Chapter 4

EMBODIED SEMANTICS

The role of the sensory-motor system for language comprehension

4.1 The rationale and the structure of this chapter

What are the biological roots of human communication? How semantics is made possible by the brain? These questions represent two of the main challenges for the contemporary cognitive linguistics. Today, after years of theoretical speculations about linguistic phenomena and their relationships with the pragmatic and the social context, many biological studies inform the discussion in linguistics. The result of this trend is the emergence of a new multidisciplinary field of research based on the interaction between biological disciplines, such as neuroscience, and cognitive linguistics. Findings in this context open new possibilities for the development of innovative theoretical conceptions, shedding light on the *natural roots* of human communicative skills. Many scholars from linguistics, as well as psychologists and philosophers, look at these results with an increasing interest.

The previous section introduced several behavioral data concerning the interaction between bodily gestures and linguistic abilities, supporting the idea that human communication *is not independent* from motor intentionality. Besides to involve only behavioral evidences, a motor theory of language (see section 5) predicts a contribution of the human motor apparatus not only for language production, but for language comprehension as well. This makes it possible planning neurobiological experiments evidencing how language understanding is rooted in functions carried out by the motor system. For this reason, an empirical confirmation for the motor theory of language usage and understanding should be considered subordinated to the acquisition of an ensemble of data evidencing the activation of motor areas in the human brain as condition for both the linguistic production and linguistic comprehension. The aim of this section is to provide a critical review of the prominent neurobiological findings supporting the idea that linguistic cognition is grounded in brain’s *sensory-motor* circuitries, that is, *dynamic bodily possibilities* in which the enactment of both actions and abstract concepts rely.

4.2 Cortical multimodality and the motor theory of language understanding

For a long time the cortical systems for language and actions were thought to be paradigmatic examples of independent and autonomous functional systems or modules (Fodor, 1983). Modular models were preferred because it was thought that they were necessary for explaining neurophysiological data concerning cases of double dissociation such as those represented by patients with a predominant loss of speech *motor abilities*, but a relatively intact language comprehension (Broca's aphasia), or the reverse situations characterized by patterns of comprehension deficits with fluent speech output (Wernicke's aphasia). Coherently with this view, the pre-motor cortex was classically considered to be concerned only with the *planning*, the *selection* and the *imitation* of bodily movements (Wise, 1985), ascribing two different localizations in the brain for action execution and language understanding with no essential functional relationships. In this view language was nothing but an abstract human ability with, nothing but, practical functions.

Contemporary theoretical perspectives offer a different view. Many cognitive functions might be served by distributed interactive neuronal systems, organized in *functional networks*, rather than in local and autonomous modules (Uttal, 2003). Beside a certain degree of specialization, several brain areas are physically characterized by functional connections with many other parts of the brain. Recent brain-imaging studies have shown the presence of spread interactions between different cerebral locations during *single* cognitive tasks. Moreover, the emergence of *multimodal* areas, that is, areas characterized by the possibility to be *functionally* activated during the accomplishment of radically different cognitive tasks, such as for example *action execution* and *language understanding*, has been established (for a general review see: Fischer and Zwaan, (2008)).

In order to reconcile the modular view with the distributed accounts of cognition, one may claim that some brain areas should be considered functional core regions, while other interactions with supplementary areas *have not* a functional role. In the case of linguistic cognition, for example, the traditional core regions for language, such as Broca and Wernicke's areas, might be assumed as *functionally* crucial, whereas the activation of supplementary motor areas might be considered a redundant by-product of language processing. However, an alternative possibility is that supplementary language areas are critical as core areas, but with a more *selective* function for specific categories of knowledge, so that they are employed to process specific types of language portions and concepts (Pulvermuller, Shtyrov, & Ilmoniemi, 2005a).

The possibility of studying the role of supplementary areas in language processing is offered by the analysis of the motor and pre-motor cortex during the execution of linguistic tasks involving motor concepts, as well as motor related words and sentences. A *motor theory of language understanding* is grounded in the assumption that the action of language production and the processes of language understanding are both based on the role of *cognitive invariants*, as well as on the *multi-modal activity* of the motor cortex. In this view, the expected role of the motor apparatus for language production, that is, the expected role for words expression and for gestures execution, is coupled with the activation of the same apparatus during language processing (communicative resonance). At same time the motor system might be involved in conceptual understanding and be activated by the semantic content of a word or a sentence (referential resonance).

First to propose a theory involving a role of the motor apparatus in language cognition was Lieberman's *Motor Theory of Speech Perception* (MTSP) (Liberman et al. (1967); Liberman & Mattingly, (1985)). Even if MTSP is strictly committed with a modular conception of the cognitive activity (for a discussion about modularity and MTSP see Mattingly & Studdert-Kennedy, (1991)), this theory offers a radically different view if compared to the mainstream cognitive linguistics, assuming that speech perception and understanding are not explained by the analysis of phenomena related to the perception of sounds in general, rather it should be seen as a cognitive specialization related to phonetic gestures[1]. Following Liberman and colleagues, the object of speech perception are the intended phonetic gestures of the speakers and they are represented in the brain of the hearer as motor commands relating to articulators, so that perceiving an utterance is substantially influenced by the perception of an intended pattern of gestures[2] involving lips, tongue and other vocal effectors.

[1] This view is drastically in opposition with the assumption that speech is formed elaborating sounds that rely for their production and perception on separate processes.

[2] Evidences are represented by phenomena such as the previously introduced *McGurk effect* (see section 1.3), experimental findings such as that concerning a compatibility effect in speech understanding and speech gestures, showing how the perception of a syllable is faster when coupled with the vision of a mouthed face articulating the same syllable (Kerzel & Bekkering, 2000), and findings such as the prediction that if listeners also perceive speech gestures, speech imitation should be faster, because speech percepts may serve as instructions for imitation (Fowler, Brown, Sabadini, & Weihing, 2003).

MTSP is based on the observation that the phonetic percept is invariant even when the associated acoustic cue differs. The fact that the variation of acoustic patterns might be associated with invariant bodily gestures (tongue and lips movements for example), makes gestures and not acoustic signals the real object of linguistic perception. The guiding assumption of Liberman's theory is that speech perception and speech production share the same set of invariant physical processes. In this way, incorporating a biologically-based link between perception and production, prevent listeners from hearing the linguistic signals as a mere chain of sounds, making possible grounding speech comprehension into a relationship between acoustic signals and bodily gestures. Using Liberman's words, acoustic patterns are identified by the human cognitive apparatus as speech occurrences only if they "can be 'interpreted' as the result of linguistically significant gestures" (Liberman & Mattingly, 1985, p. 19), otherwise not.

Liberman's MTSP is based on *behavioral* evidences and lying at the level of speculation regarding its neurobiological consequences. Differently, today we have at our disposal new powerful technologies for psychological investigation and brain scanning, so that we are in the position to evaluate the effective contribution of specific cerebral areas during the execution of several cognitive tasks. TMS and brain imaging techniques, if well interpreted, might give us relevant cues concerning the role of the motor system during many linguistic processes (Boulenger, Hauk, & Pulvermuller, 2008a).

As pointed out above, Lieberman's MTSP is committed with a modular conception of human cognition (Mattingly & Studdert-Kennedy, 1991). Partially in contrast with Liberman, a non-modular version of MTSP was proposed by Fowler under the name of *Direct Realist Theory of Speech Perception* (Fowler C. , 1986; Fowler & Rosenblum, 1991). The direct realist theory of speech perception is a part of a more general theory of direct realism and asserts that for speech perception the objects are gestures instead of abstract phonemes (as for MTSP). Differently from Liberman's theory, in this view, listeners perceive gestures not by means of a specialized cognitive module, but because information in the acoustic signal specifies the human gestures that produce it. Accordingly, recent experimental findings on speech perception evidence how motor areas in the brain are characterized by a multimodal nature, instead to be encapsulated in specialized modules (Pulvermuller, Huss, Kherif, Moscoso del Prado, Hauk, & Shtyrov, 2006).

Recently, Galantucci & Fowler (2006) have proposed a reviewed account of MTSP excluding the modularity assumption contained within Liberman's early version. For Galantucci & Fowler the hypothesis concerning a biologically specialized cognitive area for speech in the brain would be reasonable only in the case some circuit of the nervous system is active "if and only if" speech is perceived or produced (p. 365). As the authors note, evidences such as these are difficult to obtain, so modular organization of speech perception can be considered a dismissible assumption.

4.3 Experimental evidences about the motor theory of speech *perception*

A discussion about MTSP requires a distinction between the analysis of the *communicative* and the *referential* dimension characterizing language production and understanding (for communicative and referential distinction see section 3). In the last decade, many imaging experiments were performed concerning the analysis of the *phonological* articulation required to pronounce a certain linguistic construction (communicative dimension). These findings are especially concerned with the localization of specific brain areas involved in linguistic tasks; many of them analyze the contribution of brain motor areas both in language production and perception. It is relevant to note that, until a decade ago, non special attention was devoted to the role of motor system in speech perception, tacitly assuming its contribution only for the production of speech-related gestures (for a general review of imaging studies concerning language see Gernsbacher & Kaschak (2003)). Recently, several imaging findings concerning the localization of linguistic functions support the idea that human motor apparatus is involved in many aspects of *speech perception*, instead of only in *speech production*.

In a brief communication appeared in *Nature Neuroscience*, Wilson et al. (2004) showed that imaging results evidencing how listening to speech activates *bilaterally* a portion of ventral pre-motor cortex also involved in speech production. During the experiment ten subjects were scanned with fMRI while listening and producing a list of meaningless monosyllables. Results significatively show that across subjects approximatively 70% of voxels in precentral gyrus and central sulcus region activated during speech production were also activated during speech listening (p. 701), showing a substantial overlapping between brain areas involved in two apparently different cognitive functions.

In another fMRI study Pulvermüller et al. (2006) have tested the hypothesis according to which as speech sounds are produced through different articulators somatotopically map on different areas of motor and pre-motor cortex, so the perception of speech sounds produced by a specific articulator movement may also activate its somatotopic motor representation in precentral gyrus. The experiment was based on three different localization tasks consisting in performing silent movements of the lips as miming consonant–vowel syllables (motor experiment), articulation of tongue related phonemes (articulation experiment) and in listening a stream of consonant-vowel syllables (speech perception experiment). Results indicate that the perception of speech during the listening task activates the same motor circuits in pre-central cortex that are activated when muscles generating speech sound are moved during silent experiments involving lips and tongue (p.7868).

Accordingly, in a fMRI experiment performed by Wilson & Iacoboni (2006), authors investigate the role of motor areas in processing acoustic inputs, examining how neural responses to non-native phonemes varying in the extent to which they can be articulated. For Wilson and Iacoboni, if speech motor areas are modulated by factors such as nativeness, and phoneme producibility, this would be assumed as an evidence of the claim that the motor system represents *linguistic* features of perceived speech. To test these hypothesis twelve monolingual native English speakers were asked to listen to a series of 25 non-native phonemes and 5 native phonemes while scanned with an fMRI machine. The experiment evidenced that cortical regions respond bilaterally more to non-native phonemes in the superior temporal lobe and that more difficult the phonemes is to produce, more these areas are active.

Findings such as these are in accordance with the hypothesis that motor brain regions are sensitive to whether, or not, perceived phonemes are part of *speakers' motor inventory*, so that it is plausible to assume that non-native phonemes elicited great motor activity in force of the repetitive attempts to model perceived sounds as other well known phonemes (Wilson & Iacoboni, 2006, p. 322).

A different experiment of localization has been conducted by Watkins et al. (2003) using simultaneously MEP recording and TMS, but with similar outcomes of previous introduced imaging studies. The aim of this experiment was to examine weather speech perception modulates the activation of the same motor areas involved in speech production. During the experiment eight subjects participated in a trial focused on EMG record of the lips muscles, while another seven subjects participated in a control experiment involving EMG records of hand muscles. In both groups a transcranial magnetic stimulation (TMS) was addressed to the primary face motor cortex of all subjects (figure 1). Authors' expectations were that the size of the MEP in lips muscles elicited by TMS of the primary motor face area would be increased distinctively by the concomitant perception of speech sounds and by the visual perception of lips movements, while the MEP in hand muscles not. To test this hypothesis four experimental conditions were monitored: two concerning speech listening and observation (listening to speech and viewing speech-related lips movements) and two concerning listening and viewing non-speech related sounds and gestures (listening to non-verbal sounds and viewing eye and brow movements).

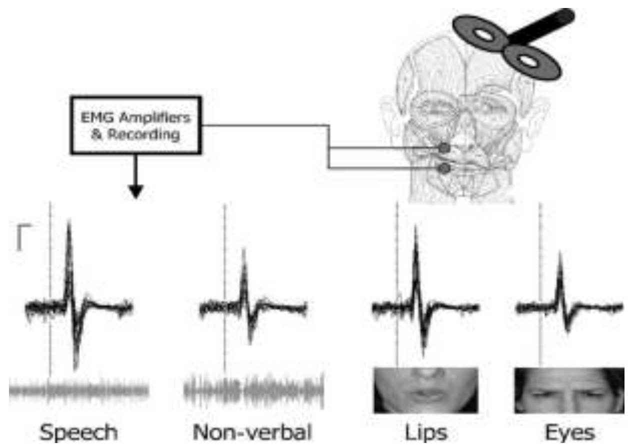

Figure 1 (Watkins et al., 2003 – p.990)

Final results show that the MEP elicited under speech perception is greater than those elicited under the condition in which subjects observe movements of non-speech related effectors (such as eyes and brow), or listen non-speech related sounds. This kind of findings also shows that speech perception enhances excitability of the same motor areas underlying lips movements for speech production (particularly in the left hemisphere).

Watkins et al.'s work can be considered a confirmation of another célèbre experiment performed by Fadiga et al. (2002) where authors tested the possibility that passive listening of an inventory of words and pseudo-words might induce the activation of cortical centers specifically involved by gestures for speech production. During the experiment Fadiga et al. recorded motor evoked potentials (MEPs) from the tongue muscles in subjects instructed to listen words and pseudo-words characterized by a double ‘‘f”, requiring virtually no tongue movements, or a double ‘‘r”, that requires marked tongue movements to be pronounced. In this experiment, during the verbal item presentation the left motor cortex of the participants was stimulated with single-pulse TMS administered over the area corresponding to the tongue motor representation. Results showed that listening words containing a double consonant “r” significatively determines an increase of tongue MEP larger than that induced by listening to pseudo-words and words characterized by non-tongue gestures. The experiment demonstrates that two independent effects can be considered at work during the trial "(i) when the stimuli contain a double "r" there is a strong facilitation of tongue muscles independently of whether stimulus is meaningful or not; (ii) the meaningfulness of the stimuli induces a facilitation of tongue MEPs that is independent of stimuli phonological characteristics" (p. 401). The fact that phonemes requiring a strong activation of tongue muscles elicit, when perceived, the activation of motor centers controlling tongue muscles is considered by the authors the evidence that language perception is grounded in a multimodal *acoustic / motor resonance*.

In spite of the their revolutionary role, all the abovementioned studies are inherently correlational, and don't give any stringent evidence concerning the functional role played by the motor areas in speech perception, so that no final conclusions can be drawn in support of a motor theory of speech perception.

To solve this problem, Meister et al. (2007) have recently proposed a TMS experiment aiming to figure out the effective role of the pre-motor cortex during speech perception tasks, trying to demonstrate that the activation of motor areas is not *epiphenomenal* for speech understanding. To test this hypothesis authors temporarily disrupted the activity of the left superior temporal gyrus with repetitive TMS trials of 15 minutes (p. 1659) and tested subjects on a speech perception task. All subjects were also tested in a control color discrimination task, whereas a subgroup of subjects was tested also in a tone discrimination task. Results analysis show that TMS directed over the left pre-motor cortex affects speech perception influencing syllables discrimination ability, but is not influent on color perception. Following authors' analysis, data suggest that phonetic discrimination is not only the outcome of a process performed at the auditory level, but it is also an activity *causally* involving the role of the motor system.

More recently, D'ausilio et al. (2009) have proposed another experiment aiming to figure out the functional link existing between speech perception and the motor system activation. The work starts with a critical comment to Meister and al.'s findings (p. 381), evidencing how 15 min TMS might have modified the activity of a larger network of areas, potentially including non-motor sites such as posterior receptive language centers. Moreover, for D'ausilio et al., the previous experiment lacks of an adequate degree of specificity, in that no evidences concerning an *effector-specific* effect is showed (for example that disturbing the activity of the tongue area in the brain induces specific deficits in the perception of tongue-related phonemes).

To test the functional contribution of the motor systems during specific speech-perception, a list of phonemes involving lips-related gestures (such as those used to pronounce the phonemes[b] and [p]) and tongue-related speech gestures (such as for [d] and [t]) were presented to ten subjects in a phoneme discrimination task, while TMS pulses were applied just prior to each stimulus presentation with the intention to *selectively prime* the activity specifically in the lip or tongue areas in motor cortex. D'ausilio et al. (2009) hypothesized that focal stimulation facilitates the perception of the concordant phonemes when TMS is directed to the related effectors area (e.g. [b] and [p] with TMS directed to lips area), but that there would be inhibition of perception of the "discordant items" (e.g. [d] and [t] for lips case) (p. 382). As hypothesized, the reaction times for recognizing lip-produced phonemes is faster than that of tongue-produced ones when the lip area is stimulated, while the stimulation of the tongue-related area induces the reverse outcome. Findings of this kind support the idea that TMS stimulation of specific sectors of the brain motor area primes neurons involved in lips and tongue gestures increasing the excitability of these sectors and that faster reactions in phonological tasks can be assumed as evidences concerning the "causal" contribution of the excited areas to speech perception. Authors propose that results such as these might be of interest in the rehabilitation programs for aphasia, supporting the adoption of TMS trials in conjunction with a language-action therapy based on both the recent findings about action-perception circuits and the standard rehabilitation protocols (p. 383).

Although the remarkable list of neurobiological findings reviewed above supports the core assumption of MTSP that human motor apparatus is involved in speech comprehension, they can't be considered evidences supporting an exhaustive theory of language understanding. Particularly, fMRI experiments (Wilson et al., 2004; Pulvermüller et al., 2006; Wilson & Iacoboni, 2006) can be used to localize with approximation what brain areas are involved during speech perception tasks, but no *functional connections* can be derived from them. The emerging of an activation in a specific brain area during the execution of a certain task, as the result of a *subtractive strategy* used to prepare fMRI experimental sets, shows a pure correlation between physiological locus and a certain assignment. Differently, TMS-based experiments (Watkins et al., 2003; Fadiga et al., 2002; Meister et al., 2007; D'ausilio et al., 2009) can be used to evidence the presence of functional relationships between selected brain areas and cognitive aptitudes, but they are inadequate to make explicit the effective nature of this link. The reviewed TMS experiments based on the induced excitement, or the temporary impairment of specific brain areas, make it possible the evaluation of several behavioral consequences such as, for example, reaction time variances, but they don't evidence what kind of functional link connects the motor areas with a more complex neural network involved in processing high cognitive functions such as language usage and understanding.

TMS experimental findings reviewed above reveal how the motor apparatus *modulates* speech perception showing the presence of prime effects that relate the *elicitation of the motor apparatus* and the *execution of phoneme recognition tasks*, but no information concerning the complete speech perception process can be derived from this kind of experiments. Moreover, it's reasonable to assume that the motor apparatus is not the only functional brain area involved in speech recognition tasks, so that it is also plausible wondering whether the motor apparatus role during speech perception is causally involved in it. As noted by D'ausilio et al. (2009) the inhibition experiment performed by Meister et al. (2007), because of the excessive duration of TMS stimulation interval, doesn't show without doubts that the impairment of motor apparatus is strictly related with phoneme recognition inability, but leaves unchanged the hypothesis that motor apparatus has only an epiphenomenal role in speech perception. At same time, the TMS stimulation experiment performed by D'ausilio et al. (2009) shows clearly the presence of a correlations between specific motor effectors areas (lips and tongue) and phoneme recognition tasks, but it doesn't demonstrate the *necessity* of this correlation.

Is the function exploited by the motor apparatus *essential* for speech perception process? Answering this question two experiments should be performed: 1) one based on the evaluation of the consequences related to the impairment of specific sectors of the motor apparatus, aiming to show the nature of motor involvement during speech perception; 2) the other aiming to show the nature of the contribution of the motor apparatus in speech perception analyzing the exact time of its intervention during a specific speech task.

Notwithstanding an uncertainty related with the causal role of the motor system in speech perception, the interpretation of the available neurobiological data induces to hypothesize the presence of a *communicative resonance* of the motor apparatus during speech related tasks. This condition supports and promotes further studies aiming to establish the effective role of motor specific effectors areas during passive language listening (Fischer & Zwaan, 2008).

4.4 Experimental evidences about a motor theory of language *understanding*

It could be useful to emphasize again that speech perception tasks are not equivalent to semantic understanding tasks. The interpretation of the data concerning the neurobiological basis of communicative gestures doesn't imply that motor apparatus might play an essential role in *semantic comprehension*. So, to support the idea that semantic is also biologically grounded in a form of *motor cognition*, and that an action-sentence compatibility effect can also be found through neurobiological analysis, as well as through behavioral studies (see section 3), a different ensemble of experimental findings concerning *referential* understanding must be exhibited. This hypothesis, generally known as the *Embodied Semantic Theory* (EST), is now the object of several experimental findings evidencing how motor related words and sentences comprehension are somatotopically mapped on the motor areas of the human brain.

EST states that concepts generally related with motor action perception and execution are grounded within the same sensory-motor areas in which the enactment of that concept relays (Aziz-Zadeh & Damasio, 2008; Glenberg & Kaschak, 2002). Following this line, the concept of ‘‘kicking” would be represented by the same sensory-motor areas of the brain that control kicking actions, as well as the concept of ‘‘grasping” would be represented in sensory-motor areas involved in planning and executing grasping actions. Furthermore, EST has been extended by George Lakoff (Lakoff & Johnson, 1999) to include all metaphor projections involving motor representations under the assumption that the sensory motor system has the right kind of structure to characterize both sensory-motor and more abstract concepts (see also section 4 and Gallese & Lakoff, (2005)). EST advocates the claim that the sensory motor system not only provides structures for conceptual contents, but more radically characterizes the actual semantic value of many concepts in terms of the way our bodies function in the world.

EST rules out the hypothesis that a unified meaning center governs language understanding, instead it supports a *dynamic* view according to which words are processed by distributed neuronal assemblies with a cortical organization that reflect words' semantic. EST predicts that parietal pre-motor regions involved in action planning should be active both when acting and when understanding corresponding motor-related linguistic constructions. Moreover, following the extend version of EST neurobiological results such as these should be evident not only for literal sentences but for the corresponding metaphorical constructions as well (Feldman & Narayanan, 2004; Gallese & Lakoff, 2005) .

Findings about the somatotopical activation of the motor system during imagination tasks of voluntary movements are already present within the scientific literature. For example, Ehrsson et al. (2003) investigated whether the imagery of voluntary movements of different body parts activates somatotopical sections of the human motor cortices using functional magnetic resonance imaging. Result showed that imagery of hand movements specifically activates the hand sections of the *contralateral* primary motor cortex, the *contralateral* dorsal premotor cortex and a hand representation located in the caudal cingulate motor area. Moreover, when imagining making foot movements, the foot zones of the posterior part of the *contralateral* supplementary motor area and the contralateral primary motor cortex are active. Results such as these show that imagery of action engages the somatotopically organized sections of the primary motor cortex activating specific bodily parts representations. This supports the idea that the *content* of the mental motor image, in this case the body part, is reflected in specific patterns of motor cortical activation.

Following this line, EST is based on the idea that semantic information conveyed by language are made possible by specific brain responses related to bodily structures and bodily possibilities. Recent studies concerning correspondences between bodily effectors and cerebral cortical areas support the idea that many semantic mechanisms are grounded in action-perception systems of the brain. Several brain activation patterns deduced from imaging studies reveal fine grained differences between categories such as those concerning objects use and perception, furthermore the same evidences reveal that information about objects are grounded in the same neural subsystems that are also active when we perceive and use the same objects (Martin, Wiggs, Ungerleider, & Haxby, 1996; Martin & Chao, 2001; Beauchamp & Martin, 2007).

In order to test if the semantic understanding share the *resonance mechanism* identified for the previously introduced speech tasks, many experimental findings can be addressed. Introducing further results, *single word comprehension* tasks and *sentence understanding* task should be distinguished.

First, relevant evidence concerning single word comprehension are represented by a dual task PET experiment performed by Damasio et al. (2001). In this study ten subjects were scanned when retrieving single words denoting actions performed both with and without an implement, while other ten different subjects were scanned when retrieving words denoting spatial relations between objects. Results were finally subtracted to control tasks involving respectively objects name retrieval and faces recognition. In both cases significant activations were revealed in frontal and parietal association cortex including motor and pre-motor regions (Damasio, Grabowski, Tranel, & Ponto, 2001, p. 1060).

In an imaging experiment Kemmerer et al. (2008) used fMRI to scan subjects while they make semantic judgements involving five classes of verbs such as running verbs, speaking, hitting, cutting and change of state verbs. Judgements were based on the distinction of semantic components constituting verbs meanings such as parameters like *action*, *motion*, *contact*, *change of state* and *tool use*. Authors hypothesized that the action component depends on the primary motor and premotor cortices, that the motion component depends on the posterolateral temporal cortex, that the contact component depends on the intraparietal sulcus and inferior parietal lobule, that the change of state component depends on the ventral temporal cortex, and that the tool use component depends on a distributed network of temporal, parietal, and frontal regions.

To test these hypotheses, authors observed subject brain activity with fMRI while they performed a task requiring analytic processing of the idiosyncratic semantic features that differentiate between the verbs in each class. Participants were required to retrieve and compare aspects of the meaning verbs. Each test involved the presentation of three verbs in a triangular arrangement (Figure 2) and subjects were asked which of the two bottom verbs was more similar in meaning to the verb on the top (p. 22).

trudge

limp stroll

Figure 2

Moreover, in order to have a baseline condition against which to evaluate performances, subject were also required to perform another task with meaningless strings of characters (Figure 3).

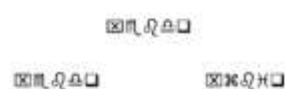

Figure 3

Consistent with the hypothesis that action component of verbs meaning are mapped on motor apparatus, results show that the retrieval and strategic comparison of semantic features of running, hitting and cutting verbs activate sector of the motor cortex.

In a more accurate fMRI experiment Hauk et al. (2004) tested the hypothesis that single action words (verbs) understanding activates the motor cortex in a somatotopic fashion that overlap activation patterns observed for movements execution of relevant body effectors. In this experiment subjects were asked to passive reading fifty words of three semantic categories concerning face, arm and leg actions, while hemodynamic activity was monitored. It is important to note that subjects were kept naïve about the scope of the experiment and that they were explicitly discouraged to perform movements in the scanner during the word reading experiment. Final results confirm the initial hypothesis showing increasing hemodynamic activity in effectors specific primary motor area for arm and leg related words, while the pre-motor region was somatotopically activated by arm and face related stimuli (Hauk, Johnsrude, & Pulvermuller, 2004, p. 303). Moreover authors suggest that the emerging link between action execution and action-words understanding reflect the Hebbian learning principle (Hebb, 1949) according to which if words perception frequently co-occurs with specific bodily actions may facilitate the generation of shared neuronal circuits that are both involved in specific action executions and action-words semantic understanding (se also the distinction between the *lexical access* and the *access to word meaning* introduced in the previous section).

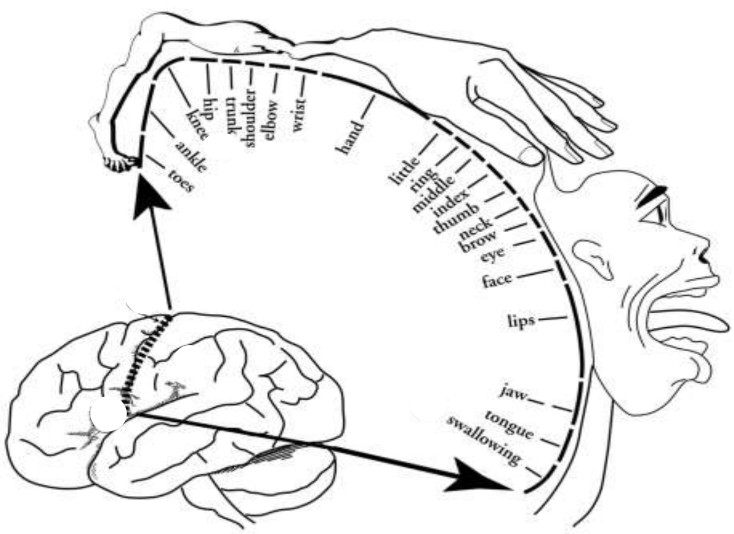

Figure 2 - The Homunculus, based on Penfield's classic diagram.

Experiment such as those performed by Damasio and Hauk show that action-words perception activates the same areas involved in related actions execution. This phenomenon is different from the communicative resonance evidenced during speech actions in that it involves the activation of motor areas related to the content of a term instead of motor areas involved by speech articulation, but it is not enough to show that a *functional* relationship between somatotopical reactions and semantic understanding exists.

In order to make clear if specific motor areas activations may reasonably reflect word comprehension (meaning access), or instead only a secondary process produced by the word perception, Pulvermüller et al. (2005a) tried to precise the time point in which cortical activations occur during a single verb understanding task. During this MEG experiment, using the same Hebbian paradigm implied by Hauk et al. (2004), subjects were asked to listen spoken action words and pseudo-words while brain magnetic field was recorded. Also in this case, data analysis shows that face and leg related verbs elicit different patterns of activity within the motor area, moreover it shows that words specifc activations arise early within 200 msec after the stimuli presentation[3].

As noted by Boulenger et al. (2008a), despite these finding, a major argument against the assumption that cortical motor regions are involved in action word semantic processing is that, even though the activity in motor regions is observed within 200 ms after stimuli onset, it could nonetheless result from mental imagery that occurs after the word has been identified. To esclude the hypothesis that hearing an action verb activates the motor system because the subject conjures up the image of an action just after having understood the verb, Boulenger et al. (2008) investigated cross-talk between single action-words understanding and cortical motor processing using visual words presented too fast to be consciously perceived by the subject, so that they should not trigger mental motor imagery. Authors predicted that subliminal displays of action verbs during motor preparation will interfere with motor processes and thus delay or diminish the amplitude of the *readiness potential* of motor cortex if compared to concrete nouns. To test this hypothesis, in a EEG experiment participants were asked to touch a home-pad located in front of them with their right thumb and index finger held in a pinch grip position, while fixating a monitor. On appearance of a preparation-signal they had *to prepare* to leave the home-pad to reach and grasp an object. The preparation signal remained on the screen for 500 ms and was immediately followed by two successively displayed pattern masks (each for a duration of 100 ms), followed by a 50 ms display of the orthographic stimulus (action verb, concrete noun or consonant string), followed by another two successively displayed pattern masks. Finally, the last mask was replaced by the go-signal after which subjects had to perform the reaching and grasping movement as fast and accurately as possible.

Kinematic parameters and readiness potential both reveal that subliminal displays of action verbs during movement preparation have a stronger impact on ongoing motor processes than the subliminal display of generic concrete nouns. This shows that action words do not only interfere

[3] A result that is also confirmed by the previously introduced behavioral experiment performed by Boulenger et al. (2008a), see for a description section 3.

with movement execution but also with movement preparation[4]. Moreover the experiment shows that a functional correlation between action planning and language understanding is independent from a secondary immagination processing that can be considered conflicting with the subliminal character of this experiment. Subjets don't perceive consciously the word stimulus, so their action-immagination is can't be involved in the task. Moreover motor imaginery activate the pre-motor cortex *bilateraly* (see for example the activations reveled in Ehrsson et al., 2003), while congruent maps for action observation and language were observed with more frequency in the left hemisphere.

In addition to the single *words comprehension*, EST asserts that *sentences understanding* are also grounded within the same sensory-motor areas in which the enactment of action and motor concepts relay. This supposition appears to be of crucial value within the definition of a general theory concerning the effective linguistic practice. In the real life, actions descriptions usually require the employment of more than an individual word or a verb, but involve complex constructions defined by phrasal components such as subject, verbal predicate and at least a complement. To test if the effective linguistic praxis involving motor concepts is really tied to the possession of a body characterized by *motor abilities* and *motor possibilities*, experiments should show that action-related sentences modulate the activity of the motor system. Thus, if language processing of action-related sentences relies on sensorimotor representations and not on abstract and a-modal units, then activations should be observed in areas coding for action execution as well. Today, a group of evidences appear *partially* to support this hypothesis.

In two experiments performed by Buccino et al. (2005) TMS and a behavioral paradigm were used to assess whether listening to action-related sentences *somatotopically* modulates the activity of the motor system. During the first experimental section authors recorded motor evoked potentials (MEPs) from hand and foot muscles when single pulse TMS stimulating disjointedly the hand motor area and the foot motor area in the *left* hemisphere. During the experiment participants were asked to attentively listen to different acoustic stimuli consisting of hand-action-related sentences and foot-action-related sentences. They were also asked to attentively listen to abstract content sentences, as control. During the experimental session they listened repetitively to the same sentences, changing the stimulated motor area (hand motor area

[4] Results also show that subliminal displays of random strings of consonants during movement preparation had a similar impact on movement kinematics and on the readiness potential as subliminal displays of action verbs. Authors declare that are not able to explain the phenomenon

or foot/leg motor area) and the corresponding recorded muscles. All action-related sentences used during the task expressed a concrete action on an appropriate object (e.g. he sewed the skirt; he kicked the ball), while abstract sentences expressed an abstract action (e.g. he loved his land). During acoustic stimuli presentation, the single-pulse TMS was automatically triggered by a computer in concomitance with the end of the last syllable of the verb, so that the subjects were considered aware of the content of the verb.

Results show that listening to hand action-related sentences induces a decrease of MEP amplitude recorded from hand muscles, as well as listening to foot-action-related sentences induces a decrease of MEP amplitude recorded from foot muscles. On the contrary, listening to abstract content sentences leads to results which don't differ from those obtained during listening to action-related sentences involving different effectors from the one somatotopically represented in the stimulated area.

Because in the TMS study participants were not explicitly required to semantically process the listened sentences, a second behavioral test was proposed. In this trial, as in the previous experiment, participants listened to different types of sentences: hand-action-related sentences, foot action-related sentences, and abstract-content-related sentences. Participants were asked to make a judgment on sentence content, giving a motor response (either with the hand, or with the foot in two different sections) when the listened sentence expressed a concrete action (hand/foot-action-related sentences), and refrain from responding when the sentence expressed an abstract content. During the task execution reaction times were measured. Coherently with the finding of the TMS experiment, the behavioral data showed that reaction times were slower when participants responded with the same effector that was involved in the listened action.

According to the authors, these data strongly support the notion that the processing of language material modulates, *at least for sentences expressing a motor content*, the activity of the neural motor system in the *left* hemisphere and that this modulation specifically concerns those sectors of the motor system where the effector involved in the action described by the sentence is represented.

Results such as those are confirmed by similar fMRI experiments performed by Aziz-Zadeh et al. (2006) and Tettamanti et al. (2005). In the latter, 17 native Italian speakers were scanned while they were passively listening to sentences describing actions performed with the mouth (e.g.,‘‘I bite an apple’’), with the hand (e.g., ‘‘I grasp a knife’’), and with the leg (e.g. ‘‘I kick the ball’’). In addition, as a control condition, participants listened to sentences with an abstract content (e.g., ‘‘I appreciate sincerity’’). As in the previous experiment, results show that listening to action-related sentences activates a left-lateralized fronto-parieto-temporal system, which is activated also by action execution and action observation, while the activations associated with abstract sentences, when compared to action-related sentences, were only found bilaterally in the posterior cingulate gyrus, a brain region that is not related to action representation.

However, while the results of these studies clearly demonstrate that motor regions are recruited during processing of action-related language, they do not clarify the crucial question about the *functional role* of these areas for semantic understanding, so that the *necessity question* (are cortical motor regions critical to word understanding?) is still unsolved. A crucial test concerning the role of motor regions in language comprehension might come from studies that show selective deficits in action-related language processing following lesions in motor regions of the brain.

Accordingly, cases of pathological impairment involving the motor system can represent an insightful field of study. In an experiment Bak et al. (2001) investigate the nature of the aphasia in a group of patient with MND (motor neurone desease)[5] showing that action-verb production and comprehension are selectively vulnerable in association with a *bilateral* motor system impairment. The finding of a selective deficit in verb action processing in association with MND suggests that the neural substrate underlying verb representation is strongly connected with prefrontal cortex and the cortical motor system. This result is also confirmed by a study conducted on two members of the same family affected by a progressive movement disorder and dementia associated with a selective verb use and understanding deficit (Bak, et al., 2006).

Recently, Boulenger et al. (2008) examined the impact of Parkinson's disease on lexical decision for action words. Following authors hypothesis, if premotor and motor regions that are involved in movement preparation and execution play also a role in action word understanding than Parkinson patients, that are usually characterized by an impairment of the motor system, when deprived of dopaminergic treatment (levodopa), should show selective deficits in processing action related words but not in processing other classes of words, such as concrete nouns. According to this hypothesis, results showed that processing of action words can be selectively disrupted following a pathology that affects the motor system. Parkinson disease patients, without dopaminergic treatment, that is when the motor disability is strongest, don't

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[5] Also called in Europe and North America LAS (Lateral Amyotrophic Sclerosis).

show prime effects during tasks involving action verbs and words, while show prime effect on non-action words. Moreover, the experiment shows that levodopa treatment, increasing functionality of the motor system, also restores the possibility to induce prime effects for action words.

A confirmation that naming of actions depends from structures located within the *left* premotor/prefrontal areas of the brain is showed by experiments performed by Tranel et al. (2001), and Tranel et al. (2003). In both experiments, results suggest a partial support to the hypothesis that there is a functional segregation of the distinctive neural systems subserving naming of actions and naming of concrete objects and the left pre-motor cortex appears related to the retrieval of specific visuomotor aspects of action concepts. Thus, while lesions in the left inferotemporal region is statistically associated with defective naming of concrete entities, but not with normal naming of actions, lesions in the left motor and pre-motor cortex is associated with defective naming of actions.

An analogous function of the motor system, but situated in the *right* hemisphere, has been showed by Neininger & Pulvermüller (2001) where patients with lesions in the right frontal lobe showed most severe deficits in processing action verbs, whereas those with lesions in their right temporo-occipital areas showed most severe deficits in processing visually-related nouns. This double dissociation in the cortical patients makes it evident that lesions in different areas of the right hemisphere affect the processing of different word categories, supporting the idea that intactness of right frontal cortical areas appears to be *necessary* for the optimal processing of action verbs and that of right temporo-occipital areas appears to be *necessary* for the processing of visually-related nouns.

Contrasting Neininger & Pulvermüller (2001), an elegant transcranial magnetic stimulation (TMS) experiment performed by Aziz-Zadeh et al. (2005) showed that the temporary disruption of the right motor areas functioning doesn't influence semantic processing but only speech production, whereas multiple TMS on the left motor areas produces both difficulties concerning the articulation and the use of the words. The authors started from a result of Stewart et al. (2001) concerning the distinction of two different types of overt (aloud) speech impairmet induced by repetitive TMS over two different left hemisphere sites. The first type, called ‘‘motor’’ was determined by stimulation of a "posterior" site located in the motor area of the frontal lobe, and was associated with EMG activity evoked in lower facial muscles, while the second one, called a "non-motor", was caused by the stimulation of an ‘‘anterior’’ part coinciding with the Broca's area and was not associated with EMG activity in orofacial muscles.

Experiments show that also covert speech production activates the motor system. McGuigan & Dollins (1989) showed with EMG that tongue and lip muscles are activated in covert speech in the same way as during overt speech. An fMRI study by Wildgruber, et al. (1996) showed primary motor cortex activation during covert speech. Aziz-Zadeh et al. (2005) measured times of latencies in a syllable counting task while a repetitive TMS was addressed on the areas individuated by Stewart et al. (2001), not only within the left hemisphere but on the symmetric regions within the right hemisphere as well. Authors measured the impact of repetitive TMS on both the production of overt speech and for the production of covert speech (silent), assuming that silent speech should not involve the use of orofacial articulators but only a semantic processing. Results show that overt and covert speech impairment are induced with similar patterns by repetitive TMS in the left hemisphere, so that both the Broca's site and the posterior/motor site of the left hemisphere can be considered involved in covert speech as they are in overt speech. In contrast, the right hemisphere posterior/motor site elicits overt speech impairment, but it does not interfere with covert speech. Authors hypothesize that the overt speech impairment in this case can be considered due exclusively to a motor interference with the activation of the orofacial muscles.

4.5 Toward an embodied theory of semantics

At the beginning of this section it was introduced the hypothesis that both the cognitive processes of language perception and language understanding could be based on the role of cognitive invariants grounded in the multi-modal activity of the motor cortex (Motor Theory of Language Understanding). Today, this hypothesis can find empirical support in an increasing number of experimental data, showing how the motor apparatus is involved in language processing at different levels.

The results obtained with both action words and action sentences contrast the view that meaning processing is localized in a unitary cortical locus − for example an area that is anterior, inferior or posterior to Wernickes area in the left temporal lobe or in the inferior frontal cortex. Somatotopic semantic activations of the motor system cannot be explained by a unitary semantic and conceptual structure that processes all word meanings in the same cortical locus, instead it requires the assumption of a multimodal apparatus (2005a).

Concerning what it was previously called the *communicative* dimension of language processing (see section 3), many imaging experiments show that the motor apparatus is selectively (somatotopically) activated by hearing different speech sounds produced through different body-effectors such as lips and tongue (Fadiga et al. 2002, Watkins et al., 2003; Pulvermüller et al., 2006). Furthermore, TMS experimental findings reveal that the motor apparatus *modulates* speech perception showing the presence of prime effects between the *elicitation of the motor apparatus* and the *execution of phoneme recognition tasks* (D'Ausilio et al., 2009). Despite their relevance, no information concerning the complete speech perception process can be derived from the actual experimental evidences, so that at the moment it's not possible to infer conclusions concerning the functional role of the motor apparatus during speech processing in the brain. How the motor apparatus interacts with other brain areas during the production of linguistic gestures? What is its position within the neurobiological causal chain ending with language production?

To solve these questions two experiments should still be performed, one aiming to evaluate consequences on language perception of the impairment of specific sectors of the motor apparatus such as those representing tongue and lips (multi-pulse TMS study, or lesion/pathology study); the other aiming to show the nature of motor apparatus contribution in speech perception analyzing the exact time of its intervention in a more complex neural network involved in processing specific speech tasks.

Notwithstanding the actual uncertainty concerning the character of necessity ascribable (or not) to the contribution of the motor apparatus, the large number of reviewed evidences shows a somatotopic activation of motor areas during speech hearing tasks. This condition makes it possible the identification of a *resonance* phenomena involving both the left and the right motor cortex. Neural motor areas controlling mouth, tongue and lips movements appear to be elicited by hearing speech sounds involving the use of the same effectors, so that this kind of motor resonance can be also referred as a form of *neural simulation process* (see next section for more details on the notion of simulation).

On the other side, concerning the referential dimension of language, a large ensemble of experiments show that also the semantic understanding is based on a similar resonance mechanism as showed for speech perception. As in the previous case, the involvement of the motor apparatus in language processing shows a selective character for the bodily effectors involved in the semantic content of linguistic items. Experiments show that motor apparatus is somatotopically activated by single words and verbs, as well as by sentences, describing actions involving the use of bodily effectors (Damasio et al., 2001; Kemmerer et al., 2008; Hauk et al. 2004, Buccino et al. 2005, Aziz-Zadeh et al., 2006; Tettamanti et al., 2005). Moreover, a group of studies conducted on patients with motor cortex impairment partially support the hypothesis that brain motor regions are *functionally* involved in language comprehension, so that a lesion in the motor areas of the brain might induce consequences on semantic understanding of motor related linguistic constructions (Tranel et al., 2001; Tranel et al., 2003; Pulvermüller et al., 2001; Boulenger et al., 2008). Notwithstanding these intriguing results, the comprehension of the effective functional role of the motor apparatus during semantic processing remains an unsolved question, in that actually no evidences clarify the respective contribution of left and right motor regions, as well as no evidences show the consequences on semantic processing of a disruption of specific body parts representations within the motor system.

As observed for speech perception, also within the set of reviewed experiments concerning semantic understanding, it's remarkable the absence of TMS studies addressed to evaluate which consequences on semantic comprehension relate to a temporary inhibition of the motor areas representing bodily effectors. If specific regions of the motor cortex controlling bodily effectors are *causally* involved during the understanding of action related words and sentences, it is conjecturable that the selective impairment (through multi-pulse TMS, for example) of hand, foot, or leg motor regions should produce consequences on the use and understanding of action-related linguistic constructions involving respectively hand, foot and leg motor activity.

Also in this case, as observed for speech perception, the absence of evidences supporting the *necessity* of motor processing for language comprehension makes it possible only to hypothesisze that the semantic understanding of motor related words and sentences functionally involves the activation of specific motor regions of the brain. Notwithstanding, the selective activation of motor brain areas controlling bodily effectors during words and sentences understanding is sound with the hypothesis that semantic comprehension of action-related constructions is embodied through the intervention of *simulative processes* involving the motor system.

Along this line, next section will be devoted to a detailed clarification of what does it mean in this context the reference to *motor simulative processes*. In order to develop a general theoretical framework, we temporarily abandon the linguistic analysis performed within the previous chapters, turning our attention on the debate concerning the role of the simulations procedures for social cognition.

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