Overview of consumer-oriented brain computer interfaces

Christina Bork
Universität Passau
Lehrstuhl für Informatik mit Schwerpunkt Eingebettete Systeme
Innstr. 43
94032 Passau, Germany
bork01@stud.uni-passau.de

ABSTRACT

This paper provides an overview over brain computer interfaces oriented at consumers. Aspects for the comparison will be usage-domain, technical details of the sensors, run-times, operating systems, application programmer interfaces, usability and the differences seperating them from devices at the professional market.

1. INTRODUCTION

There are widespread possible applications for BCIs. This paper generally addresses non-invasive methods of BCIs. Invasive methods do require some kind of surgery on the user's head. Non-invasive means that anybody could use these BCIs without any surgery needed. Let consumer-oriented be defined as devices that are available at the market for private customers.

A first possible application for BCIs would be as a new intuitive input-method. Especially for people with disabilities, paralysis or full paraplegia, this scenario might be very useful. Possible applications could range from comminication to aid in living their lives more autonomously. For example to ride a wheelchair that is controlled by your thoughts might help you in daily routine, as having a speech synthesizer like Steven Hawkings. Prostheses, being controlled by your thoughts in the same way as natural limbs, might also be possible.[2]

For non-handicapped people it might also serve as a tool to learn how to properly relax and concentrate. Considering this you could literally get to know yourself better. There are several games teaching the user how to learn to shift and hold their attention and concentration with BCIs. These are called neurofeedback games - the user is getting direct feedback from the screen, which influences further actions. Developers at the Consumer Electronics Show (CES) 2008 showed various possible applications.[8] Most of these games have already become reality and some are introduced in later paragraphs. Games could also assist in treatment for people with mood disorders or attention deficit hyperactivity disorder (ADHD). Apps which use the output of BCIs could assist in therapy for example. Most therapies are usually only performed for a short period of time - these games could provide a fun way to keep our mental and emotional health in check by doing exercises everyday. Many people have fitness trackers and go for a jog several times per week, but few people go through mental exersices.

Another important aspect in our day-to-day lives is safety. From a statistical perspective, the potentially most dangerous aspect endangering our lives is traveling by vehicles. Thus the safety of passengers traveling in vehicles should be valued highly. On the road many accidents happen, because drivers are drowsy or just do not pay their full attention to the road. With commercial BCIs installed in every vehicle, a tired driver could be noticed and the vehicle could refuse to run. Also if there are signs of the driver becoming more tired while driving, the system could alarm the user and propose a pause. Some car-manufacturers already have systems for detecting drowsiness not based on BCIs. Using BCIs could make these systems more accurate and reliable. Some cars feature installed breath tests that must be completed before starting the engine. BCIs could also be a similiar voluntary option to guarantee the driver's and passengers' safety.

Also for most people quantifying their everyday life seems to become a habit. As mentioned before, many people now use smartwatches and fitnesstrackers to keep track of their workout performance and sleep schedule. Keeping track of your own emotions and mental state could just be seen as the next consequent step.

Last but not least, research might also profit from data being captured by a huge base of users - if some everyday users of BCIs might decide to allow sending collected data to the researchers' servers. This also brings up a lot of unseen ethical questions, in terms of privacy protection. The freedom of thought should still be protected. As futuristic as most scenarios seem, several commercial BCIs are already available at the market for consumers. Thus, this paper aims at a comparison to evaluate how they perform in comparison to each other and in respect to their cost.

2. THE BODY OF THE PAPER

2.1 Electroencephalography (EEG)

EEG is a technique which measures the electrical activities between different electrodes placed on the head of a person. Usually it refers to non-invasive methods. There are four different basic sine-like brain wave patterns distinguished by different frequencies. Alpha waves (8-13 Hz), beta waves (more than 13 Hz), theta waves (4-8 Hz) and delta waves (0.5-4 Hz).[79] A higher frequency usually corresponds to a higher brain activity. Alpha waves appear in people who are relaxed or meditating. Closing your eyes usually helps in archieving this state. Beta waves are associated with high mental activity, e.g. having an active conversation. Theta waves can occur when executing a routine task with longer duration or daydreaming. They appear for example when driving on a freeway, running through a quiet forest, or brushing your hair. The delta waves indicate very little awareness. A person sleeping deeply without dreams could have these.[26] The placement of electrodes is standardised in the so called 10-20 electrode system which assigns a letter-digit combination to each position. It was first defined by H.H.Jasper. These standard placement points on the head are called Fp1, Fp2, Fz, F3, F4, F7, F8, Cz, C3, C4, T3, T4, T5, T6, P3, P4, O1, O2, M1 and M2. The number of channels that can be measured is always lower or equal to the number of electrodes. There are various extensions with more electrodes. The '10% system' or '10-10 system' consists of 74 electrodes and is defacto standard. Up to 64 Channels can be measured with it. 128 and 256 channel systems are also becomming common. A proposed '5% system' or '10-5 system' by[54] would have 345 possible electrodes.

2.2 Metrics for comparison

It is important to have a clear definition of metrics which aid in an objective comparison. Thus this sections aims to describe the metrics which are taken into consideration for the comparison of the different products.

2.2.1 *Field of application*

The advertised field of application for the product. Some products may be placed into the market for meditation, relaxation, or gaming purposes. The location also plays a role here. There are devices which can be used at home, whereas others are suited for usage in offices or laboratories.

2.2.2 *Technical details of sensors*

Describes a brief overview of special features for each product. Defined by how many electrodes the system does have, how it is calibrated, how many emotions and other mental states it can classify. The sampling rate is also taken into consideration, if available.

2.2.3 *Operating system (OS)*

The OSs supported by the product. Some devices are only supported by smartphones, e.g. Android and iOS. This metric is quantitive (how many OSs?) and qualitative (which OSs?)

2.2.4 *Application programmer interface (API)*

A brief overview of APIs for developing new applications using the BCI. It is important to mention which software development kits are available for which OSs. Also additional tools aiding the software development can be regarded if available.

2.2.5 *Run-time (RT)*

Describes how long the device can be used with one charge of energy. Also whether rechargable batteries or single usage batteries are used. Manufacturer information is primary taken into consideration. If reviews are available the measured RT can be compared with it.

2.2.6 *Contrast to professional solutions*

Describes the differences to solutions on the professional market, if resources are available. A contrast to other devices introduced can also be taken in consideration. With this, we can get an overview on how the devices perform in comparison to each other. A basic estimation of the raw performance of the EEG should be archieved with this. The available signal quality is the most important factor for this metric.

2.2.7 *Usability*

The effort it takes to maintain the device and the time it takes to set the device up and to take it down. For classical EEG, a special gel is needed which is cleaned up after. This procedure takes a lot of time. Also, it is a discomfort which is probably not acceptable for consumer devices. Many users would most likely not want to go through this inconvenience, every time they use a product. Getting an idea of perceived comfortability might also help. Reviews from users or studies if available can be included. The weight of a headset is a fundamental issue for comfortability. The heavier it is, the faster users are getting tired from wearing it.

2.3 Headsets

With the metrics and EEG defined, the EEG headsets can now be introduced in the following paragraphs.

2.3.1 *Emotiv EPOC*

The Emotiv EPOC/EPOC+ (EPOC) headset is available for $799, "designed for practical contextualized research and advanced[..]BCI applications". It is placed in the market as one of the higher quality headsets in terms of technical specs. This is emphasized by it being also used in research and referenced in many research papers.

Speaking technically, it has 14 wet electrodes which combine to 7 pairs of electrodes. Two sensors are used as references. These are placed in the following 10-20 system locations: AF3, AF4, F7, F3, F4, F8, FC5, FC6, T7, T8, P7, P8, O1, and O2.[24] Thus a 14 channel EEG can be obtained. Data is first internally sampled at 2048 Hz and then downsampled to 128 Hz before usage.[40] The analog-digital converter (ADC) works with a resolution of 16 bit samples.[6] It can be connected via BlueTooth (BT) Smart or a proprietary 2.4GHz band. Claimed RTs with its 480mAh lithium polymer (Li-Poly) battery are 12 hours with the proprietary wireless and 6 hours with the BT Smart.[15] User calibration is performed with a game, where the user is asked to concentrate on a certain task. This includes for example, lifting, dropping, pushing or rotating an object.[9] In terms of OSs, Windows, Linux, OS X, Android and iOS are supported.[13] Development is possible with a C library available for OS X, Linux and Windows. For Windows and Linux there is also python support available.[19] The Developer SDK costs 799$.

A "Community Edition" SDK is also available on GitHub.[78]

The producer also offers a drone, called "MindDrone", which can be controlled with the EPOC. This drone costs 14,99$ and relies on the C# AR.Drone 2.0 controlling library by RUSLAN-B".[18]

A scientific comparison of the EPOC and other commercial BCIs to a research grade System(g.Hlamp) "[..]show that inexpensive, wireless, or dry systems may be suitable for experimental studies using EEG[..]". The Visual steady-state response (VSSR) could be measured with a similiar sensibil-

(a) Emotiv EPOC (b) Emotiv INSIGHT (c) Melon (d) FocusBand

Figure 1: Product pictures

ity compared to a professional EEG.[23]

Roesler et al. concluded that the Emotiv headset could be used for eye state prediction. Compared to a classical professional EEG (BrainAmp), the signal quality is lower, resulting in a higher error rate.[72]

A usability test showed that the electrodes are not that securely fitted on the users head and could be moved. Although the system is not dry, the electrodes are only foam pads soaked in saline. It is similiar to sweat and dries quickly after using the headset. Thus it should not be much of a hassle to set it up, but promises better signal quality than most 'dry' systems.

Users also mentioned discomfort because the electrodes are held in place by springs on plastic arms. This results in pressure being applied on the user's head. The system weighs only 125g - but the weight is unevenly distributed which could cause discomfort for some users.[24]

2.3.2 Emotiv Insight

The Emotiv Insight (INSIGHT) is the little brother of the EPOC. It is available for $299.[16]

It is advertised as a tool to improve brain fitness with the bundled app. Brain activity should be viewable in real time.

The headset features 5 semi-dry EEG electrodes in the AF3, AF4, T7, T8 and Pz spots. Two additional sensors are placed as references. This results in a five channel EEG signal. Data is sampled with 128 Hz time resolution with 14 bit ADC samples.[13]

The transission can be caried out with either BT 4.0 Low Energy (LE) or a proprietary 2.4GHz connection.

In terms of supported OSs, the INSIGHT can be connected to personal computers (PCs) with Windows, Linux or Mac OSX. Android (4.4.3 or higher) or iOS (6,7 and 9+) smartphones are also supported.[17] It should be noted that the SDKs are available for Windows, Mac, Linux, iOS, Android, Arduino, and Raspberry Pi.

The open source Emotiv SDK "Community Edition" also supports the INSIGHT.[78] It provides access to facial expression recognition, mental commands, the 9 axis sensor and fast Fourier transform (FFT). This device should also be supported by the Emotiv SDK "Premium". In addition, this SDK supports performance metrics and raw EEG data.[14] A 480mAh Li-Poly battery powers the device. With this, it should get a RT of 4 hours minimum with BT SMART according to Emotiv. 8 hours should be possible with the proprietary wireless mode.

2.3.3 Melon

The Melon (MELON) is a kickstarter project.[43] It can be preordererd for $150. It will be bundled with a app to support meditation and improvement of focus in users. A motivation for the development was to improve mental health in its users, inspired by attention deficit disorder (ADD) and ADHD research. It is aimed to be an alternative to medication based approaches.[77] It will feature three dry electrodes resulting in a two channel EEG. The FP1 location is used for most measurements. Also on board is a 6-axis accelerometer and gyroscope. Data is transmitted via BT 4.0 LE.[42] An SDK is available for Android and iOS. Developers have access to "focus data" and EEG raw data.[43] A RT of about 8 hours should be possible with the builtin battery. It can be charged via micro-USB. In terms of usability, the melon can be ordered in three different sizes (small/medium/large) to fit the size of the user's head. The time to set the device up and take it down should be relatively small, due to the low amount of dry sensors.

Further data about this device should be available when it will be released to the general public.

It should be noted that the manufacturer website was not available anymore when this paper had been written.[41] Robert Nadler who tested the device's SDK mentioned that Melon had been acquired by another company. No new information has been released since then.[46]

2.3.4 FocusBand

The FocusBand (FB) can be purchased for $500.[76] A proposed field of application is the training for golf players.[1] A golf training app is also mentioned in the quickstart manual.[39] The SDK overview proposes possible apps for "sports, wellness, business & gaming". The FB features three dry silver oxide sensors resulting in a two channel EEG. These sensors are placed on the forehead. Data is transmitted via BT.[74] A RT of twelve hours is claimed. It can be charged via microUSB. The official app is available for iOS and Android. Most training apps and games are iOS only.

An SDK is available for $735.[75] Officially supported OSs by the SDK are iOS and Android. Windows should be available in the future. The API provides access to "avatar states", raw EEG data and status. Avatar states is an array of boolean values with possible mental states, classified by the builtin algorithm. These are: Blink, Face_Tension, Anxiety, Wide_Focus, Medium_Focus, Narrow_Focus, Quiet_Eye, Left_Brain, Light_Mushin, Medium_Mushin and Deep_Mushin. Raw EEG data can be accessed as integer per channel. Status contains battery level and signal quality.

It looks like a normal headband. As the system is dry it should be set up and taken off in a relatively short time.

2.3.5 QUASAR DSI 10/20 / Wearable Sensing DSI-24

The Dry Sensor Interface (DSI) is a commercial BCI developed by QUASAR and licensed to Wearable Sensing. A child-sized version is also available as 'DSI-24-C'. As there is no stated retail price the manufacturer has to be contacted directly for a quotation.

It should be set up in under 5 minutes and be comfortable to wear for over 8 hours. QUASAR's brochure states "the DSI is a headset prototype designed to operate in a laboratory or office environment".[64] This device can be purchased by consumers but it is often used by researchers.

From the technical perspective it features 21 dry EEG sensors.[66] These sensors are located in the international 10/20 System. One additional sensor is used as reference. The product offered by Wearable Sensing supports BT with 300Hz sampling. It is powered by hot-swappable lithium ions (Li-Ions) batteries, with a claimed RT of 24 hours. For "easy-to-use data acquisition", DSI-Streamer Software is shipped with the headset.[71] Concerning OS, Windows XP, 7 or higher are supported. Data can be exported to comma separated value (CSV) files. Real time data can be obtained by a TCP/IP socket connection. An API written in C is also available.[67] Scripts for MATLAB demonstrating on-/offline usage and the C API can be downloaded at [70], however a login is required. The procedure of setting the device up for usage can be seen live at [68]. It is necessary to configure all indivial (21) electrodes with a "screwdriver" until a satisfying signal quality is reached. Cleanup is carried out after usage with a provided electric brush and isopropanol.[65] This BCI is also quite heavy with a specified weight of 600g. An usability test with the prototype version also showed that the helmet design proves to be rather inflexible. It is difficult to fit for different head sizes. Similiar to the EPOC, spring-loaded metal arms can generate pressure, thus resulting in discomfort for users with large heads.

The heavy design also caused "neck pain and headaches" for some participants.

It is also difficult to accomodate the electrodes correctly because the system is so easy to set up and dry (no gel or saline is needed).

This resulted in not getting any signal from one user with long, thick hair.[24]

2.3.6 Melomind

The myBrain Melomind (MIND) is a kickstarter project. Two batches of products have already been produced and delivered to preorderers. It will be sold for a initial cost of $399. Learning efficient relaxation is advertised as the primary area of application. The goal is to provide a way to "reduce the impact of stress and protect you against its negative effects."[45] It is designed for sessions of 15 minutes.[10] Speaking of technical details, it features 2 spring loaded dry EEG electrodes and 2 additional sensors. This makes a two channel EEG signal possible. As the headset also consists of a stereo hifi, an audio jack is included for this part. Audio can also be transmitted via BT 4.0. LE profile is used for EEG data.

In terms of supported operating systems, there is an app available for iOS (iPhone 4S or higher) and Android (4.4 or higher).

When it comes to RT, 6 hours are claimed by the technical specifications. The device can be charged via an included USB charger.

Information about an API or SDK has not been provided yet by the manufacturer. A possible SDK has been announced in the frequently asked questions (FAQ).[45] In comparison to other devices, the audio part is special.[21]

It looks like a regular hifi headset and can also be used as one. The EEG sensors can be taken off for this purpose.

Business insider reviewer Leanna Garfield stated, that the two additional sensors are a bit uncomfortable.[22]

2.3.7 InterAxon MUSE

The InterAxon Muse (MUSE) is available for €299 at [84]. This seems to be the newer (2016) version. An older (2014) version of this headset does also exist. Advertisement categorizes the MUSE as a tool to learn and improve meditation for customers. An App is available which guides the user in this task.

For scientists, clinicians and researchers the proposed applications range from "cognitive neuroscience, to brain health, psychotherapy, music cognition".[34]

This headset features seven dry sensors. Five of them are placed at the forehead and one conductive rubber sensor is placed at each ear. The corresponding 10-20 locations are TP9, TP10, AF7/F7, Fpz, AF8/F8. Exact position can vary due to the head size.[34] This results in four to six channels. Supported sampling rate by the '16 version is 256Hz for EEG. The '14 version supports 220Hz and 500Hz. BT 4.0 aids in connecting with the device. It has two micro-usb ports for charging.

Android and iOS smartphones are the two officially supported OSs supported by the MUSE app.[83]

A SDK for developing an Android/iOS app can be downloaded at [35]. The library "LibMuse" for the headband is provided with documentation, as are example applications for Android Studio, Xcode and the Unity 3D engine.

Research tools can be downloaded for Windows, Mac and Linux. These provide insight into the data obtained by the MUSE. They consist of following components: MuseIO which sends out Open Sound Control (OSC) messages to other programs. OSC is a multimedia network protocol. MuseLab is a tool for vizualization of brainwave data. It further processes the data received by MuseIO. MusePlayer can play previously recorded data from MuseIO. This can be useful for developing and testing applications for the MUSE.

A runtime of up to five hours is claimed by the spec for the '14 version. The '16 version should run for up to ten hours.[82] Charging time is 2.5 hours. The '16 version has a 1.5 hour fast charge option.

According to the manufacturer the device "has been tested against industry standard EEG systems[..]"[34] The test consisted of distinguishing different modes of brain acitvations.

A scientific comparison from a neutral source could not be found.

Allowed head circumference ranges from 52cm to 60cm and the weight is only 60g which makes it very light.[34]

Patrick Beuth from ZEIT ONLINE has reviewed the device. He states that it takes a few times and minutes to set it up until a good signal quality is reached. Especially when

(a) QUASAR DSI (b) Melomind (c) InterAxon MUSE (d) NeuroSky MindWave

Figure 2: Product pictures

one is using the device for the first time. Before each usage, the device needs to be calibrated by letting the user think.[7] According to [20], the MUSE is much more comfortable to wear in comparison with the following NeuroSky. It should be noted that both have a similiar weight.

2.3.8 NeuroSky MindWave & BrainWave

The NeuroSky MindWave (MWAVE) Mobile Plus Starter Kit is available for €149. It features the MindWave Mobile Plus EEG Headset and additional Software - "Brainwave Visualizer", "SpeedMath" and the "MindWave Tutorial". The "Myndplay Edition" for €178 additionally contains four other programs, mostly games & entertainment - "ManUp", "ZombiePop", "Meditation Journal" and the "MyndPlay EEG Media player with 4 movies". The Headset alone can be obtained for 79,99$ at [4]. NeuroSky advertises it as a tool to train "concentration, focus and relaxation abilities". It is claimed to be capable of detecting a focused and relaxed mind state in the user.

The headset features BT 2.1 and is powered by a single AAA battery for a claimed RT of 8 hours. It weighs only 90g. The Chipset used is a ThinkGear ASIC Module (TGAM). It features one EEG channel only at 512Hz sampling rate. According to the datasheet it should be able to detect eyeblinks. The claimed range of detectable brainwaves is 3-100Hz. It only features one sensor on top of the user's head, "located above the left or right eye".[52] Windows, Mac, Android and iOS are officially supported plattforms.[81] In terms of SDK, they can be downloaded for Windows and OS-X with no cost at [51]. Android and iOS sites were not available at the time of this paper.

There are three methods to obtain data from the headset.

The easiest one is using the ThinkGear Connector (TGC), which initiates the connection to the headset. TGC itself is supported by Windows and Mac OSX. The data from the headset is then obtained via sockets. Thus all languages supporting sockets can use this approach.

Another approach is using either the provided shared library, which comes as .dll and .bundle format. This approach runs on Windows, Max OSX and Window Mobile natively. Code can be written in C/C++, C# or Java. Alternatively, a J2ME.jar library is available for J2ME plattforms like mobile phones.

The hardest way to obtain the data is by reading the ThinkGear Communications Protocol (TGCP) directly, through the serial port, and parse the binary data. All systems and languages, which can read serial I/O, can use this approach.

All these approaches rely on NeuroSky's eSense algorithm. It assigns numerical values ranging from zero to 100 to the raw EEG data obtained by the sensor.[48] 'Attention' is the first type of eSense meter, which relies more on beta waves. The other type is called 'meditation'. It makes more usage of alpha waves.[50][47]

In terms of contrast to professional devices, according to Roesler et al. "the [MWAVE] headset is not suitable for even a simple task as the classification of the eye state." Due to the bad quality and low quantitiy of the sensor, serious EEG experiments or control applications should not be possible.[72]

Ekandem et al. compared the MWAVE with the EPOC.[12] The MWAVE does take less time to set up and clean after usage. On the other hand the signal quality is inferior to the EPOC. The system looks almost like a 'normal' headset. As the electrodes are dry it can be set up and taken down very quickly. Due to the low weight it should be comfortable to wear for multiple hours.

Despite this, a reviewer at venturebeat.com stated that he "can't wear the Neurosky for more than 30 minutes without getting a headache."[20]

NeuroSky also offers cat ears, which are responsive to the EEG measured. Advertised as a toy, the position of the ears change in accordance with the mood of the user.[80]

2.3.9 Plattforms

Third party support for the different BCI headsets is an important aspect. Besides the apps delivered by the manufacturer, many other usecases can be imagined. Also most of these apps are only showcases of what could be done with the hardware. Many users would probably not want to buy a headset with no apps available and developers would not want to publish an app without a solid amount of users and thus potential customers. This is were plattforms come in. They provide a way to have a manufacturer independent layer between a specific headset and software. Consumers and manufacturers gain from this, as BCI applications could be used and developed not depending on a specific BCI headset.

2.3.9.1 OpenBCI.

OpenBCI is a kickstarter open source project. The two most important products are the OpenBCI Ganglion Board (Ganglion) and the Ultracortex Mark IV Headset (UC).[37] It is aimed at a target audience from research scientists, to high school students and do-it-yourself (DIY) neuro-hackers. Proposed field of application is learning and research for future neuro-engineers and scientists. Neurofeedback is also a possible application usecase. Alot of other possible BCI usecases are mentioned for OpenBCI without specializing into a specific area.[44]

2.3.9.2 OpenBCI: Ganglion.

The arduino compatible microcontroller is available for $99 at kickstarter.[44] It is open source and the final price in the store is $199.[56] It is needed for the UC. It features different 4 input channels for brain, heart, muscle and accelerometer sensors. Different sampling rates can be chosen, particularly 128, 256, 512 and 1024 Hz. For transmitting the data, BT 4.0 LE is supported. A MicroSD card slot is also onboard. It is powered by 4 AA batteries and draws a maximum power of 15 mA under usage. This should yield a minimum RT of around 40h with very cheap batteries(400mAH), up to 300h with premium ones($\sim$ 3000mAh).[87]

2.3.9.3 OpenBCI: Ultracortex Mark IV Headset (UC).

The UC is a 3D-printed EEG headset. It can either be obtained to print-it yourself for $ 349.99 with 8 sensors or for $ 449.99 with 16 sensors. Alternatively it is also available completely assembled for $ 799.99 / $ 999.99.[60]

The 8/16 dry sensors are placed in the 10/20 system. There are up to 61 different possible sampling locations.

For supported OSs, Mac OS X (OSX), Windows(32/64-bit) and Linux(64-bit) are all supported by the applications.[55] With the ”OpenBCI_Processing” software for example, the captured data can be viewed and analyzed in real time or recorded and played back later.[59] Also dummy data can be generated synthetically.[57]

When considering APIs, a python 2 library is available with documentation.[58] Another proprietary language called ”Processing” which is based on Java could also be used.[59] A standard battery is not included. The recommmended battery pack has a capacity of 500mAh.

According to the manufacturer site, research signal quality should be attainable.

In terms of usability, the headset is offered for small, medium and large head sizes. Thus it should be able to fit for the average user. The sensors' position can be individually adjusted to archieve a good comfort. A Youtube video from Conor Russomanno shows, that the headset can be fitted for usage in under 30 seconds.[73] No cleaning of the user's head is needed afterwards, as the sensors are dry.

2.3.9.4 SDKs for brain-computer-interfaces.

Generally, SDKs for BCIs could be very useful to develop applications running independent of the hardware used or developed for. One particular existing SDK for this purpose is the open source project Open Virtual Brain Environment (OpenViBE). [32] It aims to be an abstraction layer for different devices. There are numerous devices (over 30) supported, including the EPOC(Research Edition providing raw EEG data) and OpenBCI devices via Cyton. Additional support for other devices could be added, if access to raw EEG data is possible.[33]

2.4 Existing applications using (commercial) BCIs

2.4.1 Emotion recognition

Researchers at the University of Canberra stated, ”[..] experimental results show that we can use the Emotiv headset for emotion recognition”. ”Support Vector Machine, k-Nearest Neighbour, Naïve Bayes and AdaBoost.M1” were used as learning algorithms and classifiers.[61]

2.4.2 Robot Arm

Astaras et al. developed a 6 axis robotic arm that can be controlled by using the EPOC or MindWave.[5]

2.4.3 Attention powered car

There is an attention powered car prototype by the Royal Automobile Club of Western Australia (RAC). It uses the EPOC to measure the drivers attention in experiments. Only by having the driver's full attention, the prototype car is operating normally. Disturbances in the attention lead to a brake at around 15 km/h.[62]
A similiar implementation with the MWAVE has been proposed by Chaudhari et al.[11]

2.5 Comparison at use cases

2.5.1 Relaxing & Meditation

A comparison between the EPOC and MWAVE from Maskeliunas et al. showed, ”for [..] concentration and relaxation of subjects, the Emotiv EPOC device has performed better (as measured by the recognition accuracy) by 9%.” Also that ”[..]attention and meditation data is separable more easily in case of the Emotiv data.”[40]

NeuroSky's eSense algorithm features a meditation meter. However it is important to note, that NeuroSky discourages the usage of its eSense algorithm for therapeutic purposes or neurofeedback.[50]

As mentioned in the introduction of the MUSE, it should be very comfortable to wear. The EPOC is around 2 times and the MWAVE 1.5 times heavier than the MUSE.

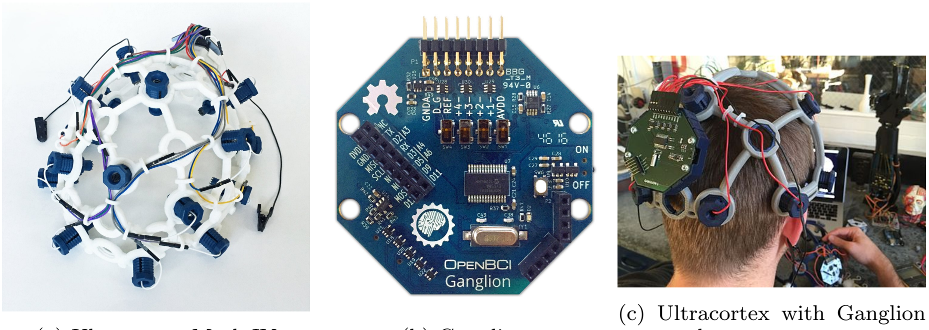
This could be an advantage for the MUSE, as users probably can not relax as good with a uncomfortable device compared to a more comfortable one.

Also, MUSE has been designed especially for this usecase and is primary advertised for it than for other purposes.

MIND is also very promising in this usecase, as it is also specificially built for relaxation. Its app supports ten levels and sessions, ”lasting anywhere from three to 15 minutes”.[22] The audio speakers of the headset provide the user with supporting neurofeedback. When the user is feeling stress the music gets louder. In my opinion this could be a little bit counterproductive. The experience is directly gamificated, as points are earned relative to the performance of the relaxation.

For the remaining devices, required information could not be found for this usecase or the devices were not available yet.

2.5.2 Medical games: ADHD



(a) Ultracortex Mark IV (b) Ganglion (c) Ultracortex with Ganglion mounted

Figure 3: OpenBCI product pictures

An available game created by Crooked Tree Studios / Lat Ware for the NeuroSky MindWave is "Throw Trucks With Your Mind". It is a competetive "multiplayer game developed by Crooked Tree Studios". The principle of concentrating on tasks, such as lifting objects, can be trained with this game. Its creator Lat Ware participated in experimental neurofeedback therapy as teenager for his ADD. This inspired him to imagine other usages for EEG. The game can be purchased in the NeuroSky online store[49]

A project called OpenViBE also created a game, which teaches children with ADHD to hold their attention in the classroom.[36]

3. CONCLUSIONS

Alot of scenarious, which would have been dubbed as sci-fi only a few years ago, have become possible thanks to commercial BCIs. The future will show which applications will become part of our everyday lives.

By just comparing the headsets, a clear winner cannot be defined.

The EPOC is a good alrounder with high signal quality and many research-grade usages. For the price offered, the customer also gets many channels. On the other hand, it is not very comfortable to wear for longer periods of time.

Its cheaper sibling INSIGHT is more comfortable to wear, but has fewer sensors. It could profit from the SDKs being available for both products.

The MELON seems like an interesting product and comfortable to wear, featuring two sensors. However, the company who offered it was sold, therefore no new information is available at the moment.

The FB is very similiar in terms of design and it also features a two channel EEG. It is a bit more expensive though, considering the hardware offered. An SDK is available for it, extending possible use cases.

Looking at the DSI, it has almost professional signal quality, but I doubt many private customers would buy it. It is quite pricey, very heavy and uncomfortable to wear. On top of that, its helmet design is not very asthetic.

In contrast, the UC from the OpenBCI plattform is also an interesting device. Despite looking similiar to the DSI, its design is a bit more lightweight. It also has almost as many channels as its competitor, when the 16 channel version is taken for comparison. Also it should be much more cheaper to acquire. Like the DSI, it is aimed at pro-users, researchers, and also hackers rather than the average end-user. Available SDKs and documentation also seem very promising.

Like the MELON and FB, MIND offers a two channel EEG for a rather high price. However, a normal audio headset is included. Applications are rather limited, as no SDK is available yet.

MUSE on the other hand is very comfortable to wear and features nice design. Like the MELON, FB and MIND it only supports smartphone OSs. In addition, the advertised areas of application are a bit limited.

In comparison, the MIND is a direct rival of the MUSE, also being advertised for relaxation&meditation. At the moment, there is too little information about the device from independent sources, as the device has not been available for sale that long.

Another rather cheap competitor is the MWAVE. In spite of featuring only one channel and being not as comfortable as the MUSE, it only costs one third compared to the EPOC and MUSE. In addition, the power consumption is low and most popular OS are supported.
Summing up, spotlighting one specific device as a winner is not possible - every BCI has its own intended field of application where it succeeds.

Table 4 compares the different aspects.[85]

4. ACKNOWLEDGMENTS

5. REFERENCES

[1] FocusBand – eine neuartige Trainingsmethode bei Golf Vital. `http://www.golfvital.ch/focusband-eine-neuartige-trainingsmethode-bei-golf-vital/`. [Online; accessed 01-May-2017].

[2] Kommunikation per Badekappe. `https://www.dasgehirn.info/entdecken/brain-computer-interface/kommunikation-per-badekappe-5774/`. [Online; accessed 01-May-2017].

[3] Amazon. Muse: The brain sensing headband. `http://www.amazon.com/Muse-The-Brain-Sensing-Headband/dp/B00PL9G16W`. [Online; accessed 01-May-2017].

[4] Amazon. NeuroSky MindWave Headset. `http://www.amazon.com/NeuroSky-80013-001-MindWave-Headset/dp/B00A2UQUXY`. [Online; accessed 01-May-2017].

[5] A. Astaras, N. Moustakas, A. Athanasiou, and A. Gogoussis. Towards brain-computer interface control of a 6-degree-of-freedom robotic arm using dry

Metric	**Emotiv EPOC/EPOC+**	**Emotiv Insight**	**Melon**	**FocusBand**
Price in $	799 (**-**)	299 (**0**)	150 (+)	500 (+)
Field of application	Research, Gaming.	Brain fitness.	Meditation, Mental health.	Sports, Wellness, Business, gaming.
EEG Sensors	14+2 (+)	5+2 (**0**)	1+2 (**-**)	3 (**-**)
Max. EEG Channels	14 (+)	5 (**0**)	2 (**-**)	2 (**-**)
Sample rate in Hz	128(**-**)	128(**-**)	250(**0**)	128(**-**)
OS	OSX, Win, Lin. (**0**)	OSX, Win, Lin, And, iOS. (+)	And, iOS. (**0**)	And, iOS. (**0**)
API and cost in $	Developer(799), Open Source(0)(+)	Developer(799), Open Source(0)(+)	currently n.a.(**-**)	Developer(735) (**0**)
Run-time in h	12(+)/6(**0**) with BT	8(**0**)/4 with BT (**-**)	8 (**0**)	12 with BT(+)
Usability	(**0**)	(**?**)	(**?**)	(+)

Metric	**Dry Sensor Interface**	**MyBrain Melomind**	**InterAxon Muse**	**NeuroSky MindWave**	**Ultracortex Mark IV Headset**
Price in $	n.a. (**-**)	399 (**0**)	249 (**0**)[3]	79.99 (+)[4]	Fully assembled: 799.99(8 sensors) / $ 999.99(16 sensors).(**-**)
Field of application	Health applications in offices and labs.	Learn relaxation, Stress reduction.	Meditation, Brain health, Psychotherapy.	Concentration and relaxation.	Research, Learning, Neurofeedback, Therapy
EEG Sensors	21+1 (+)	2+2 (**-**)	5+2 (**0**)	1 (**-**)	8/16 (+)
Max. EEG Channels	21 (+)	2 (**-**)	6 (**0**)	1 (**-**)	8/16
Sample rate in Hz	240/960(+)	?	220/500('14)(+) / 256('16)(**0**)	512(+)	128, 256, 512, 1024(+)
OS	?	And, iOS. (**0**)	And, iOS. (**0**)	And, iOS, OSX, Win.(+)	OSX, Win, Lin.(**0**)
API and cost in $	C API, MATLAB(on-/offline)(**0**)	n.a.(announced)(**-**)	0(+)	0(+)	Java-based, Python, Open Source(+)
Run-time in h	24 with BT (+)	6 (**0**)	5('14)(**-**)/ 10('16)(+) with BT	8 (**0**)	?
Usability	(**-**)	(**0**)	(+)	(**-**)	(+)

Evaluation:

(+)	above average
(**0**)	average
(**-**)	below average

Figure 4: Comparison of headsets

EEG electrodes. *Advances in Human-Computer Interaction*, 2013, 2013.

[6] T. Autodidacts. Neurotech hardware roundup 2016. http://www.autodidacts.io/neurotech-hardware-roundup-eeg-bci-tdcs-neurofeedback/#musethebrainsensingheadband. [Online; accessed 01-May-2017].

[7] P. Beuth. Muse schaut ins Gehirn. http://www.zeit.de/digital/mobil/2014-10/muse-headband-eeg-hirnstrommessung-meditation-test, 2014. [Online; accessed 01-May-2017].

[8] J. Bloom. Playing games with your mind. https://www.theguardian.com/technology/2008/feb/21/research.games, 2008. [Online; accessed 01-May-2017].

[9] E. Bonnert. GDC: Spiele steuern mit der Macht der Gedanken. https://www.heise.de/newsticker/meldung/GDC-Spiele-steuern-mit-der-Macht-der-Gedanken-182129.html, 2008. [Online; accessed 01-May-2017].

[10] B. Caddy. How mind reading wearables let us delve inside our brains. http://www.wareable.com/wearable-tech/looking-inside-the-brain-2219, 2016. [Online; accessed 01-May-2017].

[11] D. Chaudhari and P. Patil. Emerging neurosky mind-wave bci system to perceive drowsiness. *International Journal of Advances in Electronics and Computer Science*, 2:8–10, 2015.

[12] J. I. Ekandem, T. A. Davis, and J. E. G. I Alvarez, M T James. Evaluating the ergonomics of bci devices for research and experimentation. *Ergonomics*, 55:5, 2012.

[13] EMOTIV Inc. Comparison chart. http://www.emotiv.com/comparison/. [Online; accessed 01-May-2017].

[14] EMOTIV Inc. Developers. http://www.emotiv.com/developer/. [Online; accessed 01-May-2017].

[15] EMOTIV Inc. EMOTIV EPOC+ 14 Channel Mobile EEG. https://www.emotiv.com/product/emotiv-epoc-14-channel-mobile-eeg/. [Online; accessed 01-May-2017].

[16] EMOTIV Inc. EMOTIV Insight 5 channel mobile EEG. http://www.emotiv.com/product/emotiv-insight-5-channel-mobile-eeg/. [Online; accessed 01-May-2017].

[17] EMOTIV Inc. INSIGHT. http://www.emotiv.com/insight/. [Online; accessed 01-May-2017].

[18] EMOTIV Inc. MindDrone, Fly AR.DRONE 2.0 with your mind, facial or head movements or by keyboard. https://www.emotiv.com/product/minddrone/. [Online; accessed 01-May-2017].

[19] EPFL. EMOTIV EPOC HEAD SET. https://wiki.epfl.ch/sinlab/emotiv. [Online; accessed 01-May-2017].

[20] G. FERENSTEIN. Hands-on with the Muse brain sensing headband — the most important wearable of 2014 (exclusive). https://venturebeat.com/2014/05/24/hands-on-with-the-muse-brain-sensing-headband-the-most-important-wearable-of-2014-exclusive/, 2014. [Online; accessed 01-May-2017].

[21] E. Fiolet. Melomind brainwave reader audio headset teaches you to relax. http://www.ubergizmo.com/2016/04/melomind-brainwave-reader-audio-headset-teaches-you-to-relax/, 2016. [Online; accessed 01-May-2017].

[22] L. Garfield. I tried headphones that can supposedly train your brain to relax — here's what happened. http://www.businessinsider.com/mybrain-melomind-relaxation-headphones-review-2016-5?IR=T. [Online; accessed 01-May-2017].

[23] T. S. Grummett, R. E. Leibbrandt, T. W. Lewis, D. DeLosAngeles, D. M. W. Powers, J. O. Willoughby, K. J. Pope, and S. P. Fitzgibbon. Measurement of neural signals from inexpensive, wireless and dry eeg systems. *Physiological Measurement*, 36:1469–1484, 2015.

[24] W. D. Hairston, K. W. Whitaker, A. J. Ries, J. M. Vettel, J. C. Bradford, S. E. Kerick, and K. McDowell. Usability of four commercially-oriented EEG systems. *Journal of Neural Engineering*, 11, 2014.

[25] P. Halbmayer, G. Hoelzl, and A. Ferscha. A dynamic service module oriented framework for real-world situation representation. In *The 6th International Conference on Adaptive and Self-Adaptive Systems and Applications, ADAPTIVE 2014, May 25 - 29, Venice, Italy*, pages 79–84, March 2014.

[26] N. Herrmann. What is the function of the various brainwaves? http://www.scientificamerican.com/article/what-is-the-function-of-t-1997-12-22/.

[27] G. Hoelzl. A personalised body motion sensitive training system based on auditive feedback. In T. Phan, A. Montanari, and P. Zerfos, editors, *Proceedings of the* 1^{st} *Annual International ICST Conference on Mobile Computing, Applications, and Services (MobiCASE09)*, volume 35 of *Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering*, San Diego, California, USA, October 26-29 2009. ICST, Springer. ISBN: 978-3-642-12606-2.

[28] G. Hoelzl, A. Ferscha, P. Halbmayer, and W. Pereira. Goal oriented smart watches for cyber physical superorganisms. In *Workshop on Collective Wearables: The Superorgansim of Massive Collective Wearables, at 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp 2014), Seattle, USA*, pages 1071 – 1076, September 2014.

[29] G. Hoelzl, P. Halbmayer, H. Rogner, C. Xue, and A. Ferscha. On the utilization of smart gadgets for energy aware sensitive behavior. In *The 8th International Conference on Digital Society, ICDS 2014, March 23 - 27, Barcelona, Spain*, pages 192 – 198, March 2014.

[30] G. Hoelzl, M. Kranz, A. Schmid, P. Halbmayer, and A. Ferscha. Size does matter - positioning on the wrist a comparative study: Smartwatch vs. smartphone. In *The Third IEEE International Workshop on Sensing Systems and Applications Using Wrist Worn Smart Devices, at 2017 IEEE International Conference on Pervasive Computing and Communications (Percom 2017), Kona, Big Island, Hawaii, USA*, pages 703 – 708, March 2017.

[31] G. Hoelzl, M. Kurz, and A. Ferscha. Goal processing and semantic matchmaking in opportunistic activity and context recognition systems. In *The 9th International Conference on Autonomic and Autonomous Systems (ICAS2013), March 24 - 29, Lisbon, Portugal, **Best Paper Award***, pages 33–39, March 2013.

[32] Inria Rennes. Frequently Asked Questions. http://openvibe.inria.fr/faq/, 2017. [Online; accessed 01-May-2017].

[33] Inria Rennes. Supported acquisition devices. http://openvibe.inria.fr/supported-hardware/, 2017. [Online; accessed 01-May-2017].

[34] InteraXon Inc. muse
the brain sensing headband
technical specifications, validation, and research use. http://developer.choosemuse.com/hardware-firmware/hardware-specifications. [Online; accessed 01-May-2017].

[35] InteraXon Inc. Developer kit. http://www.choosemuse.com/developer-kit/, 2016. [Online; accessed 01-May-2017].

[36] J. Kite-Powell. Applying a Brain-Computer Interface for children with ADHD. https://www.forbes.com/sites/jenniferhicks/2012/06/17/openvibe-applying-brain-computer-interface-for-children-with-adhd, 2012.

[37] P. König. OpenBCI: Offene Gehirnschnittstelle im Crowdfunding. http://www.heise.de/make/meldung/OpenBCI-Offene-Gehirnschnittstelle-im-Crowdfunding-2911844.html, 2015. [Online; accessed 01-May-2017].

[38] M. Linden. Gehirn lenkt Drohne. http://www.golem.de/news/brainflight-gehirn-lenkt-drohne-1502-112591.html, 2 2015. [Online; accessed 01-May-2017].

[39] F. P. Ltd. Focusband - quick start guide. http://flightscope.com/product/focusband/. [Online; accessed 01-May-2017].

[40] R. Maskeliunas, R. Damasevicius, I. Martisius, and M. Vasiljevas. Consumer-grade EEG devices: are they usable for control tasks? *PeerJ*, 4:e1746, 2016.

[41] Melon. 404. http://www.thinkmelon.com/. [Online; accessed 01-May-2017].

[42] Melon. How does the Melon headband differ from competitive eeg products? http://melon.helpjuice.com/121680-how-does-the-melon-headband-differ-from-its-competitors. [Online; accessed 01-May-2017].

[43] Melon. Melon: A headband and mobile app to measure your focus. http://www.kickstarter.com/projects/806146824/melon-a-headband-and-mobile-app-to-measure-your-fo?lang=de. [Online; accessed 01-May-2017].

[44] J. Murphy and C. Russomanno. OpenBCI: Biosensing for everybody. http://www.kickstarter.com/projects/openbci/openbci-biosensing-for-everybody, 2017. [Online; accessed 01-May-2017].

[45] myBrain Technologies. Melomind : the relaxing headset. http://www.kickstarter.com/projects/865795124/melomind-the-ultimate-relaxation-headset. [Online; accessed 01-May-2017].

[46] R. Nadler. Melon headband android sdk. http://bobonmedicaldevicesoftware.com/blog/2016/03/21/melon-headband-android-sdk/. [Online; accessed 01-May-2017].

[47] NeuroSky Inc. Development - which API is right for me? http://developer.neurosky.com/docs/doku.php?id=which_api_is_right_for_me. [Online; accessed 01-May-2017].

[48] NeuroSky Inc. esense(tm) meters. http://developer.neurosky.com/docs/doku.php?id=esenses_tm. [Online; accessed 01-May-2017].

[49] NeuroSky Inc. Throw trucks with your mind: Revolutionizing entertainment with neurogaming. http://developer.neurosky.com/wp-content/uploads/2016/07/Throw_Trucks_With_Your_Mind_Revolutionizing_Entertainment_with_Neurogaming.pdf. [Online; accessed 01-May-2017].

[50] NeuroSky Inc. What is eSense? http://support.neurosky.com/kb/science/what-is-esense. [Online; accessed 01-May-2017].

[51] NeuroSky Inc. Windows developer tools 3.2. https://store.neurosky.com/products/pc-developer-tools. [Online; accessed 01-May-2017].

[52] NeuroSky Inc. Think Gear // TGAM Features + Technical Specifications. http://www.seeedstudio.com/document/pdf/TGAM%20Datasheet.pdf, 2011. [Online; accessed 01-May-2017].

[53] O. Nickel. Ein Graph sagt mehr als tausend Worte. https://www.golem.de/news/wacom-brainwave-ein-graph-sagt-mehr-als-tausend-worte-1701-125503.html. [Online; accessed 01-May-2017].

[54] R. Oostenvelda and P. Praamstrac. The five percent electrode system for high-resolution EEG and ERP measurements. *Clinical Neurophysiology*, 112:713–719, 2001.

[55] OpenBCI. Downloads. http://openbci.com/downloads, 2017. [Online; accessed 01-May-2017].

[56] OpenBCI. Ganglion board (4-channels). http://shop.openbci.com/collections/frontpage/products/pre-order-ganglion-board, 2017. [Online; accessed 01-May-2017].

[57] OpenBCI. OpenBCI_Processing. http://github.com/OpenBCI/OpenBCI_Processing, 2017. [Online; accessed 01-May-2017].

[58] OpenBCI. OPENBCI_PYTHON. http://github.com/OpenBCI/OpenBCI_Python, 2017. [Online; accessed 01-May-2017].

[59] OpenBCI. THE OPENBCI GUI. http://docs.openbci.com/OpenBCI%20Software/01-OpenBCI_GUI, 2017. [Online; accessed 01-May-2017].

[60] OpenBCI. Ultracortex "mark iv" eeg headset. http://shop.openbci.com/collections/frontpage/products/ultracortex-mark-iv, 2017. [Online; accessed 01-May-2017].

[61] T. D. Pham and D. Tran. Emotion recognition using

the Emotiv EPOC device. In T. Huang, Z. Zeng, C. Li, and C. e. Leung, editors, *Neural Information Processing. ICONIP 2012. Lecture Notes in Computer Science*, volume 7667. Faculty of Information Sciences and Engineering, University of Canberra, Australia, Springer, Berlin, Heidelberg, 2012.

[62] W. Pluta. Auto bremst Unaufmerksame. https://www.golem.de/news/bci-auto-bremst-unaufmerksame-1309-101830.html, 2013. [Online; accessed 01-May-2017].

[63] W. Pluta. Fliegen mit Gedankenkraft. https://www.golem.de/news/brainflight-fliegen-mit-gedankenkraft-1405-106758.html, 5 2014. [Online; accessed 01-May-2017].

[64] Quantum Applied Science and Research, Inc. Dsi 10/20 simple ambulatory no-prep dry EEG system. http://www.quasarusa.com/pdf/DSI_1020_E-brochure.pdf. [Online; accessed 01-May-2017].

[65] Quantum Applied Science and Research, Inc. DSI-24: Doffing. https://www.youtube.com/watch?v=5YysIJiKEVU. [Online; accessed 01-May-2017].

[66] Quantum Applied Science and Research, Inc. EEG:DSI 10/20. http://www.quasarusa.com/products_dsi.htm. [Online; accessed 01-May-2017].

[67] Quantum Applied Science and Research, Inc. Frequenty asked questions. http://www.wearablesensing.com/support_faq.php. [Online; accessed 01-May-2017].

[68] Quantum Applied Science and Research, Inc. Set-up for DSI EEG devices. http://www.youtube.com/watch?v=mD1J7lDJBhM. [Online; accessed 01-May-2017].

[69] S. Reiffert. Using thoughts to control airplanes. tum researchers demonstrate: Brain controlled flight is possible. https://www.tum.de/en/about-tum/news/press-releases/detail/article/31531/, 5 2014. [Online; accessed 01-May-2017].

[70] Wearable Sensing. Download area. http://www.wearablesensing.com/support_downloads.php. [Online; accessed 01-May-2017].

[71] Wearable Sensing. DSI-24. http://www.wearablesensing.com/DSI24.php. [Online; accessed 01-May-2017].

[72] O. Roesler, L. Bader, J. Forster, Y. Hayashi, S. Heßler, and D. Suendermann-Oeft. Comparison of EEG devices for eye state classification. 2014.

[73] C. Russomanno. Ultracortex & openbci gui demo by conor russomanno. http://www.youtube.com/watch?v=agV1B2l-QLw, 2017. [Online; accessed 01-May-2017].

[74] T 2 Green Pty Ltd. Focusband – HOW IT WORKS. http://focusband.com/focusband/. [Online; accessed 01-May-2017].

[75] T 2 Green Pty Ltd. FocusBand SDK Developers kit. http://focusband.com/product/focusband-sdk-developers-kit/. [Online; accessed 01-May-2017].

[76] T 2 Green Pty Ltd. FocusBand Starter Pack. http://focusband.com/product/focusband-starter-pack/. [Online; accessed 01-May-2017].

[77] R. Taylor. 'brainwave' Melon headband measures focus levels. http://www.bbc.com/news/av/technology-29339090/brainwave-melon-headband-measures-focus-levels. [Online; accessed 01-May-2017].

[78] T. E. Team. Emotiv sdk - community edition. http://github.com/Emotiv/community-sdk. [Online; accessed 01-May-2017].

[79] M. Teplan. Fundamentals of eeg measurement. *MEASUREMENT SCIENCE REVIEW*, 2, 2002.

[80] TITAN Commerce Continental Services GmbH. Necomimi - brain controlled cat ears see what makes your ears wiggle. https://www.mindtecstore.com/en/component/jdownloads/send/12-necomimi/52-datasheet-necomimi-en. [Online; accessed 01-May-2017].

[81] TITAN Commerce Continental Services GmbH. Neurosky mindwave mobile plus EEG headset. https://www.mindtecstore.com/en/component/jdownloads/send/14-mindwave-mobile-brainwave-starter-kit/35-datenblatt-mindwave-mobile-plus-de?option=com_jdownloads. [Online; accessed 01-May-2017].

[82] TITAN Commerce Continental Services GmbH. InteraXon Muse EEG Headset Ihr persönlicher Meditationsassistent. https://www.mindtecstore.com/en/component/jdownloads/send/44-muse/189-datenblatt-muse, 2016. [Online; accessed 01-May-2017].

[83] TITAN Commerce Continental Services GmbH. muse the brain sensing headband READ ME. https://www.mindtecstore.com/en/component/jdownloads/send/44-muse/182-manual-muse-de-en-fr-it-es, 2016. [Online; accessed 01-May-2017].

[84] TITAN Commerce Continental Services GmbH. InteraXon Muse - Color: Black. https://www.mindtecstore.com/en/muse, 2017. [Online; accessed 01-May-2017].

[85] G. Udovičić, A. Topić, and M. Russo. Wearable technologies for smart environments: A review with emphasis on bci. In *2016 24th International Conference on Software, Telecommunications and Computer Networks (SoftCOM)*, pages 1–9, Sept 2016.

[86] Wikipedia. Open sound control. https://en.wikipedia.org/wiki/Open_Sound_Control. [Online; accessed 01-May-2017].

[87] WikiPedia. AA battery. https://en.wikipedia.org/wiki/AA_battery, 2017. [Online; accessed 01-May-2017].