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ARTICLE
Are Electrode Caps Worth the Investment? An Evaluation of EEG Methods in Undergraduate Neuroscience Laboratory Courses and Research

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Electroencephalography (EEG) is a common neuroscience technique that is more accessible to undergraduate programs than expensive techniques such as fMRI and single-cell recording. The use of EEG can provide undergraduates with firsthand neuroscience research experience without taking too many financial resources away from a program. There are multiple types of EEG equipment that can be used, including individual electrodes and electrode caps. This study used surveys administered to students who were in a neuroscience laboratory course, conducting research, or participating in research in order to discern which of these two EEG setups is preferred by undergraduates. According to average reaction scores calculated from the surveys, laboratory students tended to prefer individual electrodes over electrode caps, and when explicitly asked about their overall preference, a majority of laboratory students chose individual electrodes over electrode caps. Additionally, comparable levels of improvement in learning objectives and the quality of data collected in laboratory sessions were found across methods. Student researchers' ratings revealed a marginal preference for caps over individual electrodes, and all 5 researchers surveyed chose caps on a discriminate choice question. Research participants' ratings of caps and individual electrodes, however, were not significantly different. These results do not point to a concrete recommendation of one setup over the other but rather suggest that either setup could be a viable option. Therefore, we conclude that programs can comfortably decide which to use based on their own needs and resources as well as the relative advantages and disadvantages of each setup. For example, individual electrodes may be better for programs with low budgets looking to introduce students to EEG data recording, whereas electrode caps may be better for programs looking to better prepare students for future EEG research or to perform multichannel recordings.

Key words: EEG; individual electrodes; electrode caps

Electroencephalography (EEG) is one of the many techniques used in neuroscience research, and it is one that is more accessible to undergraduate programs than other common techniques such as fMRI or single-cell recording. It is less expensive than other methods, is noninvasive, and poses relatively few physical risks to participants. Furthermore, EEG is a versatile technique that can be used to examine a variety of aspects of brain functioning and to introduce students to a range of analytical techniques (Nyhus and Curtis, 2016). EEG data can be collected by affixing individual electrodes to a subject's scalp or by using an electrode cap to assist with electrode placement.

While electrode caps make affixing electrodes to the scalp easier (Blom and Anneveldt, 1982), they also may feel restrictive to participants since they cover the whole scalp and generally need to be held down with straps anchored around the chin or chest. An additional concern with using electrode caps is that they must be cleaned and hung up to dry after each use, while individual electrodes can simply be cleaned with alcohol swabs and are available for reuse immediately. Even if headbands are used to help hold individual electrodes in place, those can simply be thrown into the wash and do not need to be cleaned by hand.

Prior research, however, highlights some of the potential advantages associated with using electrode caps. Caps help eliminate mechanical issues with EEG recordings by ensuring that electrodes are placed precisely, adhere to their proper positions, and maintain sufficient contact with the scalp (Blom and Anneveldt, 1982). In Blom and Anneveldt's study, the technician and the subjects preferred the cap, and the application of the cap was faster and easier for a single technician to perform. Additionally, EEG recordings obtained with individual electrodes and with caps were of similar quality (Blom and Anneveldt, 1982). Blom and Anneveldt note that technicians fitting electrode caps need to have prior experience with the cap placement procedure in order to minimize artifacts caused by procedural errors such as inadequate filling of electrode cavities and interference from hairs separating the electrodes from the scalp. The same can be expected to be true for undergraduate students. Inexperience can easily be addressed, however, by giving instructions to those responsible for set up and providing a chance to practice using the equipment before collecting data.

While some tout electrode caps as the favored type of equipment for multichannel recordings (e.g., Teplan, 2002), individual electrodes may have particular advantages in certain settings. Individual electrodes can be used for electromyography (EMG) and electrocardiography (ECG) as well, making them more versatile. In clinical settings where caps may not fit appropriately, such as if patients have skull defects or head circumferences for which there is not an appropriate cap size, using individual electrodes and measuring proper placement by hand may be preferred (Blom and Anneveldt, 1982). Moreover, the use of caps would be precluded if pressure could not be placed on a patient's skull or if participants were injured in such a way that prevented the cap from being secured in place (Blom and Anneveldt, 1982). Clinical settings use other setups as well, such as Electrical Geodesics, Inc.'s Geodesic Sensor Nets (GSNs; Ferree et al., 2001) which do not require scalp preparation or abrasion but can increase initial cost.

When purchasing EEG equipment, consumers must decide whether electrode caps are worth the investment. Electrode caps cost hundreds of dollars in addition to the cost of recording equipment, and disposable syringes must also be purchased to use with the cap for abrading the skin and applying the conductive paste to the electrodes. In contrast, Q-tips and cotton rounds can be used with individual electrodes, and thus, this method is cheaper to continue using over time.

The use of a virtual EEG program such as that discussed in Miller et al. (2008) can avoid the costs incurred through the use of EEG equipment and provide a wide range of students with valuable learning opportunities. However, access to physical equipment is important to give students firsthand experience with the setup and cleanup procedure as well as the opportunity to design and conduct their own experiments.

Due to financial restrictions on equipment purchase for undergraduate laboratory courses and research laboratories, faculty need to take into account the cost of equipment relative to the benefit for laboratory students, student researchers, and research participants. When Roanoke College's Neuroscience Concentration was created, both individual electrodes and electrode caps were purchased as the caps were thought to possibly have the added benefits of improving signal quality and of being perceived as more professional. After some initial testing, the decision was made to use individual electrodes because of the technical ease and reduced cost. As a result, previous student EEG studies at Roanoke College have exclusively used individual electrodes for data collection (e.g., Hurless et al., 2013; Kennedy et al., 2014). In order to guide our future use and to provide information for instructors and researchers at other institutions, this study examined how students in an introductory neuroscience laboratory course, student researchers, and research participants feel about using individual electrodes as compared to caps for EEG studies and exercises. Data quality and accomplishment of learning objectives were also compared across methods.

MATERIALS AND METHODS

Participants: A total of 40 Roanoke College undergraduate students were recruited for the three separate portions of this study from three separate sources detailed below. The study was conducted in accordance with the guidelines of the Roanoke College Institutional Review Board.

Fifteen students enrolled in PSYC/NEUR 330: Principles of Neuroscience were used for the laboratory student reaction portion. It is an introductory neuroscience course that is a requirement for the neuroscience concentration and an elective for the psychology major. The lecture portion of the class meets for 3 hours per week, and the laboratory component meets for 1.5 hours per week. Three of the labs that students completed in the laboratory portion of the course during the second half of the Spring 2016 semester required EEG data collection. There were two laboratory sections that semester – a Monday section with 8 students split into three groups and a Wednesday section with 7 students split into three groups. Two students in the Monday section did not complete all surveys. Each student assisted with the equipment setup and had their neural activity recorded at least one time.

Five student researchers experienced with the use of individual electrodes and caps participated in the researcher reaction portion.

Twenty students were recruited for the research participant reaction portion through Sona, the Psychology Department's sign-up system, where potential participants were able to view information about the study and register for time slots. These participants were pre-screened via questioning. If they were susceptible to seizures or did not have normal or corrected-to-normal vision then they were not eligible to participate. They were additionally warned that the procedures could possibly induce migraine headaches. Research participants provided informed consent and received 1 unit of class participation credit for their time.

Equipment: A PowerLab 26T from ADInstruments was used to record the EEG signals. Either lead shielded individual electrodes that came with ADInstruments' Intermediate Teaching System or electrode caps from Electro-Cap International were used to transmit signals from the participants' scalps to the PowerLab unit. The Intermediate Teaching System costs $3,500-4,500, and a set of two EEG caps costs $750-1000. For the laboratory sessions, all data was recorded in a typical classroom environment. For the research participant reaction portion, all trials were conducted in a dark room with minimal possible distractions. Stimuli were presented to subjects using SuperLab 4.5 from Cedrus Corporation, and the temporal presentation of stimuli was recorded with a StimTracker device also from Cedrus Corporation. Each SuperLab and StimTracker setup costs $1500-2000. All software was run on a Dell XPS 15z laptop. Subjects viewed stimuli on the laptop's internal 15" widescreen monitor while an external 17" Dell monitor viewable only to experimenters presented the output of the EEG signals through LabChart 7 software from ADInstruments. Microsoft Excel and SPSS (IBM Corporation) were used for all data analysis.

Individual electrode setup: Basic EEG setups used either one or two channels. For both, the ground electrode was placed on the left side of the forehead approximately halfway between the eyebrows and hairline (FP1). The positive channel 1 electrode was placed approximately an inch above the inion (the bump on the back of the head;

OZ), and the negative channel 1 electrode was placed on the right side of the forehead halfway between the eyebrows and hairline (FP2). When a second channel was used, the positive channel 2 electrode was placed in the center of the top of the head (CZ), and the negative channel 2 electrode was placed on the right earlobe (A2). Electrodes were secured in place with elastic headbands. One was wrapped around the head, and when two channels were used, an additional headband was wrapped from under the chin to the top of the head. All electrodes were filled with electrode conductive paste except for the A2 electrode which used a disposable electrode. Q-tips were used to apply the paste, and paper towels were used to wipe it off. Alcohol wipes were used to clean the electrodes after most of the paste had been removed.

Electrode cap setup: Only three or five of the possible 20 electrodes were utilized depending on whether one or two channels were recorded. The electrode on FP1 was used as the ground electrode, and the electrode on FP2 was used as the positive channel 1 electrode. The electrode above and to the left of the inion (O1) was used as the negative channel 1 electrode. When a second channel was used, the CZ electrode was used as the positive channel 2 electrode, and the electrode on the left side of the head (T7) was used as the negative channel 2 electrode. Disposable sponge discs were placed around the inside of the electrodes used. Caps were secured in place by attaching straps on the sides of the cap near the ears to chest strap. After the cap was secured on the participant's head, conductive electrode gel was injected into the electrodes with disposable syringes and needles. Caps were washed after each use with Ivory soap and water.

Laboratory assignments: Three experiential labs out of ten in PSYC/NEUR 330 included an EEG component and were adapted by the last author for class use from the EEG exercises found on ADInstruments' website (http://www.adinstruments.com/education/labchart-experiments/neuroscience). All labs were designed to facilitate the course learning outcomes of utilizing basic neuroscience techniques, explaining the theories behind these techniques, and interpreting the results of experiments. For the set of EEG labs in particular, measurable learning objectives were the ability to acquire quality data, self-reported understanding of brain activity as electrical voltage observable at the scalp, and comfort with the hardware/software combination used to record the electrical voltage. The assignment sheets for these labs are available on the last author's faculty page (see below).

The initial EEG lab covered basic recording procedures using a one-channel setup as well as the exploration of possible participant artifacts and instrument problems that can result in poor data quality. Students were instructed to collect one block of clean data with voltage oscillations within +/- 60 µV, three blocks containing participant artifacts (blinking, eye movements, and head movements) that had voltage magnitudes greater than +/- 100 µV, and three blocks containing known instrument problems (too little conductive gel or paste, too much hair beneath the electrodes, and loose/unconnected electrodes) likely to cause recording traces visually distinct from clean data.

The second EEG lab used auditory stimulus presentation to examine alpha waves with a one-channel setup. The goal was to observe alpha waves, defined as a peak in the FFT spectrum in the range of 8-13 Hz. The magnitude of the peaks was defined based on the contrast between the peak response and the reference response. The peak response was individually determined, either 9.4 or 10.9 Hz, which then determined the reference Hz, either 6.3 or 7.8 Hz. The reference Hz accounts for the 1/f noise function present in the FFT spectrum of all groups. Contrasts above 0 were necessary for clear peaks with a possible range of -1 to 1.

The final EEG lab included visual stimulus presentation and the measurement of event-related potentials (ERPs) using a two-channel setup. The goal was to observe a P300 ERP, defined as a transient response occurring 300-400 ms after stimulus onset, with voltage change statistically different from baseline voltage measured across the 100 ms prior to stimulus onset and decreasing in magnitude within 200 ms.

Surveys: Surveys given to laboratory students, student researchers, and research participants focused on determining the overall impression of using individual electrodes and of using electrode caps. More specifically, they asked about preference, comfort for participants, difficulty of use, and professionalism. The authors intended for questions of professionalism to be considered in relation to how well a student's experience characterized their expectations for the technical standards of EEG recording. Naïve students were expected to convey whether or not they perceived the equipment as clearly unprofessional. Some questions asked about the setup or cleanup of equipment in particular or about the subject's experience with the equipment during the task. The questions either required a discriminate choice of individual electrodes or caps or a rating on an 11-point scale of -5 to +5, with 0 as a neutral value. The scale for questions about comfort ranged from -5, "Very Uncomfortable" to 5, "Very Comfortable." The scale for questions about professionality ranged from -5, "Very Unprofessional" to 5, "Very Professional." Questions regarding difficulty were the only ones with negative scores representing positive feelings and vice versa. The scale for questions about difficulty of setup and cleanup ranged from -5, "Very Easy" to 5, "Very Difficult." The scale for questions about difficulty added to the task by the equipment ranged from -5, "Much Less Difficult" to 5, "Much More Difficult." Scores on questions related to difficulty will be given here in relation to "Ease" or "Difficulty Removed" instead of "Difficulty" or "Difficulty Added" so that higher numbers will refer to more positive reactions for all scores across all measures.

Laboratory students were also given pre- and post-lab surveys meant to assess their learning, their comfort levels, and the impact that the lab had on those factors, as done in Nichols (2015). Pre-lab surveys asked how well students understood the concept of brain activity as electrical voltage at the scalp on a scale from 0, "No Understanding" to 10, "Complete Understanding" and how comfortable the students were with using the PowerLab/LabChart combination for EEG recordings on a scale from -5, "Very Uncomfortable" to 5, "Very Comfortable." Another question asked about understanding of concepts specific to each lab but was not incorporated into analyses as it was not consistent across labs, unlike the other questions. The post-lab surveys asked identical questions and, for each item, how much the students felt that particular lab influenced their understanding/comfort levels on a scale from -5, "Much less" through 0, "No Change" to 5, "Much more."

See *JUNE* Supplementary Materials for the surveys.

Procedure: The laboratory student reaction portion of the study began with a mixed factorial design so that all students would experience both methods and effect of order could be tested. As such, for the first two EEG labs, students were assigned to use either individual electrodes or electrode caps. The Monday section used the caps for the first lab while the Wednesday section used individual electrodes and vice versa for the second lab. For the third lab, students chose which equipment to use to complete the lab assignment. After each of the first two labs, laboratory students were given a survey to assess their reactions to the equipment. An average rating score for each student was calculated based on their responses to the four scale-based questions on each of these two surveys. After the final lab, students were given a survey that forced them to make clear-cut distinctions between the two methods. Additionally, students were given pre- and post-lab surveys regarding their understanding and comfort levels each week. In total, the surveys took 5-10 minutes per week. Students had 1.5 hours each week to complete the components of the lab, including setup, data collection, and analysis.

Student researchers, including the four student authors, were asked to complete a short, 5-minute survey about their reactions to the two EEG methods. An average rating score for each researcher was calculated based on their responses to the four scale-based questions. Student researchers had from 3.5 to over 50 hours of experience running participants using EEG equipment.

The research participant reaction portion of the study also used a mixed factorial design. Participants were randomly assigned to either experience the one-channel individual electrode setup or the one-channel electrode cap setup first, with 10 participants in each condition, but all were exposed to both methods. Once participants gave informed consent, they were given a cotton round with abrasive gel on it and asked to abrade the skin on their foreheads. The equipment was then set up, and a stack of books with a pillow on top was placed in front of participants for them to rest their chins on during the course of the experiment. Participants then viewed a set of 80 black and white images of faces and 20 black and white images of fingerprints in a random order. They were asked to focus their gaze on the center of the screen and blink each time they saw a fingerprint. They viewed the complete set of stimuli two times total, once with each setup. A set of trials lasted approximately 3 minutes. At the end of the entire EEG procedure, participants were given a survey examining their reactions to the two methods. Participants were then debriefed and told about the objectives of the current study, namely to examine reactions to the EEG recording methods. The EEG recordings themselves were discarded. All in all, this study took 25-30 minutes for each participant: approximately 5 minutes for initial setup, 5 minutes to clean up the initial setup and set up the next portion of the study, around 6 minutes total to run through the stimuli and conduct the EEG, and no more than 10 minutes for cleanup of the second setup, completion of the survey, and debriefing. An average rating score for each participant was calculated based on their responses to the five scale-based questions.

RESULTS

Laboratory student perspective: Average scores on individual items and across all items on the post-lab equipment surveys completed during the first two EEG labs are reported in Table 1. Average laboratory student ratings of individual electrodes were significantly higher than average laboratory student ratings of caps ($t([12]=2.213$, $p=0.047$; Figure 1a). Individual electrodes were also rated as being significantly easier to set up than caps ($t(12)=-2.497$, $p=0.028$). There was not a significant difference in ratings of ease of cleanup ($t[12]=1.102$, $p=0.292$), comfort for subjects ($t[12]=2.051$, $p=0.063$), and professionality of method ($t[12]=-1.066$, $p=0.307$).

Differences in the ratings on the surveys administered after the first two labs were compared across sections using an independent samples *t*-test. The ratings of ease of setup for the first lab were significantly different ($t[11]=5.899$, $p<0.001$), with Monday's lab rating the caps as difficult to set up ($M=-0.83$, $SD=1.60$) and Wednesday's lab rating the individual electrodes as easy to set up ($M=3.45$, $SD=0.98$). There was, however, no significant difference between the two sections' ratings of setup ease for the second lab ($t[13]=0.976$, $p=0.347$). Across lab sections, no significant difference was found in ratings of setup ease for individual electrodes ($t[13]=1.149$, $p=0.271$), but there was a significant difference in how the two lab sections rated ease of cap setup ($t[11]=5.746$, $p<0.001$). The Monday section's ratings were significantly lower ($M=-0.83$, $SD=1.60$) than Wednesday's ($M=3.29$, $SD=0.95$), meaning the Wednesday lab found the process of setting up the caps during their second exposure to EEG methods to be much easier than the Monday lab did during their first exposure to EEG methods.

As shown in Figure 2, for the final EEG lab, 5 of 6 groups — totaling 13 students — chose to use individual electrodes and only one group of 2 students chose to use caps (a). On an individual basis after the completion of the lab, 9 stated they preferred individual electrodes overall, 5 stated they preferred caps (b), and 1 circled both options, noting that their preference would depend on how many electrodes were needed. In terms of participant comfort

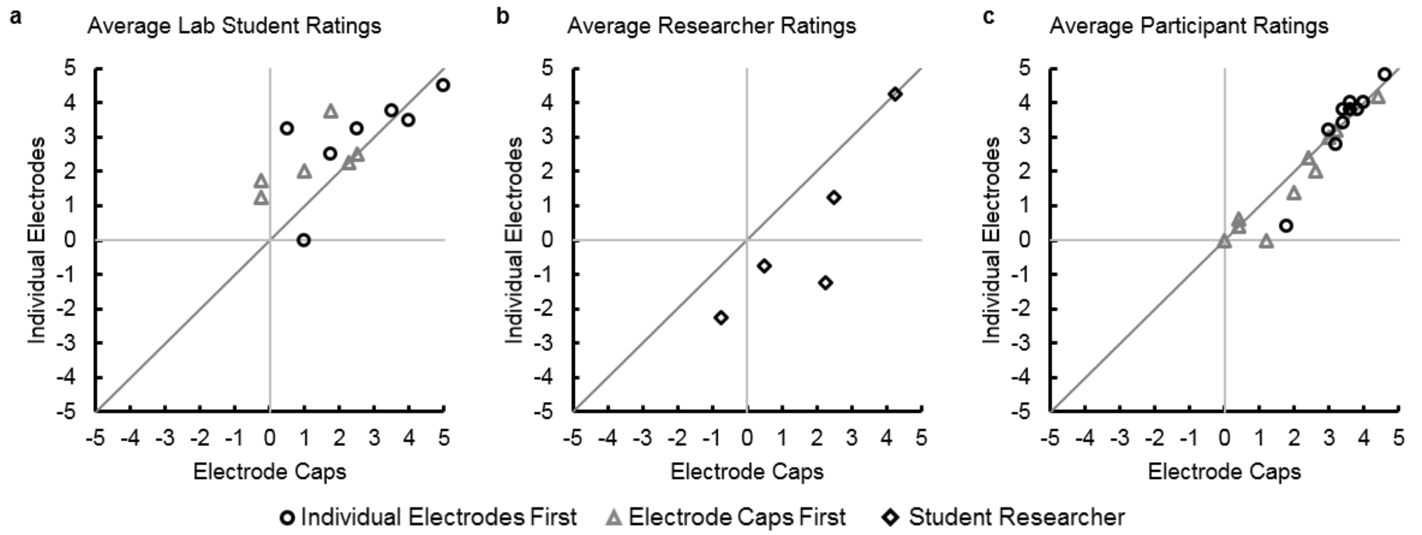

Figure 1. Scatterplots display average scores of laboratory students (a), student researchers (b), and research participants (c). Scores were calculated for each individual based on their responses to survey questions about the individual electrode method and the electrode cap method that used 11-point scales of -5 to 5 with 0 representing neutral. Responses were reverse-coded when necessary so that a higher score denotes more positive feelings. Lines of equality between the methods are displayed in dark grey. *a.* Average student ratings of individual electrodes were significantly higher than average student ratings of caps, as shown in the plot with data points consistently above the line of equality. The lowest points on the line tend to be triangles while the highest points are circles, but there is no significant difference between these groups. *b.* Average researcher ratings of caps are consistently higher than the rating of individual electrodes, demonstrated in that most data points are below the line of equality. *c.* Average participant ratings of individual electrodes and caps are not significantly different, as can be seen in how the data points cluster near the line of equality. Triangles tend to be lower on the line than circles, and the difference between these groups is significant.

Measure	Method	*N*	*M*	*SD*
Ease of Setup*	Electrodes	15	2.93	1.58
	Caps	13	1.38	2.47
Ease of Cleanup	Electrodes	15	3.13	1.69
	Caps	13	2.62	2.06
Comfort for Participants	Electrodes	15	2.60	1.77
	Caps	13	1.08	2.50
Professionality of Method	Electrodes	15	2.27	1.71
	Caps	13	2.69	1.25
Average Lab Student Ratings*	Electrodes	15	2.63	1.23
	Caps	13	1.94	1.59

Table 1. Laboratory student responses to the post-lab equipment surveys administered after the first two labs. Measures for which there is a significant difference ($p<0.05$) between individual electrodes and caps are marked with an asterisk.

(c), 7 selected individual electrodes, and 8 selected caps. 9 chose caps as being easier for researchers to use while 6 chose individual electrodes (d). When asked about which was quicker to set up (e), 7 picked individual electrodes, and 8 picked caps. 11 selected individual electrodes as having the quicker cleanup speed (f), and 4 selected caps.

Finally, 10 stated individual electrodes were more professional (g), 4 stated caps were more professional, and 1 wrote that both setups were equally professional.

Data quality: Data collected during the three EEG labs was checked in relation to the particular assignment goals and compared across EEG methods. Screenshots of the actual student data can be seen in the *JUNE* Supplementary Materials. Overall, both methods allowed for the recording of data that was of sufficient quality to meet the goals of the assignments, and there was no clear or consistent difference between the methods.

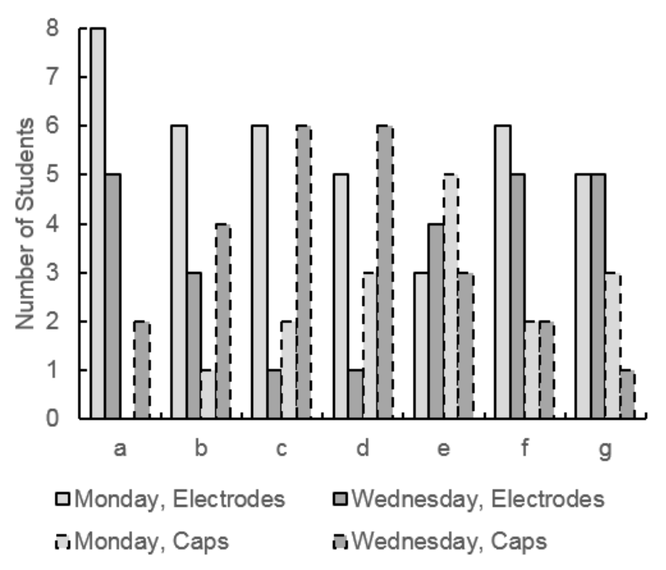

Figure 2. Laboratory student responses to final discriminate choice survey. Results are separated by lab section to facilitate comparison. Questions are as follows: *a.* equipment used in final lab, *b.* personal preference, *c.* more comfortable for participants, *d.* easier for researchers, *e.* quicker setup, *f.* quicker cleanup, and *g.* more professional.

For the first EEG lab, across the six groups, 100% were able to record clean data, 94% of the participant artifact blocks showed the desired effects (one block for a group using caps exhibited an unexpected instrument problem instead), and 56% of the instrument problem blocks showed recordings clearly different from clean data (an equal number of blocks for the individual electrode and caps methods looked fairly clean with at most a bias slightly above or below a neutral baseline). Screenshots of all the data collected for this lab can be seen in *JUNE* Supplementary Figure 1.

For the second EEG lab, all six groups were able to observe alpha waves (*JUNE* Supplementary Figure 2), with observed contrasts of 0.62-0.91 for individual electrodes and 0.48-0.79 for caps.

For the third EEG lab, though five of the six groups recorded signals consistent with ERPs (*JUNE* Supplementary Figure 3), only three groups recorded data that was at least marginally significant based on the given definition. That included two of five groups using individual electrodes and the one group using caps.

Learning objectives: Average understanding scores are displayed in Table 2, and average comfort scores are displayed in Table 3. Paired samples *t*-tests showed a significant improvement in understanding of brain activity as electrical voltage observable at the scalp ($t[14]=5.850$, $p<0.001$) and comfort levels working with the hardware/software setup ($t[14]=3.560$, p=0.003) from the first pre-lab survey to the second post-lab survey. In those two labs, each student was exposed to both EEG methods, yet no significant differences between methods were found for either understanding or comfort levels.

The average self-reported understanding level on the first pre-lab survey was 6.47 ($SD=1.73$) and showed a significant increase for both the first lab ($t[14)]=13.569$, $p<0.001$) and the second lab ($t[14]=4.000$, $p=0.001$), with 13/15 students indicating an increase, 2/15 indicating no change, and an average total increase of 1.93 ($SD=1.28$). However, there was no significant difference in the change in understanding between electrode methods within a single lab when tested for individual labs using independent sample *t*-tests (both *p*'s>0.35) nor when grouping by EEG method, combining across both labs, using a paired samples *t*-test ($t[14)]=0.00$, $p=1.00$).

The comfort level for the first pre-survey was 1.20 ($SE=1.93$) and showed a significant increase for both the first lab ($t[14]=6.094$, $p<0.001$) and the second lab ($t[14]=3.595$, $p=0.003$) with 12/15 students indicating an increase, 3/15 indicating a decrease of one point on the scale, and an average total increase of 1.87 ($SD=2.05$). As with the understanding levels, there was no significant difference in the change in comfort between EEG methods within a single lab when tested for individual labs (both *p*'s>0.15) nor when combining across both labs by grouping based on method ($t[14]=0.286$, $p=0.779$).

The third lab involved student groups choosing their preferred method, resulting in unequal numbers of groups using individual electrodes and caps, and the wording of the question on comfort was expanded to include an additional piece of hardware, making it incomparable to the first two labs. The increase in reported level of understanding on the pre-lab survey and the post-lab survey was found to be significantly above zero using a paired samples *t*-test ($t[13]=3.045$, $p=0.009$). Even though the reported level of comfort on the pre- and post-lab surveys was not significantly different ($t[13]=1.031$, $p=0.321$), the student-reported impact on comfort levels of 2.64 ($SD=1.69$) did show a significant difference from a neutral score of 0 according to a one-sample *t*-test ($t[13]=5.845$, $p<0.001$). Data on student reports of the impact of any particular lab on understanding and comfort are qualitatively similar to the differences in reported levels within labs for all other items and therefore are not reported here.

Measure	Method	*N*	*M*	*SD*
Pre-First Lab Understanding	Electrodes	7	7.00	1.91
	Caps	8	6.00	1.51
Post-First Lab Understanding	Electrodes	7	8.71	0.95
	Caps	8	7.25	1.91
Pre-Second Lab Understanding	Electrodes	8	7.38	1.06
	Caps	7	7.86	1.68
Post-Second Lab Understanding	Electrodes	8	8.00	0.76
	Caps	7	8.86	1.07
Pre-Third Lab Understanding	Electrodes	13	7.15	1.95
	Caps	2	9.00	0.00
Post-Third Lab Understanding	Electrodes	12	8.25	1.22
	Caps	2	9.00	0.00

Table 2. Laboratory student levels of understanding. No measures show a significant difference between individual electrodes and caps.

Measure	Method	*N*	*M*	*SD*
Pre-First Lab Comfort	Electrodes	7	1.14	1.77
	Caps	8	1.25	2.19
Post-First Lab Comfort	Electrodes	7	3.57	0.98
	Caps	8	3.13	1.55
Pre-Second Lab Comfort	Electrodes	8	2.50	1.07
	Caps	7	2.00	1.53
Post-Second Lab Comfort	Electrodes	8	3.00	0.76
	Caps	7	3.14	1.57
Pre-Third Lab Comfort	Electrodes	13	2.31	1.89
	Caps	2	1.50	0.71
Post-Third Lab Comfort	Electrodes	12	2.58	1.62
	Caps	2	2.50	1.62

Table 3. Laboratory student levels of comfort. No measures show a significant difference between individual electrodes and caps.

Student researcher perspective: Average scores are reported in Table 4. All five student researchers chose caps on a discriminate choice question. Researcher responses to more specific questions were compared across methods. A significant difference was found between the ratings of ease of setup ($t[4]=2.804$, $p=0.049$). Researchers felt that caps were easier to set up than individual electrodes. The difference in average reaction score was marginally significant ($t[4]=-2.657$, $p=0.057$; Figure 1b), with the rating of caps being higher than the rating of individual electrodes. Ratings of comfort for participants, ease of cleanup, and professionality were not significantly different (all *p*'s>0.2).

Consistencies in responses were examined for each method, and variability across researchers was the norm. Only the professionality of the caps was rated on the same side of neutral for all researchers. Amount of prior experience possibly influenced the ratings of two measures: ease of setup, where the less experienced researchers rated both methods as easier (potentially because they were not solely responsible for verifying that the setup was completed successfully), and professionality of individual electrodes, where the less experienced researchers rated the measure as professional but the more experienced researchers rated it as unprofessional.

Measure	Method	*N*	*M*	*SD*
Comfort for Participants	Electrodes	5	0.40	3.13
	Caps	5	1.20	3.42
Ease of Setup*	Electrodes	5	-0.80	3.03
	Caps	5	1.80	2.59
Ease of Cleanup	Electrodes	5	1.20	3.90
	Caps	5	1.60	1.82
Professionality	Electrodes	5	0.20	3.11
	Caps	5	2.40	1.95
Average Researcher Ratings	Electrodes	5	0.25	2.57
	Caps	5	1.75	1.93

Table 4. Student researcher responses. Measures for which there is a significant difference ($p<0.05$) between individual electrodes and caps are marked with an asterisk.

Research participant perspective: Average scores are reported in Table 5. A paired samples *t*-test showed no significant difference in research participants' average ratings of individual electrodes and caps ($t[19]=-1.300$, $p=0.209$; Figure 1c). However, participant ratings of comfort during cleanup were significantly higher for caps than for individual electrodes ($t[19]=-2.208$, $p=0.040$). Ratings of comfort during setup, comfort during procedure, difficulty removed from the task by the equipment, and professionality of setup were not significantly different (all *p*'s>0.49).

In order to test for an effect of order of exposure, an independent samples *t*-test was used to compare all ratings of both methods across the order condition to which participants were randomly assigned. Six measures displayed significant between-subjects differences: average rating of individual electrodes ($t[18]=2.813$, $p=0.012$; Figure 1c), average rating of electrode caps ($t[13.370]=2.912$, $p=0.012$; Figure 1c), comfort of individual electrodes during procedure ($t[13.275]=3.025$, $p=0.010$), comfort of caps during procedure ($t[10.907)]=3.111$, $p=0.010$), comfort of individual electrodes during cleanup ($t[15.416]=2.748$, $p=0.015$), and professionality of caps ($t[18]=2.316$, $p=0.033$). In each of these six cases, the means for participants who completed the task with the individual electrode method first were higher than the means for participants who completed the task with the cap method first. A Repeated Measures MANOVA was used to test for within-subjects contrasts, but there was no significant interaction between the within-subjects factor of method and the between-subjects factor of order of exposure ($F[5,14)]=0.731$, $p=0.612$). This means that it is not possible to tell whether it is the method used first or second that drives the effect.

Measure	Method	*N*	*M*	*SD*
Comfort During Setup	Electrodes	20	3.05	2.26
	Caps	20	2.85	2.35
Comfort During Procedure	Electrodes	20	3.10	1.94
	Caps	20	3.20	1.74
Comfort During Cleanup*	Electrodes	20	2.75	2.36
	Caps	20	3.45	1.85
Difficulty Removed by Method	Electrodes	20	0.30	1.89
	Caps	20	0.45	1.76
Professionality of Method	Electrodes	20	3.60	1.57
	Caps	20	3.55	1.82
Average Participant Ratings	Electrodes	20	2.56	1.56
	Caps	20	2.70	1.34

Table 5. Research participant responses. Measures for which there is a significant difference ($p<0.05$) between individual electrodes and caps are marked with an asterisk.

DISCUSSION

Responses of students in the laboratory course indicated a preference for individual electrodes, suggesting that this equipment is perhaps not only sufficient for an introductory neuroscience lab course setting but also preferable. Regardless of method used, the data gathered in the laboratory course met the assignment goals, and the observed increases in knowledge and comfort on the pre- and post-lab surveys met the learning objectives. Responses of student researchers – and research participants to an extent – suggest an overall preference for caps, but the difference was not strong enough for a definite recommendation to be made about which setup is more preferential to use in undergraduate research settings. Therefore, the logical conclusion seems to be that although the use of caps has certain benefits over the use of individual electrodes, it is not necessary for undergraduate programs to invest their resources in caps, especially if their financial resources are highly limited.

As one PSYC/NEUR 330 student pointed out, caps would be particularly beneficial if the input of many electrodes was needed, but individual electrodes would perhaps be more ideal if only a single recording channel was needed. All in all, the decision to invest in electrode cap equipment must take into account the relative advantages and disadvantages of each method as well as a particular program's resources and needs. The learning objectives and research goals at hand are particularly important considerations. Programs focusing on introductory level experience with various types of neuroscience research or with clinical EEG methods may wish to focus on using individual electrodes, whereas programs focusing on typical research EEG methods may find the caps helpful and possibly necessary since they are more commonly used in EEG research.

An additional consideration in deciding which equipment to use for undergraduate research is that the purchase of an impedance meter, which Roanoke College does not currently have, could influence the publishability of student research. Picton et al. (2000) list the reporting of interelectrode impedance as one of the criteria for publishing ERP data as it indicates sufficient signal quality of each electrode within a cap. The lead shielded wires used for the individual electrode method have different connection structures, making them incompatible with standard impedance meters, but the output wires for the electrodes in the caps are compatible with standard impedance meters. A meter would allow students to both measure impedances and bypass individual electrodes with poor connections if necessary. Though these meters strengthen results, they cost an additional $500-700.

It is important to note that this study did have limitations that may have impacted the results. For one, the inherent structure of the labs may have affected how the students thought about the equipment. Students were given protocols to follow for each of the three labs in question, but educational research has touted the benefits of laboratory courses that focus on firsthand, authentic research experience instead and allow students to investigate questions of their choosing (e.g., Adams, 2009; Brownell et al., 2012; Kloser et al., 2013). For courses that use this kind of approach, students may develop a different perspective on the equipment and have opinions more closely mirroring those of the student researchers surveyed in this study.

Laboratory student responses were also potentially affected by the nature of the laboratory exercises as they were originally written for the individual electrode setup, which may have caused confusion and difficulty with discrepancies between the originally intended procedure and that necessary for the cap setup. This was primarily a possibility in the first lab where the known instrument problems had to be adjusted and the third lab where the observed ERP changed sign due to differences in electrode placement. However, the learning objective data showed no detrimental effects.

Additionally, the individual electrode setup used similar equipment to that of the electromyography (EMG) and human conduction velocity lab, which occurred earlier in the semester than the three EEG labs. As such, students would already have a degree of comfort with the individual electrode setup and would potentially have been intimidated by the new cap setup.

The students, furthermore, had to clean the caps themselves using Ivory soap and water, which required them to wait for the caps to soak. When students are generally looking to get out of lab as quickly as possible, anything that adds to the amount of time they have to spend in lab is likely to negatively influence their opinion. Even so, the labs were still able to be completed during the regularly scheduled lab period, and students did not report any clear differences between methods nor major frustrations regarding cleanup of either method.

Research participant survey responses indicated that the order of their exposure to the methods influenced participant ratings. Surveys were given to participants after they had experienced both the individual electrodes and the caps to allow them to make a distinction between the methods. This means, however, that the trial completed first or immediately before the survey was administered could have driven response differences. The present data is unable to differentiate these options and future data collection with surveys completed after each method would be necessary to establish the cause.

In the future at Roanoke College, we plan to introduce students in PSYC/NEUR 330 to EEG through the individual electrode method since it is more comparable to prior setups they will have used in previous labs. They will be introduced to caps later in the semester when more electrodes are needed so that they will be able to gain experience with this method as well. Student researchers conducting independent projects will likely be encouraged to use caps in order to record from multiple channels as this is common practice in EEG research.

Future studies could attempt to further discern the influences on preference. Interviewing subjects about their experiences with different equipment setups may be a good way to uncover other factors that impacted opinions. Other studies have used open-ended questions when surveying students about their experiences in a course (e.g., Brownell et al., 2013). Also, it could be beneficial to force study participants to make discriminate choices between methods, which was not done in the participant reaction portion of this study, perhaps with an additional option of neutral, to gain more clarity about the existence of an overall preference.

Supplementary Materials

All surveys and representative data collected during the EEG labs are available on the *JUNE* website as Supplementary Materials along with this article. The instruction and assignment materials used in the EEG labs can be found under Supplementary Materials at the last author's faculty web page:

http://www.roanoke.edu/inside/a-z_index/psychology/research_and_internships/undergraduate_research/dr_nichols_research_lab/supplementary_materials.

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