CS/NEUR125 Brains, Minds, and Machines

Assignment 4: Brain Modules for Language

Due: Friday, March 24

This Assignment is a guided reading of the 2011 paper, Functional specificity for high-level linguistic processing in the human brain, by Fedorenko, Behr, and Kanwisher, together with a brief 2012 update entitled, Language-selective and domain-general regions lie side by side within Broca's Area. Reading these articles will prepare us to discuss this work during our fourth Journal Club in class on Tuesday, April 4.

To begin, create a copy of this Google document and modify the title of the copy to include your name. Questions that you should submit answers to are shown in blue. A few questions are shown in purple font, to indicate that they are optional. As with labs, you'll turn in this Assignment by sharing your copy of this Google document with Ellen and Mike.

These papers by Fedorenko et al. are again primary research articles. Similar to other primary research literature, the authors are likely to assume knowledge in the reader, or leave out details that are familiar to experts. We'll try to fill in some of the assumed knowledge with this document, but we again have to accept that we won't be able to digest and understand every line in this technical paper. Our goal is not to understand every line, but to explore the methods and reasoning by which the authors attempt to clarify the functional role of brain areas previously implicated in language processing. *For the purposes of this assignment you will not need to read the Materials and Methods section of the 2011 paper or the Experimental Procedures section of the 2012 paper.*

As usual, if you use phrases from the paper in answering the questions, you must put them in quotation marks, and you should try to reformulate the idea in your own words.

Because it's easy to get bogged down in technical details in a paper, we first want to understand what is the question or hypothesis the authors are trying to address with their study. That way you can try to relate everything else you read to answering that question--and if it doesn't help address the main question, you might be able to safely ignore it.

Abstract and introductory paragraphs of Federenko et al. 2011

Q1. What is the main question or hypothesis being addressed in this study?

In motivating their study the authors refer to the "neuropsychological literature." Although it is not completely explicit, in this context the "neuropsychological literature" refers to descriptions of the behavioral and cognitive deficits that people exhibit due to damage or dysfunction in parts of their brain. One well-known relevant phenomenon from the neuropsychological literature is called Broca's aphasia.

Q2. Briefly describe what **Broca's aphasia** is. Feel free to refer to (and cite) an online source.

The next question hinges on the term "dissociations" used by the authors in summarizing previous results from the neuropsychological literature. Neuroscientists trying to understand what parts of the brain participate in which cognitive functions often talk about "dissociations" between different functions when damage to a particular area results in a deficit in one function but not another. For example, HM, who lost most of his hippocampus on both sides of his brain, demonstrated a **dissociation** between episodic memory and "procedural" skill-memory deficits, in that he lost the ability to form new episodic memories but could still learn new skills like mirror-drawing or golf. This dissociation of the deficits implies that the brain basis of episodic memory (in the hippocampus) is different from the brain basis of procedural memory.

Q3. *(Optional)* The authors say their study is motivated by an apparent discrepancy between results in the "neuropsychological literature" and results from the "neuroimaging literature." They say "the neuropsychological literature features striking dissociations between deficits in linguistic and nonlinguistic abilities." Give a concrete (made-up or not) example to illustrate what they could mean by this statement. (You do not need to look up the references.)

The dissociations between deficits reported in the neuropsychological literature suggest distinct neural substrates for linguistic and non-linguistic processes, but the authors note that the neuroimaging literature suggests there is a lot of overlap in brain areas that implement high-level linguistic and non-linguistic functions.

Q4. How do the authors suggest that the conclusion from the neuroimaging literature, that linguistic and non-linguistic functions overlap in the brain, might have been incorrect? That is, briefly explain how an fMRI study might conclude there was overlap between language-related and non-language-related areas in the brain, even if this was not the case in any particular brain.

Q5. The authors want to identify brain regions that participate in "high-level linguistic processing." What does "high-level linguistic processing" refer to? What is an example of "low-level processing" in this context?

Q6. At the end of the first complete paragraph in the second column of the first page, the authors say that "the memory probe task is more difficult in the control (nonwords) condition." How can they know this? In other words, what data or results could they cite to support this claim? (Hint: see the paragraph right after this one in the paper.) Also, what is their other, primary, name for this "memory probe task"?

The authors selected a number of non-linguistic cognitive processes to investigate for potential neural overlap with high-level language-related brain areas. **Working memory** refers to our ability to consciously "hold in mind" a number of items for several seconds--like remembering a phone number long enough to dial it. (Psychologists sometimes refer to this as "short-term" memory, but neuroscientists tend to reserve that term for recent memories that you are not "holding in mind" but which haven't yet been consolidated into a more permanent "long-term" form.)

Aside from math, working memory, and music perception tasks, the authors used a number of tasks intended to engage "cognitive control." "**Cognitive control** is a construct from contemporary cognitive neuroscience that refers to processes that allow information processing and behavior to vary adaptively from moment to moment depending on current goals, rather than remaining rigid and inflexible." (http://carterlab.ucdavis.edu/research/control.php) The **Stroop effect** is a simple example that shows how it can be challenging to respond correctly and quickly when you already have a strong tendency to respond in a "rigid and inflexible" way--one says the different response impulses "interfere" with each other. The Stroop task is to say the font color of a word; the basic effect is that it takes longer to say the font color of a word if the word names a different color. For example, the correct response to "green" is "red" but there is a tendency to hesitate because you automatically want to read the word "green." This site allows you to demonstrate the effect for yourself:
https://faculty.washington.edu/chudler/java/ready.html

Results

Q7. What does ROI stand for? Refer to the Discussion to find out which ROI from Figure 2 corresponds to "Broca's area." Give the acronym for that area and spell out the full name.

Sometimes the Discussion of a paper (especially the first two or three paragraphs) gives a more accessible summary of the results than the Results section. For this reason, people sometimes read the Discussion first to get the main points along with some perspective, before (or instead of!) trying to decipher the details in the figures and Results text.

Q8. In Figure 2 there are bars of many colors. What does the height of each bar represent--that is, what is plotted on the y-axis? Which pair of bars were compared to establish that each of these ROIs is a higher-level linguistic processing area? Be sure to mention the conditions represented by the two bars, not just their colors.

Q9. Of the remaining bars in Figure 2, which were compared to which? According to the authors, what would show that a particular ROI was "**engaged by**" a particular non-linguistic task? To answer this question see the last paragraph on page 1.

Q10. Choose the best phrase (a, b, or c below) to complete this sentence: The take-home message the authors intend to communicate with Figure 2 is that there is

a. A lot of
b. Very little
c. zero

overlap between the parts of cortex implementing high-level linguistic processing and the parts of cortex implementing the other cognitive processes they considered. Briefly support your answer.

After presenting the results of the ROI analysis shown in Figure 2, the authors go on to consider a different "whole-brain" analysis, which did not predefine regions of interest and average responses across the voxels within each region of interest the way the ROI analysis did. Now instead of grouping voxels into regions and averaging, they are considering every voxel separately.

At this point the authors begin discussing results of the analysis using a "stringent" or "liberal" "threshold." When we were talking about action potentials, the threshold membrane potential was a special value of the membrane voltage, above which an action potential would be generated. In the context of the statistical analysis in this fMRI paper, the **threshold** refers to a special value of voxel p-values, *below which* a voxel's activation will be considered statistically significant (and it will show up as colored on a brain activation map).

Remember that a **p-value** expresses a probability that a given result (different activation in two conditions) was observed by chance even if the null hypothesis is true (i.e. there is no effect; the two conditions are equal). So a very small p-value indicates a real, or at least "statistically significant" effect--but we have some freedom to choose our threshold for significance. For example, a threshold of p=0.05 would be considered *less stringent*, or *more liberal*, than a significance threshold of p=0.001.

Q11. Figure 4 shows some overlap between the high-level **language** ROIs and **verbal working memory** and **Stroop** task processing areas. What do these three tasks have in common?

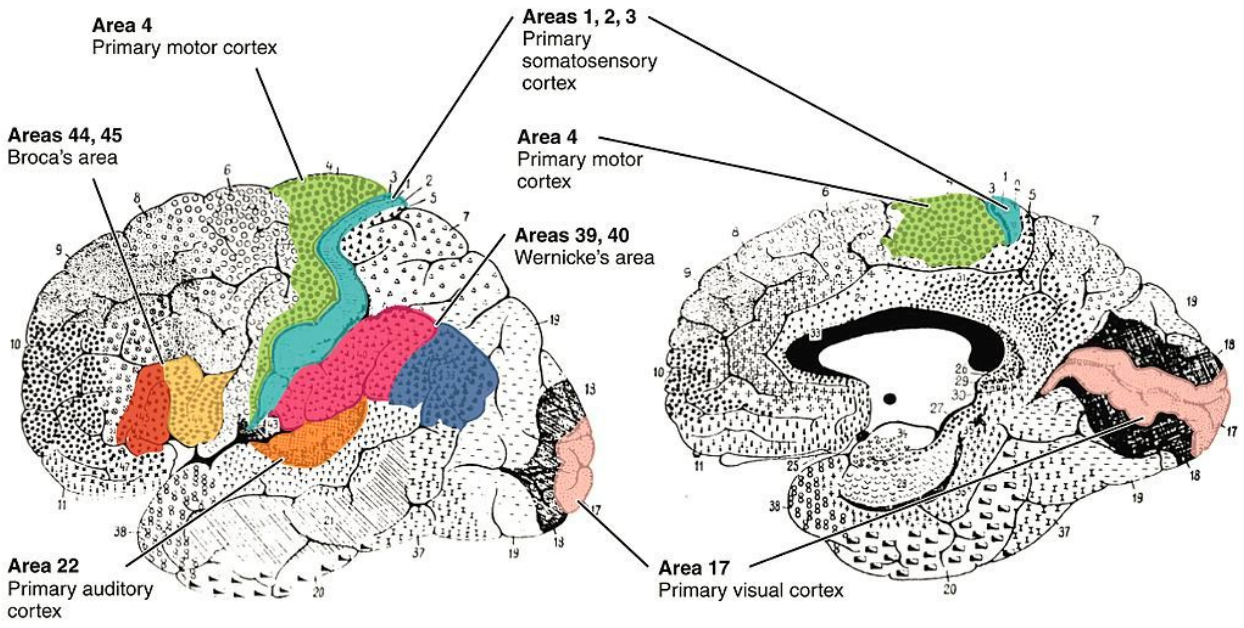
Discussion

Q12. What are some brain areas aside from the ROIs from Figure 2 that are engaged by language processing?

Federenko et al 2012

This update Report uses essentially the same experimental design as the previous paper, to further examine the overlap, or intersection, between language processing and other kinds of cognitive processing, specifically in the part of the left frontal lobe known as Broca's Area.

In describing the parts of Broca's Area they studied, and in their Results shown in Figure 2, the authors refer to "**Brodmann areas**." This is a system for dividing the cortex into different--numbered--areas on the basis of the "cytoarchitecture." "Cytoarchitecture," or "cytoarchitectonics," refers to how cell bodies are grouped together in the tissue, as revealed by slicing the brain, coloring the cell bodies with "Nissl stain," and examining the tissue through a microscope. Broca's Area is Brodmann areas 44 and 45, illustrated in the figure below (along with some other important cortical regions). These are the areas referred to as BA45 and BA44 in Figure 2.



Brodmann's cytotechtonic map (1909): Lateral surface

Brodmann's cytotechtonic map (1909): Medial surface

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Remember that imaging neurophysiologists use the term "**contrast**" to refer to a *difference of activation patterns* across the brain between two different conditions.

Q13. What two contrasts define the pink and blue areas shown in Figure 1? Why can't there be any *real* overlap between pink and blue voxels?

Figure 2 and its caption use some jargon that might be confusing to a non-specialist in fMRI. The figure is plotting responses in language-selective and domain-general subregions of BA45 and BA44. To define the language-selective subregion of BA45, the figure says (on the left) BA45 was "**masked** with Sentences>Nonwords." That just means they are considering voxels for which activation in the *sentences* condition was statistically significantly greater than in the *nonwords* condition--i.e. those are the voxels whose activations are plotted by the colored bars next to the "Language-selective" label, in the top row plot. The "Domain-general" voxels are defined by--i.e. "masked with"--a different contrast.

Similarly, when the caption of Figure 2 says a region is defined by "**intersecting**" a Brodmann area with a particular contrast, it just means those voxels within the Brodmann area where that contrast was statistically significant.

Note also that the caption of Figure 2 tells us that the y-axis of the bar plots represent "percent signal change from the fixation baseline." The signal they are referring to is the Blood-Oxygenation Level Dependent (BOLD) signal produced by fMRI. It is important to clearly state what is plotted in figures, and label axes; but in the 2011 paper the caption referred only to "responses" and the vertical axes were unlabelled.

Q14. From Q9 above (or from the 2012 article), remember how the authors determine whether an area is "engaged by" a particular brain region. According to this criterion, based on the activations shown in Figure 2, which tasks engage the language-selective parts of BA44 but not the language-selective parts of BA45?

Q15. *(Optional)* Based on Figure 2 and the same criterion as in Q16, are the *domain-general* areas of BA45 and BA44 engaged by the recognition memory task the authors used to define language-selective areas?

To understand the basic results of these papers it was not critical to read the Methods. Details in the Methods can be important though. For example, Figure 2 reports the average size of language-selective brain subregions in terms of numbers of voxels. But to understand how big "339 voxels" is, you have to know how big one voxel is.

Q16. *(Optional)* Scan the Methods to find the size of a voxel in these imaging experiments. What is the size and shape of a voxel?

Remember that David Hubel, one of the pioneers of visual neurophysiology, aspired to understand cognitive functions like facial recognition--or language understanding--"at the single neuron level." In the last two paragraphs of the current 2012 Report the authors claim their "findings offer a satisfying answer" to "the old question" about whether Broca's Area is domain-general or language-specific. (Spoiler alert: it's both, in different subregions.)

Q17. *(Optional)* From the last two paragraphs of the current 2012 Report (before the Experimental Procedures section), summarize in one or two sentences how the authors envision the "next level" of understanding how the brain processes language, to be pursued next.

Q18. Please submit two questions you have about terms, figures, concepts or anything in these articles that confused you or that you'd like to pursue further during our Journal Club discussion. For example, one question might be related to a technical detail, and another might be broader (e.g. related to assumptions, methods, interpretation, or open questions for future research).