored To Paralyzed Limbs In Monkeys Through Artificial Brain-muscle Connections (2008)	USA	○	○				○	○	

RIKEN - Robots Show That Brain Activity Is Linked To Time As Well As Space (2008)	JPN		○			○			
Netherlands Organization for Scientific Research - Neuroimaging Of Brain Shows Who Spoke To A Person And What Was Said (2008)	NLD		○			○			
Washington University - Brain Implants May Help Stroke Patients Overcome Partial Paralysis (2008)	USA	○	○			○		○	
Ecole Polytechnique Fédérale de Lausanne - Faulty Brain Wiring May Be Bypassed With Carbon Nanotubes (2008)	CHE / ITA	○	○			○		○	
University of Marburg - Effects Of Brain Exercise Depend On Opponent (2009)	DEU		○			○			○
University of Toronto - Optical Brain Imaging Decodes Preference With 80 Percent Accuracy (2009)	CAN		○			○		○	○
University of Michigan - Nanotechnology Coating Could Lead To Better Brain Implants To Treat Diseases (2009)	USA	○	○					○	
University of Utah - Paralyzed People Using Computers, Amputees Controlling Bionic Limbs, With Microelectrodes On (Not In) Brain (2009)	USA		○				○	○	○
University of California – Berkeley - Brain Develops Motor Memory For Prosthetics (2009)	USA	○	○			○	○	○	
National Institute for Physiological Sciences - Mouse Brain Rewires Its Neural Circuits To Recuperate From Damaged Neural Function After Stroke (2009)	JPN	○	○			○		○	

University of Michigan - Step Toward Better Brain Implants Using Conducting Polymer Nanotubes (2009)	USA	○	○					○	
University of Southampton - Brain-Computer Interface Allows Person-to-person Communication Through Power Of Thought (2009)	GBR		○						○
Mayo Clinic - Brain waves can 'write' on a computer in early tests, researchers show (2009)	USA		○						○
University of Leicester - Locust study promises new insights into limb control (2010)	GBR	○	○			○	○		
University of Washington - Brain-controlled cursor doubles as a neural workout (2010)	USA		○			○	○		○
University of Maryland; La Fondation Motrice - 3-D hand movement reconstructed using brain signals: Future portable prosthetic devices for movement-impaired (2010)	USA / FRA		○				○		○
University of Goldsmiths London - First direct evidence of neuroplastic changes following brainwave training (2010)	GBR		○			○			
American Friends of Tel Aviv University - Pacemaker for your brain: Brain-to-computer chip revolutionizes neurological therapy (2010)	USA	○	○					○	
Johns Hopkins University Applied Physics Laboratory - Thought-controlled prosthetic limb system to be tested on human subjects (2010)	USA		○				○		
Case Western Reserve University - Rewiring a damaged brain (2010)	USA	○	○					○	

California Institute of Technology - Controlling individual cortical nerve cells by human thought (2010)	USA	○	○			○	○		○
Society for Neuroscience - Controlling cursors with thoughts: Faster, simpler, and more accurately; advance helps people regulate their own brain response, with therapeutic implications (2010)	USA		○				○		○
Interuniversity Microelectronics Centre - Innovative neural probe senses and stimulates individual brain cells (2010)	Joint Effort	○	○					○	
Honda - Honda Asimo Gets Mindcontrol (2010)	JPN				○				○
Emotiv - Consumer Brain Control Headset Opens Door To Wireless Mind Gaming Using Nordic 2.4-GHz Transceivers (2010)	AUS			○					○
Acclair - Art Watcher's Thoughts Scanned While Looking At An Artwork (2010)	GBR			○					○
Emotiv - Browse Flickr Images With Your Thoughts (3rd party) (2010)	AUS			○					○
NeuroSky - NeuroSky Is Coming to Philippines Hospitals & Schools (2010)	USA			○					○
University of Oxford - Literally Shocking: Electric Current in the Brain Improves Math Abilities (2010)	GBR		○			○			○
Zynex - New President at Zynex to Become a Primary Medical Neurological Device Provider (2010)	USA				○	○			○

Universal McCann, Time, Inc.; EmSense - Neuromarketing study to make iPad ads more effective and enjoyable (2010)	USA			○					○
University of Chicago - Robot arm improves performance of brain-controlled device (2010)	USA		○			○	○		○
NeuroVigil - iBrain, An EEG Device for At-home Sleep Monitoring and Diagnosis (2010)	USA			○					○
University of Pittsburgh - Controlling a computer with thoughts? (2011)	USA	○	○				○		○
BrainAthlete; NeuroSky - NeuroSky's New Portable MindSet Measures Athletes' State of Mind (2010)	USA / JPN			○					○
InteraXon - InteraXon to Showcase Thought-controlled iPad Game and 3D TV Experience at CES'11 (2010)	CAN			○					○
Sciulli Digital Media Group - Web 3.0 is Here? The First Thought-controlled Social Media Network with NeuroSky devices (2011)	USA			○					○
Emotiv, Google - Google Research Award ($71,579) for Project Using Emotiv Epoc (2011)	USA			○	○				○
Mattel; NeuroSky - CES: Mindflex 2 from Mattel Comes with Multiplayer Gameplay (2011)	USA			○	○				○
Ferrari - Future Ferraris Equipped with Biometric and Psychometric Sensors (2011)	ITA				○				○
Hewlett-Packard - Hewlett-Packard to Put Mind Control in Their PCs (2011)	USA				○				○

Honda Creates Brain-Reading Driving Hat (2011)	JPN				○				○
National Institute for Physiological Sciences - Abnormal neural activity recorded from the deep brain of Parkinson's disease and dystonia patients (2011)	JPN	○	○			○		○	
Rensselaer Polytechnic - XXXY's Infinity Simulator Connects Emotiv Headset to Theatrical Flying Rig (2011)	USA		○						○
Ecole Polytechnique Fédérale de Lausanne - Multitasking with Brain-Computer Interfaces (2011)	CHE		○						○
University of Auckland, Emotiv - Robot Programmed to Respond Facial Movements with Emotiv EPOC (2011)	NZL		○	○					○
Brown University - BrainGate neural interface system reaches 1,000-day performance milestone (2011)	USA	○	○			○	○	○	
MindLab - An Insight into Mindlab's Neuromarketing in Practice (Quantifying human behaviours via EEG) (2011)	GBR			○					○
Washington University - Technique for letting brain talk to computers now tunes in speech (2011)	USA	○	○				○		○
Semiahmoo Secondary School - Science Student Aims to Win with Computer-Aided Telepathic Communications (2011)	CAN			○					○
University of Syndey - Emotiv Co-Founder Allan Snyder's "Thinking Cap" to boost creativity (2011)	AUS		○	○					○

Neurowear; NeuroSky - Show Your Mood with Brain-Controlled “Necomimi” Cat Ears (2011)	JPN / USA			○					○
University of Michigan - Navigating in a Virtual 3D Environment with Emotiv EPOC (2011)	USA		○						○
University of Liège - New Test Detects Signs of Consciousness in Vegetative State Patients (2011)	BEL		○			○			
Variety.com - Neurocinema Gives You More Honest Audience Feedback (2011)	USA				○				○
University of Western Ontario - Research turns the world upside down: New study examines brain processes behind facial recognition (2011)	CAN		○			○		○	
Brown University - Researchers map, measure brain's neural connections (2011)	USA		○			○			
Intendix - Type 5-10 Characters Per Minute with Intendix Thought-Writer (2011)	AUT			○					○
University of Michigan – Non-invasive brain implant could someday translate thoughts into movement (2011)	USA		○			○	○	○	○
University of Western Ontario - Researchers can predict future actions from human brain activity (2011)	CAN		○			○			○
IMEC - New EEG Headset From Imec to Compete Existing Brain-Reading Products (2011)	BEL / NLD / Other		○	○					
University of Manchester - Chips hold the key to understanding the human brain (2011)	GBR		○			○			
American Friends of Tel Aviv University - Cracking the code of the mind (2011)	USA		○			○	○	○	○

Albert-Ludwigs-Universität Freiburg - Getting a grip on grasping (2011)	DEU	○	○			○	○		
University of Maryland - 'Brain cap' technology turns thought into motion; Mind-machine interface could lead to new life-changing technologies for millions of people (2011)	USA		○						○
NeuroSky; Neurowear - Show Your Mood with Brain-Controlled “Necomimi” Cat Ears (2011)	USA / JPN			○					○
Toyota - Shift Gears With Your Mind When Riding the Toyota Prius Concept Bike (2011)	JPN				○				○
Puzzlebox Brainstorms - Puzzlebox Brainstorms Enables Controlling iRobot Roomba with Your Mind by using commercial BCI devices (2011)	GBR			○					○
University of Liège - Brain waves control the impact of noise on sleep (2011)	BEL		○			○			
G.Tec; Linden Lab - Second Life Avatars Controlled Via Brain-computer Interface (2011)	AUT / USA			○					○
National Science Foundation; University of Washington - Five years of funding ($18.5 Million) to Brain-Machine Connection Research (2011)	USA	○	○				○		
University of Washington - Proton-Based Transistors for Future Prosthetics and Biofeedback Sensors (2011)	USA	○	○				○	○	
KDDI; NeuroSky - Android OS Gets Mobile Brainwave Measurement System (2011)	JPN / USA			○	○				○

University of California, Berkeley - Dream Recording Device Around the Corner? (2011)	USA		○			○			○
Duke University - Brain-Machine-Brain Interface (BMBI) Enables Tactile Feedback, Explores New Sensory Channel (2011)	USA	○	○				○		
Nissan; École Polytechnique Fédérale de Lausanne - Nissan Cars to Read the Driver’s Thoughts (2011)	JPN / CHE		○		○				○
Haier; NeuroSky - Brain-Controlled TV Available in China Announced for 2011 (2011)	CHN / USA			○	○				○
Panasonic; University of Fukui - Panasonic Develops EEG Based Volume Level Fitting for Hearing Aids (2011)	JPN		○		○				○
American Friends of Tel Aviv University - Robot brain implanted in a rodent: Researcher implants robotic cerebellum to repair motor function (2011)	USA	○	○					○	
University of California, Berkeley - Study shows brain flexibility, gives hope for natural-feeling neuroprosthetics (2012)	USA	○	○					○	
University of California, San Francisco - How selective hearing works in the brain: 'Cocktail party effect' explained (2012)	USA		○			○			
National Institutes of Health - Brain-activated muscle stimulation restores monkeys' hand movement after paralysis (2012)	USA	○	○				○		

Brown University - People with paralysis control robotic arms to reach and grasp using brain computer interface (2012)	USA	○	○				○		
Albert-Ludwigs-Universität Freiburg - Brain controlled robotic arm: Scientists read out arm movements from brain's surface (2012)	DEU		○				○	○	
University of Stanford - fMRI Locates Overactive Brain Areas, Helps Fight Depression (2012)	USA		○			○			○
University of Pennsylvania - Mind reading from brain recordings? 'Neural fingerprints' of memory associations decoded (2012)	USA	○	○			○			○
Duke University - Brain center for social choices discovered: Poker-playing subjects seen weighing whether to bluff (2012)	USA		○			○			
Emotiv; NeuroSky - Emotiv and NeuroSky Update Developer Tools, More Mind-Controlled Apple Devices Anticipated (2012)	USA			○					○
American Friends of Tel Aviv University – Protein-based coating could help rehabilitate long-term brain function (2012)	USA		○			○		○	
NeuroSky - NeuroSky Launches MindWave Mobile at Gadget Show Live (2012)	USA			○					○
Newcastle University; Institute of Cognitive Sciences and Technologies - Neural interface for hand prosthesis can restore function in brain areas responsible for motor control (2012)	GBR / ITA	○	○				○	○	

National Institute of Standards and Technology; Physikalisch Technische Bundesanstalt - Noninvasive miniature sensor measures magnetic activity in human brain (2012)	DEU / USA		○				○	○	○
Albert-Ludwigs-Universität Freiburg - 'Doctor' or 'darling' -- Subtle differences of speech: Brain signals tell who someone is talking to (2012)	DEU		○			○			
University of Michigan - Better brain implant: Slim electrode cozies up to single neurons (2012)	USA		○				○	○	
Keio University - EEG Headband Aims to Monitor Real-Time User Experience (2012)	JPN		○						○
Albert-Ludwigs Universität Freiburg - Brain-machine interfaces: How do you differentiate between a mere urge and a deliberate intention? (2012)	DEU		○			○	○	○	○
Institut National de Recherche en Informatique et en Automatique; Ubisoft - OpenVibe2 Offers Open Source Brain-Computer Interface Platform, Ubisoft Supports the Initiative (2012)	FRA		○		○				○
Béziers Technology Institute; Bar-Ilan University - Robot Controlled by Human Mind Using fMRI (2012)	ISR / FRA		○						○
Stanford School of Engineering - Leap forward in brain-controlled computer cursors: New algorithm greatly improves speed and accuracy (2012)	USA		○				○	○	○

InteraXon - InteraXon Presents Its Own BCI Headset at TechCrunch Disrupt (2012)	CAN			○					○
Intel - Intel CTO Justin Rattner Wears Necomimi Onstage, Promises Intel Will Go All the Way to Mindreading (2012)	USA				○				○
Emotiv; eSharp - eSharp Links Emotiv SDK to Visual C=, Needs to Raise $3000 to Make BCI Development Easier and More Fun (2012)	AUS			○					
Global Industry Analysts, Inc. , reported by Neurogadget.com - Rise of Neurostimulation, an Industry Predicted to be Worth $6.9 Billion by 2018 (2012)	USA				○				○
Texas Instruments - The World's Lowest-Noise Chip for Non-Invasive Brain Wave Monitoring (2012)	USA				○		○		○
Institute for Ethics & Emerging Technologies - Foremost Futurist Michio Kaku About Brain-to-Brain Communication, Why the Next Step Is the Brain Net (2012)	USA		○						○
Imec Holst Centre; Panasonic - Imec, Panasonic and Holst Centre Present Their New EEG Headset Prototype (2012)	BEL / NLD / JPN		○		○				○
InteraXon - InteraXon Unveils Muse: A Sleek & Stylish 4 Sensor BCI Headband (2012)	CAN			○					○
Chalmers University of Technology - Thought-controlled prosthesis changing lives of amputees (2012)	SWE		○				○		
AIST; CNRS - Mind-controlled robot development in Japanese-French joint laboratory (2012)	JPN / FRA		○						○

Emotiv; SensoMotoric Instruments - Emotiv Partner With Eye Tracking Leader SMI to Merge Brain Response And Visual Perception (2012)	AUS / DEU			○	○				○
University of Edinburgh - Rhythms in the brain help give a sense of location, study shows (2013)	GBR		○			○			
United States Congress - BCI research must be at high level of national priority, suggests US Congressman Chaka Fattah (2013)	USA		○			○	○	○	○
University of Pittsburgh - Paralyzed man uses thoughts alone to control robot arm, touch friend's hand, after seven years (2013)	USA		○				○		
Duke University - Brain prostheses create a sense of touch: Infrared signaling could create sense of touch in artificial limbs (2013)	USA		○			○	○		
Chalmers University of Technology - World premiere of muscle and nerve controlled arm prosthesis (2013)	SWE	○	○				○		
Brown Univesity - Novel wireless brain sensor unveiled: Wireless, broadband, rechargeable, fully implantable (2013)	USA	○	○			○	○	○	
National Institute for Physiological Sciences; Univesrity of Washington - Restoring paretic hand function via an artificial neural connection bridging spinal cord injury (2013)	JPN / USA	○	○			○		○	

University of Chicago Medical Center - Sense of touch reproduced through prosthetic hand (2013)	USA	○	○				○		
Neurogadget.com on Emotiv - InteraXon raises 6M in Series-A funding, solidifies itself as a rising power in the consumer BCI market (2013)	CAN			○					○
Emotiv - Emotiv unveils Insight, a powerful new EEG headset that doesn’t require saline (2013)	AUS			○					○
The Hong Kong Polytechnic University - Novel brain training device to reconnect brain and paralyzed limb after stroke (2013)	HKG		○			○			○
University of Minnesota - Helicopter takes to the skies with the power of human thought (2013)	USA		○						○
Albert-Ludwigs-Universität Freiburg - Mapping the brain: Researchers use signals from natural movements to identify brain regions (2013)	DEU	○	○			○			
University of Washington - New tasks become as simple as waving a hand with brain-computer interfaces (2013)	USA	○	○			○	○		○
Duke University - Carbon nanotube harpoon catches individual brain-cell signals (2014)	USA	○	○			○			
Ecole Polytechnique Fédérale de Lausanne; Allen Institute for Brain Science - Neural simulations hint at the origin of brain waves (2013)	CHE / USA	○	○			○			

University of Washington - Researcher controls colleague's motions in first human brain-to-brain interface (2013)	USA		○						○
Virginia Tech - Covert operations: Your brain digitally remastered for clarity of thought (2013)	USA		○			○	○	○	○
University of Chicago Medical Center - A blueprint for restoring touch with a prosthetic hand (2013)	USA	○	○				○		
Duke Medicine - Monkeys use minds to move two virtual arms (2013)	USA	○	○			○	○		○
University of California, San Diego Health Sciences - Water-based imaging maps brain neurons before surgery (2013)	USA		○			○			
OpenBCI - OpenBCI develops an open source brain-computer interface for the masses (2013)	USA			○					○
Case Western Reserve University - Neural prosthesis restores behavior after brain injury (2013)	USA	○	○					○	
Sony; Electro-Communications University - Sony files patent for a brainwave-reading ‘SmartWig’(2013)	JPN		○		○				○
Intel - CES 2014: Intel launches RealSense brand, aims to interface with your brain in the long run (2014)	USA		○		○				○
Aurora - Aurora smart headband gives you control over your lucid dreams (2014)	USA			○					○
Dartmouth College - First evidence of common brain code for space, time, distance (2014)	USA		○			○			

University of Oxford - What makes us human? Unique brain area linked to higher cognitive powers (2014)	GBR		○			○			
MindRider - MindRider bike helmet flashes the cyclist's emotions, maps where you are stressed (2014)	USA			○					○
Cornell University - Brain signals move paralyzed limbs in new experiment (2014)	USA	○	○			○	○		
Georgia Institute of Technology - Robotic prosthesis turns drummer into a three-armed cyborg (2014)	USA	○	○				○		
The Agency for Science, Technology and Research - Thinner probe array that uses silicon-based microstructure could underpin safer neural implants (2014)	SGP	○	○					○	
Univesity of San Diego - Bioengineer studying how the brain controls movement (2014)	USA		○			○	○	○	○
Aalto University - Movies synchronize brains: Brain activity patterns show remarkable similarities across different people (2014)	FIN		○			○			
American Association of Neurological Surgeons - Proprioceptive feedback helps rehab patients learning to operate robotic prosthetic (2014)	USA	○	○				○	○	
Technical University of Munich; Technical University of Berlin - BrainFlight, German scientists make it possible to fly a plane with your brain (2014)	DEU		○						○

Johns Hopkins Medicine - Fight-or-flight chemical prepares cells to shift the brain from subdued to alert state (2014)	USA	○	○			○			
University of Cambridge - Modeling how neurons work together may help design robotic limbs (2014)	GBR		○			○	○	○	○
Ohio State University - New device allows brain to bypass spinal cord, move paralyzed limbs (2014)	USA	○	○					○	
University of Osaka - First BCI capable of learning commands aims to reduce mental fatigue (2014)	JPN		○				○		○
Georgia State University - Hidden variations in neuronal networks may explain differences in traumatic brain injury outcomes (2014)	USA		○			○			
University of Western Australia; Université Pierre et Marie Curie - Could your brain be reprogrammed to work better? (2014)	AUS / FRA		○			○		○	
Investigación y Desarrollo - New prosthetic arm controlled by neural messages (2014)	MEX	○	○				○		
National Institutes of Natural Sciences - Bypass commands from brain to legs through computer (2014)	JPN		○					○	
Carnegie Mellon University - Flexing the brain: Why learning tasks can be difficult (2014)	USA	○	○			○			

University of Minnesota - Yoga, meditation may help train brain to help people control computers with their mind (2014)	USA		○			○	○	○	○
Philips; Accenture; Emotiv - Philips and Accenture have partnered with Emotiv to improve the life of ALS patients (2014)	NLD / IRE / AUS			○	○		○		○
Chalmers University of Technolgy - Mind-controlled prosthetic arms that work in daily life are now a reality (2014)	SWE	○	○				○		
University of Washington - Scientists Achieve Direct Brain-To-Brain Communication Between Humans (2014)	USA		○				○		○

	Invasive?	Research Institutes Projects	Venture Projects	Corporate Projects	Total Projects	Neuro-science	Prosthe tics	Neuro-prosthetics	Non-Prosthetics / Personal Consumption
BCI Projects by USA	39	79	17	11	107	35	46	30	54
BCI Projects by JPN	3	12	4	8	24	4	1	4	14
BCI Projects by GBR	2	13	3	0	16	10	3	4	8
BCI Projects by DEU	2	9	1	1	11	6	4	3	5
BCI Projects by AUS	0	2	7	2	11	1	1	1	6
BCI Projects by CAN	0	4	5	0	9	4	0	3	7
BCI Projects by NLD	0	3	2	2	7	1	1	0	2
BCI Projects by FRA	0	5	0	1	6	1	1	1	4
BCI Projects by BEL	0	4	1	1	6	2	0	0	1
BCI Projects by CHE	2	4	0	1	5	2	0	1	2
BCI Projects by SWE	2	3	0	0	3	0	3	0	0
BCI Projects by ITA	2	2	0	1	3	1	1	2	1
BCI Projects by ISR	1	2	0	0	2	0	1	1	1
BCI Projects by AUT	0	0	2	0	2	0	0	0	2
BCI Projects by NZL	0	1	1	0	2	0	0	0	1
BCI Projects by ESP	0	1	0	0	1	0	1	0	1
BCI Projects by SGP	1	1	0	0	1	0	0	1	0
BCI Projects by MEX	1	1	0	0	1	0	1	0	0

*Note: Double counting allowed for joint projects or if project spans across different applications

*Note 2: The purpose of this analysis is to look for research trends or commercialization efforts. This analysis does not represent BCI technology levels of individual countries.

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