Brain Mechanisms for Sign Language

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General Framework

The use of modern technologies to explore brain function stimulated the discussion of the proper nature of cognition and behavior. We now have to admit that individual cognitive competences are the result of a convergence of several components. Some of these components are related to biology, some are related to environmental stimulation and some are related to the opportunity.

Language is one the competences that made human kind different from the other species. We hardly understand how this phenotype developed with the development of humans and it is necessary to work on hypothesis based on several kinds of findings.

If we take in consideration the average situation of a middle aged Caucasian human being that is not left hander that acquired oral language in a normal speaking monolingual community we can discuss the cortical organization of speech processing like, for instance, Hickok and Poeppel did (2007). These authors considered that the cortical areas involved in speech processing are organized in two main pathways: a dorsal stream that maps acoustic speech signals to frontal lobe articulatory networks and a ventral stream that processes speech signals for comprehension. This model assumes that the ventral stream is largely bilaterally organized and that the dorsal stream is strongly left-hemisphere dominant. The bi-hemispheric representation of the ventral stream has to be understood as an asymmetrical distribution of computational processes. The evidence from brain lesion studies, supports the notion that lesions of the regions involved in the right ventral stream do not disturb language. These regions when undamaged can in turn compensate for aphasia resulting from lesions on the left side. This was already suggested in the models of Wernicke and we were also able to demonstrate this effect with dichotic listening in the recovering from aphasia (Castro-Caldas and Silveira Botelho,1980).

It is necessary, however, to consider that the findings that support this model are the result of the adaptation of a certain kind of brain to a certain kind of stimulation. There are different brains and different stimuli (for a general review see, for instance, Coppens et al Eds.,1998). Deaf subjects are an example of an exception. We know very little about the importance of the absence of hearing in fetal brain development, we know for sure that the brain is not stimulated by sound and we know that communication stems on visuo-motor system different from the audio-motor system of hearing subjects. Therefore all the considerations that fed the model mentioned above need to be reviewed a least on what concerns the ventral stream. However, we know the brain cortex processes operations that are modality independent. This means that the temporal cortex processes auditory information not because the information is based on sound but because the structure of the information that is carried is best suited to be processed there. This is also true for vision: when born blind subjects read by Braille they activate the visual cortex (Sadato et al. 1998).

It is still important to consider that, from the evolutionary point of view, language is probably the result of the evolution of a macaque mirror neuron system for action perception and production (Arbib,

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2005). Indeed, since the seminal report of Rizzolatti in monkeys (Rizzolatti et al, 1996) we accumulated evidence of the importance of this system for human cognition and behavior.

Through this system both hearing and deaf subjects acquire the competence of communicating which is obviously paced by the cognitive competence of pragmatics. The difference is that deaf subjects use vision to receive information and the hands to produce communicative motor actions and hearing subjects can use two systems. For hearing subjects there is the natural preference of receiving acoustic information and producing communicative motor actions with the vocal articulatory system.

The first question that we can raise, therefore, concerns plasticity. We know that the comparison between schooled and unschooled subjects makes a difference in the development of the brain both functionally and anatomically. The comparison made between these two groups in adult age showed functional differences while subjects repeted words and pseudo-words (Castro-Caldas *et al*, 1998) and anatomical differences in connectivity through the corpus callosum (Castro-Caldas *et al*, 1999).

With this propose Allen *et al* (2008) investigated whether auditory deprivation and/or sign language exposure during development alters the macroscopic neuroanatomy of the human insula. Volumetric analyses were based on MRI data from 25 congenitally deaf subjects who were native users of American Sign Language (ASL), 25 hearing subjects with no knowledge of ASL, and 16 hearing subjects who grew up in deaf families and were native ASL signers. Significant variation in insula volume was associated with both hearing status and sign language experience. Compared with both hearing groups, deaf subjects exhibited a significant increase in the amount of gray matter in the left posterior insular lobule, which they hypothesize may be related to the dependence on lip-reading and articulatory-based (rather than auditory-based) representations of speech for deaf individuals. Both deaf and hearing signers exhibited an increased volume of white matter in the right insula compared with hearing nonsigners. They hypothesize that the distinct morphology of the right insula for ASL signers may arise from enhanced connectivity resulting from an increased reliance on cross-modal sensory integration in sign language compared with spoken language.

This study illustrates well the plasticy of the brain related to the type of information processing. Other differences are probably present that need to be acknowledged along with the better understanding of the computational processes involved both in oral and in sign language.

We have to be careful, however, when studying the correlation between function and brain organization in sign language. There are different ways of processing sign language: the subject may be born deaf from deaf parents and be raised very early through sign language, or he can be deaf and born from hearing parents that learn sign language to communicate with him, or he can hear being born from deaf parents and learn very early sign language, or sign language can be learned by hearing subjects in adult life. All this and other possibilities may have an expression in the areas of the brain that are recruited to fulfill the function. Therefore the subjects to be included in the different studies need to be well selected and the results obtained should not be generalized.

The last general question that we think it is necessary to have in mind before trying to find the biological basis of sign language concerns the proper nature of the communication system or, in other words, is sign language a language that parallels oral language in all its features or is it a different competence. Not being a linguist it is hard to make a deep analysis of this topic therefore I prefer to quote Klima and Bellugi (1979) that in there seminal work about American Sign Language wrote: "*We do not mean to argue that spoken language and sign language are essentially the same. Certainly we would be the last to argue that speech does not constitute part of the biological foundations of language. But if speech is specially selected, if sound constitutes such a natural signal for language, then it is all the more striking how the human mind, when deprived of the faculty that makes sound accessible, seizes on, perfects, and systematizes an alternate form to enable the deeper linguistic faculties to give explicit expression to ideas*"(p.315). Furthermore we have still to consider that as we have differences in the structure of oral languages around the world, which matters for mind-brain correlations, it is possible that such differences are also present among sign languages.

Lesion Studies

The classical method to interpret brain function was based on the observation of patients that for some reasons acquired a brain lesion. There are several theoretical arguments against this method. The main argument is also a classical one and was raised by Jackson in the XIX century. Jackson claimed that *"to locate the damage which destroys speech and to locate speech are two different things"* (*apud* Head, 1926). Other arguments are related to the proper nature of the cerebral lesions. Vascular lesions are the more frequent case and were the basis for most of the knowledge that was acquired for the past century. However, ischemic lesions are not random because they occur in vascular territories that are similar from subject to subject. When we discuss vascular aphasia we are talking about arterial syndromes. Traumatic lesions are usually multiple and therefore they are difficult to localize. Tumors are also responsible for focal syndromes, however they are progressive lesions and there are always progressive recovery mechanisms accompanying the growing process of the tumor.

Even though, we learned very early with Broca that language was dependent on left hemisphere mechanisms (Broca, 1865) and with Benson that fluent aphasias were the result of post-central lesions and non-fluent aphasias were the result of pre-central lesions (Benson, 1967). Both these aspects are important land markers in the history brain function. Therefore, studying patients with brain lesions is still a fundamental source of evidence that contributes enormously to our knowledge.

The work of Poizner, Klima and Bellugi (1987) is unavoidable to discuss the effects of brain lesions on sign language performance of deaf subjects. They report their findings in patients with both right and left hemisphere lesions. These and subsequent findings aloud the conclusion that sign language was also left-lateralized and that the classical localizations of lesions resulted in comparable dysfunction between oral and sign speakers. It was suggested that the visual component of sign language could be an important aspect to consider. As a matter of fact signs related to space seem to be disturbed by right hemisphere lesions.

Reviewing the literature on aphasia in deaf subjects, Corina (1989) considered that there is a clear indication of left hemisphere dominance for language. There were also findings supporting the relationship of anterior and posterior lesions of the left hemisphere with deficits in producing and deficits in comprehension. "*However*, this author stated (p.37), *whether the exact neural substrates underlying the symbolic systems supporting language comprehension and production are shared by spoken and signed language remains to be determined*". He quotes several single cases in which the comprehension deficit was not related to the classic lesion in Wernicke's area, and cases in which the production deficit was due to lesions away from Broca's area.

In this paper the author also reviews some aspects of neurolinguistics and the role of the right hemisphere. In the first case the disturbances in sign productions seem to parallel those found in oral aphasia, like the presence of paraphasias of different types or agramatism. Even jargonaphasia was reported in a case from 1943 (Leischner, 1943).

The question of the right hemisphere seems to be more complex. Corina (1989) considered that "*it seems reasonable to entertain the possibility that the right hemisphere damage does not disrupt linguistic function per se, but rather impairs the execution and processing of linguistic information in sign language, in which spatial information plays a particularly salient role. However, the issues become more complicated when we consider the syntactic aspects of ASL.*" There is evidence from some of the cases with right hemisphere lesions that the spatialized syntax is disturbed and Poizner et al (1987) considered that the perceptual processing involved in the comprehension of spatialized syntax involves both left and right hemispheres.

Studies on the development of the brain of hearing children revealed that there is a correlation of the growing pattern of the cortex of the inferior frontal grey matter of the left hemisphere and the development of phonology (Lu et al, 2007). On the other hand, we know that the absence of stimulation is a reason for the non development of language (see, for instance, Curtis,1977). Therefore there is a crucial period in which the stimulation induces learning and brain development. The study by Newman *et al* (2002) calls the attention for a critical period for right hemisphere recruitment in ASL processing. The authors found that the right angular gyrus was active during ASL processing only in those subjects that were native hearing bilinguals (ASL-English) and not in late learners of ASL. This finding is crucial for teaching processes: if the brain is stimulated during the critical period it develops the best structures to deal with the information and therefore we may expect that the quality of the processing is better. It is well known that learning a second language late in life is possible but is very rare that this is done without a foreign accent.

The link between findings on activation studies with lesion studies is not always easy to establish. Even concerning the involvement of each hemisphere in sign language comprehension Hickok *et al* (2002) studied a group of nineteen lifelong signers with unilateral brain lesions. The subjects were tested on comprehension with different degrees of complexity. Results showed that subjects with left temporal lobe lesions were much more impaired than the remaining subjects and subjects with right hemisphere lesions were as impaired as hearing subjects with right hemisphere lesions. The authors concluded that deaf and hearing individuals have a similar degree of lateralization of language comprehension processes and that language comprehension in sign language depends primarily on the integrity of the left temporal lobe.

Activation Studies

Contrary to lesion studies in which Nature decides the localization of the lesion and the observer tries to reveal the processing rules by finding what is disturbed and what is preserved in the performance of patients, in activation studies the observer has to design a task directed to a computational operation in order to reveal which region of the brain becomes active.

For the past decade a great number of experimental work has been published illustrating several steps of the complexity of the mechanisms responsible for comprehension and production of sign language. It is hard for the moment to make a comprehensive review of this literature. Therefore, I will review some of the work that can be considered more seminal.

May be we could start a so-called Cartesian question. Movement, which is a quality of the body and cognition, which is a quality of the mind. Willems and Hagoort (2007) reviewed recently this question focusing mainly on co-speech gestures. As the authors mentioned, co-speech gestures embody a form of manual action that is coupled to the language system. Both gestures and spoken language occur simultaneously with the intention of communicating. Therefore they belong to one integrated system of communication (*see* McNeill, 1992).

As it was mentioned above both intentional gestures and speech sounds activate the mirror neuron system. When subjects listen to meaningful syllables there are significantly more activity in bilateral precentral gyrus and central sulci than when subjects listen to meaningless sounds (Wilson *et al* 2004). If we go back to work of Petitto and Marentette (1991) that suggested the parallel development of oral and hand babbling as precursors of oral and sign language we can admit that for the general intention of communicating the brain of deaf signers and oral speakers recruits the same regions.

More recently, Corina *et al* (2007) studied in more detail the activity of this mirror neuron system while both deaf signers and oral speakers were viewing different actions. Subjects were scanned in three different conditions: intransitive self-oriented actions, transitive object-oriented actions and symbolic action-signs used in ASL. Previous research suggested the involvement of bi-lateral prefrontal cortex (PFC), parietal and superior temporal sulci (STS) activation related to this mirror neuron system (Grezes and Decety, 2001) in hearing subjects. Some authors suggested that it was possible to postulate a model of sensory motor control involving the STS, PFC and F5 in the perception of action and a reverse model used to generate predictions of movement outcome during imitated actions (Miall, 2003; Carr et al, 2003; Iacoboni, 2005). The consistency of these hypothesis in still to be definitively understood and it is well accepted that the nature of the gesture is an important factor to make differences in the activation patterns.

The results of the study by Corina *et al* (2007) demonstrated that the different classes of actions engaged the a frontal/parietal/STS human action recognizing system in an highly similar fashion. This neural consistency across motion classes was true primarily for hearing subjects. Deaf signers engaged left-hemisphere perisylvian language areas during the perception of signed language signs. They also did not engage the expected fronto/parietal/STS circuitry during passive viewing of non-linguistic actions but instead they activated middle-occipital temporal-ventral regions which are known to participate in the detection of human bodies, faces and movements. The authors suggested that deaf subjects may engage specialized neural systems that allow for rapid online differentiation of meaningful linguistic actions from non-linguistic human movements.

The study from Campbell and Capek (2008) brings new insight to the knowledge of the mechanisms that are involved in visual processing of information related to communication. The authors raised two questions: do deaf and hearing people differ in the regions activated by (silent) speechreading?, and how does the presence of mouth actions in the sign affect the cortical activation pattern? A group of deaf subjects with good proficiency in lip-reading was compared to a group of hearing subjects while viewing blocks of silent spoken words in the fMRI. For the first question the authors found that the left superior temporal cortex, including auditory regions, was strongly activated in the brains of deaf compared with hearing participants when processing silent spoken (speechread) word lists. In the second place, they found that within the signed language, cortical activation patterns reflected the presence and type of mouth action that accompanied the manual sign. Signed items that incorporated oral as well as manual actions were distinguished from signs using only manual actions. Signs that used speechlike oral actions could be differentiated from those that did not. Thus, whether in speechreading or in sign language processing, speechlike mouth actions differentially activated regions of the superior temporal lobe that are accounted auditory association cortex in hearing people. This is a good example of the plasticity of the brain as was mentioned above.

As it was mentioned above the neurobiology of sign language (and even the neurobiology of spoken language) is far from being a finished discussion. The recent paper by MacSweeney et al (2008) calls the attention to some of the outstanding questions that need clarification and that are a good way of concluding this brief review and are as follows: "*1. What is the influence of age of first language acquisition on language processing and its underlying neural systems? 2. How do memory and language systems interact and what is the impact of language modality? 3.To date, iconicity does not seem to influence SL processing. However, might iconicity have a role in semantic organization and imagery? 4. What characteristics of SL and SpL influence laterality of processing? 5. Can studies of SL give us further insights into the extent to which the mirror neuron system is involved in language processing? Are the fronto parietal parts of this system differentially involved in SL, SpL and gesture processing? 6. To what extent are regions associated with language processing driven by the intentional stance of the observer and the potentially communicative nature of the actions? 7. Speakers can hear themselves speak. Signers do not see their own signing as others see them. What are the roles of visual and proprioceptive feedback and the proposed mirror system in language monitoring? 8. Does the mouth have a gestural role in SL similar to that of the hands in SpL? Are these "gestures" processed similarly in the brain? 9. How do links between hand and vocal gestures inform our understanding of the evolution of language and its neurobiological bases?"* (p.438).

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