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THE IMPLICATIONS OF THE EXPERIMENTS INVOLVING BRAIN MAPPING FOR MODELING LANGUAGE. PART 3: PROBLEMS WITH INTERPRETING EXPERIMENTAL RESULTS

This paper examines selected brain imaging studies with a view to draw conclusions regarding the functioning of language in the brain. It focuses on difficulties involved in interpreting the results of studies employing the state-of-the-art brain mapping technology, concluding that current knowlege from such experiments being fragmentary and of a very general nature is yet unable to impose specific constraints on linguistic models.

The author also mentions briefly other physical aspects of brain structure and functioning, e.g., ones related to its molecular level organization, that do or will constrain models of language in the future.

The development of new technology such as PET (positron electron tomography), Electroencephalography, MRI, and SQUID, as well as ever more sophisticated post processing techniques, have opened a new venue for investigating the functioning of the brain, which in turn will impose constraints on models describing the functioning of natural language. Yet, the techniques of brain mapping are so advanced and complex that the results they provide are not straight forward; such results need a very sophisticated interpretation. In this article, I shall sample brain imaging studies regarding functioning of language to illustrate selected problems involved in interpreting experimental results in question and assess the potential influence of such research onto current linguistic models.

Early studies researching human brain structure and functioning led scientists to the idea of a highly modular brain with Broca's and Wernicke's areas housing the production and comprehension capacity of language, respectively. Yet, more exhaustive research involving contemporary technology has shown that Broca's and Wernicke's areas are involved in almost all language functions, rather than supporting a singular one each. Wise (1991) for instance, reports that Wernicke's area is involved in both a comprehension task involving judging word class and in a production one, that of generating verbs appropriate for a given task. Demonet (1992), on the other hand, finds Broca's area to be active in both phonological and lexico-semantic tasks.

Moreover, Broca's and Wernicke's areas do not function as homogeneous modules. For instance, Price (1996) reported that different parts of Broca's area were active under different conditions: listening to words caused activation in anterior sections of Broca's area, repeating words in posterior sections. Similarly, word comprehension and retrieval (Wise, 1991), phonological and semantic processes (Demonet, 1992), the recognition system for spoken vs. written words, (Howard 1992) nouns and verbs, (Damasio and Tranel 1993) and various categories of concrete nouns – individual people, general representations of animals, furniture, fruit, tools. (Damasio 1996) all depend on differently distributed neuronal populations. At times these maps seem to conjoin and/or overlap with areas associated with similar processes. For instance, Martin (1996) reports that tool naming also activated areas involved in verb generation. Such research reveals the complexity of linguistic functioning of the brain and thus shows that the experiments that have been carried out so far have investigated its linguistic capacity only fragmentarily.

While different parts of Broca's and Wernicke's areas are involved in various language functions in a complex way, unlike previously thought, in addition to the activation in the brain of the regions for long known to be supporting language functions, researchers using current technology have recently found other areas of the brain to be implicated in language functions, too. Damasio (1996), for instance, reports evidence showing that overt naming of specific people and of no specific animals and tools depends on higher order association cortices outside classic language areas. In general, functional studies indicate a left-hemisphere dominance for language, but many studies also find right hemisphere participation; many researchers report additional activation in the cingulate gyrus, basal ganglia, cerebellum, prefrontal, temporal and parietal cortices. Yet, the question rises, how much these other areas support language functions and how much other functions from which language functions draw. Binder (1996), for instance, reports that planum temporale, a structure hypothetically connected to language because of its relatively larger size on the left, was relatively as active in response to linguistic and non-linguistic tasks. Patel et al. (1998), in a similar vein report that processing syntactic relations in language and music takes place in the same area. Also Faust Babkoff and Kravetz (1995) have found that both hemispheres are involved in linguistic functions. Having studied word/non-word decision tasks with stimuli offered separately to the right and the left visual fields by analyzing reaction times and accuracy, the authors conclude that these activities may involve different processing strategies in each case. The left hemisphere performs decisions more quickly and accurately than the right one and can use syntactical information in a way the right hemisphere cannot. Processing in the left hemisphere seems to be more interactive, while more serial and modular in the right hemisphere. Damasio et al. (1996), on the other hand, propose that the activated sites located outside classic language centers allow simply to link information stored in various locations and these secondary structures are modified by learning rather than being additional language processing modules. Price (1996) in turn, notices that activation patterns shift depending on the test conditions and the activation of which task is substructed from the activation of which other one. Thus deciding on the areas supporting purely linguistic skills and on selecting these skills depends on the model of language and does not constitute an objective measurement.

Model dependency is, for instance, explicitly seen, e.g. in Bottini's (1994; interpretation of his studies of metaphor. Bottini et al. (ibid.), using PET, studied brain activation of the subjects who were asked to judge a series of metaphoric statements as plausible or implausible, to judge the plausibility of the literal meaning of sentences, and to identify whether a sentence contained a non-word or not. After subtracting the lexical decision task from the subjects responses to the literal meaning of sentences, Bottini (ibid.) found activation in the left hemisphere including the prefrontal and basal frontal cortex, the middle and inferior temporal gyri and temporal pole, the parietal cortex and precuneus. Determining plausibility of metaphoric expressions involved similar activation patterns plus activation in the prefrontal cortex, the middle temporal gyrus, the precuneus, and the posterior cingulate gyrus of the right hemisphere. This observation led Bottini to the natural conclusion that "the interpretation of metaphors demonstrates the specific role of the right hemisphere in performing complex operations on language such as transcending denotative meanings". Bottini further suggests that the same structures activated in interpreting metaphorical expressions are involved in processing of episodic memory and mental imagery, which systems are believed to be necessary for comprehension of metaphoric meaning.

Bottini's methodology, however, assumes Searle's (1979) classical model of metaphor which treats metaphor as additional activity imposed onto literal comprehension. Since a great number of metaphors used in daily language is rapid and seems to be automatic, while literal interpretation of scientific texts is not fast and seems to be an attended process, Searle's model has recently been questioned. To question Searle's model, researchers studied one of its implications: Searle's model requires that it takes longer to process metaphorical expressions than literal ones. Yet, Gibbs (1994) overviews numerous studies, (not monitoring brain functions, but measuring response times), on idioms, proverbs and metaphor, which show that if adequate context is provided this is not the case. Gibbs (1980, 1986) has shown that subjects take less time to read idiomatic phrases when the context supports an idiomatic interpretation than the same phrases in contexts supporting literal interpretation. Similar results with regard to metaphor have been summarized in (Gibbs, 1994). The differing results with respect to context suggest that the literal and metaphoric processes either operate in parallel and context primes one over the other or are the same process leading to separate results in varied contexts.

Operatorial Analogical Modeling of Language (Zielinska, 1995) also corroborates the later possibility. This option is also partially supported by other studies concentrating on investigating cognitive system and mental operations instead of the neural system. Keysar (1989) investigated whether metaphor and literal interpretations of a context would produce a stroop-like interference effect when a target was for example both metaphorically true and literally false. Reaction times increased in the invalid conditions but decreased in the valid conditions, suggesting that these processes may share at least some components. Blasko and Connine (1993) found in turn that response time for well known metaphors is shorter than for those expressed in other words. This again indicates the interaction between literal and metaphorical processing of information as well as the influence of practice effect.

Another problem is posed by the fact that all brain mapping techniques, except for SQUID, require averaging across subjects, Yet, Salmelin et al. (1994) report that his study of picture naming revealed considerable variation in the combination of activated sites as well as the exact areas activated across subjects, with the general processing stream moving from occipital to Wernicke's area/angular gyrus in three cases and from occipital to auditory cortex in three others. Spitzer et al. (1995) again report considerable variation in sites activated across subjects during tasks requiring covered naming of individual names. Damasio et al. (1996: 505) find that when asked to name pictures, individuals showed similar large scale architecture but that "ample variations exist in microcircuitry". Thus the averaged results we get mask individual differences in brain structuring.

A few researchers have investigated gender differences in language processing. These studies were motivated by the observation that females who suffered from stroke tend to recover language function more often and more fully than men, which in turn led to speculation that language functions in woman are distributed more widely than in men. One of the most often quoted studies examining gender differences is (Shaywitz et al. 1995). The group studied the responses of thirty eight right-handed subjects, 19 males and 19 females, using MRI to assess differences in orthographic and phonological tasks. Phonological decisions proved to be left laterized in males and bilateral in woman. The majority of researchers, however, average the results, disregarding the sex of the subjects.

The experimental results depend not only on the model assumed or individual differences between subjects but also on the technology used. Studying bilingual speakers using PET, Klein et al. (1995) find common activation sites regardless of the language their bilingual subjects used in a series of tests. Yet, clinical evidence has also shown that the brain damage in bilingual people occasionally disrupts one language but not the other. Kim et al. (1997) using MRI confirmed that, reporting that "activation sites for language production of two languages tend to be spatially distinct in Broca's area when the second language was acquired late in life [i.e. as young adults] and the same if acquired in early childhood." By contrast there was no such difference in activation sites in Wernicke's area, responsible largely for receptive skills. (This difference is also in line with the well testified difference in the level of difficulty in acquiring the so called passive and active knowledge of a foreign language.) Similarly, Yetkin et al. (1996) using MRI to study the generation of words starting with a given letter, found that in non-fluent languages the activation dropped in the parietal lobe and increased in both front-parietal and frontal areas, which suggests differences in the processing systems. The difference between the first study mentioned and the latter ones may well have been caused by a considerably better spatial resolution of the MRI technique than PET. (By the way, it would be interesting to also analyze the differences in brain activity between the second and first language processing sites, especially in syntactical tasks, where one expects major differences. Second language speakers are believed to rely more on exploiting consciously grammatical rules when producing sentences, while native speakers rely on unconscious, automated skills.)

Numerous neurolinguistic studies, e.g., Nichelli et al. (1995), Just et al. (1996), have studied brain activation reflecting the meaning, including that of and above the sentence level. Yet, the research involving meaning requires the interpretation of that meaning which can be controversial whether it involves brain mapping or not. For instance, one of the most often quoted psychological experiments compares the probability of two situations expressed respectively with the sentences below:

Linda is a bank teller.
Linda is a bank teller and a feminist activist.

The researcher found that subjects estimated the probability of the second sentence as higher than that of the former one. He concluded that people do not think logically because if interpreting the sentences above as they would typically be interpreted in isolation of each other, the probability of someone being X is higher or equal to that of that person being X&Y. Yet, the first of the sentences in question contrasted with "Linda is bank teller and a feminist activist" could also be interpreted as "Linda is a bank teller and not a feminist activist". Or the latter of the two sentences, in the context of the former one, could be interpreted as "Linda is a feminist activist, given she is bank teller". In such cases we can no longer conclude that the subjects were irrational in their decisions. Similar problems with interpreting meaning crop up whether or not brain mapping is involved.

It has also been reported that the same activity may be carried out differently when performed by people with different backgrounds. It has been discovered that in amateur chess players what is active is temporal lobe, while in professional players temporal lobe along with parietal lobe, the latter of which houses long term memory. The researchers concluded that while amateurs reason, chess masters go over known situations. The results could additionally reflect the difference between symbolic thinking vs. thinking on data.

Of crucial importance for constructing linguistic theories is also the research answering the questions on correlating individual cell types with minimal semantic representation, i.e., sem-level correlation. Neurons in visual cortex have been found that react selectively, e.g., to lines sloping at varied angles, to color but not to shape, to shape but not colour, to stimuli moving in a given direction, even to recognizing faces. This latter observation considerably opens up the possibilities of what can be treated as a basic encoding, i.e., an atomic concept. A related announcement has been made recently by Roger Carpenter of Cambridge. After studying the reaction time of brain cells to two consecutive light flashes with MEG, he found that the brain reacted only to one of the flashes. Interestingly, the time of reaction, as well as to which of the two flashes the cells responded, seemed to be completely random. This observation, in turn, indicates the relevance of quantum mechanical effects in brain processes.

Another issue relevant for constructing models of language regards deciding whether only conscious or also unconscious activity of the brain contributes to our linguistic skills. The issue of consciousness has been approached from experimental biological perspective, e.g., by Crick and Koch who set out to research the differences between neural processes that correspond to some conscious experience and those that do not. The researchers found that some neurons respond to visual stimuli even in asleep animal's brains. In another experiment, a neural response to visual stimuli has been recorded even when the animal did not report noticing it. In experiments in which subjects were presented a separate stimuli to each eye, the reserchers found that while some neurons, those at the beginning of the visual path, get activated even without conscious perception of certain visual stimuli, other neurons, those located farther on down the visual path, respond only when the same stimuli is perceived by the subject consciously. Therefore not all neural activity is conscious, and interestingly some stimuli seem to be analyzed on both levels. Such experiments indicate that to some degree we are not conscious of the neural activity that contributes to the creation of our conscious perception, or to the way the brain generates consciousness.

Yet, there could be neurons in some other region that control the ones identified as responding to unconscious perception. Thus these other neurons could be determining conscious perception. To rule out such a possibility for neurons in a selected area, Newsome W.T. of Stanford University, electrically stimulated the neurons responsible for registering directed movement. He found out that subjects reported noticing movement in a given direction despite the absence of electrical stimulation.

Full understanding of conscious visual perception requires taking into account also such issues as attention and memory, especially operational memory. Desimone R. with his coworkers of National Institute of Mental Health found the neuron response to be dependent on where and which stimuli the subject was expecting. So the states of consciousness get created in response not only to visual stimuli but also past experience. It's only reasonable to expect that in the case of language behavior, such dependence cannot be neglected, either. Buchsbaum et al. (1982), for instance, reports evidence connecting hallucination and hearing voices to the activity in the right temporal lobe. This evidence comes from experiments in which the scientists measured brain activity of the brains of schizophrenics during verbal hallucinations using cerebral glucography coupled with positron tomography.

Using language, however, is even more complex than being or not being conscious of what we are saying or hearing. Using language seems not to be tantamount to purely physiological processes, whether conscious or not, but also to involve our mind. Yet, before the brain mapping experiments can shed any light on the issue, we need to have some convincing hypothesis concerning the brain. Philosophers, however, have not been able to establish the relationship between the mind and the brain. Skeptics argue that since the mind is both the subject and an instrument of research, it can never understand the origin and mechanism of itself. Additionally, being open for inspection only to its owner, the mind is purely subjective. While some claim that the mind cannot be understood in physical terms, there are numerous theories purporting to show that states of mind are merely complex states of and operations on the brain. In view of such controversies for now we we'll need to build linguistic theories to the extend that can be done neglecting the mind. (The reviews of the notoriously difficult mind vs. body problem from philosophical perspective can be found e.g. in (Edelman 1993), (Searl 1992), (Sergent et al. 1992).

Conclusions

Physical aspects of the brain must impose constrains on models of language. Functional mapping studies using PET, MRI, EEG and MEG appearing in literature since the mid-1990s have provided a wealth of insight into the organization of various language functions in the brain. The studies sampled above indicate, however, that linguists must view the results of such research as preliminary; the information they provide is still fragmentary, imprecise, and hypothetical; unable as yet to impose clear boundary conditions on language models. This is true for several reasons.

First, these studies are designed making the assumption that selected language functions observed in controlled artificial situations sufficiently reflect general components of natural language functions. Second, the measurements quoted do not reflect in a unanimous way neuronal activity corresponding to a selected linguistic skill. Instead they depend on the comparison (subtraction) of the brain activity during the performance of two consecutive tasks, assuming that the difference between those two tasks depicts a single linguistic function and nothing more, plus that these basic brain functions are additive. Therefore, the results reported depend strongly on the model of language assumed. In fact, as Sergent et al. (1992) notice, the subtraction paradigm assumes the modularity of brain functioning in a bottom-up serial fashion that it sets out to prove by its very methodology. Third, the data from experiments using different techniques reflects different, sometimes incompatible methodological and theoretical assumptions. Fourth, the necessity of averaging across subjects masks individual differences in how subjects perform tasks, while it has been shown that both sex, and even background may influence certain aspects of cognitive skills. Fifth, since a change of activated area with task repetition has been reported, the dependence of the activated area on the order of tasks performed is thus not unlikely. Sixth, it is hard do identify purely linguistic functions and differentiate these from other cognitive skills supporting linguistic ones, such as sound and sign recognition. Seventh, the majority of the research published does not consider the frequency distribution of the signal recorded. Eighth, like other psycholinguistic research, neurolinguistic research often relies on interpreting meaning, which can be problematic. Ninth, the brain mapping experiments do not reveal the functioning of individual neurons or their groups. (To hypothesize about such group behavior, all sorts of mathematical formalisms are used, e.g., neural network models. As to the functioning of individual neurons, a few words about the molecular level functioning of neurons is added in the post word.) Finally, the conclusions drawn from the research results often tend not to be justifiable, such as drawing conclusions about the syntactic site in the brain, given the activation area during tasks requiring selecting suffixes (just as it was with numerous psychological experiments in '70s that claimed, for instance, to confirm Chomsky's model by observing that complex sentences take longer to process than simple ones.)

What can be reliably concluded from brain mapping studies is that linguistic functions are widely distributed in the brain, with some areas being especially implicated in linguistic activities and that the linguistic functions are interrelated in a very complex way still being explored.

Post word

The constraints on linguistic models coming from physical structuring of the brain are not limited to the relationship between a group activity of specific groups of neurons and respective linguistic tasks activating them. In addition to investigating neuronal activity of the brain carrying out linguistic tasks, i.e., by looking at its global level organization, linguistic models will be constrained by the molecular level organization of the brain underlying its global level functioning. While full understanding of that relationship is still a distant task, molecular biology has discovered a lot of what is going on within a single cell making up neural networks. Although it is not the purpose of this article to outline this rapidly-growing field here, a few sentences will be added to complete the picture presenting the potential influence of brain functioning knowledge onto linguistic theories.

Concentrated effort to find the genetic bases of neuron functioning as determined by the functioning of the brain on a molecular level started coming from medical studies trying to understand various illnesses. Studies of autistic people, for instance, have contributed to our better understanding of the molecular and genetic mechanism responsible for being able to move our attention to successive stimuli, which is a prerequisite for using language. Stromland et al. (1992) researched the epidemic of autism in children whose mothers took thalidomide and were able to locate the place in the brain and timing critical for the onset of autism in these children. This discovery in turn let Rodier (1996) discover the gene HOXA1 conducive to the sickness, i.e. blocking the ability to move one's attention to successive stimuli.

Another one of the crucial processes allowing language use and allowing general learning skills that has been looked at from the molecular perspective is the process of forming memory traces. It was a Canadian psychologist, Donald Hebb (1949), who proposed that a memory trace in the brain is the result of two neurons connected with each other being active at the same time, thus building, or reinforcing, the synapse connecting these two. This in turn allows the flow of neurotransmitters, chemical substances which reflect an information flow. Next, it was discovered experimentally that hipocamp synapses get reinforced when stimulated with high frequency electric forces while low frequency electric impulses decrease the strength of synaptic connection leading to so called long term depression LTD (depression of the strength of the synaptical connection). These two processes of strengthening and weakening of synapses respectively may account for writing and erasing information in the brain (Squire 1987)

The molecular mechanisms controlling the plasticity of the brain, in turn, (Malenka and Nicoll 1999), are caused by NMDA receptors which are tiny channels located on cellular wall of post synaptical neurons regulating the influx of Na ions to neurons. To open the channel, two signals are required: the attachment of a neurotransmitter and the depolarization of the cellular wall (i.e., a relevant electrical charge distribution change). This feature, i.e., the requirement of two independent signals for the connection to be activated, makes NMDA an ideal candidate for instanciating Hebb's model. This hypothesis has been supported by the study of knockout and Doogie mice, i.e., genetically modified mice in whose brain NMDA has been blocked or reinforced, respectively. The modification involved substituting the gene leading to the production of NR2A, units of NMDA, which are active in adult mice with the one leading to the production of NR2B, units of NMDA active in young mice. NMDA with NR2B units opens the connection between two neurons for about twice as long as do the NMDAs with the NR2A units, which probably accounts for stronger modification of the given synapse. Consequently the knockout mice lost the ability to change the strength of neural connections in hipokamp, while in Doogie mice this ability increased. Tsien (2000) genetically engineered Doogie mice and showed that in adult Doogie mice the synaptical connection is active approximately twice as long as in the control group. He also reports that Doogie mice have significantly outperformed their unmodified cousins in all memory experiments carried out, which tested a variety of memory skills.

Tsien (2000) speculates that the change with age may have evolutionary significance of giving better chances of survival to young mice that have not reproduced yet. From a linguistic point of view, NMDA receptors, being an ideal system of registering co-occurring signals, could serve as a foundational mechanism for categorization processes. We might also hypothesize that the modification of synapses lasting longer in young brains (stronger modification) might cause gross categorization (averaging signals over longer time), while the modification of the synaptical connection opened for a shorter time in response to the same stimuli later on in life could allow subtle adjustments in existing categories by averaging signals over a shorter time.

It has also been discovered that receiving and transforming signals in the brain, necessary for language processing, relies on the structure of cellular communication paths. The first to identify some particles transmitting signals in cytoplasm were Krebs and Fisher (Nobel Prize 1992) and Earl W. Sutherland (Nobel Prize 1997). Since then it has been discovered that the signaling paths in cells are made as if of lego blocks; selected proteins become connected with joining modules and adapter proteins. A limited number of basic modules allows to build signaling routes specific for a variety of signaling proteins. Having a modular signaling path allows to build a number of connections that may cooperate without having to produce a very high variety of building material. Even more so, by introducing a single new module, its connection to already existing ones substantially increases the number of new possible signaling routes just as adding an extra digit to phone numbers for a given city increases the number of potential new phone numbers.

Another type of discovery on the molecular level relevant for modeling language regards finding the first gene directly responsible for language performance. The damage of FOXP2 leads to problems with controlling tongue and lip movement as well as with grammar acquisition without influencing non-verbal intelligence. FOXP2 also regulates the activity of other genes. The discovery was made by studying the genes of a British family in which speech problems were hereditary. FOXP2 is not likely to be the only gene influencing verbal skills. The search has just started.

It also needs to be remembered that the brain does not exist on its own, i.e., without the rest of the body. Gould (1999) has shown that the neurogenesis in hipokamp in mice has been significantly higher in mice living in enriched environments and participating in learning experiments. Gerd Kemperman and Fred H. Gage (1997) in turn have shown that physical activity alone (putting in a running wheel) also leads to an increase of neurogenesis in mice.

Although at the moment the investigation of the brain functioning can provide only general answers as to the functioning of language, in the not so distant future, we may expect much more conclusive constraints that will need to be imposed on models of language.

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