The Journal of Undergraduate Neuroscience Education (JUNE), Spring 2016, 14(2):A91-A96

# ARTICLE
# Incorporating an ERP Project into Undergraduate Instruction

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Electroencephalogram (EEG) is a relatively non-invasive, simple technique, and recent advances in open source analysis tools make it feasible to implement EEG as a component in undergraduate neuroscience curriculum. We have successfully led students to design novel experiments, record EEG data, and analyze event-related potentials (ERPs) during a one-semester laboratory course for undergraduates in cognitive neuroscience. First, students learned how to set up an EEG recording and completed an analysis tutorial. Students then learned how to set up a novel EEG experiment; briefly, they formed groups of four and designed an EEG experiment on a topic of their choice. Over the course of two weeks students collected behavioral and EEG data. Each group then analyzed their behavioral and ERP data and presented their results both as a presentation and as a final paper. Upon completion of the group project students reported a deeper understanding of cognitive neuroscience methods and a greater appreciation for the strengths and weaknesses of the EEG technique. Although recent advances in open source software made this project possible, it also required access to EEG recording equipment and proprietary software. Future efforts should be directed at making publicly available datasets to learn ERP analysis techniques and making publicly available EEG recording and analysis software to increase the accessibility of hands-on research experience in undergraduate cognitive neuroscience laboratory courses.

*Key words: Electroencephalography (EEG); event-related potentials (ERPs); neuroscience education, laboratory course*

The goals of an undergraduate neuroscience curriculum include: 1) introducing students to experimental methodology, design, and data analysis, 2) advanced awareness of a particular field within neuroscience, 3) critical and independent thought, 4) effective communication skills, and 5) ethics (Ramirez et al., 1998; Wiertelak, 2003; Ramirez, 2005; Wiertelak and Ramirez, 2008). However, undergraduate laboratory courses are often constrained by having pre-packaged experiments and little opportunity to have real research experience. In addition, students do not often have the opportunity to learn techniques currently used in neuroscience research. Specifically, in cognitive neuroscience, the prohibitive cost and time investment to use common techniques prevent students from gaining first-hand research experience. Therefore, students do not experience the true nature of research within cognitive neuroscience.

Electroencephalography (EEG) is a relatively cheap, non-invasive method that is commonly used in cognitive neuroscience research. However, direct experience with EEG in undergraduate courses is often limited to analysis of previously collected data (Miller et al., 2008). In order to engage students in a real research experience we have developed a one-semester course, Laboratory in Cognitive Neuroscience at Bowdoin College, that includes a group project in which students design and implement their own EEG experiments. In Laboratory in Cognitive Neuroscience, students with no previous EEG experience and little computer programming experience successfully completed an EEG experiment. The group project gave students experience in research methods and in all steps of event-related potential (ERP) analysis as well as practice presenting their research. Through the design of their own EEG experiment, students gained invaluable experience in the complexities of a real science endeavor, which is not possible in a lecture course or in a laboratory course using pre-packaged experiments or analysis of previously collected data.

In the sections below, we describe the Laboratory in Cognitive Neuroscience course including the hands-on group project. First, we describe the structure of the course and preparation for the group project. Second, we describe the steps involved in the group projects including design, implementation, and analysis of behavioral and EEG data, and presentation of group project results. Finally, we discuss student evaluations of the group project and future directions aimed at increasing problem-based learning (Albanese and Mitchell, 1993; Savery, 1996; Schuh and Busey, 2001) and real research experience in cognitive neuroscience in undergraduate laboratory courses.

## COURSE STRUCTURE

Laboratory in Cognitive Neuroscience at Bowdoin College is one of four neuroscience laboratory courses and typically enrolls 20 students. In addition to the course instructor, Bowdoin College has shared laboratory instructors that help run laboratory sessions and assist students with laboratory procedures. The course includes both a lecture portion meeting twice a week for 1.5 hours each and a laboratory section meeting once a week for three hours. Although the neuroscience laboratory courses at Bowdoin College are flexible in the structure, the Laboratory in Cognitive Neuroscience includes a lecture/journal club portion during the twice-weekly meetings and laboratory activities during the once a week laboratory meetings. During the lecture/journal club portion of the course, students read background materials on cognitive neuroscience methods (e.g., Luck, 2014) and primary research articles (chosen by the instructors) implementing cognitive neuroscience methods (EEG and functional magnetic resonance imaging) to study human cognition (including ERP components related to perception, attention, memory, emotion, language, executive function, and decision-making). Therefore, the lectures/journal club meetings provide practice in reading primary scientific research and essential background knowledge on the methods and topics of research in cognitive neuroscience. During the laboratory portion of the course, students participate in activities designed to teach them research techniques in cognitive neuroscience and then apply what they have learned by designing and implementing their own EEG experiment.

## GROUP PROJECT

The laboratory includes multiple weeks of preparation prior to conducting the group project. First, students do online training in the ethical conduct of human research and we discuss writing an APA style research paper. Second, students tour the EEG laboratory and practice setting up and recording EEG data. In this laboratory, students practice applying the electrode cap, inserting conductive gel, checking impedances, and viewing the raw EEG recording. It also provides an opportunity to experience the challenge of running an EEG study and dealing with noise in the EEG recording. The assessment for this laboratory includes written responses to questions about the laboratory setup, EEG data analysis steps, and ERP components that are discussed in the lecture/journal club. Third, students conduct ERP analysis on previously collected data provided from an EEGLAB workshop. This dataset comes from an experiment similar to Bentin et al. (1996). Subjects were shown pictures of faces or common objects (e.g., a shirt). EEG was recorded with Brain Amps (Brain Products, Munich, Germany). Once students are familiar with the task and the expected results based on previous literature on the N170 effect, a face-related ERP component that peaks around 170 ms after stimulus onset over occipital channels (Luck, 2014), they preprocess the EEG data for one subject and combine the data with other subjects for statistical analysis. Students conduct preprocessing and analysis of EEG data using freely available open source analysis toolboxes for MATLAB, EEGLAB (Delorme and Makeig, 2004) and ERPLAB

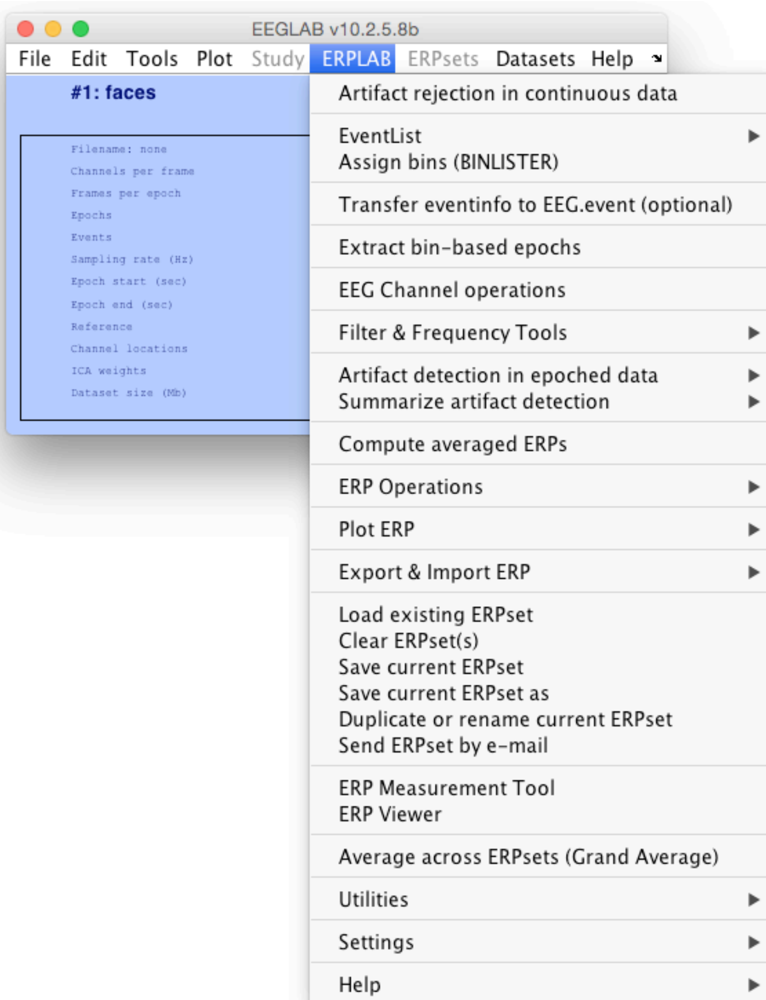


*Figure 1.* The EEGLAB graphical user interface (GUI) with ERPLAB toolbox installed. All ERP analysis tutorial steps were performed through the GUI.

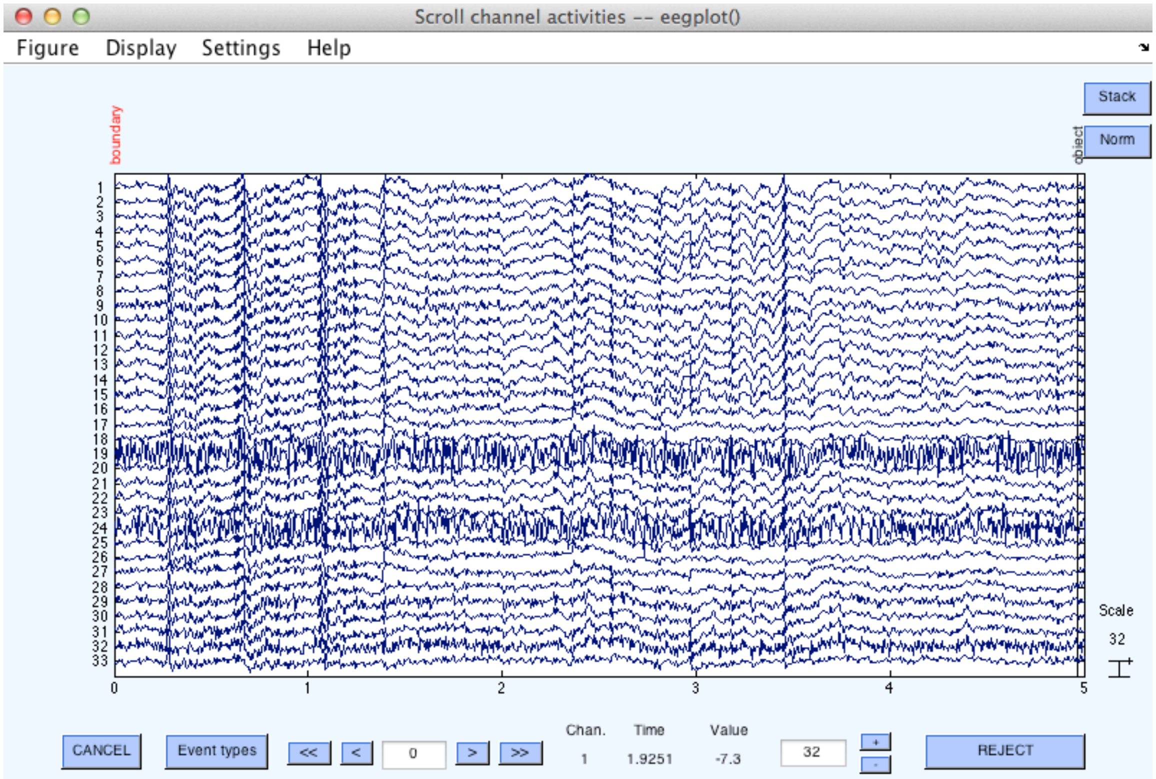


*Figure 2.* Raw data plotted in EEGLAB. After each preprocessing step students were instructed to plot and scroll through the EEG data to see how the data changed following bad channel replacement, filtering, epoching, and artifact detection. Time is on the X-axis and channels are on the Y-axis.

(Lopez-Calderon and Luck, 2014) (Fig. 1). A detailed analysis tutorial provided by the instructor led the students through each step of the EEG analysis. The ERP analysis tutorial and data are available through the Educational Resources in Neuroscience (ERIN) website (http://erin.sfn.org). EEG preprocessing includes loading and plotting the raw EEG data, loading the channel locations, creating a list of task conditions, interpolating bad EEG channels, filtering the data to get rid of electrical noise, segmenting the data relative to stimulus onset, baseline correction, rejecting artifacts from blinking and additional noise, and re-referencing the data to an average of all the EEG channels (Fig. 2). ERP analysis includes averaging the EEG across trials to create ERPs, plotting the ERP waveforms, and extracting the amplitude values for the N170 effect in right and left occipital channels. Once amplitude values are extracted, students combine the results with results from additional subjects for statistical analysis. Students then perform a 2 stimulus (face/object) x 2 hemisphere (right/left) repeated measures ANOVA and follow-up t-tests on the N170 effect in SPSS. The results show a robust N170 effect that is greater for faces than objects over right occipital channels. Specifically, the results show a main effect of faces vs. objects and an interaction between stimulus and hemisphere such that the difference between faces and objects is greater in the right hemisphere (Fig. 3). Therefore, the ERP analysis tutorial provides detailed step-by-step instructions on preprocessing EEG data and statistically analyzing ERP results. The assessment for this laboratory includes a paper written in APA format on the N170 effect and the results of the data analysis.

Following completion of the ERP analysis tutorial, students formed groups of four and designed an EEG experiment on a topic of their choice. Although the projects were student led, there were guidelines and restrictions on the experimental design to ensure the feasibility of each project (e.g., maximum 2 x 2 factorial design, 15 minutes total for each task, and only visual and audio stimuli). After forming a group and brainstorming ideas the groups chose a topic and presented their ideas to the entire class through oral presentations and through a written proposal. Both the oral presentation and the written proposal included background on the experimental question, the design of the task in enough detail for someone to implement it (e.g., description of stimuli, number of trials, timing of trials) and how it would be implemented with EEG, predicted outcomes based on previous literature (e.g., specific ERP components and amplitude or timing differences between conditions), possible limitations in the design and how they would be addressed. The oral presentation and written proposal serve two purposes; 1) they require students to formalize their ideas and design an experiment to test their ideas and 2) they allow an opportunity for students to get feedback from the instructors and fellow students on the design, predicted outcomes, potential problems, scope and feasibility of their group project.

In the next five laboratory meetings students programmed their experiment and tested participants. First,

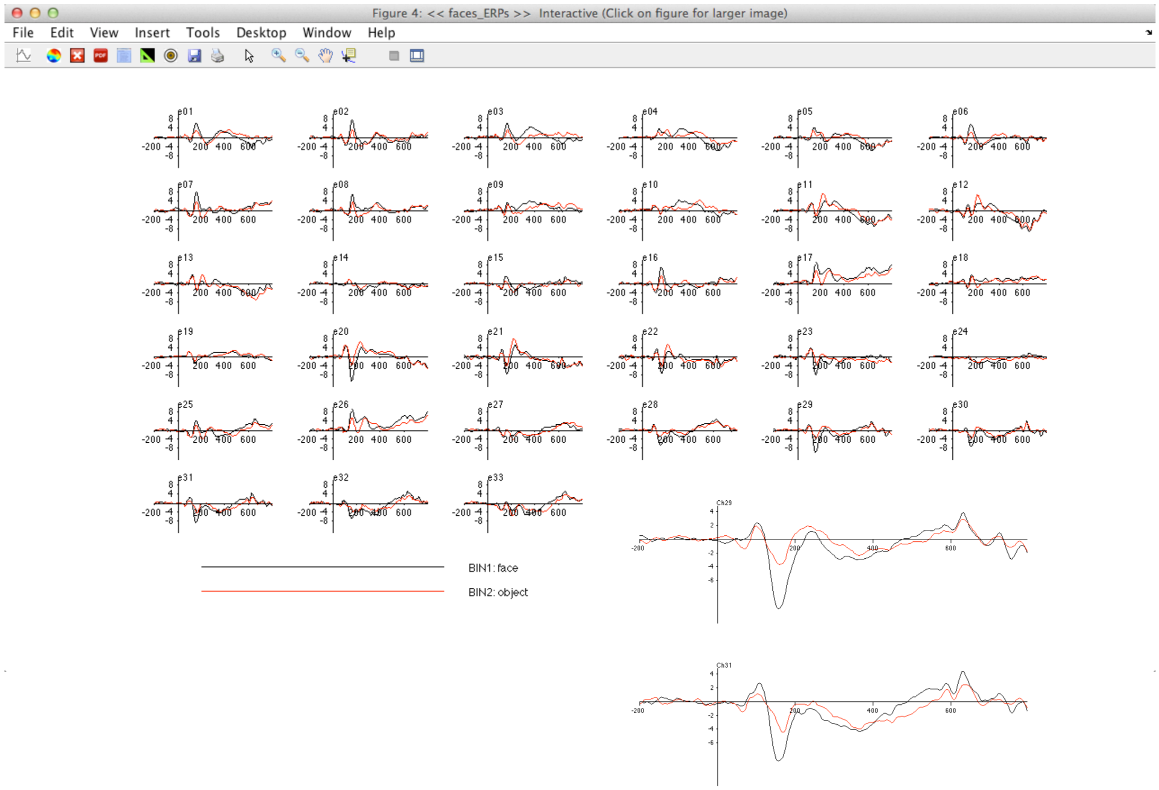


*Figure 3.* ERPLAB output of the results of the ERP analysis tutorial dataset. ERPs for each electrode are shown and can be enlarged and used for presentation. Enlarged ERP graph from the two electrodes analyzed showing a greater N170 effect for faces compared to objects. Time is on the X-axis (-200 ms to 200 ms) and amplitude is on the Y-axis (-8 μV to 8 μV), black= face, red = object.

students completed the EPrime tutorial that goes through the design and behavioral analysis of a simple conceptual priming task. Second, students implemented their experiment for the group project in EPrime, with the assistance of the instructors, integrated it with the EEG recording software (Brain Vision Recorder), and fully tested their experiment to ensure the EPrime experiment was time-locked correctly with the EEG recording. Group project topics included: categorization of unambiguous and ambiguous gendered faces, how emotional priming affects the oddball effect, how levels of processing affects memory encoding, how emotion affects decision-making, and how the frequency of words affects language processing by examining the ERP components cited in the proposal of the experiment (e.g., P3, LPP, N400 and P600) (Luck, 2014). Over the course of two weeks students collected behavioral and EEG data on 20 subjects (fellow classmates). In lieu of regular laboratory sessions, students signed up for two hours of experimental testing and two hours of participating in the experiments, which was overseen by the laboratory instructor. The calendar was coordinated through Google calendar. Subjects were tested exactly like they would be in an actual EEG experiment run in the laboratory. Behavioral tasks were run in EPrime and EEG was recorded with a 64-channel actiCHamp system (Brain Products, Munich, Germany).

Once all data were collected, students analyzed both the behavioral and ERP results from their experiment. They followed the analysis steps previously laid out in the ERP analysis tutorial and the EPrime tutorial. The process of analysis was flexible such that some groups split up the task by having each member preprocess a portion of the data and other groups preprocessed all subjects together. Once preprocessing was completed on all subjects, the groups were encouraged to plot the ERP results and think about their data in the context of their previously predicted results. The wealth of EEG data is such that it is often difficult for students to know when (which time points) and where (which channels) to focus their analysis on. The instructors emphasized the importance of a theory driven approach and the avoidance of a scientific fishing expedition. However, as with real scientific endeavors, after plotting their results, some groups modified their analysis to focus on different time points, channels, or other potentially interesting ERP components than what had previously been proposed. Then they performed the appropriate statistics to analyze their results. The final results of the group project were reported in a presentation and a paper formatted for publication in a research journal that was counted toward the final grade in the course.

## OUTCOMES AND EVALUATION

The group project provided students the opportunity to directly participate in the scientific process. They learned about the ethics of human research, designed and implemented an experiment, tested participants, analyzed behavioral and EEG data, and presented their results orally and written. They gained real research experience, public speaking experience, practice in writing articles for publication, and experience working collaboratively on an experiment. By designing their own experiment they engaged in critical and independent thought and gained expertise in an area of cognitive neuroscience. They gained an appreciation for the strengths and limitations and the types of questions that can be answered with the EEG technique. By analyzing their own data they learned about the complexities of data analysis. Although a basic statistics course is a prerequisite for the laboratory course, for many students this was the first time they had applied statistics to actual data.

In addition to the outcomes for the course, students gained hands-on experience with EEG that could be transferred to future work in the laboratory. Students have gone on to work in our EEG laboratory and used their EEG experience to gain employment after graduation (both academic research assistant positions and in neuromarketing). Therefore, the training they received in the laboratory course reduced faculty time training students to do independent EEG research.

These outcomes were supported by student evaluations of the group project and the course. At the conclusion of the group project, students were asked to fill out an anonymous survey for each member of their group (including themselves). The survey gave students the opportunity to evaluate each other and to convey to the instructors the contribution of each student to the group project. The survey was administered online through Qualtrics and included five questions about ability to work in a group, level of effort, dependability, intellectual contribution, and overall contribution to the project. The survey indicated that most students contributed significantly to the group project and had a positive experience working with their peers. In addition to the group project evaluation, students commented on the group project in the course evaluation. We compiled the course evaluations and examined responses relevant to the group project and categorized them into two types of comments related to the goals of an undergraduate neuroscience curriculum (experience with methodology, design, and data analysis, and advanced awareness of cognitive neuroscience and the EEG technique). We report the number of each of these types of comments followed by a few representative examples of the comments made. Generally, students had a positive experience with the group project. Students appreciated the opportunity to be involved in real research. Specifically, thirteen students (65%) mentioned the group project as the part of the course they liked the best and that they gained a deeper understanding of conducting research. Students also reported a better understanding of cognitive neuroscience methods and the strengths and weaknesses of the EEG technique. Four students (20%) mentioned gaining a deeper understanding of cognitive neuroscience and five students (25%) mentioned advanced understanding of the EEG technique. For example, students made comments such as:

“I liked the chance to do self-directed research.”

“The course consisted of reading three scientific articles every week, as well as presenting multiple times in front of a class, as well as working extensively as a group to create, conduct, analyze, and report a study that you work on throughout the semester. Through this, I felt as if I learned a lot about a field I have had no prior experience in entering the course.”

“I liked that the emphasis of the course was on a long term extended research project instead of exams. I felt like through conducting group research I gained a better sense of what cognitive neuroscience is all about."

“I learned so much about the ERP field as well as how to set up and perform ERP experiment, very informative and useful…I liked that we got to design and run our own experiment, valuable skills for the future.”

“I now really understand the way EEG data can be used to understand the brain along with the limitations of the technique…I enjoyed the group projects.”

Although for the most part the feedback on the group project was positive, there were comments indicating room for improvement. First, two students (10%) reported difficulty with the statistical concepts necessary to conduct their analysis. We found that a review of statistics as well as scaffolding knowledge through guided statistical analysis of the ERP tutorial data was important to prepare students for conducting analysis of their own group project’s results. We also emphasized the importance of planning the analysis approach in the early stages of designing the experiment. In addition, two students (10%) with little computer programming experience commented that they were not prepared to handle the technical issues that arose in the processing and analysis of the EEG data. These technical issues provided an important learning experience as encountering and solving technical issues is very common in real research. Students learned to utilize the ERP analysis tutorial, online help for both EEGLAB and ERPLAB, and assistance from the instructors to find solutions to these technical issues.

In addition to these assessments, to further examine the effectiveness of problem-based learning we compared the paper from the group project to the paper written following the ERP analysis tutorial as well as to a previous semester of the laboratory course that did not include a hands-on research project. Compared to the ERP paper on the tutorial dataset, students demonstrated a deeper understanding of their chosen topic, research design and analysis, and the EEG technique. In addition, at the end of the course, the students who took the course including the group project gained a deeper understanding of the EEG technique and practical skills that have prepared them more for upper-level neuroscience courses, including a seminar that focuses on reading primary research utilizing EEG. In this seminar, students who conducted their own EEG project refer to their experience with the group project and use it as a basis to describe to other students the EEG technique. Therefore, the group project enhanced student learning compared to assignments that did not include a hands-on research component.

## CONCLUSION

Here we have presented a model of a student designed research project using a common technique in cognitive neuroscience (EEG). Through problem-based learning (Albanese and Mitchell, 1993; Savery, 1996; Schuh and Busey, 2001) students were able to learn EEG and test novel ideas which led to a deeper understanding of research in cognitive neuroscience that may be useful in a number of courses at the undergraduate or even graduate level. Additionally, it prepared students to work in an EEG laboratory. We believe that providing real research experience in Laboratory in Cognitive Neuroscience met the goals of an undergraduate neuroscience curriculum by introducing students to experimental methodology, design, and data analysis, plus provided advanced awareness of cognitive neuroscience, an opportunity for critical and independent thought, practice in effective communication, and exposure to ethics in human research. The group project was made possible through the availability of open source software (EEGLAB and ERPLAB), but it also required access to EEG recording equipment and proprietary software (EPrime and MATLAB). In order to increase accessibility of research in cognitive neuroscience in the undergraduate curriculum, efforts should be made to increase publicly available data and freely available recording and analysis software for learning cognitive neuroscience techniques.

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Received July 10, 2015; revised November 06, 2015; accepted November 12, 2015.

This work was supported by administration at Bowdoin College. The authors thank the students in Laboratory in Cognitive Neuroscience 2175 for technical assistance, execution, and feedback on this laboratory exercise.

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