Accessible Electroencephalograms (EEGs): A Comparative Review with OpenBCI's Ultracortex Mark IV Headset

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***Abstract*—By evaluating the OpenBCI Ultracortex Mark IV EEG headset's affordability, accessibility, and accuracy, it can be compared to other commercial- and medical-grade EEGs that have been evaluated previously. Nine participants used the Ultracortex Mark IV for the P300 Speller classification task, with the accuracy being measured along with the time required to set up the Mark IV, the participants' comfort, and the participants' perceived ease of setup. These results were then compared to previous evaluations of other EEG headsets. The OpenBCI Ultracortex Mark IV's cost-effectiveness ratio is relatively low compared to the other EEG systems, and its ease of use and speed of set up are notably better than the other headsets being compared.**

***Keywords*—Brain-Computer Interface (BCI), Electroencephalogram (EEG), Accessibility, Usability, Consumer-Grade, Cost-Effectiveness, P300 Speller**

I. Introduction

Electroencephalography is the study of electrical activity in the brain. Electroencephalograms (EEGs) are the most widely used devices for measuring signals passed between neurons [1]. With such a growing field as brain-computer interfaces (BCI), researchers are looking for more convenient products to perform their studies. Medical-grade EEGs tend to be high-quality, making them extremely reliable but more costly and time-consuming to use. Most medical-grade EEGs use wet electrodes, which require conductive gel. Due to their high initial expense and ongoing operating costs, along with the required set up time, medical-grade EEGs are seldom a convenient option for non-medical researchers.

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Consumer-grade EEGs are becoming the standard in research and BCI applications. Researchers have written papers comparing the quality and performance of various electrodes and amplifiers but few have compared the entirety of different systems, including price, setup time, usability, user experience, and performance. As consumer-grade EEGs become more mainstream, affordable, and reliable; new headsets are being created and introduced into the world of BCIs, creating a greater need for a comparative review of the available products.

Some headsets are designed for a specific task, such as sleep cycle studies or meditation, while others are designed to be the more affordable and accessible versions of medical-grade EEGs. OpenBCI's Ultracortex line of commercial-grade EEGs offer several key elements that make them appealing to researchers, such as, the ability to 3-D print exactly what pieces are needed instead of overbuying parts that come prepackaged containing a certain quantity. Not only does this feature reduce the overall product price, but it also allows for creative modifications. By comparing the Ultracortex Mark IV headset to previously evaluated commercial and medical-grade EEGs, we aim to provide a valid assessment of its usability and cost-effectiveness.

II. Related Work

Researchers have already performed studies to see where particular aspects of EEG systems rank among the rest, but few have produced comprehensive reviews for entire systems [2], [3]. As the field of BCI grows, so too will the amount of research available on consumer-grade EEGs. There have been studies to compare the performance of wet vs. dry electrodes, wet vs. semi-dry vs. dry electrodes, consumer-grade vs. medical-grade amplifiers, varying numbers of electrodes, signal quality, and classification accuracy [2]–[7]. The one thing that these studies have in common is that they focused on proving the worth of some aspect of an EEG system.

In some ways it can be misleading to compare only one aspect of an EEG system, for example, comparing the performance of two headsets when using the same electrode placements for both. It is extremely difficult to perfectly replace one headset with another and position the electrodes in exactly the same spot. Misalignment of electrodes can result in noise and unwanted artifacts in the signal data. This type of obstacle led [4] to use one set of electrodes while simultaneously recording data for both the consumer-grade and medical-grade amplifiers. An issue with this approach appears when looking at the electrode positions used for the data recording. For example, the OpenBCI system does not offer some of the same electrode positions in their headsets as other commercial- and medical-grade systems. Even though the comparison yielded similar EEG readings to the medical-grade EEG, the OpenBCI headset, as a whole system, might not give the same results due to the different electrode configurations.

On the approach of comparing EEG systems as a whole, [2] laid the groundwork by comparing the usability of three EEG headsets using a P300 Speller task. The three headsets varied in the type of electrodes used and the number of channels that were supported. Classification accuracy was calculated allowing for each headset to utilize a different number of electrodes. Taking this study a step further, [3] closely followed the protocol in [2] for three new headsets, but used a motor-imagery task and added a cost analysis. The three headsets used in [3] used the same number and placement of electrodes for the motor-imagery task. In order to fully compare the results of [3] to [2], prices for the headsets used in [2] were estimated from online research. These two studies most closely relate to the study presented in this paper, which proposes to investigate the usability, cost-effectiveness, and aesthetic appeal of the OpenBCI Mark IV EEG headset for a comprehensive evaluation against previously tested consumer- and medical-grade EEGs.

III. Materials

The headset used for the study outlined in this paper was the Ultracortex Mark IV EEG Headset from OpenBCI. OpenBCI offers three purchasing options for the Mark IV headset, print-it-yourself, unassembled, or pro-assembled, as well as three sizing options: small, medium, and large. The prices for the printing options vary depending only on the number of nodes desired, either 8 or 16, and are as follows (in USD as of the time this paper was written) $349.99 - $449.99, $599.99 - $699.99, and $799.99 - $999.99, respectively[1]. The biosensing board(s) does not come with the purchase of a Mark IV headset because the headset is compatible with all OpenBCI boards. This allows the customer to choose a board equipped for monitoring a specific number of channels without having to overpay for more channels than needed. The 4-channel Ganglion Board costs $199.99[2]; the 8-channel Cyton Biosensing Board costs $499.99[3]; and the 16-channel Cyton/Daisy Biosensing Boards package costs $949.99[4]. The remaining parts needed to power the headset cannot be bought through OpenBCI but are recommended for purchase from the Adafruit or Sparkfun websites. These parts are the lithium ion rechargeable battery and the battery charger, which cost (in USD) $7.95 and $5.95 from Adafruit[5] and $4.95 and $8.95 from Sparkfun[6], respectively.

Two BCI software systems, OpenBCI and OpenVibe, were evaluated before the start of this study to see which better met the needs for recording and interpreting EEG data from a P300 Speller task. OpenBCI has a built-in impedance feature, which provides a means of checking the signal quality for each electrode. Since signal quality is pertinent to this study, OpenBCI was used for impedance checking. OpenVibe has an impedance checker, but only those headsets that provide impedance values can use the impedance mode; this is not the case for the Mark IV. However, OpenVibe was chosen for data acquisition due to its built-in capabilities and provided examples of data recording and interpretation for various tasks. A P300 Speller project that came with the OpenVibe software was edited to closely follow the task used in [2]. P300 Spellers are used to elicit a positive P300 wave that appears around 300 ms after an expected event. These types of waves are called event-related potentials (ERPs) and are studied because they are considered to reflect the decision making process used in stimulus evaluation or categorization. A P300 Speller task works by randomly flashing through rows and columns of a matrix of letters while a user focuses on a target letter he or she wants to use for spelling. After so many repetitions of focusing on the target letter, a pattern is observed, and the BCI system can select the desired letter.

IV. Methods

For the purpose of this study, a 16-channel print-it-yourself Mark IV EEG Headset was purchased, printed, and assembled (refer to Fig. 1). Using polylactic acid (PLA), the large headset frame was 3-D printed as two separate hemispheres, front and back, per the instructions provided in the OpenBCI assembly guide [8]. Also printed, using PLA, were 35 inserts for the electrodes to screw into, the Cyton board's mount and cover, and 36 wire clips for securing wires. Parts that were not printed but provided by purchasing the print-it-yourself Mark IV headset include: (2) #4 screws, (3) ribbon cables, (16) spikey units, (4) flat units, (14) comfort units, and (2) ear clips [9].

[1] https://shop.openbci.com/collections/frontpage/products/ultracortex-mark-iv

[2] https://shop.openbci.com/collections/frontpage/products/pre-order-ganglion-board?variant=13461804483

[3] https://shop.openbci.com/collections/frontpage/products/cyton-biosensing-board-8-channel?variant=38958638542

[4] https://shop.openbci.com/collections/openbci-products/products/cyton-daisy-biosensing-boards-16-channel?variant=38959256526

[5] https://www.adafruit.com/category/889

[6] https://www.sparkfun.com/categories/54