# ARTICLE
# Recommendations for Developing an EEG Laboratory at a Primarily Undergraduate Institution

**Patrick Ledwidge, Jeremy Foust, & Adam Ramsey**
*Department of Psychology, Baldwin Wallace University, Berea, OH 44017.*

Given its relatively low cost and minimal required space, an EEG laboratory provides the most feasible human cognitive neuroscience technique to implement at primarily undergraduate institutions (PUI). However, neuroscience programs at PUIs may be deterred from incorporating EEG methods into their research programs and/or classrooms due to limited funds and resources. This article provides recommended guidelines for faculty researchers looking to set up an EEG lab at their host PUIs with an emphasis on feasibility. We offer considerations regarding infrastructure, equipment, personnel, and potential sources of funding. A case study is also provided, describing the successful implementation and development of an EEG/ERP lab at a Midwest PUI, Baldwin Wallace University. Our goal is to offer diverse options for starting a new, or revitalizing an existing, EEG lab. We contend that such a laboratory at a PUI will advance undergraduate students' access to interdisciplinary neuroscience research and curricular opportunities.

*Key words: electroencephalography (EEG); event-related potentials (ERP); neuroscience education, primarily undergraduate institution (PUI)*

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Recorded from the ongoing electroencephalogram (EEG), event-related potentials (ERPs) reflect the electrical activity of neurons that underlie cognitive and sensory processing. Cognitive neuroscientists use EEG and ERPs to investigate the neural processes underlying, for example, attention, memory, inhibition, and language. The primary advantage of EEG is its high-level of temporal precision (typically 250-1000 Hz) at a relatively low-cost. Consequently, for neuroscience programs at PUIs, EEG provides one of the most feasible human brain-imaging tools to incorporate into new or existing laboratories in which space, funds, and advanced research personnel may be limited.

Hans Berger published the first recordings of the human EEG in 1929 (Berger, 1929). During his initial successful recordings, needles were inserted deep into the periosteum (Collura, 1993). Using an oscillograph and galvanometer, the EEG was plotted on streams of paper. At this time, however, calibrations of EEG recordings between subjects were not possible and interpretation was limited to single subject data only. Since this time, EEG recording methods have become increasingly more safe, feasible, and reliable. This has increased the implementation of EEG across neuroscience labs and advanced our understanding of the relationships between the human brain and behavior.

Relative to other neuroimaging methods (e.g., fMRI, MEG), EEG labs are relatively inexpensive to start-up and maintain. Consequently, EEG/ERP provide a feasible human cognitive neuroscience technique that students at PUIs may use in the classroom or research space. The use of EEG methods in neuroscience courses may vary from the analysis of archival data (Miller et al., 2008), to data collection and analysis (Marshall et al., 2011; Shields et al., 2016). Impressively, Nyhus and Curtis (2016) demonstrated the successful implementation of a one-semester laboratory course in cognitive neuroscience in which students experienced project design, computer programming, EEG data collection, ERP processing, statistical analysis and manuscript development. Adding an EEG/ERP lab to a neuroscience program at a PUI would advance neuroscience curricula and research experiences, reflecting the evolving interdisciplinary field of neuroscience.

From the perspective of the faculty member, this may also create research collaborations using multiple species, an increasing interest of funding agencies such as the National Science Foundation (NSF). In fact, the NSF is prioritizing funding mechanisms for interdisciplinary research programs that "explore questions that span organizational levels, scales of analysis, and a wider range of species optimal for experimental exploration of brain function" (National Science Foundation Division of Integrative Organismal Systems, 2018).

An EEG lab may also welcome prospective neuroscience students who would otherwise opt out of working with non-human organisms due to lack of interest, allergies, and/or animal welfare concerns. Consequently, there may be a sizable population of students whose interests in neuroscience are currently unmet. An EEG lab may meet these interests. Such a lab would also diversify the curriculum of a neuroscience program, expanding students' scope of career opportunities in the neurosciences.

Established gold-standards for developing an EEG laboratory (Luck, 2014a) may not always be achievable for neuroscience programs at PUIs in which resources are often limited (e.g., funding, personnel, space). Consequently, the purpose of this article is to offer recommendation guidelines (equipment, infrastructure, undergraduate training, funding) for neuroscience programs and/or faculty interested in developing an EEG laboratory, with particular emphasis on *feasibility*. We conclude with an in-depth case study of how an EEG laboratory was developed at Baldwin Wallace University. This article is not intended to be an introduction to EEG/ERP data collection/analysis. For such a

comprehensive review, we direct the reader to Steven Luck's (2014a), "Introduction to the Event-Related Potential Technique."

## DESIGNING THE EEG LABORATORY

EEG recordings are highly influenced by the environment in which the data are collected. To increase the likelihood of finding a true effect, human electrophysiology strives for a high signal-to-noise ratio (SNR). In brief, the electrical signal you record to a given manipulation should be larger than those voltage fluctuations unrelated to your study. The SNR decreases as a result of, for example, unreliable recordings, extraneous auditory sounds, electrical interference, air quality in testing space, type of electrodes used, participant compliance, and researcher error. Consequently, sufficient planning is necessary when developing an EEG lab to ensure that your future data maintain the highest possible SNR. In the proceeding section, we review the considerations that concern EEG researchers before setting up a new lab.

### Location and infrastructure

Universities, Schools, and Departments may vary in the size and type of space available for an EEG lab. For example, programs may allocate funds to construct a new space or adapt an existing space. Alternatively, available funds may not exist for infrastructure changes. Elevators and other large machinery produce a large electrical current and may add unwanted noise to your data. Thus, if possible, it is preferable for your lab to be located far from such large sources of electrical noise.

At a minimum, an EEG lab used for investigative research should maintain its own space separate from other classrooms or laboratories. An independent lab will minimize distractions during testing. The size of the lab will depend on the scope and expected productivity of the research program. With certain EEG acquisition systems, it is possible to collect data in a space as small as 100 square feet. However, additional space is often needed for storing equipment, maintaining files, and training students. If the purpose of the laboratory is for both research and teaching, departments should consider how many persons may be occupying the space at any given time. Two student researchers per EEG recording session are typical. Consequently, a minimum of three persons (two researchers and one participant) should be able to work comfortably in the EEG acquisition room. Additional space and equipment may be needed for computer programming, data processing, and also instruction.

The data acquisition space should be large enough that a participant could sit 100-200 cm from the computer monitor displaying the stimulus presentation sequence. This distance will minimize the electrical interference from the monitor (LCD monitor is recommended because it produces less electrical noise than CRT monitors) that may add noise to the EEG and subsequently reduce the SNR. This distance should be short enough, however, that the participant can comfortably view the stimuli. For visual stimuli it is strongly recommended that participants are screened for normal/corrected-normal vision prior to acquisition. All research personnel and equipment (other than the monitor) should be situated behind the participant to avoid potential sources of distraction.

If possible, it may be advantageous for the participant and researchers to be separated into two different rooms. In such a set-up, the participants are seated immediately on the other side of a wall that separates them from the researchers. This is advantageous for two reasons. First, the researchers are able to discuss the incoming EEG during acquisition without distracting the participant, which provides an advantageous training environment. Extraneous auditory stimuli, such as that from conversations, will likely decrease the SNR, lead to messier data, and potentially mask otherwise present effects. Second, it allows for data collection to occur in a dark or dimly lit room which is particularly advantageous for studies examining visual processing. Cleaner visual ERPs (e.g., N100, P100) are recorded when there is a larger contrast between figure and ground (e.g., white words on a black background in a dark). This may be less critical when examining later cognitive ERP components, such as the P300 (reflecting attentional allocation/context-updating; Polich, 2007) and N400 (lexical-semantic access/retrieval; Kutas & Federmeier, 2011).

The caveat with the two-room set-up is that investigators may want a method of observing the participant during testing. Motor movements produce large artifacts in the EEG and, consequently, reduce data quality. Consequently, it is critical to determine whether or not the participant is following instructions and/or moving during acquisition. Researchers view the ongoing EEG as it comes in real-time and are thus able to visually detect these artifacts. However, determining the cause of an EEG artifact (e.g., neck movement, eye blink, chewing, wiggling nose) by observing the data alone often takes years of training. Consequently, it is helpful to observe the front of the participant during acquisition, particularly for undergraduate researchers who are new to EEG.

One option is to install a camera in the testing room that faces the participant and live-streams out to the second room. This would require the space and funds to install both the camera itself and an additional monitor in the researcher room. A second option would be to install a two-way window into the shared wall. As a result, researchers may observe the participant from behind and thus determine if the participant is making gross motor movements, not including those localized to the face (e.g., blinking, wiggling nose). This option also allows for greater training opportunities for new undergraduate researchers. That is, PIs may use this as an initial training tool for students in real time without creating any additional unnecessary distractions that could interfere with data quality.

It is important to note that the two-room testing set-up may require a method of communication between the participant and researchers (Luck, 2014b). You may choose to install a microphone system in each room to allow for rapid communication. Since the rooms are immediately adjacent to one another, having the researcher enter the testing space when appropriate can easily facilitate communication. In such instances, we recommend that the

researcher be present in the room with the participant to review task instructions.  For studies in our lab, we include a sufficient number of practice trials to ensure the participant is completely clear on how to perform the task.  During such practice, the researcher is always in the testing room with the participant to answer any questions and provide direct feedback if necessary.  If the researchers need to give additional instructions to the participant during acquisition, the stimulus presentation sequence is always paused, providing the opportunity for a researcher to enter the testing space.

It is common for many studies, particularly those that are longer than 7-10 minutes, to program tasks into block-designs, which allows for scheduled breaks to occur systematically and periodically during acquisition.  These provide additional opportunities for researchers to enter the room to communicate with the participant.  However, it is important that these breaks should be rather short so that the participant does not become distracted from task demands.

When designing his EEG lab, the first author (PL) considered installing an electrically shielded recording chamber, also known as a Faraday Cage.  As Luck (2014b) reviews, shielded chambers may not be necessary and may actually lead to poorer data quality.  Recording chambers that are poorly ventilated are particularly problematic for longer data collection sessions (e.g., > 20 mins) because the lack of ventilation leads to more perspiration.  On the scalp, when glands fill with sweat they alter the electrode-scalp impedances (the connection between electrode and scalp), which ultimately cause large voltage changes over a period of seconds called *cephalic skin potentials* (Kappenman & Luck, 2010).  Skin potentials are particularly problematic with high-impedance electrodes as they already maintain a relatively poor connection with the scalp compared to low-impedance electrodes.  The advantages and disadvantages of low and high impedance electrodes are discussed in a later section.

## Sound attenuation

When setting up your EEG laboratory, extraneous noise entering the testing room should be limited.  Outside noise can, among other things, distract the participant, interfere with the data collection, and reduce the SNR of your EEG.

Soundproof rooms prevent outside noises from entering the testing space and, consequently, remain the gold-standard for EEG recording.  In particular, any noise above 2 kHz is largely eliminated (Ingris, 2014).  The price associated with a sound booth may vary based on model and size.  For example, a WhisperRoom sound booth costs approximately $4,000-$28,000 depending on size and level of sound attenuation (WhisperRoom, 2018).  In addition, Mini Audiology Booths from IAC Acoustics range from $4,000-$5,000 based on size (IAC Acoustics, 2018) with additional options for larger sound booths at a steeper cost.  However, a complete soundproof room may not be necessary and, in fact, may actually produce more artifact-laden data compared to that collected in a sound-attenuated room.  Sound booths, like shielded recording chambers, provide poor air ventilation and, consequently, can lead to

rapid increases in temperature and skin potentials as previously discussed.

Inexpensive "low-tech" methods are cheaper alternatives to sound booths and may be moderately effective in limiting the influence of outside noises on the EEG recording.  For example, acoustic panels are a type of sound absorption product that dampens sound within a space.  Because the primary concern is extraneous sounds entering the testing space, acoustic panels should be mounted on the outside, not inside, walls of the recording room.  Prices may range from $20-80 per panel based on manufacturer and size (ATS Acoustics, 2018).  Thick blankets, such as quilts, provide another low-tech method and can also block outside sounds (Luck, 2014b).

Rather than blocking noise from entering the recording space, some labs may choose to *mask* outside noise (Luck, 2014b).  In one of PL's previous laboratories, testing occurred in non-soundproof rooms within a larger collaborative research space.  When multiple testing sessions occurred simultaneously (especially in adjacent rooms), it was difficult to avoid noise interference.  Consequently, a white noise machine continuously ran during EEG recording.  White noise machines have proven to be surprisingly effective in reducing the interference from noise outside the testing environment.  In fact, because the machine was small and turned on prior to participants' arrival, they rarely recognized the white noise until it was turned off at the end of the session.  One caveat of white noise machines is they may add additional electrical noise to your EEG recording and reduce the SNR.  Consequently, you'll want to place the white noise machine as far from the participant as possible.  Prices may range from $30 to over $80 depending on make and model (Conair, 2018; Homedics, 2018).  An EEG researcher strives for collecting the cleanest possible recordings.  To do so, it is critical to consider sound attenuation when developing your lab.

## Electrical grounding

When designing your lab, you'll want to make sure that all outlets that may be used for data collection equipment are *electrically grounded.*  Electrical grounding ("grounding," "earthing") prevents the participant from experiencing any electric shock in the case of an electric short.  In brief, a grounded electrical outlet has three holes.  When a plug is inserted into the top two holes (one is "active" the other is "neutral') of the socket, a circuit is created.  The two paths are transmitted to the circuit breaker and then onto the source of electricity (e.g., the electrical line outside your building).  The bottom hole of the outlet is for the ground plug on your socket.  This is for the grounding wire ("return path") which is connected to the neutral path.  The ground path connects to a metal object (often a pole or rod) that is buried into the ground ("Earth Ground").  In the case of a lightning strike, the electrical charge from the EEG amplifier will flow to earth ground and not the participant.

## Lighting

When setting up your testing environment, it is important to consider how you illuminate the area.  Traditional AC-current lights (e.g., incandescent, fluorescent, etc.) can

produce line noise, which will interfere with your EEG recording.  To reduce the amount of electrical noise that is introduced into your data, fluorescent ballast systems should be avoided, as well as lamps that are powered by a typical wall outlet.  Instead, effort should be taken to utilize lights powered by DC current (Luck, 2014b).

If you do not have a large area to illuminate or if your lab has limited funding, one option is to use inexpensive battery powered LED lights, such as Tap Lights, that are often used to light small areas of the home.  The benefit of these lights is their simplicity of use, installation, and operation.  However, these generally small lights can also prove difficult in evenly lighting up an entire testing chamber or room.  Care must be taken to ensure that the testing area is comfortably lit.

Labs that require a large illuminated area might consider using interior LED light strips or light bars, powered by a DC power supply.  LED strips can be found in most home improvement stores, and the range of offerings is quite large.  Therefore, most institutions will be able to find products that suit their budget and their testing area's needs simply due to availability.  Although LED strips are very convenient, easy to install, and mostly cost-effective, it should be noted that some of these products have dimming and color changing capabilities.  Unless your lab requires these functions, products with this added functionality might be best avoided as they produce extra electrical noise.  Finally, labs with smaller, enclosed testing areas will want to take care that their lighting choice does not produce enough heat to increase skin potentials (Luck, 2014b).

Similar to LED light strips, many different types of 12V DC power supplies are available to the consumer, with widely varying prices.  Some institutions might prefer battery-powered supplies which can minimize the amount of electrical noise produced.  These units might prove to be more expensive in the long run, however, as they will require regular battery changes. Other types of power supplies plug into a typical wall outlet and output DC current to the lighting fixtures in your lab.  Naturally, these types of power supplies should be located as far from the participant as possible, since converting the current produces electrical noise and reduces the SNR of the EEG.  Products also vary in complexity of set up (i.e., some only require cords, while some require internal wiring), so it is critical to purchase the power supply that best suits the needs and capabilities of your institution and personnel.

The recommendations in this section were intended to provide researchers with options for maximizing the clarity of their data.  As LED technology continues to improve, it will become even easier for researchers to purchase products that fit their labs' illumination and budgetary needs.  If a lab has limited funding for DC lighting, it will be critical to arrange the testing area such that all sources of AC powered lighting are as far away from participants as possible in order to maximize the clarity of the data.

**Additional space**
It is also important to consider how much laboratory space you may want for procedures that are unrelated to EEG data collection.  At a minimum, you will want access to a sink and an active water line.  If you are using saline-based electrodes, they will need to be rinsed and sterilized after each application.  Even with gel-based electrodes, you will want to have a faucet or sink in the lab for washing off gel.  However, if an accessible sink is nearby, you may not find it necessary to have one in your lab.

An additional consideration is the amount of space required for computer programming, data processing, and/or data analysis.  One may also consider if the lab space will be used for non-EEG related research activities.  It is common to maintain a separate space used for consenting participants and also administering surveys, interviews, and behavioral assessments.  Additional space may also be warranted for classroom instruction, lab meetings, and an office for a lab manager. When funds are limited, PIs should weigh the benefits of additional space against the added costs that could be devoted towards EEG equipment and software.

## EEG RECORDING EQUIPMENT
Choosing the hardware that will best suit a new EEG lab involves considering the goals of one's research program and institution.  These considerations range from practical (e.g., cost) to more technical aspects; the weight of each of these factors will vary between labs.  In an effort to assist programs interested in setting up a new EEG laboratory, this section will provide a review of significant factors that will aid in choosing a configuration.  Then, we will present an overview of five representative EEG systems to provide researchers with a range of options that cover a variety of needs: Electrical Geodesic Inc.'s (EGI) Geodesic EEG System, BioSemi's ActiveTwo, Brain Products' actiCHamp, BioPac and Advanced Brain Monitoring's B-AlertX, and Emotiv's EPOC.

The price of the EEG system is often one's first consideration.  The cost will depend on your need for hardware, software, amplifier(s), and tech support.  The prices provided hereinafter are those for a complete system configuration.  Even though funds may be limited at a PUI, we contend that starting an EEG lab is still possible.  While some complete packages can cost more than $100,000, most companies offer multiple configurations with widely varying prices.  For example, while BrainProducts's actiCHamp system may cost approximately $80,000 for a 128-channel configuration, the 32-channel package is approximately $43,000 (J. Drucker, Brain Products's, personal communication, January 30, 2018).  Lower cost systems also exist such as Emotiv's $799 EPOC (Emotiv, 2018), which may be an option for laboratories with limited funds or those who wish to purchase several packages for neuroscience laboratory courses. Both of these examples will be described in greater detail below, but the range of prices should serve as an indicator that systems exist that meet the needs of most budgets.

Another factor to be considered when buying EEG equipment concerns number of electrodes and their impedance levels (low v. high).  A greater number of electrodes are often reflected in a higher price, such as in the actiCHamp system. The specific electrode configuration will most likely depend on the goals of your lab (e.g.,

teaching, research) and research questions. Importantly, there is non-trivial trade-off between number of electrodes and quality of EEG recordings. It has been suggested, however, that the quality of EEG recordings from a high-density system is no worse than those from low-density systems (Luck, 2014c). Electrodes used in high-density configurations (e.g., 128-256 channels) tend to maintain higher impedances than low-density systems (e.g., 9-32 channels), which may lead to greater noise (e.g., skin potentials) and unwanted variability within your EEG recordings. For example, Kappenman and Luck (2010) reported more skin potentials in recordings from a high-impedance, rather than low-impedance, system which dramatically reduced statistical power. However, high-impedance electrodes are quicker to apply and reduce the risk of infection or disease transmission associated with the scalp-abrasion necessary for low-impedance electrodes. High-density systems are necessary for labs interested in determining spatial sources of evoked potentials (i.e., source localization). According to the undergraduate student, those in laboratory courses tend to favor the use of fewer, individual electrodes, whereas student researchers prefer the use of electrode caps (Shields et al., 2016).

The type of electrode a system uses should be taken into account. Active electrodes maintain hardwired "pre-amplifiers," rendering them less susceptible to electrical noise than passive electrodes (Luck, 2014b). Consequently, they are more commonly used in EEG configurations than passive electrodes. Active electrodes best serve researchers who have less control over their testing room's layout, and might have to deal with additional electrical noise. Active electrodes are, however, more expensive than their passive counterparts which are usually used in lower-cost and wireless systems, such as Emotiv's EPOC.

Finally, when choosing an EEG configuration, consider the amount of time it takes to apply the electrodes, check the impedances, and record the EEG. Application time can vary widely between systems, from five minutes to more than thirty. Major determinants of setup time are the number of electrodes and the conductive medium used. Some systems such as BioSemi's ActiveTwo utilize a conductive gel paste to reduce impedances. Electrode application tends to be longer with gel-based systems since it must be applied to each electrode after the cap is fitted to the participant. Naturally, this becomes increasingly problematic with increased number of electrodes. Clean-up time also is longer with gel-based systems, due to rinsing remaining paste out of the participant's hair. The benefit of a gel system is that it creates a stable connection with the scalp that improves over the testing session (Luck, 2014b). In contrast to gel, other systems such as EGI's high-density electrode nets use a saline-based solution to decrease impedances and improve the electrode-scalp connection. The benefit of this system is that it reduces setup time since a researcher can soak an entire electrode net before application. The disadvantage of saline is that impedances may increase over the course of testing, requiring researchers to reapply saline to electrodes manually as the testing session proceeds. Some wireless systems utilize

variations on the gel and saline systems, and will be described individually in the system overviews. Table 1 provides a summary comparison of the five EEG configurations that we review in the following section.

**Review of five representative systems**
The five EEG systems reviewed in this section all boast the ability to record reliable EEG and may be used for both teaching and investigative research. However, when appropriate, we report on research demonstrating that some configurations outperform others. We will compare these five systems on their cost, electrode type, electrode application medium, number of electrodes, and set-up time.

Electric Geodesics' GES 400 series configuration is one of three wired EEG systems that will be discussed. Prices for a complete EGI Geodesic configuration range from approximately $30,000-$175,000 depending on electrode array and purchase of additional hardware (e.g., amplifier), software, and technical support (M. Hartman, EGI, personal communication, November 17, 2016; J. Nichols, EGI, personal communication, January 18, 2018). EGI offers configurations of 32, 64, 128, and 256 active-electrodes. This is a high impedance system that utilizes saline solution as its conductive medium. Application time typically takes 5-15 minutes for two researchers. Labs whose research focuses on source localization might consider a high density EGI system. EGI also offers installation and training for laboratories who purchase their equipment. For labs with limited funding, a new EEG investigator might instead consider EGI's GES 405, 32-channel system, which would include support and training (Electrical Geodesics, Inc., 2018).

BioSemi's ActiveTwo is also a wired system with a range of configurations and prices range from approximately $20,000-$87,000 for 16- and 256-channel systems respectively (BioSemi, n.d.). The low-impedance active electrodes are applied using a gel so set-up time will take longer than saline-based electrodes. A cap is first fitted to the participant's head. Syringes are used to inject the conductive gel into holes for the electrodes. Finally, the electrodes are snapped into place in the cap. Since each electrode is handled individually, it can take two researchers 20 minutes to set up a 64-electrode cap (Hairston et al., 2014). Although the initial setup time is longer than EGI's, the gel provides a more stable connection to the scalp recordings over the course of the recording session. Like EGI, the ActiveTwo system offers a 256-channel configuration, providing another possibility for labs interested in source localization techniques. Electrode caps are also offered in a configuration of 16 electrodes, which might be enticing for labs wanting the low maintenance of a gel system and a limited budget.

Like EGI and ActiveTwo, Brain Products's actiCHamp is a wired system with active electrodes that are available in many configurations ranging from approximately $43,000-$80,000 for 32-channel and 128-channel configurations respectively. A higher-density 160-channel system is also offered. Due to the construction of their actiCAP, it takes approximately 10-20 minutes to apply the electrodes depending on the configuration (J. Drucker, BrainProducts,

| System | Approximate cost for full configuration | Electrode Type | Conductive Medium | Electrode Configurations | Application time |
|---|---|---|---|---|---|
| **Electrical Geodesics:** *Geodesic System* | 32-channels ≈ $30K 128-channels ≈ $130K 256-channels ≈ $175K | High impedance: Active | Saline | 32 -256 | 5-15 mins. |
| **BioSemi:** *Active Two* | 16-channels ≈ $20K 256-channels ≈ $87K | Low impedance: Active | Gel | 16 – 256 | 10-30 mins. |
| **Brain Products:** *actiCHamp* | 32-channels ≈ $43K 160-channels ≈ $80K | Low impedance: Active | Gel | 32 - 160 | 10 mins. |
| **BioPac and Advanced Brain Monitoring:** *B-Alert X10* | ≈ $11-16K | Low impedance: Passive | Gel | 9 | 5-30 mins. |
| **Emotiv:** *EPOC* | ≈ $799 | High impedance: Passive | Saline | 14 | 5 mins. |

*Table 1.* Review of five representative EEG systems.

personal communication, January 30, 2018). Electrodes snap into placeholders on caps of varying sizes. A unique capability of the actiCAP are LED lights that change color based on the electrode's impedance level (Emmerling, 2017). A slit by each electrode allows for the application of gel.

BioPac products are known for their user-friendliness and utility within undergraduate neuroscience courses. Students may use these packages to record and study aspects of human physiology, including motor neuron activity and heart rate. Instructors already using BioPac packages may consider incorporating the BioPac and Advanced Brain Monitoring B-Alert X10 into their teaching and/or research. The X10 system can be used as a wired or wireless system. In wireless mode, the unit transmits signal to your recording device via Bluetooth. Unlike the previously discussed systems, the B-Alert X10 is not offered in multiple arrangements. The 9-channel passive-electrode configuration costs approximately $11,000-$16,000 depending on the inclusion of additional software for monitoring cognitive states based on EEG spectra power densities (J. Anderson, BioPac, personal communication, January 30, 2018). The electrodes attach to a plastic strip that is fitted around the head. The system includes strips of different sizes to accommodate a range of head sizes. The B-Alert X10 is a gel-based system in which adhesive rings are placed around electrodes into which gel is inserted. It has been praised for its ease and speed of initial application, but its software package is reportedly slow to display impedances (Hairston et al., 2014). It should be noted that Advanced Brain Monitoring also offers the B-Alert X24, which is a 20-channel configuration for those who would like additional scalp coverage.

Finally, the EPOC from Emotiv Systems is a 14-channel wireless headset and costs approximately $799 (Emotiv, 2018). In addition to the benefit of low cost, the EPOC system is also fast to set up (Hairston et al., 2014). The system is comprised of 14 plastic arms attached to a headset, each with an electrode on the end. This system uses sponge pads pre-soaked in saline as its conductive medium, which allows for shorter setup times than a gel-based system. The headset is only available in one size, however, and the arms, although flexible to an extent, do not easily reach their intended areas on very large and very small heads, which may lead to unreliable recordings (Hairston et al., 2014).

Researchers have investigated the utility of the EPOC as a brain-computer interface (BCI) device, such as during mental imagery (Bobrov et al., 2011). The EEG recorded from the EPOC has demonstrated the ability to identify mental states above chance levels (Bobrov et al., 2011). However, its efficacy is significantly lower compared to data recorded from both the actiCAP (Bobrov et al., 2011) and BioSemi (Nijboer et al., 2015). Compared to the EPOC, participants also rated the BioSemi as more comfortable (Nijboer et al., 2015).

The EPOC has demonstrated the ability to reliably record the P300 ERP (Duvinage et al., 2013) with a significant intraclass correlation (0.74-0.80) with the Neuroscan system (Badcock et al., 2013). However, the EPOC produced a significantly lower SNR than a medical-grade configuration (Duvinage et al., 2013). This may result from the electrode configuration of the EPOC which does not include midline electrodes where the P300 is maximally recorded. Consequently, relative to other systems, this device may be poorly suited for research investigations, particularly when a

high SNR is necessary to identify ERPs of interest (Duvinage et al., 2013).

It should also be noted that the EPOC outputs data in a processed manner, and requires a monthly subscription to software to access the device's raw EEG data. The EPOC is lauded for its user-friendliness and low start-up cost, but the fragile headset and imprecise electrode placements may necessitate future maintenance costs (Duvinage et al., 2013). The EPOC may be well suited for a laboratory course. Although used in research investigations, it tends to underperform relative to higher-cost alternatives (Badcock et al., 2013; Bobrov et al., 2011; Duvinage et al., 2013).

The EEG system best suited for one's needs is a balancing act between its performance relative to other systems, intended use (teaching, research), and budgetary concerns. Any of these five systems may be used for both teaching and research purposes. For example, EGI configurations are widely used in both research and clinical settings, and investigations include those on neural mechanisms of sleepiness (Camfferman et al., 2017), emotional processing (Tsolaki et al., 2017), autism spectrum disorder (Clawson et al., 2017), and sports-related concussion (Ledwidge & Molfese, 2016; Hudac et al., 2017). Published studies using the BioSemi Active Two system include those on ambiguous discourse comprehension (Dwivedi & Gibson, 2017), body perception (Stekelenburg & de Gelder, 2004), and as a device for BCI applications (Nijboer et al., 2015).

However, a system used primarily for a neuroscience lab course likely does not require the number of electrodes or hardware/software requirements of a high-density configuration, such as that offered from EGI and BioSemi. A lower-cost alternative such as the B-Alert X10 or EPOC may be better suited for teaching purposes. For laboratories intending to use their EEG equipment for both investigative research and teaching, it is critical to identify a system that produces reliable recordings and is also rather durable for the purposes of a lab course.

## PERSONNEL AND TRAINING

Following a considerable training period (≈ 20-40 hours depending on the PI's intended level of autonomy for the students), undergraduate research assistants are fully capable of collecting reliable EEG recordings. As a result of the extended training period, it is in the lab director's best interest to train dedicated students who are able to commit to multiple semesters of research. This section will outline the components of a successful EEG lab including recommendations for training, the opportunities for lab managers, the lab manual, and the application process.

The extent of the lab procedures that you will expect students to perform will vary based on the goals of the lab. At the onset of training, it is important to emphasize the overall purpose of the research and "why" the lab is performing these procedures (Ledwidge et al., in press). This will help student better understand the goals of lab and to troubleshoot in the case of equipment malfunction. The lab director should expect to devote regular and continuous training to each individual student or in small groups of 3-4

students. This ensures that each researcher receives individualized hands-on training and that experimental drift, the divergence from research protocols over time, is avoided (Ledwidge et al., in press).

As in all human neuroscience labs, students should first be trained on lab protocols, safety, and ethical standards regarding human subjects. Students may also be involved in the development of study-specific IRBs, as obtaining approval is a necessary step prior to beginning any research procedures. Following, you will likely dedicate the largest portion of training to electrode placement and EEG acquisition. It is important that the lab director emphasizes the importance of precision and accuracy during electrode placement, as differences between student researchers may add extraneous variability to your data and, consequently, reduce its reliability. Once research assistants are trained on how to accurately place electrodes on the scalp, they should learn how to record reliable EEG. This includes instruction on monitoring the EEG to detect for participant compliance and movement artifacts (e.g., eye blinks). For evoked potential studies, students are also likely to work with stimulus presentation software such as E-prime and Psychopy.

The lab director may choose to hire a lab manager to assist with training research assistants, coordinating schedules, and possibly even managing one or more projects. The lab manager is often an advanced undergraduate student who has one or more years of lab experience but may also be a recent graduate. A well-trained and experienced lab manager may oversee data collection, process and analyze the EEG data, present at conferences, and also contribute to the writing process.

Regardless of the size of your EEG lab, we recommend the development of a lab manual (Ledwidge et al., in press). Initially, it serves as an outline for training new undergraduate researchers. The lab manual should include all aspects of training. This may include procedures directly related to human subjects research (e.g., informed consenting, ethics), using the EEG equipment, accurately applying electrodes and identifying artifacts. The lab manual is a working document; it should be updated annually and available to all members of the research team.

An application and/or interview process will help the lab director determine if a prospective student is a good fit for the research team. When reviewing applications, the PI may consider the students' time they are willing to research in the lab. The amount of time that each EEG recording session lasts is project-specific. It is not uncommon, however, for an evoked potential study to last between 1-2 hours with additional time needed for data maintenance, entry, and processing. Therefore the PI should determine the minimum amount of time that research assistants should work in the lab in order to contribute in a meaningful capacity.

Since an EEG lab may present many new experiences to undergraduate students, predicting students' ability in the lab can be difficult. At a minimum, research assistants should be detail-oriented and careful with scalp measurements and EEG recordings. For instance, measuring the head and placing electrodes should be done

in a precise manner in order to obtain the cleanest possible recordings. GPA is one potential metric to measure students' prospective lab performance. However, academic success may only weakly predict a student's research skills. As a result, PI's may consider evaluating applicants on multiple outcomes other than academic performance.

Factors such as precision, interacting with the participant, and thinking logically to fix problems are important. In addition, the lab director may consider the amount of time a student can dedicate to research and his/her motivation for joining the lab (e.g., career interests). A student's prior course work also may provide a point of consideration. PL found that students who have a deeper interest in understanding the mechanisms of human behavior contribute to the lab in more significant ways.

## BUDGET AND FUNDING

The available sources of funding will largely influence the design and set-up of the EEG lab. Successful funding proposals are those that align their needs with the larger initiatives of the institution (Reiness, 2012). As Reiness (2012) recommends, funding proposals that require immediate decisions will likely be met with rejection. Early conversations about the development of the lab should include relevant college-level administrators (e.g., provost, academic dean, department chair). These stakeholders are critical for solidifying initial funding for building the laboratory space. In this section, we outline recommendations for securing funds for your lab. Before asking for funds, we recommend creating a budget of expected costs and priorities. Barring access to large amounts of funds, a sound booth may not be necessary, but EEG hardware should be that which is commonly used in peer-reviewed publications if the lab will be used for research purposes.

During the initial planning phase, consult with electricians, carpenters, and heating/cooling specialists (either at your school or externally) to develop a budget for your infrastructure costs. Identify EEG equipment/software that suits your lab and budget and contact their sales teams for quotes. Ask the sales representative about the computer hardware/software that the EEG equipment requires for use because you may need to create additional lines in your budget for this hardware. Note that there are open source toolboxes for ERP processing and analysis, such as EEGLAB (Delorme and Makeig, 2004) and ERPLAB (Lopez-Calderon and Luck, 2014).

Once you calculate the expected costs for infrastructure and equipment, budget the annual cost for maintaining the lab. For example, you may choose to purchase annual customer support access for EEG acquisition/processing software. Will you require a laundering service for towels and/or lab coats? You may also choose to hire a full- or part-time lab manager or lab technician. Depending on the size of your budget, you may have to seek start-up and/or continuous funding through competitive internal grants. Although these grants may be too small to fund an entire lab, they may cover the full or partial dividend of your remaining budget.

If expenses remain unfunded you may choose to apply for external funding. There are several grant-funding mechanisms whose goal is to support undergraduate laboratories and equipment purchases. For example, the National Institutes of Health (NIH) Parent R15 grant, Academic Research Enhancement Award (AREA), funds biomedical research at public or non-profit private institutions that receive less than $6 million in NIH funding per year. This mechanism is for small research projects that focus on enhancing undergraduate involvement (U.S. Department of Health and Human Services, National Institutes of Health, 2018). The National Science Foundation (NSF) offers the Research in Undergraduate Institutions (RUI) and Research Opportunity Awards (ROA) grants which fund faculty research at PUIs and also encourages collaborative proposals with faculty/students at other institutions (National Science Foundation, 2018a). Through the Major Research Instrumentation program, the NSF also funds proposals solely for the purchase of large-scale research equipment. Typically, these proposals are for a single piece of equipment ranging from $100,000-$4,000,000. However, proposals for less than $100,000 are also accepted in the fields of math, social/behavioral sciences, and economics from eligible non-Ph.D. granting institutions (National Science Foundation, 2018b). Your institutions Office of Research may help you to identify additional appropriate private and government funding mechanisms to jump-start your lab.

## EXAMPLE

Baldwin Wallace University is a Higher Learning Commission accredited private regional institution located in an inner-suburb of Cleveland, Ohio. Baccalaureate degrees are conferred from more than 80 areas of study. Graduate programs include Master's of Business, Master's of Education, Master's of Public Health, Physician Assistant, and Speech-Language Pathology. The Department of Psychology and Neuroscience Program are both housed in the School of Social Sciences within the College of Arts and Sciences.

Undergraduate student researchers in the EEG Laboratory primarily hail from the Department of Psychology and Neuroscience Program, although the departments of biology, chemistry, mathematics, and public health are also represented. The Psychology Department and Neuroscience Program confer approximately 60 and 20 Bachelor of Science degrees every year, respectively. The neuroscience program at Baldwin Wallace began in 1999 and has a rich history of supporting undergraduate research on the neurobiological bases of behavior (Morris et al., 2015). Faculty in the Neuroscience Program maintain active research programs on (a) the behavioral pharmacology of taste in rats; (b) sensory modulation of behavior (*C. elegans*); and (c) neuronal differentiation (*Danio rerio*).

With the support of university administration, the College of Arts and Science, and the School of Social Sciences, PL developed a cognitive neuroscience laboratory focused on the use of EEG/ERP methods that would contribute to both the Department of Psychology and Neuroscience program. The lab was funded internally. Eight months elapsed from the initial development of the lab until its completion, including all infrastructure changes, equipment purchases

and installation.

An existing space (approximately 320 square feet) was reconstructed to fit the necessary specifications of the EEG lab (See Figure 1). Two walls were erected to partition off the EEG acquisition room (C) and researcher room (B) from a larger collaborative research space (A). Individual temperature control HVAC systems were installed in each room to maximize air ventilation. This was particularly important in room C for limiting skin potentials during EEG recording.

The lab was hardwired for internet hook-ups and all electrical outlets were grounded. The previous recessed lighting poorly illuminated the room and were subsequently replaced with LED lights. The shared wall between rooms B and C includes a two-way 34"x34" window for participant observation. Room B includes one computer for EEG acquisition and another for stimulus presentation. VGA cords connect these two computers with the participant monitor. A conduit beneath the window allows the VGA cable to run between the two rooms. A speaker was mounted above the window in Room C for auditory stimulus presentation.

EEG is recorded from EGI Net Amps 300, NetStation 5.4 software, and HydroCel Geodesic 256 electrode-channel nets (EGI, Inc., Eugene, OR, USA). To attenuate extraneous sounds from entering the room, acoustic panels were mounted on the outside wall of room C. Two additional workstations exist for groups of 2-3 students to work on computer programming, ERP processing/analysis, statistical analysis, and manuscript development. Cabinets and countertops in rooms A and B provide sufficient storage for equipment and research materials. A faucet was installed for cleaning the HydroCel electrode nets. A filing cabinet stores all hard copies of coded data.

Students' interest began within the initial weeks of the lab's development. PL is the lab director and a volunteer lab manager assists with training and coordinating research projects. During the lab's first semester, ten undergraduate research assistants were trained on human subjects research, EEG equipment set-up, electrode application, data acquisition, and data maintenance. Competitive internal funds were awarded for funding participant compensation. Students were also awarded funds for completing mentored summer research projects and conference travel. Data collection began one year following initial development of the lab.

At the curricular level, PL is housed in the Department of Psychology and teaches courses on Behavioral Statistics, Physiological Psychology, Cognitive Neuroscience, and Neurocognitive Disorders. Senior thesis projects are also ongoing in the EEG lab. Current research projects in the lab include those investigating ERP markers of (a) language comprehension, (b) cell-phone induced divided attention, and (c) sports-related concussion induced changes to the language network.

## CONCLUSION

Primarily undergraduate institutions often tout to students the importance of receiving a multidisciplinary education. Neuroscience programs at PUIs have the opportunity to
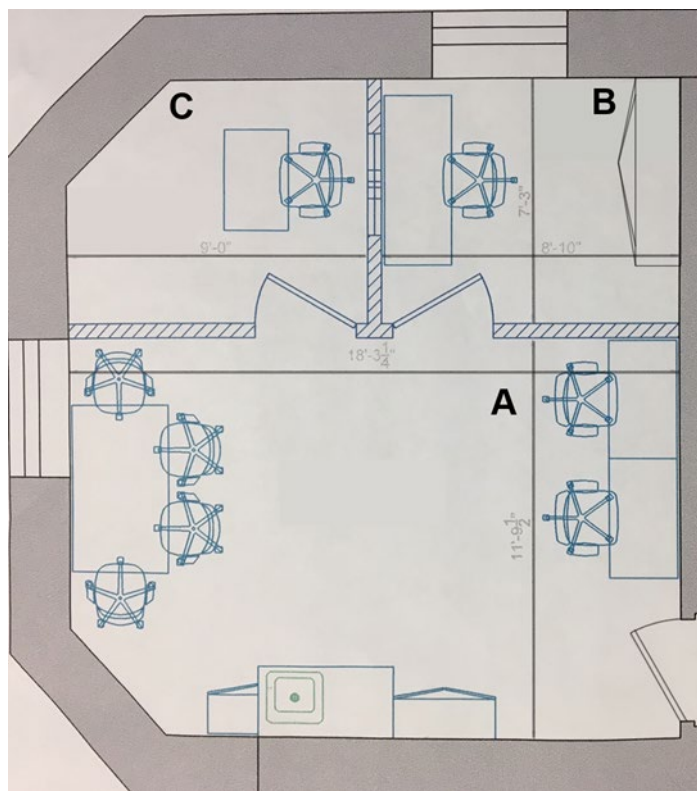


*Figure 1.* Blueprint of EEG lab at Baldwin Wallace University.

meet the recent rapid growth of interdisciplinary sciences, such as cognitive neuroscience. EEG brain recording methods are relatively cheap and feasible compared to other neuroimaging methods. However, the design and set-up of an EEG lab poses non-trivial consequences on EEG data quality. As a result, care and planning is recommended for principal investigators and stakeholders who are interested in developing a new EEG lab. Successful development of such a lab will lead to increased interdisciplinary curricula in the neurosciences and diversify undergraduate student research experiences. As a result, students may obtain an increased understanding of the functional neural underpinnings of human behavior, which will subsequently prepare them for graduate/professional school and an increasingly interdisciplinary workforce.

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Address correspondence to: Dr.  Patrick S.  Ledwidge, Department of Psychology, Baldwin Wallace University, 275 Eastland Rd., Berea, OH 44017.  Email: pledwidg@bw.edu