# An Exploration of a Simplified EEG System in Studying Sex by Hemisphere Differences

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## Abstract

Recently there has been much development of low-cost, publicly accessible EEG systems. While many of them are marketed to consumers for non-scientific purposes, here we investigate whether one system, the EMOTIV Epoc+, can be used to collect data for research. We attempted to replicate findings of sex by hemisphere differences during negative emotional arousal, but while our data suggests some sex differences, more investigation is needed. We found the EMOTIV system able to collect data usable for our purposes. While it is not as easy to use as advertisement would suggest, it is still much more practical and accessible than traditional EEG systems. Further studies with the system are certainly needed, but we conclude that it can be used to investigate some EEG questions.

## Introduction

Electroencephalography (EEG) has changed greatly since its invention in 1924. In the past few years many new EEG systems have popped up marketed towards consumers to be used for biofeedback, commonly meditation (e.g., the Muse system). In order to make them accessible to consumers, many of these systems are priced at a few thousand dollars or less, sometimes less than $1000. Traditional EEG systems, on the other hand, cost tens of thousands of dollars, and the price can increase greatly with the quality of the system and software. After such an investment, it would be impractical to replace a traditional EEG system every few years, but less expensive systems could be easily replaced to keep up with the pace of technological advancements. However, the critical question is whether these cheaper systems—often advertised to consumers for biofeedback—are capable of recording EEG at the quality needed for research.

Beside cost, traditional EEG systems often take quite a bit of time to set up, use gel which leaves hair and/or skin messy afterwards, and can be uncomfortable for the participants to wear. These factors can discourage subjects from wanting to participate, and also may cause fatigue before data collection begins. Newer and more expensive systems may take less time to set up, but the trend has also been towards using more densely packed electrodes. While more electrodes allows for greater spatial accuracy, they also take much longer to set up which may cause them to be impractical, even in a clinical setting (Chu, 2015).

For our investigation, we decided to use the EMOTIV Epoc+ system. We looked into other systems as well, but many of them have few electrodes (such as the Muse system or the EMOTIV Insight), no ability to save data, or other serious flaws for research. The Epoc+ has 14 channels in standard locations, is described as being suitable for research, and is reasonably popular. There are online forums for help and discussion of the system and its uses, and there is a variety of published papers about the system. Additionally, we had received contact information from the creator of the system, Geoff Mackellar, who said we could send him questions. Because this system sits on top of hair and does not make direct contact with the scalp, we expect that EMOTIV Epoc+ may have a decreased signal-to-noise ratio compared to traditional EEG. However, unless the noise is too great or somehow interferes with the signal in ways that cannot be filtered out, we hope that the practicality of the system will allow for more data to be collected in order to overcome the decreased signal-to-noise per participant.

In addition to exploring the usefulness of this system in research, our goal in the present study is to see if we can replicate the findings of Davidson and others who showed that alpha power is decreased in the right frontal regions in females when negative emotions are induced, whereas alpha power is decreased in the left frontal regions for males when negative emotions are induced (Davidson et al., 1976; Miller, 2002; Smit et al., 2007).

If the system proves useful in studying sex differences, the long-term goal would be to recruit larger numbers of participants, and extend our populations. We could look at groups besides cisgender heterosexuals, or look into sex and gender along a spectrum or related to various genetic factors. We could also look further into the effects of hormonal contraception and the menstrual cycle in females which we have reason to believe also affect brain function (Nielsen et al, 2011; Andreano & Cahill 2010). For these groups, we could also look at people other than college students to see if the findings stay the same. The system is very portable, so if it was necessary to go to certain populations in order to gather data from them, that would also be possible. But before investigating any of these questions, a baseline of typical differences between cisgender, heterosexual males and females is needed. And before a baseline can be established, we need to first develop a better idea of the general usefulness of this system for studies of this nature.

## Methods

### Participants

Participants were college students from the University of California, Irvine, recruited using Sona Systems and compensated with extra credit. A total of 31 subjects participated in the study. The data from 8 subjects were excluded due to system calibration issues. The data from 4 of the females were excluded due to excessive noise (excessive blinking during stimulus presentation, resting the headset on the chair and creating movement, and head movements due to illness), leaving us with analyzed data from 5 males and 14 females. The participants filled out a consent form and provided their sex, their age, whether they had any caffeine that day, and whether they were taking hormonal contraception. They could also optionally provide information about their sexual orientation and their gender identity. Four of the participants whose data were analyzed left one or both of the optional questions blank. Of the female subjects whose data was analyzed, four were taking hormonal contraception, and one identified as lesbian. The rest of the participants identified as cisgender and heterosexual.

### Materials

We bought the EMOTIV Epoc+ in November of 2016 for $799 before tax. Later we purchased an additional set of electrodes to speed up the sensor cleaning process (more information in the Discussion). We also paid $49 per month for EMOTIV's Pure•EEG software which is needed for saving data. The headset has 16 channels, 2 of which are used for reference (Figure 3). The electrodes come in a container to store them when the system is not being used to keep them hydrated and the headset dry. Each electrode is a little plastic cup that twists and locks into place on the headset. In the cup is a gold contact with a protective coating and a removable felt pad. The system uses general purpose contact lens solution to saturate the felt pads for connectivity. The headset connects to a computer with a bluetooth USB stick, and it is said to get 4 hours of battery life per charge.

*Figure 1*. The EMOTIV Epoc+ headset. The frontal electrodes (AF3, F3, F7) have been circled in red. This picture is an official photo from EMOTIV.

To induce emotional arousal we used a slideshow which consisted of 10 slides of neutral images followed by 10 slides of negative images. The images were taken from the International Affective Picture System (IAPS), and each one was set to a height of 3 inches (Figure 2). This size was used to reduce the need to use eye movements in order to see the whole picture. Each image slide was shown for 2 seconds, followed by a 5 second fixation cross during which the subjects had been instructed to blink if possible. We showed all the neutral slides before all the negative slides because, according to Davidson, Ekman, et al., "negative affect elicited by the negative films tended to persist longer than the positive affect elicited by the positive films. If we had counterbalanced the order of positive and negative films, the persisting negative mood would have interfered with the intended effect of the positive films” (1990).

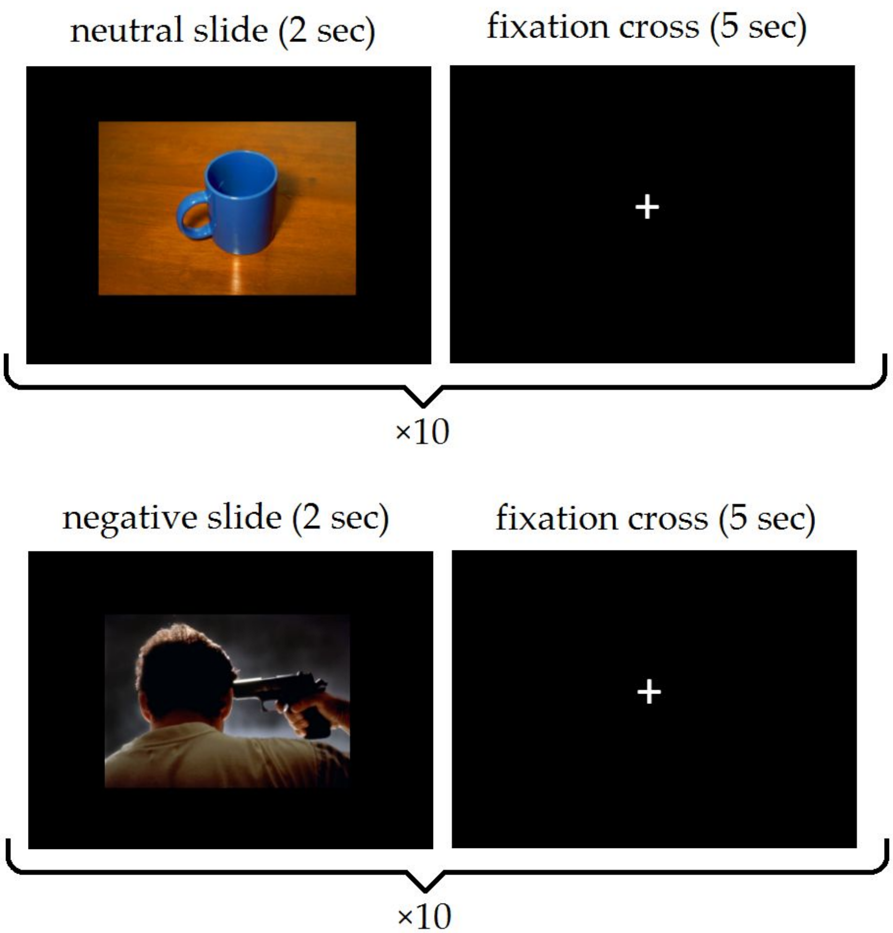


*Figure 2*. Slideshow shown to participants. Participants were shown 10 neutral slides followed by 10 negative slides. A fixation cross was shown for 5 seconds in between slides to allow time to blink.

**Procedure**

After filling out the consent and information forms, participants were fitted with the headset. The goal was for the electrodes to sit correctly and for all, or as many as possible, of them to have good enough contact to turn green in the system software (Figure 3, see the Discussion for more information on the software and impedance). In some participants, electrodes further back on their head would not turn green (had high impedance), but we only used data from frontal electrodes, so this was not an issue.

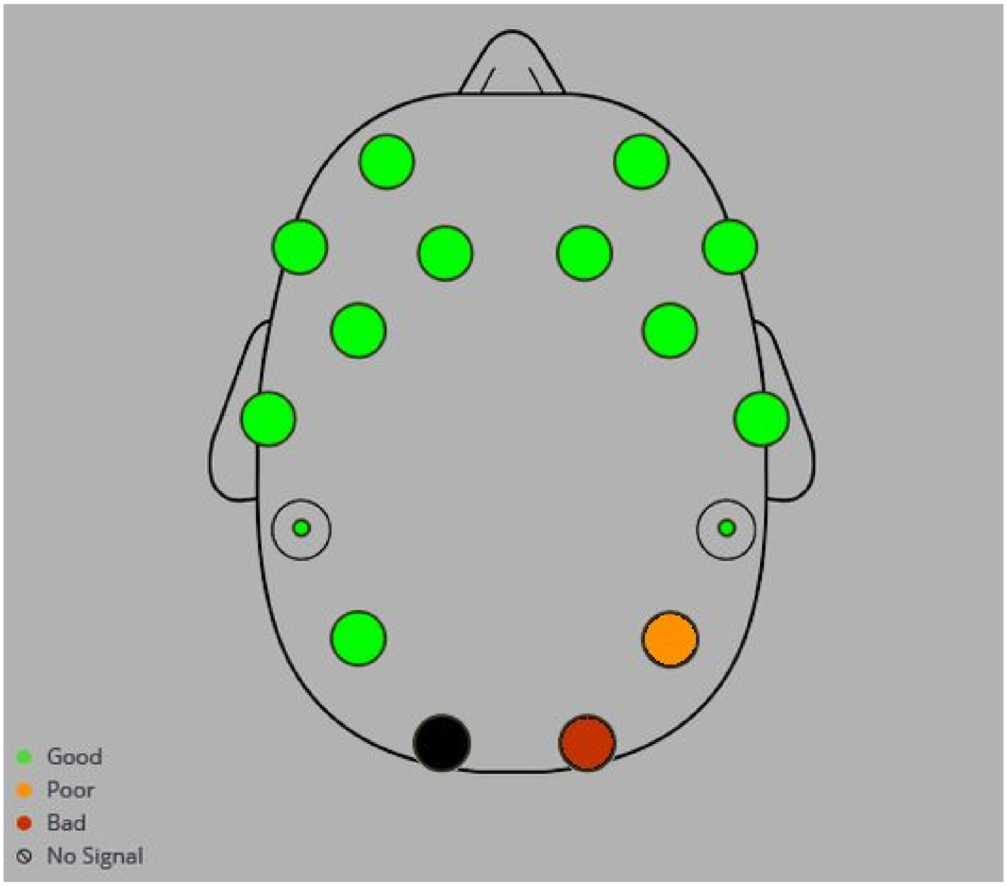


*Figure 3*. Epoc+ Electrode Contact Quality. An example of how the system shows connection quality and the electrode locations. The reference electrodes are the ones with the small green dots.

After having the system calibrated, the participants were seated in a darkened room approximately 3 feet away from a computer screen. They were instructed to close their eyes for approximately 30 seconds, and then leave their eyes open for approximately 30 seconds while relaxing and sitting as still as possible. Next they were shown an instruction slide to remind them to sit still and look at the center of the screen. This was followed by the slideshow which lasted for 140 seconds. After the slideshow, the headset was removed and the participants were free to leave. The electrode pads were removed and cleaned with a mixture of isopropyl alcohol and contact lens solution between participants.

**Analysis**

Data was imported into EEGLAB, and the 3 frontal electrode channels on each side (AF3-AF4, F3-F4, F7-F8, Figure 1) were extracted. The middle one second of data from each slide presentation was filtered to get data from the 8Hz to 13Hz range (Figure 4). The middle one second of data was used to avoid noise (such as blinking) at the onset and conclusion of stimulus presentation, and the range was chosen to get all information in the alpha range. As previously stated, we excluded the data of four subjects from analysis due to excessive noise.

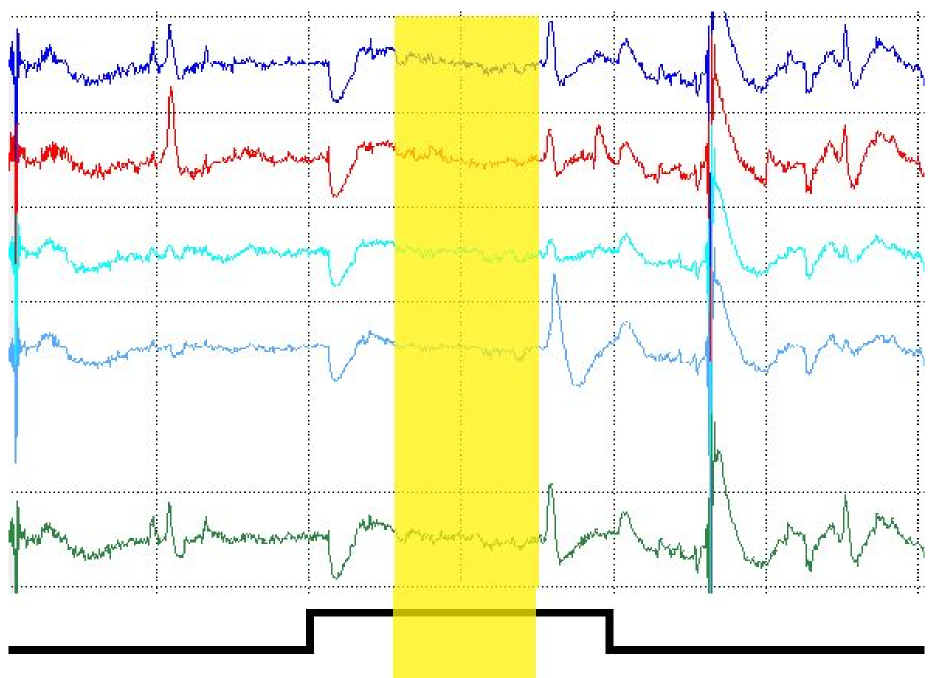

*Figure 4*. Example of data analyzed from stimulus presentation. Yellow represents the middle one second of data we analyzed from the 2 seconds of data collected per image slide. This removed any artifacts at stimulus onset or conclusion.

A toolbox for EEGLAB was used to provide the Frontal Alpha Asymmetry (FAA) index from each of our one-second chunks of data (Tesar, 2016). Frontal Alpha Asymmetry is computed by taking the log of the alpha power in the right hemisphere and subtracting the log of the alpha power in the left hemisphere. We modified the toolbox to provide the direction in addition to the magnitude of the asymmetry. After we got an FAA for each electrode for each slide for each subject, we averaged all the FAAs for a subject's neutral slides and all the FAAs for a subject's negative slides. A difference score was computed for each subject by subtracting their negative FAA average from their neutral FAA average. This difference score represents a participant's change in asymmetry from viewing neutral slides to viewing negative slides.

## Results

For each subject, all FAAs (Frontal Alpha Asymmetries) for the neutral slides were averaged, and all FAAs for the negative slides were averaged. A paired t-test was run on these neutral and negative averages. No significant difference in alpha power between neutral and negative slides was observed with $p = .362$. When broken down, for females $p = .929$ and for males $p = .181$.

A 2-sample t-test was computed on the difference scores for males and females with $p = .086$. No significant difference was found between females on hormonal contraception and those not on hormonal contraception.

To simulate what the p values might be if we gathered more data following the same trend from male subjects, we tried duplicating their data and running the same t-tests. In other words, we ran the same t-tests, but there were 10 data points for males, 2 of each data point we gathered. The 2-sample t-test comparing changes in asymmetry between males and females was significant with a $p = .0381$. Additionally, when duplicating the neutral and negative slide FAA averages for males, the paired t-test resulted in $p = .0375$.

| | Mean | Standard Deviation |
|---|---|---|
| Females | 0.0077 | 0.3193 |
| Males | -0.3305 | 0.4566 |

*Table 1*. Average difference between FAA for neutral slides and FAA for negative slides. The negative number denotes a change in asymmetry to the left.

The female average is not significantly different than zero, meaning that we observed little change in asymmetry from neutral slides to negative slides. The male average is negative, suggesting that there was a shift of alpha asymmetry to the left when viewing negative slides. This is, however, agnostic to what direction the asymmetry was while viewing neutral slides. For example, it could be that there was already left asymmetry, but it increased, or it could mean that there was right asymmetry that shifted to left asymmetry, or something else. The average for males, however, was also not significantly different than zero, so further work on data from more males is needed. It is also notable that the standard deviations for both males and females are very large compared to the means, so there is a great deal of variability among subjects.

## Discussion

The primary outcome of this study is learning that the EMOTIV system is a very practical way to gather EEG data, but not without drawbacks of its own. That we were able to observe a p value of .086 with a very small sample size is very promising that further research with this device into sex differences and other areas will be fruitful. Additionally the data we have so far would suggest a partial replication of previous findings of increased left hemisphere activity in males during negative emotional arousal. Specifically, though, we observed a shift to the left in activity, and further investigation is needed to learn about the details of this shift. Also, we would like to further investigate why we did not replicate the findings of increased right activity in females. Since the data for females did not show a difference in activation between neutral and negative slides, perhaps their data was noisier than for males. This could be due to most of the females having longer, thicker hair. We should investigate what can be done to produce better contact with the scalp in people with longer hair.

We plan to continue this study and recruit more participants, hopefully gathering usable data from 20 males and 20 females. At that point we should have enough data to determine whether the differences we mention here are statistically significant or not. And we will look more into the specifics of activity when viewing neutral slides, to see what is happening in the observed changes in asymmetry. To look for effects of hormonal contraception, we also need to gather more participants in that group. And it may be worth looking into the effects of caffeine or medications. In the current study only two people reported having caffeine that day before participating, but it is known that various drugs can affect EEG recordings. But given that we are looking at changes within subjects, hopefully these effects will not be particularly large.

As expected, we found the system to be much faster to setup and use. It took about 15 minutes total per subject, versus at least an hour based on our previous experience with traditional EEG systems. Also, the system left no residue from the electrodes. It left slight dampness in hair which subsided quickly, and when it messed up the styling of participants' hair, they seemed good-natured about it. And no discomfort was reported from any participants from wearing the headset. Indeed, from my own experience, the headset only became bothersome when I wore it for over an hour, and even then it was no great irritation.

One of the biggest benefits to this system, especially if we are able to overcome some of the issues we found in this study, is that it uses simple materials. Besides the headset and electrodes themselves being cheap, contact lens solution is available at many stores, and the system's charging port is a standard  USB-MiniB port. Also, all of these materials are light and fit into a box, making them easy to transport nearly anywhere. An EEG system like EMOTIV's is supposed to be easier to use, making it attractive not only to consumers, but to researchers who do not have extensive EEG experience. We found the Epoc+ to not be nearly as easy to use as was advertised, and we encountered a variety of problems along the way, but we have no evidence to assert that these difficulties were more than would be encountered in learning to use any other system. It was also immensely helpful to be in contact with the creator of the system who answered questions and gave us pointers when we got stuck. Subsequent studies, now that we are more familiar with the Epoc+, its quirks, and issues to look out for, would doubtlessly run more smoothly.

Of note, however, is the fact that of the 31 participants recruited, we could not gather data from 8 of them. In other words, we could not gather data from about ¼ of the participants recruited. Effectively this reduces the amount of data gathered per unit of time from 400% to 300% that of traditional systems. But the number of participants dismissed was much higher at the beginning than it was at the end after more experience. In the future it may be that this does not provide a significant issue, especially given that we are still talking about 3 times the number of subjects gathered than before.

Initially we started out with only one set of electrodes, so we wanted to make sure the electrodes were clean before being used on a new participant. We were assured by the maker of the system that the contact lens solution contained antimicrobials, but we decided to clean the electrode pads with isopropyl alcohol after being placed on each participant's head. However, this seemed to cause problems and prevent the system from calibrating for some subjects. We believe this is because the alcohol desiccated the electrode pads and took more time for them to become saturated with the contact lens solution which makes them conductive. Establishing a rhythm to clean the pads and give them enough time to soak in the solution between subjects seemed to eliminate this issue, but if a subject showed up early (relative to when the previous subject ended), sometimes the system would not calibrate, presumably because the electrodes did not have enough time to become saturated. However, we cannot be sure that this is the reason, or the only reason, the system would not calibrate. Calibration seemed to also be related to getting the reference electrodes to sit properly on the head. But the reference electrodes are located in an especially difficult spot to get the headset to sit correctly, particularly on people with lots of hair, and which electrodes are used as reference cannot be changed. In further research we would continue the system of cleaning and re-saturating the pads, leave more time between subjects, and have multiple sets of electrodes to try to decrease the number of subjects that would need to be turned away because of calibration issues.

To improve this study overall, we would like to use the knowledge we have gained so far and control for more variables that were not accounted for in this current study. The best way to do this would probably be to run a control experiment, where as much as possible the participants experience the same things, but data is collected with a traditional EEG system. This would eliminate any issues arising from differences between the way this experiment was run and the way experiments we compare it to are run. And we would be able to look at more specific differences in data gathered between the two types of systems.

In order to increase the signal-to-noise ratio, we could show each subject 20-30 neutral images and 20-30 negative images. This would not cause the length of the slideshow to be excessively long for subjects to sit through (our 20 slides was only about 2 minutes, plus the minute of eyes open/eyes closed), and would double or triple the data for each participant. Showing many negative slides, however, may desensitize the participant, so there is probably a limit to how helpful increasing the number of slides can be. Also, it would be good to verify that the negative IAPS slides were sufficiently arousing. It is possible that given how old some of the pictures are, our population of college students was not particularly affected by the slides. However, our analyses suggest that if we had more male participants we may have seen a significant different between neutral and negative slides, so perhaps we ought to focus instead on why a difference was not observed in females. We need to determine whether this is because we did not properly induce negative emotional arousal, or whether something else (like longer hair adding noise) interfered with their data.

Creating a way to ensure accuracy and consistency of electrode placement would also help future research. Each electrode has a label consistent with the International 10-20 system (technically the Modified Combinatorial Nomenclature), but given that the headset is flexible enough to fit multiple head sizes and can be placed too far back or too far forward, the actual location may vary from where it is supposed to be located. We attempted to keep the frontal electrodes in the right place according to the system specifications of using 2 finger lengths above the eyebrows, but if more precise locations are needed, a system for placing the headset appropriately ought to be devised. We considered stil measuring the subject's head and using the calculations to line up key electrodes (in our case, frontal electrodes) which should not be very difficult to accomplish, but would add more time to the procedure. At the very least, it ought to be investigated how variant the locations are and whether they are close enough to provide fairly consistent data or whether location correction is a necessary step to add.

There are also drawbacks to the system that cannot be as easily overcome. For instance, one of the biggest problems we had was a lack of good documentation when we ran into issues with the system. There are forums that provide answers to many questions, but they can be difficult to sort through, outdated, or missing necessary information. Additionally, there is no thorough getting-started guide or document for help with common issues. If we had not been in contact with the creator of the system, we may not have been able to complete this study in a timely fashion. Also the Epoc+ is used by many people for many different purposes, so it seems that EMOTIV's resources are stretched thin in helping people with all their questions.

One example of the issues regarding documentation, and also system design, is that the system does not provide specific information about electrode impedance. As shown in Figure 3, the software will tell you using color when the electrodes have "good" or "bad" connection, but the parameters for making this determination are not listed. This also means that you are not able to set a level of impedance that you think is acceptable. Eventually we emailed the maker of the system to find out the level used by the system and were told that it is around 15 kΩ, but the system does not measure or keep track of that information. Assuming 15 kΩ is accurate, that impedance is probably fine in most cases, but the fact that this cannot be verified is worrisome.

EMOTIV also has their own proprietary software for recording data which does not have very much flexibility of functionality at this time. While, according to an email, they are planning to launch improved software soon, they are also increasing the monthly costs of this software. The cost of the software is billed automatically each month, so if you want to save money you need to make sure to unsubscribe from the software when you do not need to record. And the current costs mentioned here are for 50 recordings a month. For more recordings than that, the prices increase. Based on their current model, in order to log in to your account so that you can record data, an internet connection is needed, which limits to a degree where the system can be used. Also, the design of the headset itself could prevent it from being usable in some sorts of studies. For instance, it has no way to measure along any midline locations. And in general, the headset needs to be handled somewhat carefully. It is not extremely fragile, but it is not very durable either, and even when it is taken care of, wear and tear can build up with unknown effects. For example, deposits can build up at various locations on the electrodes, and it is unclear what effect this has on readings or impedance. We do not know how often the headset itself would need to be replaced, but the electrodes would likely need to be replaced on a somewhat regular basis, depending on how much the system is used and how well it is kept. Even so, it is likely that the long-term cost of this system will still be much cheaper than the tens of thousands of dollars for a traditional system, and the up-front cost is certainly much lower.

## Conclusion

The EMOTIV Epoc+ collects real EEG data and appears to be sensitive enough to pick up usable signal, depending what is being studied. Many factors in this study were not strictly controlled for, and more data needs to be collected and analyzed. However, depending what one is studying, the Epoc+, and perhaps other similar systems, show promise for increasing the practicality of using EEG and extending the populations data is gathered from.

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