ARTICLE
The Cognitive Neuroscience of Sign Language: Engaging Undergraduate Students' Critical Thinking Skills Using the Primary Literature

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This article presents a modular activity on the neurobiology of sign language that engages undergraduate students in reading and analyzing the primary functional magnetic resonance imaging (fMRI) literature. Drawing on a seed empirical article and subsequently published critique and rebuttal, students are introduced to a scientific debate concerning the functional significance of *right-hemisphere recruitment* observed in some fMRI studies of sign language processing. The activity requires minimal background knowledge and is not designed to provide students with a specific conclusion regarding the debate. Instead, the activity and set of articles allow students to consider key issues in experimental design and analysis of the primary literature, including critical thinking regarding the cognitive subtractions used in blocked-design fMRI studies, as well as possible confounds in comparing results across different experimental tasks. By presenting articles representing different perspectives, each cogently argued by leading scientists, the readings and activity also model the type of debate and dialogue critical to science, but often invisible to undergraduate science students. Student self-report data indicate that undergraduates find the readings interesting and that the activity enhances their ability to read and interpret primary fMRI articles, including evaluating research design and considering alternate explanations of study results. As a stand-alone activity completed primarily in one 60-minute class block, the activity can be easily incorporated into existing courses, providing students with an introduction both to the analysis of empirical fMRI articles and to the role of debate and critique in the field of neuroscience.

Key words: teaching, critical thinking, primary literature, cognitive neuroscience, sign language, fMRI, undergraduates

Undergraduate science courses often face a tension between the coverage of *scientific content* versus *scientific process skills* (American Association for the Advancement of Science, 2009; Coil et al., 2010; Osborne, 2010). Whereas content learning relates primarily to the key findings, theories, and models in a scientific discipline, process skills encompass the range of skills needed to *do* science, including but not limited to interpreting data, designing experiments, and engaging in evidence-based argumentation and critique (Coil et al., 2010; Osborne, 2010; Association of American Medical Colleges, 2012). Although content and skill learning are invariably intertwined, there is a recognized need to incorporate stronger training of process skills into science education (American Association for the Advancement of Science, 2009; Coil et al., 2010; Osborne, 2010).

One way to develop students' scientific process skills is to incorporate focused activities and discussion based on empirical, primary articles (e.g., Muench, 2000; Hoskins et al., 2007; Hoskins, 2008; Hoskins et al., 2011; Willard and Brasier, 2014). For students, engaging the primary literature can be markedly different from reading sets of "facts" in a textbook. Reading in the primary literature typically requires a number of process skills, such as interpreting data and graphs, critiquing experimental design, and proposing alternative interpretations or future studies. Reading the primary literature can be particularly beneficial when it allows students to engage a controversy or paradigm shift in the field, modeling the thought process and dialogue inherent to science (e.g., Hoskins, 2008). Indeed, a recent survey indicated that, among undergraduate neuroscience faculty, the most important core competency for undergraduate neuroscience programs is critical and integrative thinking (ahead of basic neuroscience knowledge), with the ability to read and analyze a primary research paper the most essential element of critical and integrative thinking (Kerchner et al., 2012).

An emerging literature provides general suggestions for faculty members wishing to incorporate the primary literature into undergraduate science courses (e.g., Janick-Buckner, 1997; Muench, 2000; Hoskins et al., 2007; Hoskins, 2008; Hoskins et al., 2011). Articles, for example, should be carefully selected so they are appropriate not only to course content, but also to students' existing content knowledge, which may be limited. In some cases, sets of articles can be selected that either represent a series of sequential experiments from within the same laboratory group, or different perspectives on a scientific controversy. Scaffolding is also suggested, where focused activities or questions allow students to practice specific scientific process skills such as interpreting the data, graphs, and figures from a research paper or proposing possible follow-up experiments. Similarly, specific questions or activities can be included that require students to demonstrate an understanding of the experimental methods and how different patterns of results would relate to specific hypotheses.

In addition to these general suggestions, more specific guidance has been provided for a small subset of neuroscience-related courses. For example, sets of readings or specific course structures have been identified for advanced courses in cellular biology (Janick-Buckner, 1997) and developmental neurobiology (Hoskins et al., 2007; Hoskins, 2008; Hoskins et al., 2011; note these activities have also been used in general biology courses). Another recent paper has described how primary readings regarding two key controversies were used in a freshmen seminar introducing students to neuroscience (Willard and Brasier, 2014). These examples provide a valuable resource for faculty teaching similar courses and wishing to incorporate the primary literature, as article selection and/or scaffolding activities are included as part of the documentation. However, similar resources are not available for the range of courses in the neuroscience curriculum, leaving the challenge of article selection and scaffolding activities to individual instructors. As well, many of the specific examples published to date involve complete redesign of courses to focus exclusively on reading in the primary literature (e.g., Janick-Buckner, 1997; Willard and Brasier, 2014). As such, there remain few concrete examples of modular activities using the primary literature that can be incorporated into existing neuroscience courses. However, modular activities may be particularly valuable to faculty, who report that some of the largest challenges to teaching scientific process skills are the time-consuming nature of teaching those skills and the need for students to have adequate content knowledge to make engaging in process skills possible (Coil et al., 2010).

The goal of the present paper is to describe a stand-alone, primary literature-based activity that can be easily incorporated into existing cognitive neuroscience courses. The activity focuses on the neurobiology of sign language processing. This topic is less commonly covered in cognitive neuroscience textbooks (e.g., see Gazzaniga et al., 2009; Ward, 2010) but provides a natural complement to typical course units on spoken language processing. Traditional coverage of the neurobiology of *spoken* language often emphasizes the prominent role of the left-hemisphere in language processing, as well as distinctions among subsystems within language, such as production versus comprehension or syntax versus semantics. However, within the literature on sign language processing, one area of debate concerns the extent and functional significance of *right-hemisphere recruitment* observed in some fMRI studies of sign language processing. Importantly, there is not an agreed upon answer to this question (e.g., for different perspectives and data on this issue, see Newman et al., 2002; MacSweeney et al., 2002; Emmorey et al., 2005; Capek et al., 2009; MacSweeney et al., 2009; Malaia and Wilbur, 2010). Thus, the activity described below is not designed to provide students with a specific conclusion regarding the debate. Instead, the set of articles provide a rich opportunity for students to consider key issues in experimental design and interpretation of the primary literature using functional magnetic resonance imaging (fMRI), one of the neuroimaging methods commonly encountered in the primary literature in cognitive neuroscience.

Specifically, the readings and activity described here engage students in critical thinking regarding the cognitive subtractions used in blocked-design fMRI studies, as well as possible confounds in comparing results across different experimental tasks. As such, instructors implementing the activity should be familiar with fMRI methodology, including boxcar diagrams and the logic of cognitive subtractions, particularly with regard to the selection of baseline tasks and the challenges of isolating a cognitive process of interest. The readings and activity also allow students to consider general experimental design issues related to heterogeneity of participant characteristics, and the need for multiple experiments to rule out alternative explanations. By presenting articles representing different perspectives, each cogently argued by leading scientists and published in peer-reviewed venues, the readings and activity also model the type of debate and dialogue critical to science, but often invisible to undergraduate science students.

MATERIALS AND METHODS

Materials

The activity uses a set of three articles: a seed empirical primary research study (Neville et al., 1998), followed by a subsequent critique of the study (Hickok et al., 1998) and rebuttal from the original authors (Corina et al., 1998). This set of articles thus allows students to engage in a debate in the field, including critical analysis and discussion of study design and proposal of possible follow-up studies. The articles also explicitly expose students to the conflict and controversy inherent to scientific findings. Below, an overview of each article is provided, before describing the classroom activity.

The first article, *“Cerebral organization for language in deaf and hearing subjects: Biological constraints and effects of experience”* (Neville et al., 1998), is a brief, eight-page empirical fMRI study that examines whether processing of sign language by native, fluent signers recruits a similar, left-lateralized network of brain areas typically associated with spoken language processing. The study includes two separate fMRI tasks designed to isolate English and ASL processing, respectively. The English language task includes alternating blocks of trials in which participants view either declarative sentences presented one word at a time or consonant strings presented one string at a time. The subtraction of neural activity elicited during the consonant strings condition from the declarative sentences condition is used to isolate processing associated with English. The ASL task includes alternating blocks of trials in which participants view a video of a signer producing either sentences in ASL or non-sign gestures that are physically similar to ASL signs. The subtraction of neural activity elicited during the non-sign gesture condition from the ASL sentences condition is used to isolate processing associated with ASL. Critical to both the English and ASL subtractions is the assumption that, to the extent that an individual is naïve either to written English or to ASL, the subtraction should yield no distinct neural activity, as the subtractions are designed to remove activity associated with general visual processing, etc common to both conditions. However, any unique activity that remains following subtraction will isolate processing specific to the linguistic nature of either the English or ASL stimuli.

The seed article includes three different participant groups: (1) hearing, monolingual native English speakers unfamiliar with a sign language, (2) congenitally deaf native signers of ASL, who also learned English late, and (3) hearing, bilingual native English speakers, born to deaf parents, who also learned ASL as a native language. All three groups complete both the English and ASL fMRI task. The primary finding indicates that a similar set of left-hemisphere regions associated with language processing (e.g., Broca's and Wernicke's area, and other left-hemisphere regions) are recruited both when native English speakers process English or when native signers process ASL, suggesting that these regions are "amodal" for language, and recruited even for visual-gestural signed language. However, a second key finding indicates that native signers, whether deaf or hearing, additionally recruit an extensive network of right hemisphere regions during sign language processing. The authors interpret this second finding to indicate that sign language has unique characteristics that place functional demands on the right hemisphere, possibly attributable to the use of spatial syntax in sign language (i.e., the placement of signs in visual space to communicate syntactic relations).

The second article, *"What's right about the neural organization of sign language? A perspective on recent neuroimaging results"* (Hickok et al., 1998), is a four-page critique of the seed article. The critique takes issue with the unique right hemisphere recruitment observed during ASL processing. Specifically, the critique raises concerns about the subtraction used to isolate English language processing. The authors argue that English processing should not be isolated using visually presented words, but rather with audio-visual talking heads. The authors argue that the use of printed English presents a critical confound in the comparison of "ASL" and "English," with any unique activity in response to ASL possibly attributable to 'extra-grammatical' information, such as prosody, facial expressions, and nonlinguistic visual features which are also present in audio-visual spoken language but absent in printed English. The authors argue that a more appropriate method of isolating English language processing would be to use audio-visual talking heads, which would be more similar to real-life language processing and likely to engage right-hemisphere regions. To further support their argument that the right hemisphere is not functionally significant to sign language processing, the authors present data showing that left-hemisphere lesions in signers are more likely to lead to sign language aphasia than right hemisphere lesions. The authors argue that the lesion data further support their contention that the right hemisphere activity reported in the original article may not be critical for sign language processing per se, but rather an artifact of processing extra-linguistic features available in the signing stimuli, but absent from printed English. The article thus claims that the similarities in left-hemisphere recruitment is the most interesting finding in the paper, and that there is not compelling evidence that the right-hemisphere recruitment for ASL is unique to signed languages or critical for ASL processing.

The third and final article, *"Response from Corina, Neville, and Bavelier"* (Corina et al., 1998), written by the authors of the seed article, provides a rebuttal to the criticisms raised. The rebuttal acknowledges that spoken language processing may indeed recruit right-hemisphere regions more than printed English processing, but the authors argue that the right hemisphere recruitment for spoken English is never as spatially extensive or statistically robust as apparent with ASL. The rebuttal also defends the use of written English in the study, arguing that it was not a control condition per se, but rather provided a *within-modality* comparison between English and ASL. Had the authors used audio-visual talking heads, there would have been a different set of confounds created by the auditory stimulation present in the English condition but absent in the ASL condition. The authors further argue that activity in the ASL subtraction cannot be explained by facial expressions and non-linguistic gesture, as the non-sign subtraction included similar features and such activity would therefore be removed in the cognitive subtraction. Finally, the authors note that discrepancies between fMRI and lesion studies may reflect the aspects of language assessed in each type of study. The authors argue that tests of language processing used in lesion studies generally emphasize production, and thus may miss important deficits in comprehension, particularly for spatial syntax, whereas the fMRI tasks are based solely on language comprehension. Additionally, lesion studies generally include individuals with different etiologies of deafness and experience with signed languages, including age of acquisition of sign language. Heterogeneity in the participant population included in lesion studies may make it more difficult to identify the neural regions important to signed language when learned natively and fluently.

Methods

The main activity required approximately 60 minutes of class time, with an additional 10-15 minutes used in the class period prior to and following the discussion for class preparation and final debrief.

In the class period prior to the discussion, the instructor led a short pre-discussion of sign language. Based on their knowledge of sign language and/or short video clips of ASL played from youtube (https://www.youtube.com/), students identified similarities and differences between signed and spoken language. This pre-discussion was used to introduce the question of whether the neural systems recruited during signed language would be similar to or different from those identified as "classical language areas" (e.g., Broca's and Wernicke's area of the left hemisphere). Students were then divided into three groups, with each group assigned to one of the different participant populations studied in the seed article (e.g., hearing monolingual English speakers). Students completed a pre-discussion handout as homework, answering the questions with respect to their group's assigned participant population. The handout included four questions, focused on ensuring students understood the basic logic, methods, and findings from the study:

1. What are the basic characteristics of your participant group (number, age, hearing status, language status, and proficiency)? What was the purpose of including this group in the study?
2. Draw a boxcar diagram representing the fMRI experimental design used to isolate (a) "English" and (b) "ASL." What was participants' task?
3. What brain regions were recruited in this participant group for (a) "English" and (b) "ASL"? [it's ok just to give the big picture findings – you don't have to list everything!]
4. What is the relevance or significance of these activations (i.e., what is *most* important about the pattern of results in the question above with respect to big picture questions about the signing brain)?

Students were also asked to read the critique of the article in preparation for class discussion. (Note: The activity could be modified to divide the discussion across two smaller activities in subsequent class periods, in which case the critique of the article would be discussed in a later class period. This modification would allow students to come up with their own critiques of the seed article before reading the critique by Hickok and colleagues.)

In the next class period, approximately 60 minutes were devoted to the article discussion. Students were divided back into their three groups, with one group for each of the three participant groups represented in the study. Approximately 10 minutes were provided for students to recap the basic methods and fMRI contrasts used and resolve any discrepancies across group member answers. As students discussed the article, the instructor drew a large 2 x 3 grid on the whiteboard, with rows representing Task ("English" vs. "ASL") and columns representing Participant Group ("Hearing-NonSigner" vs. "Hearing-Signer" vs. "Deaf-Signer"). In each cell, schematic outlines of the left and right hemisphere were drawn. The instructor asked each group to fill in simple focal points of brain activity representing the key areas responding to each subtraction for their respective participant group. This encouraged students to abstract away from the extreme detail of the article to highlight, visually, the key findings of the paper. It also involved extraction and recoding of information from Figure 1 and Figure 2 of the seed article. An example of what a completed grid might look like is provided in Appendix I. As shown in the example final grid, this extraction makes visually clear that robust left-hemisphere recruitment is observed whenever a group processes their native language. In contrast, right hemisphere recruitment is observed during ASL processing in native signers of ASL (whether deaf or hearing) as well as in deaf signers processing written English.

A whole-class discussion followed, in which the class was asked to consider the full pattern of data on the board. Each group briefly presented the main results for their participant group. The class was then asked to identify the key findings from the paper. The instructor ensured that students identified the unique recruitment of right-hemisphere regions for native ASL signers processing ASL, as well as the common recruitment of left-hemisphere regions whenever a group processed their native language (English or ASL). Some students also observed the smaller right-hemisphere activity in the "English" contrast by the deaf native signers. This provided opportunity for brief discussion of the effects of late and imperfect learning of English by deaf signers, who do not have access to a spoken language. If raised, the instructor could include mention of the robust literature showing that deaf signers often have lower English reading ability (Conrad, 1979; Marschark and Harris, 1995; Dyer et al., 2003), with other literatures showing that increased reading ability is associated with a shift toward increasing left-lateralization during reading (Turkeltaub et al., 2003; Yamada et al., 2011). The instructor ended this portion of the discussion by focusing students on the right-hemisphere activity observed during sign language processing which was the key finding that became very controversial in the field, leading to an academic debate with a published critique of the article.

Next, students returned to their small groups to discuss the Hickok et al. critique and generate possible follow-up experiments. Groups were asked to address the following questions:

1. What are the primary claims and arguments in the critique? What challenges are raised to the experimental design or findings in the Neville reading?
2. Of the criticisms raised, which do you find most compelling and why?
3. Based on the critiques – or additional criticisms you might raise – what follow up study would you like to see conducted? What information would you hope to gain from the follow up study?

Following small group discussion, the entire class convened to discuss these issues. Student discussion focused on different possible comparisons to ASL, including the benefits and drawbacks of using printed English (which includes no auditory component, similar to ASL) versus audio-visual talking heads (which includes facial expression and prosody, similar to ASL). Students were encouraged to clearly describe possible follow up experiments. For example, if students proposed an fMRI study using audio-visual talking heads, they also needed to identify a possible baseline condition for the cognitive subtraction. For the next class period, students were asked to read the rebuttal from the original study authors, paying attention to which responses or new pieces of evidence they found most compelling.

The next class period, approximately 15 minutes were devoted to final discussion of the rebuttal and set of articles as a whole. The instructor led the class in a group discussion of the main points raised in the rebuttal. The instructor also revisited some of the experimental designs proposed by students in the previous class period, asking whether any changes might be warranted. The discussion ended with a consideration of production versus comprehension as different components of language processing. Depending upon student interest, the discussion could also include possible modifications to evaluations for language aphasia, and the importance of participant characteristics in studies of sign language processing. This latter issue can also be applied to future studies discussed in class or read in the literature. This encourages students to attend to possible confounds in a study, or reasons for discrepant findings across studies.

The author has used variations of the activity seven times in mid-level psychology courses in Cognitive Neuroscience (the only pre-requisite for the course is Introductory Psychology), as well as in courses on Language and Literacy Acquisition. The activity described can be used completely stand-alone or, at instructor's discretion, additional related articles could be assigned or presented in future class periods (e.g., Newman et al., 2002; MacSweeney et al., 2002; Emmorey et al., 2005; Capek et al., 2009; MacSweeney et al., 2009; Malaia and Wilbur, 2010). These studies generally provide some, but not all, of the data students hope to see (e.g., comparisons of neural activity to signed language versus audio-visual talking heads, and effects of age of acquisition on neural systems recruited during sign language processing.)

To assess student perceptions of the activity, a section of students who completed the activity as part of a Cognitive Neuroscience course were invited to complete an optional, supplemental evaluation of the activity at the end of the course. The course enrolled 23 students, 74% of whom were in their junior or senior years. The survey was anonymous and included six questions about the activity (see Table 1), using a scale ranging from 1 (strongly disagree) to 5 (strongly agree). All but one student (96%) completed the optional survey.

RESULTS

Table 1 presents the mean and standard deviation for student responses to each survey item, as well as the percent of students who "agreed" or "strongly agreed" with each item. As indicated, student feedback was positive for all items, with means above 4.0 ("agree") for all questions. 95% of students "agreed" or "strongly agreed" that the set of articles was interesting (M= 4.27, SD=0.54), with a similarly high 91% of students recommending including the readings in future classes (M= 4.32, SD = 0.63). Several questions were used to identify whether students felt the activity as a whole improved their ability read empirical fMRI articles. These items indicated that students felt the assignment helped them to *read and understand* the methods and results sections of empirical fMRI studies (M = 4.27, SD = 0.62). Students also indicated that the activity helped them to *critically evaluate the design* of an fMRI study, including consideration of different control conditions included (M= 4.32, SD = 0.70) and to *consider alternate explanations* of study results (M = 4.45, SD = 0.66). Students reported that after completing the assignment, they felt *better prepared* to read empirical articles using the fMRI technique (M= 4.32, SD = 0.72).

DISCUSSION

The activity described here provides a means for faculty teaching courses in cognitive neuroscience to engage students in reading the primary fMRI literature. Students reported finding the set of articles interesting, and that the activity improved their ability to read and understand empirical fMRI studies. The activity specifically improved students' self-perceptions of their ability to engage in critical analysis including evaluating the experimental design (e.g., considering different possible control conditions) and considering alternate explanations of study results. As a stand-alone activity primarily completed in one 60 minute class block, the activity can be easily incorporated into existing courses, providing students with a guided introduction both to reading empirical fMRI articles and to the role of debate and critique in the field of neuroscience.

The activity addresses a key concept in cognitive neuroscience courses: the design and interpretation of fMRI studies. By highlighting the key role of cognitive subtractions, the assignment specifically engages students in thinking critically about what cognitive processes are isolated in a given subtraction. The activity provides a structured introduction to reading and analyzing fMRI studies, which can be valuable in preparing students to read independently in the cognitive neuroscience literature

Question prompt	*Mean (SD)*	*% Responses 4 or 5*
I found the set of articles interesting.	*4.27 (0.54)*	*95%*
The assignment helped me to *read and understand* the methods and results section of an empirical fMRI article.	*4.27 (0.62)*	*95%*
The assignment helped me to *critically evaluate the design* of an fMRI study (e.g., considering different control conditions included).	*4.32 (0.70)*	*86%*
The assignment helped me to *consider alternate explanations* of study results.	*4.45 (0.66)*	*91%*
After completing this assignment, I felt *better prepared* to read empirical articles using the fMRI technique.	*4.18 (0.72)*	*86%*
I would recommend including these readings in future classes.	*4.32 (0.63)*	*91%*

Table 1. Text of anonymous supplemental evaluation form provided to students, with mean and standard deviation (SD) for each item provided. Responses were given on a scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree), with a neutral midpoint of 3.

as part of term papers or other course projects. More generally, the activity can expand coverage in units on the neurobiology of language processing to include discussion of manual-gestural languages, which are often omitted or covered only very briefly in cognitive neuroscience textbooks (e.g., see Gazzaniga et al., 2009; Ward, 2010).

Three features of the set of articles used in the activity are particularly noteworthy. First, the articles address a topic that requires minimal background knowledge on the part of students. While students may have more extensive background on the neurobiology of language, the only critical background is an appreciation for the dominant role of the left hemisphere for spoken language processing. Even brief discussions of Broca's and Wernicke's aphasia can establish the role of the left hemisphere, as well as foreshadow possible distinctions between comprehension and production. Second, the articles themselves are very short and readable. This can be a challenge in cognitive neuroscience, where technical language or fine theoretical distinctions can render the primary literature less accessible to students early in their training. This set of articles addresses a larger-scale question (the contribution of an entire hemisphere to language processing), and all of the authors write clearly and concisely. Finally, the articles present competing views that specifically address experimental design issues and interpretation. In cognitive neuroscience, one challenge for students is the critical analysis of the cognitive subtraction used and identifying what specific cognitive processes the subtraction can isolate. Thus, the articles reflect a consideration of key components identified as important for the selection of empirical readings in science-based courses (Muench, 2000).

This activity can be situated in the larger context of efforts to engage undergraduate science students in reading the primary literature. For example, the activity shares elements of the C.R.E.A.T.E. method pioneered by Sally Hoskins and used in undergraduate developmental neurobiology and introductory biology courses (Hoskins et al., 2007; Hoskins, 2008; Hoskins et al., 2011). Under the C.R.E.A.T.E. method, students consider the concepts and issues from the paper introduction, read the article with annotation of figures and transformation of data into different formats (graphs or charts), elucidate hypotheses (relate each figure to a hypothesis), analyze and interpret the data (relying on analysis and annotation of figures and tables from the text), and finally think of the next experiment that might be conducted. The present activity, though not formally within the C.R.E.A.T.E. framework, emphasizes analysis and interpretation of data, including linking findings from the figures to different conclusions. The present activity also engages students in thinking about the next experiment, with scaffolding that prepares students for considering the pros and cons of different cognitive subtractions, which is particularly critical to cognitive neuroscience experimental design. Other efforts at engaging undergraduate students in reading the primary literature emphasize introducing students to debates within the field, where students can read different perspectives on a scientific controversy (Janick-Buckner, 1997; Willard and Brasier, 2014). Thus, both this activity and others that are focused on the reading of empirical articles emphasize the iterative process of science and role of not only of current experiments, but future experiments, to advance our understanding.

By reading different perspectives on a scientific controversy, the activity also provides students the opportunity to experience argumentation and debate as a key part of the scientific enterprise. The importance of argument and debate in science is widely acknowledged, as is its relative under-emphasis in science courses (Osborne, 2010). Noting the importance of critique and debate in science, a recent review article argued "Critique is not, therefore, some peripheral feature of science, but rather it is core to its practice, and without argument and evaluation, the construction of reliable knowledge would be impossible" (Osborne, 2010 p. 464). The present activity engages students in considering "how we know" what neural systems are recruited by sign language processing, with implications for conclusions about the similarities and differences between signed and spoken language processing. Rather than presenting students with "facts" about sign language processing, the activity emphasizes analysis of the methodology and the validity of particular contrasts and comparisons. The activity also explicitly models for students how scientists both critique one another and must respond to criticism and questions. Rather than identifying the "correct" answer, students are encouraged to consider the role of future research in helping to adjudicate different possibilities as well as appreciate the nuances of relative contributions of particular brain regions, moving beyond an all-or-nothing binary classification of neural regions as involved or uninvolved in a particular cognitive process. Encouraging this type of skeptical, critical evaluation of neuroscience findings may be particularly important given the evidence that the mere presence of neuroimaging information or figures with brain scans can influence the evaluation of associated scientific reasoning (e.g., see McCabe and Castel, 2008; Weisberg et al., 2008). Rather than turning off critical thinking when encountering neuroscience evidence or images, students need to be empowered to *engage* critical thinking and evaluation skills in these contexts.

The activity described here can be imported directly as a stand-alone activity in existing cognitive neuroscience courses. The activity can also be used as a framework for selecting articles to incorporate primary readings into undergraduate neuroscience classes. Indeed, future research should identify other current controversies and relevant, readable empirical articles for inclusion in existing neuroscience courses. A recent textbook for cognitive neuroscience highlights several debates in cognitive neuroscience (Slotnick, 2012) and could be used by instructors wishing to incorporate key controversies in the field as a more central focus in the course (the sign language right-hemisphere debate is not included in this book). Future research should also include direct assessments of student gains using aligned questions to assess not only student self-perceptions, but also student performance following inclusion of the activity. Direct assessments will be important for assessing the degree to which student performance achieves key learning objectives for neuroscience programs, including critical thinking and the ability to read and analyze empirical articles (Coil et al., 2010; Kerchner et al., 2012).

By incorporating primary articles and active debate and discussion into science courses, undergraduate students can experience the dialogue of science and develop key science process skills. The activity and set of articles described here provide one means for faculty wishing to incorporate primary readings into cognitive neuroscience courses to do as a modular component of existing courses.

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Note: See Appendix I on page A73.

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Appendix I

Example completed grid described in primary article. The data transformation can be used to reinforce the robust left-hemisphere recruitment observed whenever a group processes their native language. In contrast, right hemisphere recruitment is observed in native signers of ASL (whether deaf or hearing) as well as in deaf signers processing written English. The absence of any activity for ASL in the Hearing-Nonsigner group can further support discussions of cognitive subtractions, with the absence of activity not indicating an absence of brain activity, but rather an absence of *differential brain activity* between the (unfamiliar) ASL signs and the (equally unfamiliar) non-sign baseline task.