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Tuning the Language Organ: A New Perspective on the Role of Broca's Area in Language Processing

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For more than a century, lesions to the left frontal operculum have been implicated in a constellation of linguistic deficits affecting the production of words and sentences and the comprehension of certain syntactic structures. However, the preponderance of the evidence fails to support the link between this structure, Broca's area, and this syndrome, Broca's aphasia. Rather, numerous neuroimaging and neuropsychological studies have converged on the hypothesis that Broca's area is involved in selecting information among competing alternatives. Here, I explore the possible link between this putative selection mechanism and some deficits that are commonly observed in nonfluent aphasia. The ability to explain certain linguistic deficits as a failure of a more general selection mechanism may have far-reaching implications for the study of language.

I am going to start with a very brief video clip from an experiment that I will return to at the end of this talk. You will see a patient trying to follow the instruction, "Put the cow in the bowl onto the plate." First, you will hear the experimenter say the instruction, then you will hear the patient, N. J., repeat the instruction correctly, but you will see that he does not perform the task correctly.

[Professor Thompson-Schill plays a video clip of a man picking up a cow doll and putting it in a bowl, then he says, "Uh oh."]

As you can see, he makes an error putting the cow on the plate, which he also realized at the end. Why does he make this error? It is possible that he did not understand some part of the instructions, like what "the plate" or "the bowl" means. It is possible he is having trouble parsing the syntactic structure of the sentence—understanding that "in the bowl" modifies "the cow," instead of being a destination. Today, I am going to argue that something else is going on here. Specifically, I want to suggest that the error this patient is making is better described as nonlinguistic. Rather than considering this a semantic or syntactic problem, this patient has a problem with a more general cognitive control ability, an inhibitory control process. Furthermore, this deficit is linked to the part of the brain known as Broca's area.

Paul Broca is credited not only with describing this area, but also with the birth of neuropsychology. In 1861, he wrote, "A faculty that can perish alone without those that are nearest to it being altered is obviously a faculty independent of all the others." That is to say, a special faculty. He outlined the idea of looking at disorders and carving cognition at its joints. The specific disorder that he was describing is captured in this quotation, "Somewhere in these frontal lobes, one or several convolutions holds under their dependence one of the elements essential to the complex phenomenon of speech, which must not be confused with the general faculty of language." Broca was actually very clear in this paper that he was not talking about a language disorder; he considered it to be a speech disorder, and he cautioned people about thinking about this as a language area. Nonetheless, a confusion with the general faculty of language happened, as demonstrated by the name of the disorder normally associated with this area, Broca's aphasia. Broca did not use that term, he described an *aphemia* speech disorder, but today people talk of Broca's aphasia.

Some of the symptoms of Broca's aphasia include problems with speech articulation (apraxia), reduced utterances (nonfluent/telegraphic speech), problems understanding syntactically complex sentences (receptive agrammatism), problems retrieving single words, and so on. The main thing to note about this classic description of Broca's aphasia is that it has become synonymous with Broca's area—especially as it is described in just about any textbook you can find. As it turns out in the research literature, patients with Broca's aphasia do not all have lesions in Broca's area. Perhaps more critically, patients with damage to Broca's area do not all have Broca's aphasia; according to one estimate in a 1985 paper, approximately 35% of patients with lesions to Broca's area do have Broca's aphasia. What exactly is this area doing? Why is the association so weak?

One possibility is due to the fact that Broca's aphasia is really an umbrella term for a variety of disparate symptoms. They may hang together only by virtue of the fact that these patients tend to have huge lesions, affecting lots of different structures. A more sensible approach to a structure-function mapping is to pick out a single symptom and see if you can find the necessary neural substrates, rather than to try to localize the syndrome. One example of this approach examines the articulatory deficit referred to as apraxia of speech by looking for correspondences in the overlays of their lesion profiles. In a group of about 20 patients who had apraxia of speech, there was a very small area that was damaged in 100% of these patients. In a comparable sized group of patients without apraxia, the same area was implicated in 0% of the patients' lesion profiles. Those kind of numbers are a whole lot better than 35%. Trying to find a relationship between a brain structure and a very specific function is a much more promising approach to the neural bases of language.

The other thing I want to point out about this area is that area critical for apraxia of speech is not Broca's area, it is part of insular cortex, which is hidden between the frontal and temporal lobes. Converging evidence from a number of neuroimaging studies has supported the hypothesis that a region of insular cortex is necessary for the successful articulation of speech. Broca originally hypothesized that some portion of the frontal lobe was important for speech production. We now know that his classic patient, like the patients in this study, had a lesion that included insular cortex—it was a very extensive, deep lesion. What about the part of the brain that Broca could see from the outside, the cortical lesion? Does damage to that area cause a language deficit? What would the deficit be if the area were damaged all by itself?

There are a number of hypotheses currently circulating about the function of Broca's area. Many of these are driven by neuroimaging studies conducted over the past 10-15 years. Early on, a number of studies concluded that Broca's area plays a critical role in either representing or retrieving semantic information. Others have argued that Broca's area plays a critical role in phonology—representing or retrieving speech sounds. A somewhat related idea is that Broca's area is part of an articulatory loop for verbal working memory. From the patient literature on aphasia, there is a very prominent theory which states that Broca's area is the seat of syntax. As you can see, all of the classic sub-divisions in language have been attributed to Broca's area.

I am going to argue that all of the evidence points, instead, to a nonlinguistic function, and that the better hypothesis is that Broca's area is important for *selection*. What I mean by that is that Broca's area is important for guiding the selection among competing alternatives, in at least two circumstances: 1) in a weakly constrained situation, when indeterminacy warrants selection among possible responses; or, 2) in a situation in which on act might be the most likely but another is possible. These are each situations that would produce a conflict that needs to be resolved. My suggestion is that Broca's area is functioning to facilitate that conflict resolution process.

This idea is not entirely new with respect to the part of the brain surrounding Broca's area: the prefrontal cortex. Luria wrote, "The frontal lobes are in fact a superstructure above all other parts of the cerebral cortex, so that they perform a far more universal function of general regulation of behavior than that performed by the posterior associative centers." A more recent statement along these lines comes from Miller and Cohen (2001), "To deal with this multitude of possibilities and to curtail a confusion, it is commonly held that the prefrontal cortex is particularly important." When you have lots of competing things activated, you have to resolve the resulting conflict.

When people have talked about what Broca's area does, it has always been considered an island in prefrontal cortex. The fact that this bit of tissue is sitting in prefrontal cortex, that people have described in these terms, tends to be ignored. Instead, because of an historical association with something like Broca's aphasia, people are looking for a language-specific explanation. An alternative is to examine the evidence in the literature using these more general notions.

With respect to semantic abilities, this analysis begins with a classic paradigm dating back to the earliest neuroimaging studies, using verb or action generation tasks. These tasks involve prompting a subject with a concrete noun and asking the subject to produce an action word associated with that noun. In 1988, Steve Pederson and his colleagues reported that compared to just reading the words, the verb generation task led to increased activation in the vicinity of Broca's area. In response to this finding, we reasoned that one of the things that happens in the verb generation task is that you have to ignore all the other things you know about the noun that is used as the eliciting prompt. For some items, those other things would be very strongly activated, and for other items, they would be weakly activated. For example, when I say SCISSORS, you say CUT. When I say PIANO, you say PLAY. When I say CAT, you say ...DOG. I think I noticed an error there. The point is that many of these items have a strong association with an action response, if I asked you to say the first word that comes to mind, you would probably say CUT for SCISSORS, and PLAY for PIANO, but there is no strong action response associated with CAT.

Another experiment manipulated the amount of competition involved in the task, and you can see that over three different experiments with the same group of subjects, we found an effect of the amount of competition (a *Selection* effect) on brain activation in Broca's area. When we take this task to patients with brain damage, comparing those with damage including Broca's area to controls with frontal damage sparing Broca's area and to undamaged elderly controls, we observed normal performance for the low selection items and higher error rates for the high selection items. An error was defined as an omission after 20 s with a reminder after 10 s, or saying something that was not an action response, like seeing CAT and saying DOG. This finding suggests that the ability to do this task is a consequence of cognitive function under competition. And, it appears that there is a tight linking of that ability to Broca'a area, specifically. Furthermore, there is a correlation between the number of errors in the high selection task and the amount of damage to the posterior portion of Broca's area, Brodmann's area 44. We can explain over 90% of the variance in behavior by knowing the amount of damage to Broca's area. In contrast, overall lesion volume does not explain any of the variance in these data, nor does amount of damage to adjacent regions.

One concern pertinent to these kinds of experiments is the task difficulty. It could be the case that it is just more difficult to make a response to CAT than to SCISSORS—increasing selection demands is something that would make a task more difficult. To rule out task difficulty, we constructed a task that is not more difficult with respect to response time and accuracy, but would still be subject to selection demands. This is a priming study where we asked people to generate actions or colors, and over the course of the experiment, some items repeated in one of two conditions. For example, if I say TAR, you might say BLACK for color or SPREAD for action. In one repetition condition, subjects reported the same attribute as the first time they saw an item, and they showed a priming effect relative to novel items (approximately 200 ms reduction in response time). In another repetition condition, the attribute switched and there was still a priming effect, albeit smaller, relative to the novel items. Despite the fact that the different attribute task is easier (faster and more accurate) with a repeated than a novel item, we predicted that there would be an increase in activity in Broca's area, and only in Broca's area, because we would be making this other information about the repeated items more available. Now, when you are asked the color of TAR, the fact that you can spread tar, for example, is just a little more available, and there is a little more competition in contrast to the same attribute condition when you just reported the color of tar. Relative to novel items, we found a decrease in Broca's area activation for the same attribute condition, but an increase for the different attribute condition. So, this activation pattern is not just due to task difficulty.

Another approach to assessing the role of Broca's area in accessing semantic information uses picture naming tasks. Most models of picture naming include not only a semantic activation/retrieval process, but also a process that can be described as selecting between all of the various representations activated by the picture. Perhaps it is this latter process that is driving the activity in Broca's area, the selection process, and not the retrieval of semantic information. In order to manipulate selection, we used normative name agreement data as measure of competition. Some pictures have high naming agreement, in which case everyone agrees to call this picture an APPLE and that picture a HAMMER, while other pictures have lower agreement, in which case this picture could be a BLOUSE, a SHIRT, a TOP, etc. This study used normative name agreement as a proxy measure of competition in a picture naming task, and there was increased activation for the low agreement pictures relative to the high agreement pictures, and the effect was specific to Broca's area.

In other semantic studies, there is evidence of increased activation in the naming of pictures of manipulable objects after naming pictures of tools. Because Broca's area is sitting in pre-frontal cortex right next to the pre-motor cortex—right next to the hand and mouth area of the motor strip—it was proposed that maybe Broca's area is storing motor representations, among them the semantic representations about what to do with tools. Following up on our previous experiment, we examined whether controlling for name agreement between pictures of manipulable objects and pictures of animals would eliminate the effect, and the answer is provocative. In prefrontal cortex, there is a big name agreement effect, but no effect of picture category. In contrast, just posterior in pre-motor cortex, there is an effect of category with a lower effect of agreement.

This outcome is appealing, because many of reports in the literature on tool-naming tend to find a swath of activation that includes both pre-frontal and pre-motor areas, and discuss the finding as if it were a single function. The current result is useful because it shows that these areas might be contributing in different ways. Moreover, half of the subjects were left-handed and varied the degree to which they used their right hand for tools, and there was a very high correlation (.88) between estimates of their use of the right hand and how much activation was found in left pre-motor cortex. This effect was specific to pre-motor cortex and also to naming tools. This is consistent with the notion that our conceptual representations are tied to sensorimotor systems, so that when we think about these manipulable objects, we are activating the part of the brain that manipulates them; and, for people who use their right hand, that is left pre-motor cortex, but we do not see that relationship just anterior in Broca's area.

We also used the name agreement paradigm (not just tools and animals) with the patient that I opened the talk with, N.J. This patient is a 63 year old male who had a single infarction to the pre-central branch of the middle cerebral artery. His lesion includes all of Broca's area, and it is relatively specific to Broca's area. He is a highly educated and very intelligent subject. Broca's aphasics tend to show slight impairments in picture naming. If we take into account picture name agreement, we can predict when those impairments will show up. Plotting percent correct picture naming (a correct response would be anything that normal controls produce) as a function of high versus low name agreement, we see that N.J.'s performance is in the normal range for the high name agreement items (low selection) but several standard deviations below the normal controls for the low name agreement items (high selection). The role of Broca's area in picture naming tasks appears to be modulated by variation in selection demands (name agreement) across different sets of items.

Next, I will turn to another way of manipulating competition in picture naming within items, using semantic context effects. In this task, subjects name items one at a time as quickly as possible. Over time, the items are repeated. In one condition, the repeating blocks are arranged in groups of semantically related items (semantically blocked). In another condition, the repeating blocks contain items that are semantically unrelated to each other. For normal subjects, the response times to name the picture are slower in the related than in the unrelated case—there is interference to name a particular item when a subject has been naming other related items. For a group of control patients with damage to other frontal areas (not Broca's area), there are some unreliable differences in the error rates for picture naming in the semantically related and unrelated conditions. For a group of patients that we believe have damage to Broca's area (we are currently verifying the anatomical speculation), there is a much bigger difference in error rates between the related and unrelated items. In other words, they have greater errors in the semantically related condition than brain damaged controls, suggesting that they are experiencing particular problems with interference. The effect grows over the course of the experiment; they start off the same and the error rate grows over each repetition.

The last experiment in this section uses a verbal/category fluency task, which is a standard test to assess frontal lobe function and semantic knowledge. In this task, subjects are asked to name as many members of a category that they can think of within 20 seconds. Previous research compared fluency for big categories, like ANIMALS and FURNITURE, versus small categories, like FARM ANIMALS and BEDROOM FURNITURE. Intuitively, it seems easier to name big categories rather than small categories, because there are more candidates. However, for big categories like ANIMALS, there are so many options that there is much more competition, and you could get stuck in semantic space. We reasoned that prefrontal cortex might be important for getting you unstuck. Normal subjects can provide many more members of ANIMALS than FARM ANIMALS. Patients with Broca's area damage might get stuck in a small semantic region and would show no increase in the number of items for the larger category. For patient N.J., the difference in the number of items retrieved for large versus small categories is much smaller than that for normal age-matched controls or for non-Broca's area frontal damaged controls. This is consistent with the notion that N.J. is getting stuck in a subcategory when asked to name items from the larger category.

Across all of these experiments, we find that in situations where there is little competition or conflict and the demands for selecting among different representations are minimized, Broca's area seems relatively unimportant. This is not consistent with the notion of this area as the Semantic organ. We should see activation there whenever there is semantic processing. Even when the semantic task is easier, and subjects can perform it more quickly, if you increase the amount of competition, there is an increased reliance on Broca's area.

More briefly, now I will turn to the notion that Broca's area is the seat of phonology, or phonological processing. In previous fMRI studies where subjects are asked to make rhyming judgments, numerous researchers have observed activation in Broca's area, and argued that it is engaged by phonological processing. Our study used two different working memory tasks. In the semantic working memory task, subjects had to remember five words in the order in which they saw them, and were later probed whether a target item occurred in a particular position (for instance, "Was KNIFE the third item?"). Moreover, the subjects were prompted to make the judgment on the words either in forward order, or they had to reorder the items according to increasing size. In contrast, the other working memory task (which I consider a phonological task) the subjects had to remember nonwords in order or they had to alphabetize the items (more or less phonological, but clearly non semantic). There was no difference between the semantic and phonological tasks in activation in Broca's area. There was an equivalent increase in activation for performing either re-ordering task over the forward ordered task. Why did we find no difference in the phonological task?

In our recent review of studies that directly compared phonological and semantic tasks, some found a difference in activation in Broca's area and some did not. Two of the studies that did not find a difference, like ours, used nonwords, and there were no studies reported with nonwords where they did find a difference. The differences reported for phonological and semantic tasks could be due to the fact that the phonological tasks used words, which have irrelevant semantic information, and the subjects have to suppress this information. In our study, we compared two phonological tasks—one used words and the other used nonwords. The task was to chose which word or nonword contained the same the vowel sound as a target item. If we are correct in our interpretation of the findings in the literature, there should be more activation in Broca's area for the task that used words versus the one using nonwords. In addition, we had an analogous set of conditions that manipulated the degree of competition for two semantic tasks, one high and one low. Broca's area showed greater activation for the high versus low competition semantic task, and more activation for the phonological task using words versus nonwords. If this area is responsible for retrieving phonological representations, there is no reason to find more activation for words than for nonwords. There is increased activation when there is a greater task demand to inhibit irrelevant semantic information.

A related hypothesis claims that Broca's area is an important part of the phonological loop for verbal rehearsal. This claim has the advantage that it seems to be related to other things that people have said about the prefrontal cortex, unlike any of the other hypotheses. Unfortunately, it does not have the data on its side. In a meta-analysis of spatial and nonspatial span tasks and also delayed response tasks, where there was an unfilled interval, only one study with nonspatial/verbal tasks found impairment in a simple working memory task. In contrast, when the interval was filled with some sort of distraction, there are more studies reporting impairments. The authors of this study argued that working memory is a multi-component set of processes that contribute to performance on these tasks. Some of those might best be described as mnemonic, the memory part, but some are non-mnemonic, the working part. Those could involve processes like selection and inhibition, which are very important when there is distracting information.

Like most good ideas, Luria's 1973 book on neuropsychology said it first: "Destruction of the frontal lobes leads not so much to a disturbance of memory as to a disturbance of the ability to inhibit orienting reflexes to distracting stimuli." This statement was based on findings with monkeys that had lesions to prefrontal cortex. It is well-known that they are impaired in working memory tasks, but if you turn the lights off during the delay period, their performance is normal. That can not be explained by a simple mnemonic account.

This next paradigm I would like to discuss tests specifically whether Broca's area is important for a non-mnemonic component, prevention of interference. This is a simple delayed response task with a twist. The subject first sees a display with four letters; then, there is a brief delay; and, last, a probe is displayed. The subject simply has to say whether that probe was in the memory set. On some trials where the correct answer is NO, the probe item had been lurking in the previous set (Recent No). On other trials where the correct answer is NO, the item had not been present in the previous 2 sets. The logic is that in the Recent No trials, the familiarity of the item acts as a competing source of information about the status of the probe in the current trial. In both a recent PET study and an fMRI study, activation in Recent No trials was associated with increased activity in Broca's area.

We examined this effect in two ways. One way investigated inhibitory control and performance on this task in an individual difference study with college students. We gave them a self report measure called the Disexecutive Questionnaire (DEX). We were interested in whether subjects' scores on this test would be correlated with their performance on a working memory task. For overall performance, using all the items, we found no correlation. Instead, if we correlated performance on the DEX with the magnitude of the interference effect in the working memory task, we found a striking correlation. Subjects who show really big interference effects are the ones endorsing items like, "I act without thinking."

Stronger evidence linking Broca's area specifically comes from a case study with another patient, R.C., who suffered a ruptured aneurism resulting in a lesion centered in Brodmann's area 45. This is a little more anterior than I have been showing, but still in Broca's area. Comparing this patient's performance to a number of control subjects, his performance on a working memory task was similar to a number of other frontal patients. In terms of baseline working memory performance, items with no interference, R.C. performs normally. For the interference effect, his performance is 6 standard deviations outside of his age control group, both in response time and in error rate. A simple manipulation that has a probe item being shown in a previous trial was enough to reduce his performance from somewhere around 90% to around 70%. This was a huge effect. Also, across all subjects there is no correlation between baseline performance on this task and the interference effect, which shows that these are really two dissociable systems. And, the non-mnemonic component is linked to the inferior frontal gyrus. It is not the memory component per se, but something to do with competition.

Finally, I want to return to the paradigm that I began with today, and to examine syntax. The syntax argument has been one of the strongest arguments in the literature about the function of Broca's area. This is based on the fact that Broca's aphasics exhibit not only production deficits, but also comprehension deficits limited to syntactically complex sentences. Can these deficits be explained as a result of a problem with competition? We decided to study temporary syntactic ambiguity as a means of seeing the effects of competition. The sentences were structured like this one: *Put the frog on the napkin in the box*. This is not a globally ambiguous sentence, but at the point that you hear, *on the napkin*, there is an ambiguity. When looking at this scene, *on the napkin* could be a destination for the frog or it could be a modifier of *the frog*. There is a strong prepotent bias to interpret *on the napkin* as a destination because whenever you hear *put*, you will always hear a destination. You do not always hear a modifier for *frog*, and in this display, you do not need a modifier for *frog*. However, as the sentence continues, and you hear *in the box*, you have to override that interpretation.

There is another way to override that bias, by presenting a scene with more than one frog in which one of the frogs is posed on a napkin and the other is not. In this situation, there is a bias to interpret *on the napkin* as a modifier, overriding the lexical bias for *put*. In eye movement tracking experiments, with two frogs in the display, subjects never look at the napkin as a destination. Interestingly, research with 5-year-old children shows that they are not influenced by context in this way—they express a strong preference that they do not override. This sounds just like what we thing the frontal lobes are doing during language processing, and furthermore, we know that the frontal lobes are one of the last areas to develop in childhood.

We examined the possibility of competition in a couple of ways. One study with college students asked them to look at these scenes and to listen to these sentences, and we examined whether they made errors of the sort the patient and children made. Under time pressure, we found that some college students made this kind of error (13 out of 40), failing to revise their initial commitment to *on the napkin* as a destination. Looking at their performance on the proactive working memory task, the error-prone students show larger interference effects (4% more errors). Finally, we looked at performance on this task with patient N.J. He was able to complete the task with a syntactically complex but unambiguous sentence. This shows that his problem is not due to syntactic complexity. Note that he was also able to repeat the sentence, which indicates that his problem is not a sentence comprehension deficit resulting from a failure of verbal working memory. The error that N.J. makes with the syntactically ambiguous sentence is the same one that the children and the college students make. Compared to frontal damaged controls, N.J. shows a large effect of ambiguity on his sentence comprehension ability.

In all of these different areas, semantics, phonology, verbal working memory, and syntax, activation of Broca's area or deficits following damage to Broca's area are affected by increasing demands for selection. Damage to Broca's area is associated with a pattern of deficits best described as an impairment in selecting between competing sources of information. The function of Broca's area is, like other regions of prefrontal cortex, one of cognitive control, rather than a unique linguistic specialization or operation.

APPLAUSE

Questions

Professor Kevin Ochsner: Every single one of the examples you gave is verbal, yet you are arguing that the functional specialization is not devoted to language. Have you done any experiments where you manipulate selection demands using completely nonverbal materials?

Professor Thompson-Schill: I am so glad you asked because I only had an hour, but Melissa Brandon, who is sitting right here, did exactly this experiment with pictures of faces. We used the working memory paradigm I just showed you, presenting four faces, a delay, and then a face prompt comes up. Some subjects apply a verbal label to these items, but the ones who label more are not the ones showing greater interference effects. We found increased activation in Broca's area for the Recent No (interference) trials with this nonverbal task. However, the activation was not specific to the left inferior frontal gyrus, it was also significant in the right inferior frontal gyrus, which I have never seen reported before. We do not know yet whether the left activation is necessary, so we have N.J. scheduled to perform this face task with us next month. The main point I want to make is that the function can be described as nonlinguistic, but there could be still, within prefrontal cortex, specializations, based on connectivity for the kind of input it is modulating. It could be doing this nonlinguistic function, but because of its connectivity, it tends to be acting on representations that we think of as linguistic. This is an open question.

Doctor Ezequiel Morsella: As you know, substantial research shows that the anterior cingulate is important for interference resolution, like in the Stroop task; what role does it play in your framework?

Professor Thompson-Schill: Some people have argued that the anterior cingulate is detecting the conflict, and then sending the signal to prefrontal cortex to do something about it. I think that is not entirely consistent with some of the data that are out there because you can get dissociations between them. If that is the story, then you should never get prefrontal activation when you do not also have anterior cingulate activation. However, that is not what is found. I prefer another interpretation based on some research with the Stroop task and a proactive interference task. The anterior cingulate is specialized for resolving conflict at the output level—it is really a response conflict. Prefrontal cortex is responsible for handling conflict that you could think of as conflict among representations, but not at that last stage of output. This would be consistent with the observation that you can get prefrontal conflict responses when you do not get anterior cingulate responses. I should also add that we tried to look at some of these effects in patients with anterior cingulate damage, and we did not find any of these sorts of effects.

Mister Christopher Summerfield: In the beginning of your lecture, you showed a slide in which it seemed that the overlap between Broca's aphasia and brain damage area was in the anterior insula, rather than in Broca's area. A number of recent fMRI papers talking about decision uncertainty have isolated activity which correlates with decision uncertainty to precisely that region. Are you saying that Broca's area is mediating the underdetermined responding in these types of tasks, or is Broca's area and this sort of adjacent bit of anterior insulate cortex doing it? Are they doing the same thing or are they doing different things?

Professor Thompson-Schill: I do not know the studies you are talking about, so I can not comment on them specifically. The function that others have described is not one that I would call a problem with competition, generally. It might be a problem with competition at the phonemic planning level. Again, another sort of output level. These patients get the phonemes, but they put them in the wrong order—that is what apraxia of speech refers to. That would definitely not be described as a general conflict function. We tend not to see activation in insular cortex. It is kind of surprising because it is the kind of thing that some people have said responds as things become more automatic, which sounds like the opposite of being important for decision making.

Professor Michele Miozzo: You have presented a very impressive array of data, but it all seems to have in common the processing of word phonology. At the conclusion of your talk, I would come out with the impression that you demonstrated that Broca's area is an organ of phonological processing, or at least, involved in the interface between semantics and phonology. It deals with selecting the right word form at the right time. So, it is really a language-specific organ.

Professor Thompson-Schill: I am not arguing whether or not these findings are language-specific. I am questioning whether the *process* is specific to language. Whether all of the data can be explained by phonological processing is more problematic. I do not see how you can explain a difference in saying that tar is black when you have just said that tar is something you spread versus when you do not have that previous information by virtue of phonological processing.

Professor Miozzo: In all of these tasks you can imagine that you have activation of multiple phonological forms as demonstrated, for example, in your data about name agreement. So, it is just a question of how many other names or words you have activated in the background, picking among a set of activated phonological forms.

Professor Thompson-Schill: So you are saying that because all of these representations that I have described are verbal, when I say there is multiple representations active, it could be specifically the phonological representations. You are saying that any time there is more information, that information could be characterized as more phonological information. So, there is no study that I could do with language that could rule out that hypothesis. I think that is why the studies moving to the nonverbal domain are important.

Professor Miozzo: I am not saying that, I am saying that the evidence that you provided indicates that phonology is really a factor in all the data.

Professor Thompson-Schill: I would say that I can not rule that out right now with the exception of nonverbal tasks. Right now, I can not distinguish between any sort of representation becoming active versus only phonological representations becoming active. Any time I manipulate how much competition there is, you could describe that as purely phonological competition. I think the test for that is with these nonverbal stimuli, and the fact we are seeing activation in this area with a nonverbal working memory task is not consistent with that story.

Professor Miozzo: You may also have selection at the level of Wernicke's area, where the hypothesis is that there is representation of lexical information. So, you also have to select at that level.

Professor Thompson-Schill: Let me clarify—I am not arguing that selection is happening in Broca's area. That is critically important—there was a slide where I said that it is guiding the selection process. For people who think of selection as a stage, any type of information processing step is going to have a selection component; information is passed through some series of stages, and you have to select something to go on. That is happening everywhere. The question is, when that process fails because you do not have a winner—either because there is too many weakly activated things (indeterminate representations), or because you are using the wrong cue so you have to shift the pattern of activation—Broca's area becomes involved with this process that is happening somewhere else. I am critically not saying that the selection is happening in Broca's area.

Professor Miozzo: This begs the question: What is the grain or the kind information on which Broca's area resolves the competition? If Broca's area does not store information that is semantic in nature, how can it decide the correct response?

Professor Thompson-Schill: I think I should refer you to Matt Botvinic's work on this, because it is the best work I know. It is about computing energy in a Hopfield net as a measure of conflict among representations, and you do not have to have knowledge of the representations themselves to make that computation. It is a beautiful work that may help clear that up.

Professor Remez: Let us thank Professor Thompson-Schill and adjourn.

APPLAUSE

Place: Kellogg Center, Room 1512
School of International and Public Affairs
420 West 118th Street
Time: 4:00 PM

Chair: Prof. Robert E. Remez, Barnard College, Columbia University

Rapporteur: Jennifer Pardo

Attendees: Hannah Bayer, Melissa Brandon, Yi-Chun Chen, Chaio-Wen Deng, Amy Endo, Simon Fischer-Baum, Molly Flaherty, Boris Gasparov, Sarah Gilman, Peter Gordon, Robert Krauss, German Kyrychenko, Jackson Liscombe, Michele Miozzo, Ezequiel Morsella, Kevin Ochsner, Ann Senghas, Anja Soldan, Christopher Summerfield, Alexandra Suppes.

Questions pertaining to this transcript should be sent to the rapporteur via email:

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