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ARTICLE
Meeting the Challenge of Preparing Undergraduates for Careers in Cognitive Neuroscience

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Preparing students for a career in cognitive neuroscience may be especially challenging due to the expense and complexity of many types of cognitive neuroscience technologies. However, it is possible to train students in cognitive neuroscience at a primarily undergraduate university (PUI) in both the classroom and the laboratory. First, we propose specific methods that can be used in the classroom to make cognitive neuroscience material accessible. We also suggest ways to introduce cognitive neuroscience methodology through lab-based courses or activities. Second, we offer suggestions on how to conduct more complex functional magnetic resonance imaging (fMRI) and electroencephalogram (EEG) research with undergraduates at a small school. We hope that these suggestions will be a helpful guide for those wishing to prepare their students for further studies and careers in this exciting and challenging field.

Key words: Cognitive neuroscience; neuroscience education; electroencephalogram (EEG); functional magnetic resonance imaging (fMRI)

Preparing students for a career in cognitive neuroscience has become increasingly challenging. This may stem from the fact that the field is becoming more dependent on complex technology and graduate programs are increasing their expectations for applicants. Although both of the authors came from excellent programs at primarily undergraduate institutions (PUIs), we still found the experience of transitioning into a cognitive neuroscience laboratory to be challenging. More and more graduate programs now require a deeper understanding (and in some cases, a working experience) of cognitive neuroscience methodologies (such as fMRI, EEG, etc.). This can add an extra challenge for the students that come from PUIs who must compete with those coming from larger research universities with more extensive facilities and opportunities for cognitive neuroscience experiences. However, it *is* possible for undergraduates from PUIs to be competitive for placement in research one environments despite limited access to cognitive neuroscience equipment. The current article is a guide for faculty at PUIs who wish to make their students as competitive as possible when pursuing a career in cognitive neuroscience.

The field of cognitive neuroscience began to gain popularity in the 1980s and has been expanding ever since (Brook and Akins, 2005). Both the academic world and the public have been captivated by the possibility of delving deeper into our understanding of the neural underpinnings of cognitive processes in humans. This growing interest can be seen in the increased number of scholarly papers published over the last decade (see Figure 1 and Hennig et al., 2003), as well as in the creation of new journals focusing on cognitive neuroscience, the increase in attendance of scholarly societies such as the Cognitive Neuroscience Society.

Naturally, the expansion of the field as a whole has generated particular interest among undergraduates. Thus, these students are now more than ever in need of training and research experience in the field of cognitive neuroscience. Research experience in general can be extremely valuable for undergraduate students, enhancing personal and professional development and helping to clarify or confirm career choices (Seymour et al., 2003; Hunter et al., 2006). In addition, Kremer and Bringle (1990) found that undergraduates who participated in research were more likely to be accepted to and attend graduate schools with higher research productivity than those students that did not participate in research programs. However, gaining research experience in the field of cognitive neuroscience may be especially difficult as cognitive neuroscience equipment is often quite expensive and technically challenging (Haynes and Rees, 2006). A variety of methods are used to study cognitive neuroscience. A 2005 survey of cognitive neuroscience methods that looked at abstracts submitted to the Cognitive Neuroscience Society conference found that imaging studies comprised over a third of the abstracts, followed by electrophysiological studies (ERP and MEG), studies using patient populations, behavioral studies, studies using transcranial magnetic stimulation (TMS), and other studies including those using modeling, pharmacological manipulations, behavioral genetics, and anatomical studies (Chatterjee, 2005). The current article will focus primarily on the two most prevalent methods: neuroimaging and electrophysiological studies.

TEACHING COGNITIVE NEUROSCIENCE IN THE CLASSROOM

One of the most important factors for new students before they step into a cognitive neuroscience class is having the appropriate foundation through other coursework. Part of the complexity of cognitive neuroscience is that it is interdisciplinary by nature. Students should have a strong background in statistics, cognitive psychology, and physiological psychology. Some courses in computer science can also help students meet the demands of applying more complicated programs to their research endeavors. Specifically, students may benefit from courses that give them experience with multiple operating systems (e.g., Windows, Macintosh, Liniux and Unix). Further, as some neuroimaging software such as SPM is run through Matlab, computer science courses that teach Matlab can be useful.

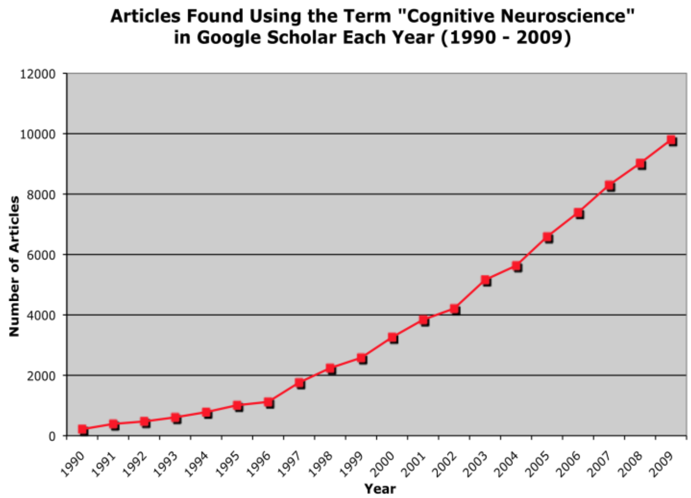

Figure 1. Number of cognitive neuroscience articles per year were found at http://scholar.google.com/advanced_scholar_search by excluding patents, restricting search results to single years and searching by the exact phrase "cognitive neuroscience."

Once these prerequisites are met, the next step is to find a way to convey the material in a clear way in the classroom. There are several very good cognitive neuroscience textbooks which can help with this, including *Cognitive Neuroscience: The Biology of the Mind* (Gazzaniga, 2009) and *The Student's Guide to Cognitive Neuroscience* (Ward, 2010) for a more general overview and *Functional Magnetic Resonance Imaging, Second Edition* (Huettel et al., 2008) or *An Introduction to the Event-Related Potential Technique* (Luck, 2005) for more specific fMRI knowledge and ERP knowledge respectively. However, because the field of cognitive neuroscience is one of both increased complexity and rapid change, these textbooks work best when supplemented with current articles. Journal articles can be helpful to reinforce technical terms and methodologies and stay current within the field. Some journals that may be especially accessible to students are *Nature Reviews Neuroscience, Trends in Cognitive Sciences,* and *Annual Review of Psychology and Annual Review of Neuroscience.* Another way to make journal articles accessible is to present them along with science news articles. *The New York Times* science section often includes new findings about the brain, with commentators debating below. Students should be warned, however, that though these commentaries are sometimes posted by experts in the field, they are often purely opinion based. In addition to allowing for ease of understanding, using these popular sources can be useful as they can also lead to discussions on how scientific articles are portrayed by the media. Another way to make this material accessible is to show clips from popular movies such as *Eternal Sunshine of the Spotless Mind* or *Memento*, which can be further examined through study guide questions (see Wiertelak, 2002 for suggestions on using movies to teach neuroscience as well as an extensive movie list). Another method to make cognitive neuroscience accessible is through in class demonstrations. One good source of cognitive neuroscience demonstrations is the Go Cognitive web project (gocognitive.net).

Case studies of brain-damaged patients can also help provide real world relevancy and allow students to understand the material on a deeper level (Meil, 2007; Olivo et al., 2009). Cognitive neuroscientist and educator, Michael Gazzaniga encourages a two-step process in understanding neuroscience: determining what level of content students need to know, and then connecting the behavior to the brain (Rasmussen, 2006). Gazzaniga suggests showing his students videos of case studies of people who have had brain damage to a certain region after students have learned about the function of that region in class. Vishton (2009) also provided one creative approach to teaching case studies. In his class, a group of students learned about single and double dissociations associated with brain damage via analogies with blenders and knives (e.g., how they lose function when they are damaged (see Vishton, 2009 for the specific analogies used). Those in his class who had critically approached the complicated material with the analogies later did significantly better when tested on it. It should be the teacher's goal to make the material accessible as students are being introduced to cognitive neuroscience, and using analogies, videos and case studies are a few ways in which to achieve this goal.

Because of the intricacies of cognitive neuroscience methodology, once students have a strong backing in psychology, statistics, and cognitive neuroscience, laboratory workshops are a good way to bridge the experience from reading about cognitive neuroscience to actually doing it. Though it can be a challenge to implement cognitive neuroscience methods within the confines of a typical class, there are a number of ways in which one can implement mini-experiments using neurochemistry, EEG and even fMRI methods. For example, Flint (2004) details a way in which students can assess levels of blood glucose and their relation to emotional arousal and memory modulation. This experiment is one that can be done easily in a classroom setting and allows the class to learn about collecting data, analyzing results, and discussing them in light of the underlying neural pathways.

ERP methods can also be used in the classroom (see Evert et al., 2002 for an example of an ERP lab exercise). At Allegheny College ERP and other psychophysiology methods have been used within the classroom for a number of different classes. With funding from the Keck Foundation, students took part in the Neuroscience and the Humanities course series which included the Neuroscience of Dance and Movement, the Neuroscience of Music, the Neuroscience and the Visual Arts, and the Neuroscience of Language (Macel, 2004). In these classes students did laboratory experiments such as collecting event-related potential (ERP) data while students engaged in a number of different exercises such as dance, music, and language. Additional information on these specific laboratory experiments can be found on the internet (http://webpub.allegheny.edu/employee/a/adale/Neurodance/titlepage.html). These types of laboratory experiments can be done in a full course such as the ones listed here or in a single class session to expose students to the methods. Linking these methods courses to experiences in the humanities may be one way to engage new students and non-majors.

Other courses have also successfully taught neuroscience methods as part of a methods-based cognitive neuroscience course. At Boston College, students get hands-on experience through a laboratory course focused on ERP. In this course, students completed laboratory assignments that targeted things such as handling the ERP equipment, applying the electrodes, gathering data, and analyzing that data. These labs were completed in class and were then analyzed outside of class. Students also proposed their own experiment and presented it to the class. Miller, Troyer & Busey (2008) suggest a similar class set up. These authors also suggest using a program called Virtual EEG in which students can access and analyze previously collected EEG data online (http://virtualeeg.psych.indiana.edu/, other publically available data sets are listed in Table 3).

It is also possible to give students experience with fMRI methodology in the classroom. At Gettysburg College, Dr. Kevin Wilson teaches students about neuroanatomy, experimental design and data analysis in a methods based class focusing on fMRI (Wilson, 2007). In addition to a lecture component, students then have the opportunity to collect and analyze data via a laboratory portion. This lab section includes a tour of the MRI facilities at a local hospital and collecting behavioral data to validate the paradigm. In addition, for each of the behavioral paradigms, Dr. Wilson also collects fMRI data for one subject for each group in the class through collaboration with the neuroimaging facilities at the University of Pennsylvania. Students are then able to independently analyze these data using what they had learned in class. This allowed students to be able to analyze novel fMRI data.

If collecting new data is not a possibility, there are a number of free online data sets, which can be used to analyze already collected data in a novel way (see Table 1). Though the Gettysburg course was an entire course dedicated to fMRI, it is also possible to teach fMRI methodology as part of a more general methods or physiological psychology course. Hurd and Vincent (2006) outline an fMRI workshop which spans four class sections in which students are given a basic overview, take a tour of an fMRI facility, complete portions of the pre- and post-processing analyses and present experimental results. Training students through these types of methods-based classes is not only beneficial to students as an introduction to cognitive neuroscience techniques, but it can also lay the groundwork for preparing students to work in ongoing research labs that use these techniques.

Thus, in the classroom, neuroscience educators can work to lay the groundwork for understanding cognitive neuroscience by helping students to engage with this complex material, using strategies in lecture that help the students connect with the material and developing laboratory workshops or lab based courses.

GETTING EXPERIENCE WITH COGNITIVE NEUROSCIENCE METHODS

Students interested in cognitive neuroscience as a career may wish to get experience with cognitive neuroscience beyond classroom and the associated laboratory exercises. Although class work can be a good introduction to cognitive neuroscience methodologies, it is difficult to get a complete grasp of the intricacies of these methods without devoting some time to work in a cognitive neuroscience research lab.

Though many educators may be familiar with cognitive neuroscience methods and may use them within their own research, it may be necessary for some educators to obtain initial training before involving students in cognitive neuroscience research within their own laboratory. This training can be obtained either by taking an introductory course (see Table 3) or by taking a sabbatical or leave of absence to learn how to use these methods at a university with established fMRI or EEG facilities. Many companies that sell EEG equipment also have free training workshops and fMRI research centers sometimes offer training courses. Some grants are well suited for gaining training at a larger institution. For example, the National Science Foundation Research Opportunity Award (NSF NOA) Supplement Opportunity is a grant that is targeted towards helping faculty at PUIs become visiting scientists and collaborate with current NSF funded projects at other institutions. Any researcher with current NSF funding can apply for this supplement to support research by a collaborator at a PUI. Some universities and colleges may also support this kind of leave. Once you have a background in methods such as fMRI and EEG, one then faces the challenge of involving students in this type of research.

fMRI Research. Many institutions have met this challenge by collaborating with local or remote research facilities. Most hospitals have an MRI scanner and some will allow the machine to be used for research or teaching purposes. However, most of these hospitals only have these scanners set up to acquire structural scans. In order to acquire functional scans, one must set up a collaboration with a hospital or university that has functional imaging capabilities. To set up such a collaboration Hurd and Vincent (2006) recommend contacting a local hospital public relations department to direct you to the head of the MRI center to determine if they are collecting functional imaging data and if they might be willing to collaborate in some capacity. Alternatively, if you know of a doctor or researcher who is currently collecting fMRI data, it may be wise to contact him or her directly in order to see if collaboration is possible.

As fMRI scanning can be expensive, significant funds are needed to use these resources. If obtaining funding to collect fMRI data isn't possible, another option is to get undergraduates involved in analyzing fMRI data that has already been collected by yourself or a collaborator. There are a number of different software programs available for fMRI (see Wilson, 2007 for a detailed list). Some of these software packages are free, but others (such as MedX and Brain Voyager) can be quite expensive. Many people use SPM with Matlab. While SPM is free, Matlab is commercial software that may come with some maintenance costs. The data can then be interpreted by using brain atlases such as the ones listed in Table 2.

Data analysis using fMRI data collected by collaborators can be conducted remotely. However, you may need access to a computer with a sufficient amount of storage space (one study can be 50-80 GB) or a large external storage unit. One can also sometimes get remote access to a computer affiliated with the hospital or research facility where the data were collected, but it can be a difficult process to gain this access in some hospital settings. Using remote access, this form of student research has been used at Boston College for student's senior thesis (DeRojas and Kensinger, 2010). This is especially recommended for advanced students with previous course work in cognitive neuroscience. If students have not had the opportunity to take a methods based fMRI course, they may gain experience by using neuroimaging datasets online as practice analysis tools (See Table 1 for some of these datasets that are available at no cost).

Perhaps one of the best ways for students to get hands-on fMRI experience is through summer internships. Students can then see the process from data collection, to data analysis (Table 5). Again, students would most benefit from an internship after taking an introductory training course or seminar on fMRI which can be found at a number of research facilities or conferences.

EEG Research. Many PUIs that may not be able to afford an fMRI set-up may find it useful to invest in an electroencephalogram (EEG). While an fMRI scanner can costs millions of dollars, not including the cost of building an MRI facility, hiring technicians, etc., an EEG costs several thousand dollars which may be more feasible. The cost of an EEG system can be quite variable based on the number of electrodes, the need to abrade the scalp or not, and the ease in interfacing with software and there are many systems to choose from. Some common systems include those produced by Biopac Cortech, Solutions, and Neuroscan. It is recommended to get a system that comes with a warranty to cut down on maintenance costs.

EEG signals can be averaged in relation to a behavioral response to examine the neural activity that leads to that behavior. These averaged potentials before, during or after a timing cue are called event-related potentials (ERP). ERP research is most commonly used in cognitive neuroscience labs (as opposed to traditional EEG). ERP can be more expensive than traditional EEG set-ups as you also may need an alternate amplifier, a stimulus device, a separate computer to drive the stimulus and a connection between the stimulus computer and the EEG system. However, an ERP system is essential in order to relate brain activity to behavior or stimulus onset.

To set up an ERP lab, one needs the proper equipment (2-3 computers, EEG, electrodes, amplifiers, digitization software, and a stimulus presentation system). When setting up an ERP lab for undergraduates to use, it is wise to obtain EEG equipment that is user friendly. However, one should keep in mind that the more expensive models tend to be the more easy to use ones, while the cheapest ones require a lot of programming and code writing in order to analyze the data (see Luck, 2005 for a chapter about setting up an ERP lab). To collect ERP data you also need an ERP recording chamber. This should be a room with little electromagnetic interference or at least a place where the interference stable over time so it doesn't interact with trial types.

Once an EEG system is acquired, the challenge is to train students to use the equipment. In order to make EEG research more accessible for undergraduate students, caps with fewer electrodes (e.g., 8-36 electrodes) may be more feasible. This helps with ease of data collection as well as cutting costs. In order to train students on using the equipment, there are a number of different training courses which students can attend (Table 4). Further, some equipment systems such as those made by EGI Dense Array Systems also include free training courses and in-depth manuals which undergraduate students can use in order to learn to operate the EEG.

Diffusive optical imaging (DOI), which uses an inferred light to measure changes in hemodynamics may also be a tool that is suited for use with undergraduates in the future (Gibson and Dehghani, 2009). It is fairly simple, low cost, and portable and has good temporal resolution. However, it has low spatial resolution and is now only beginning to be used in mainstream cognitive neuroscience research.

CONCLUSIONS

As the field of cognitive neuroscience continues to expand and develop, it is imperative to prepare students for the new opportunities they will have at both the graduate school level and beyond. We encourage the scientific outcomes of cognitive neuroscience training to be assessed in order to strengthen and develop cognitive neuroscience training programs. Outcomes can be assessed by interviewing current students, faculty mentors, and alumni (see Bauer and Bennett, 2003 and Lopatto, 2003 for examples of these methods). Assessing outcomes is crucial in order to determine what the essential features of the undergraduate research experience and what the potential benefits may be.

Although some of the challenges discussed in this article can be applied to teaching any advanced science,

Source	URL	Notes
fMRI Data Center	http://www.fmridc.org	
Motor Study Dataset	http://spinner.cofc.edu/neuroscience/fmri/data/datasets.htm	
Wellcome Trust Centre for Neuroimaging	http://www.fil.ion.ucl.ac.uk/spm/data/	
Star Plus fMRI Data	http://www-2.cs.cmu.edu/afs/cs.cmu.edu/project/theo-81/www/	
National Institute of Biomedical Imaging and Bioengineering	http://www.nibib.nih.gov/Research/Resources/ImageClinData	Clinical data sets
Brain Web: Simulated Brain Database	http://mouldy.bic.mni.mcgill.ca/brainweb/	This allows you to simulate MR Images by changing a number of different data acquisition factors. This could be useful for an in class activity on MR data acquisition.

Table 1. Access fMRI Data for Teaching Purposes

Brain Atlases for brain Coordinates	URL or Reference	Notes
Talairach Atlas	Talairach, J., & Tournoux, P. (1988). Co-planar stereotaxic atlas of the human brain: 3-dimensional proportional system: An approach to cerebral imaging (M. Rayport, Trans.). New York: Thieme.	
The Whole Brain Atlas	http://www.med.harvard.edu/AANLIB/home.html	
Talairach Daemon	http://www.talairach.org/daemon.html	Note: These online tools can give you a ballpark of where your coordinates are, but should be double checked with the Talairach Atlas.
Formulas for converting between Montreal Neurological Institute (MNI) and Talairach space	http://www.brainmap.org/	

Table 2. Brain atlas information

	Source	URL	Notes
Access ERP Data	Wellcome Trust Centre for Neuroimaging	http://www.fil.ion.ucl.ac.uk/spm/data/	
	UCSD Dataset	http://sccn.ucsd.edu/~arno/fam2data/publicly_available_EEG_data.html	
	UCI Dataset	http://archive.ics.uci.edu/ml/datasets/EEG+Database	
	PhysioBank Sleep EEG Data	http://www.physionet.org/physiobank/database/sleep-edf/	
Analyze ERP Data	Commercial Package		Buy a commercial package (see Luck (2005) for necessary components)
	Public Domain MATLAB libraries	http://sccn.ucsd.edu/eeglab/ BrainStorm: http://neuroimage.usc.edu/brainstorm/	To cut costs you can write your own analysis software, based off of free, public domain MATLAB libraries for analyzing ERP data such as EEG lab and BrainStorm.
EEG/ERP Training			There may be free training courses provided by your EEG/ERP software company.
	UC Davis ERP Bootcamp	http://erpinfo.org/the-erp-bootcamp	
	SPR Research Fellowship Training Award	http://www.sprweb.org/grants/index.cfm	

Table 3. EEG / ERP data

Source	URL	Description
University of Pennsylvania Undergraduate Summer Workshop	http://www.ircs.upenn.edu/summer2010/index.html	A two week workshop focusing on Cognitive Neuroscience
Indiana University Cognitive Science Visiting Undergraduate Program	http://www.cogs.indiana.edu/academic/visit.html	A full year program focused on conducting research and taking classes in cognitive neuroscience
Center for Cognitive Neurosceince at Duke University	http://www.mind.duke.edu/training/visiting.html	Summer research internships with individual faculty members.
iCogSci Internship and Summer Research Programs List	http://www.cogs.indiana.edu/icogsci/res.html	Provides a list of internships, many of which are specific to Cognitive Neuroscience
University of Maryland NACS Program in Neuroscience and Cognitive Science	http://www.nacs.umd.edu/program/summer.html	Summer research internships with individual faculty members.
National Science Foundation – Research Experience for Undergraduate (NSF REU)	http://www.nsf.gov/crssprgm/reu/	Each student in this program is assigned to an individual research project and is mentored by the faculty member or others in the lab. There are a number of labs to choose from, across the country. Many of these programs have labs based in cognitive neuroscience.
Faculty For Undergraduate Neuroscience Internship List	http://www.funfaculty.org/drupal/undergrad_internships_neuroscience	Many resources for summer internships, some have opportunities for cognitive neuroscience or faculty members that are doing cognitive neuroscience
Howard Hughes Medical Institute	www.hhmi.org	These grants are offered for under-graduates to complete summer research fellowships. These fellowships can be used at a university that has a cognitive neuroscience research program.

Table 4. Student research and internship opportunities

many are specific to teaching the methodology and thinking in cognitive neuroscience. A basic foundation of reading and working with articles can help to prepare undergraduates for more technically difficult aspects of thinking about cognitive neuroscience. Further, although fMRI instruments may not be available at every institution, professors can use or even share across institutions less expensive equipment like EEG, and have more advanced students examine fMRI data. By encouraging students to gain experience with fMRI and other cognitive neuroscience techniques during summer opportunities students can extend their learning beyond the classroom. Lastly, please see Tables 1-4 for a variety of teaching and research resources, access to databases and lists of methodological internships and training programs. We hope that these resources will provide the tools necessary for professors looking to include their students in this exciting and challenging field.

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