# A discussion of some aspects of neurolinguistics and the manner in which linguistic theories have been able to illuminate neuroscience and vice-versa.

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Evidence to suggest that language function is localised in the brain has been available for at least 146 years since Paul Broca dissected the brain of a deceased patient suffering from aphasia whose speech production had been severely impaired and discovered a lesion in the left hemisphere of the brain. The discovery of lesions in similar locations of eight other patients led Broca to conclude that the faculty for language was located on the left side of the brain. Given the complexities of both language and the workings of the brain, it is not surprising that progress in the field of neurolinguistics has been slow since Broca's findings in 1861. Efforts to study language within a neurological framework or obtain insights into the workings of the brain through the evidence provided by language had for many years relied heavily on data from lesion studies and were hampered by the lack of an adequate theory of language. Recent advances is neuroimaging technology and the formulation of plausible and precise theories of language in general and syntax in particular, by Chomsky and others have contributed greatly to the field.

The group of acquired pathologies known as aphasia is characterised by the occurrence of focal brain damage caused by strokes, brain tumours, brain haemorrhaging, or head wounds. It is this focal nature of the lesions and the seemingly connected specificity of language impairment that is of such interest

to neurolinguists because it offers the possibility of mapping precise language functions to specific areas of the brain which in turn has the potential to better our understanding of language and perhaps our knowledge of how to repair language functions in aphasia patients.

Damage to different regions of the brain results in very different types of language impairments. The two most well-known and studied categories of aphasia are Broca's aphasia and Wernicke's aphasia. Following on from Paul Broca's findings in the 1860's that a number of aphasia patients with language production difficulties had lesions in the frontal lobe of the left cerebral hemisphere (Broca's aphasia), Carl Wernicke, working in the 1870's observed that a group of patients with damage to the temporal lobe of the left hemisphere (Wernicke's aphasia), were able to produce language without too much difficulty, but seemed to have problems with comprehension. Both his own and Broca's observations led Wernicke to the not unreasonable conclusion that Broca's area of the brain controls language production and Wernicke's area controls language comprehension.  This idea proposed by Wernicke, Lichtheim and more recently Geschwind that particular regions of the brain control particular macro language activities is described by Shapiro (2003:346), as the "theory of the localization of 'language as activities'". According to this view, speech production was thought to depend on the motor areas located near Broca's area and comprehension relied on an area associated with auditory perception found in close proximity to Wernicke's area.

While the concept of the localisation of language function has survived (although not without being challenged), this view of language and mind seemed inadequate, not least in respect to linguistic theory. The absence of a plausible theory of language

made the task of constructing an accurate linguistic map of the mind problematic. Chomsky's revolutionary theories of language therefore provided researchers with (some of) the tools they needed to explore the neurological workings of language. The precise syntactic categorisation of language enabled linguists to accurately analyse aphasia patients' speech which in turn led to the realisation that the traditional view, that Broca's and Wernicke's aphasias were respectively production and comprehension disorders, was inadequate.

It was found that for Broca's aphasics, production problems were often mirrored in comprehension. For example, people who were unable to produce morphosyntactic affixes were also unable to understand them. These grammar deficiencies also extended to the sentence level, which meant that Broca's aphasics had to rely on the semantic and contextual features of input to aid comprehension. The externally manifested production problems of Broca's sufferers were thus, partially at least, an effect of faulty syntactic analysis or processing. At the semantic level, however, patients seemed to function more or less as normal. Wernicke's aphasics, on the other hand, generally appeared to retain normal syntactic function, but were deficient at making semantic inferences and often produced nonsensical (although often grammatical) speech. Wernicke's area therefore seemed to have a primarily semantic function, and Broca's, a syntactic one.

Further research which continued to use data from lesion victims, but which also increasingly utilised ever more sophisticated neuroimaging technology, began to suggest that this approach which mapped "linguistic levels of representation" (Grodzinsky & Friederici, 2006:240) to brain areas was also flawed:

"However, as time went by new results indicated that linguistic refinement was insufficient. Intensified cross-linguistic research on language deficits subsequent to focal brain damage (aphasia), in addition to EEG (electroencephalography), MEG (magnetoencephalography) and fMRI (functional magnetic resonance imaging) in the intact brain, revealed inconsistencies; it was gradually realized that the areas involved in syntax processing are not all in Broca's region, nor are all those that deal with semantics in Wernicke's. These results paved the way to a neurolinguistic approach to brain-language relationships."
(Grodzinsky & Friederici, 2006:240)

Recent work by neurolinguists such as Yosef Grodzinsky and Angela Friederici have used data from both aphasia studies and brain imaging to construct language maps of the brain which provide a far more comprehensive picture than previous attempts. Syntax, it appears, is not confined to one area of the brain, but is separated into subcomponents with very precise functions and is found in diverse locations all over the brain:

"In the emerging picture, syntax is neurologically segregated, and its component parts are housed in several distinct cerebral loci that extend beyond the traditional ones-Broca's and Wernicke's regions in the left hemisphere. In particular, the new brain map for syntax implicates portions of the right cerebral hemisphere."
(Grodizinsky & Friederici, 2006:240)

Before further discussing contemporary work, exemplified by Grodzinsky and Friederici, which makes extensive use of brain imaging technology (as well as aphasia data), it is first useful to examine in limited detail, some of these imaging

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techniques in order to put into perspective both their uses and limitations.

**Positron Emission Tography** (PET) traces the flow of blood in the brain through the injection of mildly radioactive water. The more active areas of the brain receive more blood flow and thus are illuminated. PET's main limitation is that because of its relatively poor temporal resolution, it is not a good measure of rapidly occurring brain activity (most brain activity is rapid). Using this technique, Caplan and colleagues (2000) found that the left perisylvian cortex (part of Broca's area) was stimulated by object gap structures, but Wernicke's region was not.

**Functional Magnetic Resonance Imaging** (fMRI) also images blood flow by using powerful magnets to measure relative haemoglobin levels. It produces images with better spatial and temporal resolution than PET although "temporal resolution is still somewhat too coarse to allow us to capture the dynamics of what brain tissue is doing at an appropriate level" (Anderson & Lightfoot, 2002:232). fMRI appears to be useful when measuring 'event related activities'. According to Shapiro (2003:346), a number of fMRI studies have suggested that "different regions appear to support different linguistic information types".

Anderson and Lightfoot (2002:232-233) make the point that one of the biggest problems with studies carried out using these haemodynamic techniques (PET, fMRI) is that the 'majority' were designed by researchers with little knowledge of contemporary linguistic theory and involve studies of individual words and written language presented visually. However, they also point out that "linguists and

neuroscientists are increasingly cooperating in this work, especially as the greater benefits of fMRI are realized by both communities" (2002:233). This cooperation has indeed taken place and as we shall see, recent research designed by neurolinguists (Grodzinsky, etc…) appears to have been more successful.

Whereas haemodynamic techniques measure blood flow, electro-chemical methods such as **Electroencephalography** (EEG) measure the electrical current of neurons. This is done by positioning electrodes on the scalp. EEG has high temporal resolution (much higher than fMRI) and can thus measure electrical brain activity in milliseconds. Much of the research carried out using EEG, involves the event-related potential technique (ERP) in which changes in electrical currents are recorded in relation to external language events (e.g.word or sentence level input). Anderson and lighfoot(2002:233) point out that in contrast to fMRI studies much of the research conducted using this technique is designed by linguists rather than neuroscientists (one of the reasons for this, they suggest, is that the equipment is much cheaper and therefore more affordable for linguists!) In particular, researchers have used ERP to study language processing. Since research carried out by Kutas and Hillyard (1983), the N400 waveform has been associated with semantic processing. Two waveforms (P600 and LAN wave) have been connected with syntactic processing .One of the drawbacks of ERP, especially when trying to construct a language map of the mind, is that it does not indicate from which area of neural tissue the electrical signal emanated.

**Magnetoencephalography** (MEG) also measures the electrical currents caused by active neurons, but can only sense signals from cortex areas located close to the surface of the scalp. However, it produces high quality temporal and good spatial

resolution. The quality of temporal resolution has been compared favourably to results obtained using intra cranial electrodes. Used in conjunction with other imaging technologies, fairly robust results can be achieved. Friederici and colleagues have used MEG to contrast semantic and syntactic variables and link them to neural activity.

Considering the relative strengths and deficiencies of all theses imaging techniques, we might predict that the most successful and comprehensive research would utilise more than one, if not all of them. Furthermore, it would seem likely that studies employing neuroimaging techniques would benefit from building upon the data from lesion studies and pose research questions that are based on a plausible language model. This three pronged tactic would appear to offer the most credible approach.

However, this is not always how research has been conducted. As Grodinsky (2002) points out neuroscientists utilising new imaging technology to study language, initially failed to make full use of the body of aphasia data that had been compiled since Broca:

"…functional imaging of language witnessed an attempt to start almost from scratch. Caught by the excitement that swept the field when neuroimaging techniques were introduced, many investigators have largely tended to dismiss aphasia data rather than seek cross-methodological convergence. Some important mistakes were repeated as a result." (Grodzinsky, 2002:5)

Additionally, in hindsight, linguistic models upon which research was based were

inadequate. For example (Petersen et al., 1990) used PET and fMRI to observe the differences in brain activity triggered by production and comprehension, a linguistic distinction (language = activities) no more precise than the one Wernicke worked with, well over a century previously.

Other early contrastive studies (eg. Mazoyer et al. 1993) used PET to try to pinpoint areas of the brain activated by known and unknown languages. These studies generally treated language holistically and employed a diverse range of linguistic stimuli. Perhaps not surprisingly, the results were also very varied; a range of neurological areas were implicated with little agreement between studies.

According to Grodzinsky, these anatomically incongruent findings result from the insufficiently defined levels of linguistic analysis used by the researchers:

"…it [is] quite possible that activities or languages may not be the correct units of analysis for a precise characterization of brain/language relations. One possible reason for the lack of anatomical congruence among past studies, then, is that they made incorrect choices of analytic units." (Grodzinsky, 2002:6)

Dapretto & Bookheimer(1999) using fMRI and Friederici and colleagues (in a number of studies) using PET and fMRI and MEG have sought to separate syntactic processes from semantic processes and map linguistic subsystems to areas of the brain. However these studies also produced results with considerable anatomical overlap which would indicate that the linguistic model which informed the studies (the separation of language into subsystems) is also inadequate.

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Of course the anatomical overlap of findings could conceivably be accounted for by other factors: language is not localised-it is distributed throughout the brain; individual brains differ as to where language functions are located; or imaging equipment is not trustworthy. However, Grodzinsky(2002:7), while acknowledging that other factors may be partially responsible, believes the explanation is that these experiments are not testing what they are supposed to be testing, "caused mainly by an insufficiently refined view of linguistic structure".

For Grodzinsky, rule systems, whether they are syntactic, semantic, phonological, or lexical, provide the most revealing unit of analysis. This view is very much supported by data collected from aphasia studies which indicates that language deficiencies are rule specific. In fact, from a perspective that does not take rule type into consideration, the results obtained from aphasia studies would appear somewhat surreal. For example,  people suffering from Broca's aphasia can produce agreement inflection, but have problems with tense inflection. This has been shown to be the case across a range of languages (Friedmann and Grodzinsky, 2000).

Disruptions to comprehension are also syntactically selective and correspond to specific rules. Broca's aphasics have difficulty understanding transformational sentences such as passives, object relatives and object questions, but can comprehend non-transformational sentences (Zurif, 1995). These findings have led to the formulation of the Trace-Deletion Hypothesis (TDH) (Grodzinsky, 1986, 2000), according to which, in receptive language, the brains of aphasia patients are unable to perform transformational computations because mechanisms, localised in Broca's region, that carry out these operations, are damaged.

Cross language comparative studies which have looked at Chinese, Dutch, English, German, Hebrew, Japanese and Spanish appear to support the TDH. English speaking aphasics are able to correctly interpret active sentences, typically subject-verb-object structure. For Japanese aphasics, however, the situation is more complicated. In Japanese there are two types of active sentences: the subject-object-verb type, and the equally acceptable object-subject-verb type. The following examples are adapted from Grodzinsky (2002:4).

English: Taro (S) hit (V) Hanako (O).

Japanese #1: Taro (S) ga Hanako (O) o nagutta (V).

Japanese #2: Hanako (O) o Taro (S) ga nagutta (V).

The two sentence types are semantically identical, and in fact the only difference between them is that #2 is transformational. As the TDH would predict, Japanese speaking aphasics compute #1 correctly, but perform at chance level for #2.

Chinese, like English, is mostly, a SVO language, but whereas for English the heads of relative clauses precede the relative, for Chinese, they follow it. This reverse order is clearly manifested when the language of Chinese speaking and English speaking aphasics is contrasted. Chinese speakers' comprehension of subject relatives is at chance level and above chance level for object relatives. In contrast, English speaking aphasics' understanding of subject relatives is above chance level, and at chance level for object relatives. As Grodzinsky (2002:5) puts it, "English and Chinese thus yield mirror-image results, which correlates with a relevant syntactic

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contrast between the two languages".

Grodzinsky (2006:240) believes that "there is a regular relationship between subcomponents of syntactic theory and brain loci". That is to say, specific aspects of universal grammatical knowledge are localised in specific areas of the brain. This has led him to an attempt to construct, using data from lesion studies and neuroimagiing, a "formal syntax map (FSM)"(2006:240).

There is a striking contrast in the way Broca's aphasics comprehend two syntactic rules in particular. They can understand sentences that include verb movement (MOVE*v*) and notice when the rule has been violated, but fail to comprehend sentences that involve noun phrase movement (MOVE*xp*) and are insensitive to rule violations involving this rule. Not surprisingly, given the dramatic nature of this phenemenon, a fair amount of research has been carried out with both neurologically normal people and aphasia patients in a number of languages including English (Stromsword et al, 1996, Caplan et al, 2002, Santi & Grodzinsky, 2004), German (Roder et al, 2002, Bornkessel et al, 2005), Hebrew (Ben-Shachar et al, 2003, 2004) and Dutch (Den Ouden et al, 2004). Unlike the anatomically ambiguous results from earlier brain imaging studies, which sought to map language activities or levels of language representation to brain loci, results of studies attempting to match grammatical rules to brain location are more uniform. MOVE*xp* appears to consistently activate the left inferior frontal gyrus (IFG), as well as other regions such as the superior temporal gyrus (STG), and MOVE*v* seems to trigger activity in the left superior frontal gyrus (SFG) and the middle frontal gyrus (MFG). Additionally, binding operations ,which like MOVEv are intact in Broca's aphasics, appear to activate the middle frontal gyrus (MFG) of the right hemisphere, the left

MTG (middle temporal gyrus) and the left orbital gyrus (OG).

The FSM therefore, albeit an incomplete work in progress, seems to provide a relatively precise representation of brain-language relations in terms of syntax at least. Of course, syntax does not operate in isolation, and it is one of the challenges of the field of neurolinguistics to tease apart the various operations that occur when language is processed. How can we be sure that areas of the brain that are active during syntactic operations are not performing some other function? We can eliminate certain areas such as neural tissue linked to the motor mechanisms that control the vocal chords during speech, for example, by contrasting spoken language with sign language, but separating the various interlinked processes that occur during language operations is more problematic. This question is of course of equal relevance to other linguistic subsystems such as semantics. For example, Caramazza and Hillis (2003:182, Encyclopaedia of Cognitive Science) highlight one of the difficulties in trying to tease apart the intricately interconnected language functions of the brain in studies of Wernicke's aphasics:

"Most functional imaging studies fail to distinguish between access to auditory word forms and mapping word forms to semantics, since recognizing or saying a word is likely to 'automatically' activate its meaning." (182)

Experiments are of course designed with these difficulties in mind, but the inconsistent, anatomically overlapping results of early experiments, were probably due in no small part to a muddying of language functions. With the application of a more precise linguistic model to research, the results seem to indicate that there is less muddying, but it has not yet been eliminated. Grodzinsky, for example points

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out that although the STG is activated during MOVE*xp*, "these effects might not be purely syntactic, but are instead due to processes that implement syntax in use" (2006:243). In would seem then, that in order to maximise the accuracy of the FSM or semantic, phonological or lexical brain maps, for the purposes of elimination at the very least, it would be useful to also pinpoint regions of the brain which are involved in processing and parsing.

Friederici's Language Processing Map (LPM) aims to do just that. Whereas the FSM maps syntactic knowledge per se, the LPM seeks to locate the areas of the brain that are involved in the processing of syntax. The LPM hypothesis is seen as complementing that of the FSM in that just as grammatical subcomponents of language knowledge are individualised and localised so are the "subcomponents of the language processing system …neurologically distinguishable and localizable" (2006:241). Friederici's research has utilised all four major brain imaging techniques: PET and fMRI to map processing to specific brain regions; and EEG and MEG to measure the time scales involved. According to the model, there are three distinct processing stages. The first stage computes phrase structure based on lexical categorisation; the second establishes dependency relations between constituents; and the third stage involves the amalgamation of all available syntactic data. Briefly, stage 1 seems to activate the frontal operculum which is in the left IFG near the lower part of Broca's area and the anterior STG; stage 2 is associated with Broca's area (BA 44/45); and stage 3 is linked to activity in the left and right posterior STG. In addition, data from diffusion tensor imaging suggests that these areas are structurally connected which would seem to lend further credence to Friederici's hypothesis.

Grodzinsky and Friederici's attempts to construct language-brain maps of, respectively, syntactic knowledge and syntactic processing represent significant advances in the quest to gain a more comprehensive understanding of brain-language relations. However, despite considerable progress our knowledge of how the brain works in general and brain-language relations in particular is very limited in comparison to our knowledge of the rest of the body, for example. What we know is dwarfed by what we do not know and, to paraphrase Donald Rumsfeld, there are more unknown unknowns than there are known unknowns.

In many respects we know less about brain-language relations than we do about the relationship between the brain and other physiological functions such as the visual system. This is largely because the neurological study of language is at a distinct disadvantage to the study of other brain functions because language is, as far as we know, unique to the human species. This, for obvious ethical reasons, rules out the use of intrusive experimental techniques which are still in many ways more revealing than experiments conducted using state of the art imaging technology. For non-language cognitive functions such as vision, hearing, motor reflex etc…, intrusive research carried out on other animals produces findings that may be as relevant to humans, but because animals cannot speak, this is obviously not the case for language research. Nonetheless, research into these and other areas may have something to offer linguistics, if we suppose as Anderson and lighfoot (2002:37) clearly do, that certain aspects of the language organ have parallels in other physiological systems:

"The grammar is one subcomponent of the mind, a mental organ which interacts with other cognitive capacities or organs. Like the grammar, each of the other organs

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is likely to develop in time and to have distinct initial and mature states."

In research that started in the 1950's two nobel prize winning neurophysiologists, Hubel and Wiesel, connected microelectrodes to single cells in the cortices of cats and other animals. Through these experiments they were able to record how specific neurons in the visual system reacted to specific environmental stimuli. It was discovered that although some facets of the visual system are hard-wired from birth, much of the visual system will not develop unless triggered by patterns in the environment. If, for example, a kitten is not exposed to horizontal lines from an early age, its visual system will not recognise nor be able to develop the ability to recognise horizontal lines in future.

What does this tell us about language? Nothing directly of course, but there are obvious parallels with generative theories of grammar. Specifically, parts of the language organ (i.e. Principles) are, like the visual system of cats, hard-wired from birth and other aspects of language (i.e. Parameters) are set after being triggered by environmental stimuli (i.e. external language). If cats or other animals could speak then we would surely know more about language-brain relations and questions such as whether there is a critical period for learning language would likely be resolved once and for all. Clearly, language researchers cannot deprive children of linguistic stimuli, as kittens were deprived of visual stimuli. Sad cases such as 'Genie' who grew up in a language deprived environment, cannot provide the answers because the abuse she suffered could have impeded development generally.

Neurolinguists, therefore, face restrictions that other branches of neuroscience do not, and in some areas have little more to work with than the analogies with other

physiological systems that can be inspired by sound linguistic theory. As technology advances, this may not always be the case and indeed there is a certain amount of evidence of the existence of a critical period from imaging studies that have shown that "early" bilinguals process the two languages in overlapping areas of the brain, but bilinguals who started learning their second language after puberty process the two languages in separate areas (Anderson & Lightfoot, 2002:209). Of course, not having experience of a second language until later life is not the same as having no access to any language, but nevertheless, these findings are intriguing if potentially confusing because they not only suggest that there is a critical period, but that the brain (in the case of "late" bilinguals) may be adaptable enough to utilise different areas for language when other areas have been shut off. This could also explain why some aphasics are able to recover their language abilities. This possibility that there are substitute areas of the brain to which language functions can be transferred in the case of age related biological 'shut down' or brain damage, makes the task of constructing a language map of the brain all the more difficult.

Nevertheless, as we have seen, the signs are that neurolinguists are on the right track to plotting an accurate map of brain-language relations. Should this goal be achieved, the implications for the fields of neuroscience and linguistics and beyond are far reaching. A linguistic map of the brain could further not just our knowledge of language-brain relations, but could increase our understanding of the workings of the brain per se. Rehabilitation of aphasics, and even sufferers of other brain disorders might be improved and for linguists, an accurate map of brain-language relations would enable the empirical testing of abstract theories.

It is of course this interface between linguistic theory and neuroscience which

has propelled the advances to date, and indeed as we have seen, the failure of neuroscientists to initially apply adequate linguistic theories to their research led to less than successful results. Gardener (1985:287) explains why neuroscience needs to embrace linguistic theory:

"…a neurologist ignorant of linguistics might rely on naïve intuitions about language: one would therefore describe an aphasic patient as unable to use "small words" or to "speak in full sentences." But a linguistically trained observer will immediately be able to pose questions and introduce distinctions at a subtler level…"

Sadly, as discussed above, neuroscientists were still making similar mistakes long after Gardener wrote this.

Grodzinsky sees the relationship between the two fields as a two sided equation:

"This research enterprise must thus define brain/language relations in the form of an equation, both sides of which contain complex terms: on the one side there is linguistic behaviour, described in the best theoretical vocabulary one can find, and on the other side there are brain mechanisms, accounted for by whatever neuroscience can offer." (2002:1)

Thus, this relationship can be viewed as an equal partnership with both sides contributing to the field in an increasingly mutually dependent interaction in which linguistic theories drive neuroscientific research which in turn leads to the modification of linguistic models. The rich potential offered by co-operation between the fields of neuroscience and linguistics is envisaged by Chomsky:

" A primary goal is to bring the bodies of doctrine concerning language into closer relation with those emerging from the brain sciences and other perspectives. We may anticipate that richer bodies of doctrine will interact, setting significant conditions from one level of analysis for another, perhaps ultimately converging in true unification."

(Noam Chomsky, 2000:27)

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