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The language of action.
How language translates the dynamics of our actions.

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Abstract

The general aim of this thesis was to investigate how and to what extent the characteristics of action organization are reflected in language, and how linguistic processing of these aspects affects the motor behavior. Even though a huge amount of research has been devoted to the study of the motor effects of language, this issue is very debated in literature. Namely, the majority of the studies have focused on low-level motor effects such as effector-relatedness of action, whereas only a few studies have started to systematically investigate how specific aspects of action organization are encoded in language.

After a review of previous studies on the relationship between language comprehension and action (chapter 1) and a critical discussion of some of them (chapter 2), the thesis is composed by three experimental chapters, each devoted to a specific aspect of action organization.

Chapter 3 presents a study designed with the aim to disentangle the effective time course of the involvement of the motor system during language processing. Three kinematics experiments were designed in order to determine whether and at which stage of motor planning and execution effector-related action verbs influence actions executed with either the same or a different effector. Results demonstrate that the goal of an action can be linguistically re-activated, producing a modulation of the motor response.

In chapter 4, a second study investigates the interplay between the role of motor perspective (agent) and the organization of action in motor chains. More specifically, this kinematics study aims at deepening how goals can be translated in language, using as stimuli simple sentences composed by a pronoun (I, You, He/She) and a verb. Results showed that the perspective activated by the pronoun You elicits the motor pattern of the "agent" combined with the chain structure of the verb. These data confirm that the motor system is early affected by language processing, suggesting that it is specifically modulated by the activation of the agent's perspective.

In chapter 5, the issue of perspective is specifically investigated. In particular, this study aimed at determining how a given perspective (induced for example by a personal pronoun) modulates motor behaviour during and after language processing. A classical compatibility effect (the Action-sentence compatibility effect) has been used to this aim. In three behavioural experiments this study investigated how the ACE is modulated by taking first or third person perspective. Results from these experiments showed that the ACE effect occurs only when a first-person perspective is activated by the sentences used as stimuli.

Overall, the data from this thesis contribute to disentangle several aspects of how action organization is translated in language and then affects overt actions performed during or after linguistic processing. This constitutes a new contribution to the field, adding lacking information on how specific aspects such as goal and perspective are linguistically encoded. In addition, these studies offer a new point of view to understand the functional implications of the involvement of the motor system during language comprehension and this has a variety of implications also for understanding our social interactions.

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0. Introduction

My hand is pointing to you, I see your foot kicking a ball, “Andy gave the pizza to Bob”. Are these actions? Are these actions but at different degrees?

An actual action, an observed action, a sentence. My basic assumption is that all these are actions and are to some extent comparable. More, I suggest to assume that they share a basic mechanism which allows us to study them together and at an inter-subjective level.

The focus of our studies is on language, but assuming that language is a form of action itself. Language and action are then considered as systems which can be translated one into each other, and continuously come in dialogue. This approach is supported by assuming an embodied perspective, where the brains-bodies interactions constitute the ground of our social interactions.

0.1. Language and actions

We all communicate through action and through language, but typically a neuro-linguistic perspective has assumed these processes as separate and tended to see verbal language as primary and based on abstract cognitive processes with nothing to share with the motor system. A recent shift in perspective has led to several studies investigating the role of the motor system during language processing. The basic idea is that a mechanism of motor resonance is active very early during language processing, so that this process effectively contributes to language understanding.

But what remains of the experience of action after and before language? The experience of language is experience of action in the sense that you can have a linguistic experience of actions, even of actions which are not part of your motor repertoire. At least you know the structure, the syntax of motor acts or part of it, you know the form of the action to which you can attribute a different meaning if you are able to perform that action or not. In any case, there is always a sense for that action, which you can recognize and understand as meaningful.

If language translates action organization, then it can be re-activated even if I am talking to you of an action you have never performed. In this perspective different aspects of action organization may have different effects on overt motor behaviour, as they differently influence our social relations. In this view, experience is not the external referent of language, but language actively translates our experiences of action, changing experience itself, for example introducing different points of view on it.

This mutual translation between experience and language is then engaged in determining processes of motor resonance and/or motor simulation not only during action observation but also during linguistic processing of actions.

Experience emerges at the intersection of different relations, depending on various aspects, which can be singularly embodied or even socially embodied, overcoming the limits of the single body-brain system.

Action, each action, can be re-articulated through its configuration of points of view: from different perspectives, internal or external, action itself changes as an object of description.

Consider the role of a mechanism of motor resonance during action and language comprehension, which is the argument of this thesis. In this case two “actions” are coupled and compared, at least one actually acted and another one just linguistically described. These two actions are coupled since they are supposed to share a common neural activity (even if at different degrees) so that the result is a direct coupling between execution and linguistic re-activation of an action (see chapter 3). No form of mediation seems to be implied. But we have to consider that the same action can be re-articulated through specific configurations and points of view, so that the action emerges in a dynamical way. This is made possible also by the definition of limits (internal-external, self-non self) and of thresholds. Thanks to this process an action emerges and acquires meaning, as a specific configuration defined as the intersection of different networks of relations.

Let’s schematize this process as follow.

First, we have an action performed and realized (for example the action of grasping an object) with a specific configuration: the hand approaches the object with a specific direction and movement parameterization, the object has given properties , the action is situated in a particular environment and so on. Subsequently, under a specific aspect, point of view and pertinence, this first configuration is re-defined by another set of relations, that is for example the set of relations which refer to the position of an external observer from a specific perspective.

The same configuration can be translated in a linguistic configuration, where specific aspects are selected while neglecting others. For instance, some linguistic devices (pronouns, adverbs, verbs themselves) act to translate the actual action: the hand approaching the object quickly or slowly, with a precision grip or a force grip, in a specific time, space, with a peculiar rhythm and trend. This allows the action to be translated in verbal language, in a sort of "action observation" of different order respect to the usual visual observation. The "linguistically observed" action acquires meaning as given of a specific direction (sense) and of a goal, that is a value for someone or something.

This motor pattern is then translated into a specific neural configuration which codes some of the possible parameters and aspects defining action itself as a whole. For example, an action emerges differentially because of the effector used to perform it, hand or foot, which correspond to a specific description in the motor cortex. This configuration is coupled and compared with the one that would lead to the actual execution of that action. The configuration of the potential action depends on the others, on how the first action has been specifically built up, depending also on the agents' motor habits and practices.

At this stage, it is possible to verify this motor activation through motor tasks. For instance, asking a person to grasp an apple or a cherry after reading of someone grasping something. The specific motor pattern activated by the sentence "Giovanni was grasping a pen" affects the subsequent execution of an action if this last action shares some aspects of the one conveyed through language. For instance, grasping a pen typically requires to use the hand with a precision grip. Then, actually grasping a cherry should be more likely to be influenced by the sentence with respect to grasping an apple. The extent to which the linguistic action is detailed surely is a critical component of how the motor effect can be detected, as well as the expertise required to perform an action: we normally share the ability to grasp objects, but just some of us can correctly perform more skilled actions. A crucial point – both from an experimental and theoretical point of view – is then to clearly define *which* aspects of action we are investigating and which components of motor behaviour we expect to be affected (i.e. planning, execution, temporal sequence of actions and so on).

0.2. Goals definition and motor chains

A critical role in defining an action is played by the so-called *goal* of an action.

The recent definition given by Gallese (2009) where goals are defined in terms of "value for the system", and are structured along an axis of valence, can be very fruitful. However, we need to consider goals not strictly as the "aim" of a single subject or the final effect of her actions. In fact, we need to achieve a more general definition of goal, if we extend it to the domain of intersubjectivity.

From this point of view, goals cannot be reduced just to the final end state of an action, or to the intention of a subject; rather they are what stands for the "value" of an action. Broadly considered, the notion of value can refer to the social value, to the value for an individual in a given situation, or it can reflect the value of a single motor act (sub-goals) with respect to the action in which it is embedded. This open definition of goal allows treating action organization at a very general level, where goals can be dynamically modulated through another basic mechanism which received much attention recently: the structure of actions in motor chains (see chapter 4).

Motor chains rely on the idea of motor acts (i.e. the act of grasping) as coded both *per se* with specific parameters and with respect to the chain in which they are embedded in order to perform an action and to achieve a goal. For instance, the motor act of grasping can be embedded in the chain with the final goal to put a piece of food in a container or to take it to the mouth. In this sense, each motor act depends on the one that immediately precedes it and all depend on the final act which leads to goal achievement. These sequences of motor acts can be of different complexity, and several sequences can be combined together.

What is relevant is that each action is defined by a goal and a motor chain, but it is just a syntactical description of that action, that is the other parameters such as the kinematics are differently defined and probably coded by different neural structures. In this sense this constitutes a basic description of action which is easily translated from actual performed actions, to verbal language, gestural pantomimes, pictures and more. This is particularly due to the fact that if chains constitute the syntax of actions, then the roles in the chains (such as Subject/Object) are empty and they are locally fulfilled for a single action.

This elaboration of motor chains permits to assume them as the basic mechanism which allows for the passage between the single level of embodied processes and the level of intersubjectivity. The empty actantial roles can be easily fulfilled by more than a single, even by a group, in defining just locally their position. In this sense a motor chain is a mechanism which accounts both for single-body processes and for intersubjective relations. More, it supports our idea of a continuous translation between different languages and systems.

0.3. Experimental contribution: the structure of the thesis

The general aim of this thesis was to investigate how and to what extent the characteristics of action organization are reflected in language, and how linguistic processing of these aspects affect the motor behavior. This issue is still very debated in literature, although a huge amount of research has been devoted to the study of the motor effects of language. Large part of these studies did not systematically focus on specific aspects of action organization in order to investigate their translation in language, being more interested in low-level motor effects such as effector-relatedness of action.

After a review of previous studies and of the neural candidates to support motor resonance (chapter 1) and a critical discussion of some of them (namely the emergence of facilitation vs interference effects, chapter 2), the thesis presents three experimental chapters, each devoted to a specific aspect of action organization.

In chapter 3, I present a kinematics study designed in order to disentangle the effective time course of the involvement of the motor system during language processing. In particular, the aim was to distinguish the specific effect of timing on actions with different degrees of complexity and with different goals

In chapter 4, a second kinematics study is presented, with the aim to examine the interplay between the role of motor perspective (agent) and action organization in motor chains, verifying its behavioral effect on an overt action required as response. This study aimed at deepening how goal can be translated in language, using as stimuli simple sentences composed by a pronoun (I, You, He/She) and a verb. The basic assumption is that language encodes goals at different levels: not only at the very general level of goals as abstract entities, but at the specific level of goals as concrete entities relying on sequences of motor acts or simple actions.

In chapter 5, the issue of perspective is specifically investigated, focusing on its role in language comprehension. In particular, this study aimed at determining how a specific perspective (induced for example by a personal pronoun) modulates the motor behaviour during and after language processing. A classical compatibility effect (the Action-sentence Compatibility Effect) has been used to this aim. In three behavioural experiments I investigated how the ACE is modulated by taking first or third person perspective.

In chapter 6 I critically discuss the results from our studies, aiming at unifying their results into a general framework which could inform future research in this field.

1. Embodiment and motor resonance during language processing

According to the recent theories on embodied and grounded cognition (Barsalou, 1999; Glenberg, 1997; Zwann, 2004) meaning construction is grounded on perceptually simulating the information that is presented to the comprehender. In other words, according to these theories, meaning is the outcome of our interactions with the world. In the first part of this chapter I will review studies supporting the idea of a functional involvement of the motor system during language processing. Together with a presentation of the studies I discuss their position into the current debate, with the possible criticisms and weak points. In the second part of this chapter I review studies about the possible neural substrates of processes of motor resonance active during action observation, execution, and their linguistic understanding.

1.1 The motor system as part of linguistic processing

The involvement of the motor system in language processing is supported by both neurophysiological and behavioural studies. Neuroimaging studies have shown that action-related linguistic material such as sentences describing actions or visual presentation of single action-words activate the motor cortex in a somatotopic manner (Hauk, Johnsrude, & Pulvermüller, 2004; Pulvermüller, Härle, & Hummel, 2001; Tettamanti et al. 2005).

Tettamanti and colleagues (2005) performed an fMRI study presenting sentences describing concrete actions performed with different body parts (mouth, hand, leg) and asking participants to silently read those sentences. During the listening task the authors found the activation of a left fronto-parieto-temporal circuit with a critical somatotopic activation in the premotor cortex. Interestingly, no effect in the primary motor cortex was found. Overall, the data confirmed that a passive reading task activated circuits involved in the actual execution of actions with different effectors, thus showing that also processing concrete sentences relies on the same somatotopic organization of actual actions. Crucially, the authors found also an activation of the pars opercularis of the left inferior frontal gyrus (Broca's area), but independent from body parts. This suggests that the activation of this area is related to a more abstract coding of action, which does not rely on the somatotopic organization of motor areas. In this experiment Tettamanti et al. used sentences and a passive task, and; in addition they used a methodology that did not allow for fine-grained temporal information: all these elements constitute a confound in interpreting the data. Namely, their results does not allow stating whether the effects are related to action language processing *per se*, or whether they are the result of an explicit imagery performed by the participants. This is a crucial point and constitutes a debated issue in literature. In this case, the use of sentences was probably more likely to induce also imagery effects, while the use of single words should be more related to pure processing effects.

Supporting information is given by other studies with different stimuli, as for instance single action words in a study by Hauk, Johnsrude & Pulvermüller (2004) and on action-related sentences in the study by Aziz-Zadeh, Wilson, Rizzolatti, & Iacoboni (2006).

Hauk, Johnsrude, and Pulvermüller (2004) performed an event-related fMRI study presenting words referring to face, arm or leg actions (e.g. lick, pick, kick). Participants were required to silently read those words. This passive reading led to the activation of different sectors of motor and premotor areas, controlling motor acts performed with the same effectors of the presented words. They showed, then, that a somatotopic, effector-related activation, of motor areas accompanies the reading of action words. Differently from Tettamanti and colleagues, in this study single words were used, with no additional contextual cue which could more likely trigger motor imagery. On the contrary, the effector-relatedness of word semantics was stressed, since this constitutes a very basic element to describe an action.

Aziz-Zadeh and coworkers focused their experiment precisely on a comparison between action execution and linguistic processing of the same actions, specifically for actions performed with the hand. Their data showed that the same sectors of the premotor cortex active during action observation were also active during the comprehension of the same actions described in sentences.

However, no study directly compared execution observation and language, so that it is hard to state to what extent the three conditions effectively overlap. More, it is not possible to establish with imaging data the degree of activation of the premotor areas, which is possibly higher and more complex during the actual execution of action, and probably differ also among the visual observation and the linguistic processing.

Data from these fMRI experiments were obtained with a relatively low-level processing of actions words, that is no deep semantic processing of action words or sentences was required. However, as already stated, the degree of involvement of the motor system and its effective contribution to meaning understanding remains unclear. This is due also to the poor temporal resolution of imaging techniques: it remains ambiguous at which stage of language processing the motor activation occurs. In addition, a possible confound is given by the presence of an M1 activation in some studies (Hauk et al. 2004), and its absence in other studies (Tettamanti et al. 2005, Aziz-Zadeh et al. 2006). Since all these studies used a silent reading task, probably the different effect was not due to the task used (i.e. lexical or semantic). A possible explanation could be given by the fact that Hauk and colleagues presented action words and not sentences, whereas Tettamanti and Aziz Zadeh's studies presented action sentence compared to abstract sentences in one case (Tettamanti) and to methaporical sentences (and action observation) in the other. It is possible then that processing of complete sentences did not directly involve relatively low-level activation in M1, while recruiting a strong effector activation but together with a more abstract representation given by the premotor cortex (determined for instance by the effector and by the goals typically accomplished with that effector). On the contrary, simple words recruited also these sectors, relying on a stronger effector-dependent understanding of verb meaning.

The fMRI studies surely contribute in disentangling the spatial localization of the effects of language on the motor system. However, due to their low temporal resolution, they do not give sufficient information on the exact timing of this effect, that is they do not clarify if the involvement of motor areas effectively contributes to language processing. In fact, a strong argument in favor of this causal relation would be the presence of early activations of motor areas. Several neurophysiological and behavioral studies have recently tried to disentangle the exact timing of these activations.

Large part of these studies rely on the same assumption of a somatotopic activation of motor areas during language processing similar to the one observed during action observation and execution. They generally agree, then, on the idea that action words and sentences are mainly accompanied by strong effector-dependent activations.

Pulvermüller, Shtyrov, & Ilmoniemi (2005) used magnetoencephalography (MEG) to study the effect of listening to action verbs during a distraction task, which did not directly involve the recruitment of semantic information. Action words referred to face or leg actions were presented, and the brain activity of participants was recorded using high-density MEG. Shortly after word recognition as autonomous lexical item, an activity in the superior temporal (130 msec) and inferior frontocentral areas (142-146 msec) was detected. Face and leg actions differently activated the two areas: face-related stimuli activated inferior frontocentral areas more strongly than leg words, whereas the reverse was found at superior central sites (170 msec). The authors interpreted these results as a confirm of the somatotopy implied by the motor actions described by the verbs.

Data in support of this interpretation come from a recent TMS study by the same authors. Pulvermüller, Hauk, Nikulin, & Ilmoniemi (2005) stimulated hand and leg areas in the left emisphere 150 ms after word onset using single pulse TMS below threshold. Participants read arm and leg-related words and meaningless pseudo-word presented in written form. They had to respond with a lip movement to meaningful words, refraining to respond to pseudo-words. Data from the lexical decision task confirmed a somatotopic activation of motor areas, detectable in a facilitation of effector-related muscles during the presentation of the corresponding action words. This study suggests an early involvement of the motor system during language processing, in showing that motor effects are detectable at 150 ms after word onset. However, since 150 ms already correspond to the timing of lexical-semantic access it is not completely clear whether motor resonance simply facilitated a lexical task or if it effectively contributed to the task, preceding it. It is worth noting, however, that the timing of the effect in this study is not consistent with an explicit imaging strategy performed by the subject (such strategy does not seem useful in this task) and neither with a post-understanding imaging of actions, which should take much longer than 150 ms and should occur after full comprehension of the word.

The early involvement of the motor system is confirmed by other physiological and behavioral data coming from a TMS experiment by Buccino et al. (2005). These authors showed an interference effect during listening and reading of effector-related action verbs, as detected in the MEPs recoded from muscles of the corresponding effector. That is, MEPs amplitude decreased for hand muscles with hand-related verbs as compared to foot-related verbs, and the reverse was true as well. The behavioral data with the same stimuli and with a lexical decision task showed the same interference effect. This study is consistent with data on the somatotopic activation of the motor system during language processing similarly to action observation, thus confirming an early rectruitment of motor areas when listening or reading to action verbs. However, this study differs from other TMS and behavioral experiments in showing facilitatory effects: this issue will be discussed in greater detail in the second chapter of the thesis.

The imaging and physiological data reveal that motor areas are involved early during lexical-semantic task, thus suggesting that this involvement is part of the linguistic processing. The timing of these effects is consistent with the idea that the motor involvement is not a product of conscious imagery, but signal of early processes of motor resonance involved in language understanding. In this sense, reading an action verb, observing the action the verb describes, and performing the same action should share the same neural substrates. In this sense, the activation of action-related areas should produce effects detectable also at a behavioral level. That is, a linguistically-induced motor activation should modulate the overt motor behavior according to some aspects of the presented stimuli. A huge amount of data is now available in this field. A precursor in this field was a study by Gentilucci, Bertolani, Daprati, & Gangitano (2000). In this study, and specifically in one of the experiments of this study, the authors demonstrated the effect of single Italian words on motor responses. In fact, reading words referring to the size of an object, e.g. “GRANDE” (big) or “PICCOLO” (small), evoked the motor programs related to grasping big or small objects, thus inducing effects on the motor response of reaching and grasping an object. The effect was specifically found on the grasp component of movement, that is on the maximal finger aperture. The authors suggested that this effect relied on the semantic content of words referring to objects, thus influencing action planning and execution. Specifically, they suggested that planning of the response action was interfered by the word presented on the object. However, the effect found on a grasp aperture suggests that not only an effect of action planning was present, but that action words influenced also the online control of actions as happens for other properties of objects, such as size, volume and similar.

A similar experiment was performed by Glover, Rosenbaum, Graham, & Dixon (2004), but suggesting that the semantic information interfered with motor programs rather with online control of action. They tested this hypothesis by using nouns denoting concrete objects, associated with a specific hand aperture – in this sense their stimuli were not explicitly referred to size.

Participants were required to read a single word presented on a computer screen and then reach and grasp for blocks of different sizes. Words referred to either small or large objects (e.g. “GRAPE” or “APPLE”). Data from participants’ performances in the motor response showed that reading the name of an object with a characteristic size interfered with the planning of a grasping movement. Glover’s study confirmed that word referring explicitly or implicitly to size (as one of the possible properties of an object) influenced an overt motor response required after reading these words. However, this does not explain whether it is possible to have this effect without the concurrent planning of a motor task, that is outside a motor context.

A more recent study by Boulenger et al. (2006) aimed at disentangling the timing of the effect of single words on overt motor behavior. Two experiments used as stimuli letter strings appearing at a different timing with respect to movement onset: in a first experiment, the letter string appeared after the onset of a reaching movement, in the second experiment the letter string was presented as go-signal for movement execution. Participants had to decide whether the string was a word or a pseudo-word: they were asked to complete the reaching movement in case of a word in the first experiment, and to start and perform the movement in the second experiment.

The results showed that action verbs affected overt motor behavior: within 200 ms after movement onset, processing action verbs interfered with a concurrent reaching movement (effect detected on wrist peak acceleration). On the contrary, a facilitation was found in the second experiment: that is wrist peak acceleration increased with action words as compared to nouns. This effect was evident 550-580 ms after word onset.

A similar facilitatory effect was found in a behavioral experiment by Lindemann, Stenneken, van Schie, & Bekkering (2006).

In this experiments participants made lexical decisions in a go-no go task, after preparing a specific action. That is, participants had to prepare to pick up a magnifying glass and bring it to the eye, or to pick a cup and bring it to the mouth. A letter string was presented after action onset: target words were eye and mouth. The preparation of a congruent action (e.g. pick up the glass for eye) facilitated the lexical decision on the associated word. The authors suggest that preparing for an action activates semantic information about that action, which primes a concurrent lexical decision task.

All the studies reviewed in this first section refer to single action words or simple word combinations. However, there is evidence for processes of motor resonance both at the phonological level and at the more complex level of sentence processing.

The idea that motor resonance mechanisms are active during phonological processing is not new. A crucial role of the motor system during speech perception was explicitly assumed by the motor theory of speech perception (Liberman. Cooper, Shankweiler, & Studdert-Kennedy, 1967). According to this theory, “the objects of speech perception are the intended phonetic gestures of the speaker, represented in the brain as invariant motor commands” (Liberman & Mattingly, 1985).

Recent neuro-physiological studies confirmed this theory with experimental evidence. In particular, Fadiga, Craighero, Buccino, & Rizzolatti (2002) used TMS over the motor cortex, and specifically the sector controlling tongue muscles, to investigate the effects of single pulse stimulation during listening to Italian words and pseudo-words. Words and pseudo-words contained a tongue-trilled, double-r sound, or a non-trilled, double-f sound. MEPs recorded from tongue muscle showed an increased amplitude for listening to double-r stimuli than double-f stimuli. This was dependent on the use of the tongue to produce the double-r sound. These data suggest then that phoneme production and phoneme listening activate the same muscles, that is that execution and “observation” of linguistic phonemes rely on the same motor processes.

These data were extended by the same authors in a recent study (D’Ausilio et al., 2009), in which the functional relevance of the motor activation during speech processing was specified – hence confirming the motor-somatotopy of speech perception.

At the level of sentence processing, effects of motor resonance have been extensively found using sensibility judgment task. During this kind of task participants normally evaluate sentences which share one or more characteristics with the motor response used to perform the action, that is for instance response away or toward the body, up or down, hand shape and so on. The assumption is that participants are facilitated when performing response actions congruent with the motor processes involved in the actions linguistically described by the stimuli-sentences. The effect is mainly detected by using Reaction Times or Reading Times measures, that is measuring how "fast" participants are in responding after sentence understanding.

A well-known effect is, in this sense, the so-called ACE (Action-sentence Compatibility Effect, discussed in detail in chapter 2).

This effect relies on the compatibility between movement direction embedded in sentences ("Close the drawer") and the direction of response used by participants to ask whether the same sentences made sense or not. The finding was that action-compatible responses were faster than action-incompatible responses, hence the action-sentence compatibility effect, ACE (Glenberg & Kaschak, 2002). The ACE was found not only for imperatives, but also for descriptive sentences of two types: double object (e.g., Mike handed you the pizza) and dative constructions (Mike handed the pizza to you). Moreover, the effect was also found for abstract transfer sentences, such as Liz told you the story. However, this effect emerged on late responses, as characteristic of the semantic judgment which required the full presentation of sentence and response movement began when the sentence had been already completely understood. The effect of motor resonance, then, is rather different from the one obtained with other methodologies. However, it gives us a crucial contribution to understand the nature of stimuli capable to evoke motor resonance or not – this will be the issue of chapter 2 and of chapter 5.

As showed in this review, the available data on motor resonance connected to linguistic processes do not fully disentangle this issue. On the contrary, the data emerging from different techniques, stimuli and tasks, sometimes differ, making it hard to merge them in a unifying view. This is part of the current debate on the "necessity" of the motor system for language understanding. In summary, two hypotheses are debated: the first assumes that language understanding completely relies on symbolic, amodal mental representations (e.g., Fodor 1975). Following this approach, the meaning of language derives from an arbitrary correspondence between abstract symbols and their corresponding extensions in the world. According to this view (the ‘disembodied’ hypothesis, see Mahon & Caramazza 2008) motor activations accompanying language understanding are completely irrelevant for semantic analysis. They are consequent to processes similar to those leading the “Pavlovian dog to salivate when it hears the bell” (Mahon and Caramazza 2008) and are automatically elicited in conditions similar to those produced in S-states, as defined by Jeannerod (2001). The second hypothesis (‘embodied’ hypothesis) assumes that language understanding does rely on processes of embodiment (Lakoff, 1987; Glenberg, 1997; Barsalou 1999; Pulvermüller, 2002; Zwaan, 2004; Gallese &Lakoff, 2005; Zwaan & Taylor, 2006). Based on this view, language understanding implies the involvement of the same neural systems used to perceive or to act. This is in agreement with the assumptions of the Semantic Somatotopy Model proposed by Pulvermüller (see Pulvermüller 2005; for a review, Hauk, Shtyrov, & Pulvermüller, 2008). Together with these two radical approaches, the debate has been recently enriched by new intermediate positions. On one side, Mahon and Caramazza (2008) assume that motor representations can access and contribute to the full representation of a concept (the grounding by interaction hypothesis). On the other side, Fischer & Zwaan (2008) gave the provisional conclusion that the current research demonstrates that “motor resonance results in a deeper, higher resolution, comprehension” of a concept, so that motor resonance at least enhances comprehension of language. However, Mahon & Caramazza (2008) postulate higher level for amodal conceptual representations as compared to motor representations, whereas Fischer & Zwaan (2008) postulate that the motor representations are complementary to concept and language understanding.

Data from neurological patients are used by the different authors both to claim the functional relevance of the motor system and its complementary role together with other abstract representations of concepts. A primary criticism of embodied theories and motor resonance is given by the fact that patients with motor lesions and dysfunctions do commonly preserve some form of language comprehension. However, it is possible that the preserved ability to understand language (and in other cases, actions) remains at a low-level, which does not preserve a deep understanding of language.

In a recent study Boulenger et al. (2008) studied Parkinson's patients, showing deficits in performing overt actions. These patients showed also an abnormal lexico-semantic processing of action verbs. On the contrary, this abnormal processing was not present for concrete nouns. Under Levodopa treatment, that is when normal motor functions are restored, the same patients increased their performances during lexical processing of concrete nouns and action verbs. These data suggest that probably different processes – also at a motor level – are involved during processing of action verbs and concrete nouns. Moreover, they demonstrate that the presence of disrupted motor functions leads to a limited processing of action verbs. This suggest that, whilst a superficial form of comprehension is present, a deeper understanding of actions is impaired together with the motor functions. Bak and colleagues (2001) confirmed this hypothesis, showing electrophysiological evidence that motor neuron disease leads to a consistent and selective impairment for comprehension and production of verbs, as compared to nouns.

1.2 Action through execution, observation and language

The increasing amount of research on mirror neurons and specifically on a possible mechanism directly matching action observation and execution offers a valid (and intriguing) candidate as it immediately induced many scholars to see in them the neural substrate of the processes of motor resonance during language comprehension. However, actual action execution/observation and linguistic processing of described actions are similar but do not completely overlap. Hence, we have to bear in mind this preliminary distinction. This has been underlined by other authors, for instance Buccino et al. (2005), claiming that action observation is inherently richer than linguistic description, since some aspects of action (i.e. temporal constraints) cannot be activated through linguistic devices.

My own position slightly differs: while I agree with a distinction between the two kind of observation, real and linguistic, II think of the two as qualitatively different but not in terms of primacy of one over the other. We all have experience of how our communication (not only verbal) often relies on what is left unsaid, pre-supposed, or not completely described. In some cases this leads to mis-understandings, but more often our social interactions are successful despite (or thanks to) this. On the contrary, observing an action does often rely on incomplete situations, in which much is unseen and unknown. However, again, we can usually understand what is going on and successfully adapt our behavior, but in some cases we can’t have a complete understanding of the situation. The same is true, nevertheless, for action execution: I can have the complete motor control of an action and of its goal, but I can act in an opaque situation, which does not allow me to completely control the effects of my action.

In sum, the assumption that several translations occur among execution, observation and language leads us to the consideration that differences between these modalities are not given, but constantly vary across situations. In this sense, there may be cases where language is capable to capture and translate more aspects than what visual observation could do. In other words, the differences are of degrees and modalities, and not of absolute primacy of one form of action over the others. Bearing this in mind, I will now discuss how studies on action observation and in particular on mirror mechanisms may constitute a first basis to introduce the following experimental studies.

1.3 Is there a neural basis for motor resonance?

The largest part of the available data on a mirror neurons comes from studies with non-human primates, specifically the macaque monkey, which allow for single-cell recordings.

Mirror neurons are referred to neurons, generally found in sectors of the ventral premotor cortex, which become active for instance when the animal executes an action with the hand and when it observes the same action performed by another individual (Gallese, Fogassi, Fadiga, & Rizzolatti, 1996). Recently, Ferrari, Gallese, Rizzolatti, & Gallese(2003)recorded discharges in the premotor area F5 of monkeys both from mirror neurons during lip-smacking – the most common facial gesture in monkeys – and from other mirror neurons during mouth movements related to eating. This suggests that non-vocal facial gestures may be indeed transitional between visual gesture and speech. Mirror neurons in monkey have been also recorded in the rostral part of the inferior parietal lobule (Gallese, Fadiga, Fogassi, & Rizzolatti, 2002), and neurons activated only by the observation of movements of different body effectors were recorded in the superior temporal sulcus (STS) region (Perrett, Mistilin, Harries, & Chitty, 1990). The presence of a mirror system (involving different sectors of the premotor cortex and of other connected areas as well) in the monkey premotor cortex the mirror system has been demonstrated primarily for reaching and grasping, although it also maps the sound of certain movements, such as tearing paper or cracking nuts, onto the execution of those movements (Kohler et al., 2002). According to Rizzolatti et al. (1996) and Gallese et al. (1996) the mirror neurons' activity is involved in action representation. This motor representation, by matching action observation with execution, would constitute the basic mechanism to understand actions. In this way, individuals are able to recognize the meaning and the aim of actions performed by another individual, being provided of a direct link between actor and observer.

Mirror neurons, then, rely on the motor repertoire of the actor/observer, coding motor acts (i.e. grasping) given of a specific goal. The idea that what is coded is the “goal” of a motor act has been confirmed by several studies aimed at identifying the degree of this mirror-activation.

Umiltà et al. (2001) showed that half of the mirror neurons in F5 discharge during action observation also when the final part of the movement is occluded. Interestingly, these neurons do not discharge when the final part is precluded to vision *and* the monkey knows that no object is present. This suggests that, at least in monkeys, the simple pantomime of an action without a target object does not lead to a mirror activity. At the same time, other studies (Kohler et al., 2002, Keysers et al., 2003) demonstrated that these neurons are capable of a certain degree of abstraction. In fact, part of the F5 mirror neurons discharge not only when the action is actually observed but also when only the sound (the effect) of the actions is presented, for instance when the monkey hears the sound of the action to “crack a nut” but does not actually see the action. Recently, Ferrari, Rozzi, & Fogassi (2005) showed that the goal of the action is the crucial element for this mechanism to be activated: in fact, they recorded F5 neurons which discharge not only when mirroring an action executed with the hand or the mouth, but also when the monkey observed the experimenter grasping a piece of food with a tool. Interestingly, some of the recorded neurons showed a selectivity of discharge specific for the grasp with a tool. The very basic link between observation and execution is then the goal of the action, which is necessary and sufficient to evoke a mirror response in F5 neurons.

The importance of goals imposes to rely not only on premotor areas to investigate the articulation of mirror activity in the monkey brain: what recently emerged is the idea that an extended mirror neuron system (MNS) is present in the monkey brain, involving also areas coding a more abstract representation of action, for instance parietal areas.

Assumed that single motor acts are goal-specific, actions are constituted by sequences of motor acts with different degrees of complexity. Action is then characterized by an overall goal (e.g. eating), on which all the motor acts and their single goals depend (e.g. reaching-grasping the food, bring it to the mouth). A recent study by Fogassi et al. (2005) showed how this chained organization of actions is coded in the monkey inferior parietal lobule IPL. The same authors (Ferrari et al., 2003) had already showed that IPL contains neurons showing a mirror discharge, being then called parietal-mirror neurons.

In this study, motor neurons in the rostral sector of the (IPL), showed a discharge selective for the same motor act (e.g. grasping) when embedded in different sequences, hence actions with different goals. In the execution condition, the monkey had to (1) reach and grasp a piece of food and then bring it to the mouth, or (2) reach and grasp a piece of food and then bring it to a container. In this sense, the first motor act was the same, but the final goal of the action was different, being in one case eating and in the other placing. In a series of control conditions, the authors showed that the difference in neurons discharge and their goal-specificity cannot be explained by the kinematic differences in actions execution. In addition, the neurons with mirror activity, hence discharging both for action execution and observation, showed a similar pattern of goal-dependent action observation. Hence, some of these neurons specifically discharge for a single motor act only when embedded in the action of eating and not in placing, and the reverse as well.

Authors' claim is then that the representation of motor acts in IPL is dependent on a chain organization of actions, which is active both during observation and execution. This parietal mechanism is then hypothesized as being involved in action understanding, specifically in understanding the motor intention of others as specified by the goal of their action. What remains unsolved is how a specific chain is selected: the authors suggest that the context in which the action is performed and the object target constitute two critical cues to understand actions and hence to activate different chains. However, the parietal-specificity unlikely acts alone, but it is probably part of a more complex system, involving also the premotor cortex. In fact, since IPL has direct anatomic connections to the vPMC – this would support the idea that the parietal coding of goal influences the next stages of action organization. More, vPMC and IPL share a similar organization of receptive fields, thus it is likely that they share also the coding of motor acts specifically dependent on the action in which they are embedded.

1.4 A mirror mechanism for language?

Large part of the available data postulating a MNS for humans comes from imaging studies, aimed at individuating structures in the human brain subserving the same processes observed in the monkey brain (see for instance Decety & Grezes, 1999; Grezes & Decety, 2002; Rizzolatti, Fogassi, & Gallese, 2001).

A study by Buccino and colleagues (2001) seems of particular relevance for our topic. This fMRI study showed a somatotopic organization in the premotor and parietal cortices when observing movements of different body parts. This somatotopy corresponds to that found when the same body parts are actually moved, confirming that similar areas are recruited while observing and acting with specific body parts.

The network underlying action observation in humans, as shown by functional magnetic resonance imaging (fMRI) studies, includes premotor cortex, parietal areas and the superior temporal sulcus (STS) (Buccino et al., 2001; Grafton, Arbib, Fadiga, & Rizzolatti, 1996; Iacoboni et al., 2001; Rizzolatti et al., 1996) predominantly in the left hemisphere (Grezes, Armony, Rowe, & Passingham, 2003; Grafton et al., 1996; Iacoboni et al., 1999).

This might suggest that action observation activates only high-level motor representations. However, transcranial magnetic stimulation (TMS) studies suggest that action observation can directly influence the final cortical stage of action control in the motor cortex. When people observe actions involving a particular group of muscles, responses to TMS in those same muscles are specifically facilitated (Baldissera, Cavallari, Craighero, & Fadiga, 2001; Fadiga, Fogassi, Fadiga, & Rizzolatti, 1995; Maeda, Kleiner-Fisman, &Pascual-Leone, 2002; Strafella and Paus, 2000; Patuzzo, Fiaschi, & Manganotti,2003). These results suggest a process of motor resonance[1] based on a direct correspondence between the neural codes for action observation and execution.

The mirror circuits may have multiple functions (see for a review Rizzolatti and Craighero, 2004): for instance a mirror system may be involved in understanding the meaning (and the goal) of actions (Gallese et al., 1996). Consequently, it would allow for the implicit strategy of putting oneself "in the shoes of the agent". In other words, the observed action would activate within the observer's brain the same mechanisms that would be activated were that action intended or imagined by the observer (Gallese and Goldman, 1998). Similar processes could be involved in understanding how to interact with an object or, in other words, in extracting affordances from the observation of others' behavior. According to Gibson (1979), the affordances, i.e. the possibilities of action on an object, are provided by the visual representation of the object. Tucker and Ellis (2001) (see also Borghi et al., 2007) proposed that evoking affordances requires also the partial activation of the motor pattern required to interact with the object. Gentilucci and collegues suggested that affordances are motor representations of interactions between effector and object (Barbieri, Buonocore, Bernardis, Dalla Volta, & Gentilucci, 2007; Gangitano, Daprati, & Gentilucci, 1998; Gentilucci, 2002; Gentilucci, 2003). Grasping an object, indeed, requires the selection of a particular type of grasp and, when the hand approaches the target, the fingers are shaped (grasp opening phase) and then closed on the object (grasp closing phase). Kinematic studies (Chieffi and Gentilucci, 1993; Gentilucci et al.,

[1] The use of motor resonance is here preferred for coherence with the rest of the thesis. However, many authors use the term "motor simulation" to refer to these processes.

1991; Gentilucci, Toni, Chieffi, & Pavesi, 1994; Jeannerod, 1988; Milner and Goodale, 1995) showed that intrinsic object properties, such as size and shape, influence both the selection of the type of grasp and the implementation of the grasp kinematics, i.e. the activation of affordances. In a recent study (Gianelli et al. 2008) we showed that observation of different kinds of grasp produced an effect on a successive reaching-grasping movement, depending on a covert imitation the observed action. The effect was stronger when vision of the target and of the hand was precluded. Three additional experiments showed that the type of observed grasp influence the perception of object size. The results suggest that imitation evoked by the mirror system is involved in planning how to interact with an object and in the estimation of the properties extracted for sensory-motor integration.

A limitation in referring to these studies with respect to language is – as stated before – the fact that action observation and linguistic "observation" do not overlap. In this sense, it is possible that the activations of a fronto-central system for action observed in studies on language and in studies on action observation do not play exactly the same role in the two processes. Language translates action in a manner that re-articulates action itself, as a consequence it is possible that the same area has a different relevance depending on local cues, such as perspective. Furthermore, action organization seems to involve a very broad circuit which does not only involve the "classic" M1 and PMC typically addressed in motor resonance studies. Other areas, such as the parietal ones, are probably involved. This is a crucial point in this thesis, since one aspect specifically investigated is connected with action organization in motor acts, that is in chains. Since parietal sectors showed to be devoted to this aspects, it is likely that inducing a deep processing of goals and motor sequences activates a broad circuit involving this area in addition to the purely motor ones.

Critically, we have to consider that we do not have only motor but a variety of experiences, and that language can describe other aspects than the motor ones. In this sense, further research will have to consider the fact that we have multimodal experiences and hence multimodal descriptions of actions are capable to be activated by language. This seems to be in line with the theoretical proposal of Barsalou (1999) to consider concepts as multi-modal mental simulations. Concepts directly, or words referring to these concepts, should re-activate the traces of previous concrete experiences of these concepts: that is, visual experience, tactile experience, motor experience and so on. This would correspond to the activation of the corresponding areas. This is a broader definition of experience and consents to go beyond the purely motor level of experience. Even if this is not the specific focus of the thesis, this multi-modal description of actions has to be taken into account. However, this theory does not specifically give account nor does it consider aspects such as perspective or goals. Further research should integrate these aspects in a coherent framework.

1.5 The role of Broca's area in action

Broca's area, for long time conceived uniquely as a language-related area, seems to be involved – and with a crucial role – in the processes of action execution and observation, as well as during language production and understanding.

The ventral sector of the human premotor cortex is formed by two areas: the ventral part of area 6a alpha and Brodmann's area 44 (BA 44, Vogt & Vogt, 1919). BA 44 and BA 45, which occupy the opercular and triangular parts of the inferior frontal gyrus, form the Broca's region (Broca, 1864; Amunts et al., 1999). Classically, both ventral BA 6 and BA 44 were thought of as areas controlling oro-laryngeal movements, but with a different specialization and selectivity. The most lateral part of BA 6 was considered to be responsible for the motor control of oro-laryngeal movements, regardless of the movement purpose, whereas BA 44 was considered to be the main speech motor area. Indeed, it is well known that BA 44 is involved in encoding phonological representations in terms of mouth articulation gestures (Paulesu, Frith, & Frackowiak, 1993; Demonet et al., 1992; Zatorre, Evans, Meyer, & Gjedde, 1992). Since Broca's region occurred only in the evolution of the human brain, the search for homologies between Broca's region and ventral premotor areas of non-human primates is somehow difficult. It is interesting to note, however, that von Bonin and Bailey (1947) on the basis of their cytoarchitectonic studies suggested a homology between BA 44 and premotor area FCBm. The latter area occupies the most rostral part of monkey ventral premotor cortex, and its location basically corresponds to that of area F5 in the parcellation proposed by Matelli et al. (1985). These authors studied the macaque monkey's frontal agranular cortex by means of enzymatic method and found that F5 has a character transitional between granular and agranular cortices fitting well with that of FCBm, that according to von Bonin and Bailey (1947) has some aspects similar to those of the agranular frontal cortex but others, as an incipient IV layer, proper of the rostral granular cortex. Thus, F5 should represent the enzymatic counterpart of FCBm. The homology between area BA 44 and the rostral sector of monkey ventral premotor cortex has been recently revised by other authors (Petrides and Pandya, 1994; Rizzolatti & Arbib, 1998). According to a different view, however, a homology has been suggested between the areas 44 in monkeys and humans (Petrides, Cadoret, & Mackey, 2005). Neuronal recording and intracortical microstimulation showed that area 44 in monkey is involved in the control of oro-facial musculature. However, it is interesting to note that Nelissen, Luppino, Van Duffel, Rizzolatti, & Orban(2005) using the fMRI technique found sectors of monkey premotor and prefrontal cortices (including area 44 as defined by Petrides et al. , 2005), which were active during the observation of grasp actions. Specifically, the anterior regions responded to more abstract features of grasp actions and to presentation of objects, probably coding their "graspability". Up to now, however, no fMRI study has been conducted to demonstrate that these anterior regions, active during grasp observation, respond also to grasp execution with hand and mouth, being therefore endowed with a mirror system.

Further support to the proposal about a homology between BA 44 and area F5 comes from a series of neuroimaging studies, which have demonstrated that the role of Broca's area 44 is not restricted to speech production but that this area contains also a motor representation of hand/arm movements. Indeed, Broca'a area is involved in the execution of distal movements. Binkofski et al. (1999) found activation of BA 44 when subjects manipulated complex objects avoiding covert naming of them. In contrast, when naming was explicitly required during manipulation the activation focus was located in the pars triangularis fitting entirely into BA 45. In addition, Broca's area is activated also by the observation of distal movements. Rizzolatti et al. (1996) observed activation of this area when comparing observation of grasps with observation of objects targets of grasp. In another study (Buccino et al., 2001) the observation of transitive (i.e. acted upon an object) and intransitive (i.e. mimicked upon an object) actions of the hand, such as grasping an object, determined two areas of activation, one corresponding to the pars opercularis of IFG and the other located in the precentral gyrus. Interestingly, there was activation also to the observation of mouth movements, such as biting a piece of food, which partially overlapped the hand representation. However, the activation was more ventrally located than that found during mouth observation. BA 44 was activated also when participants observed human silent speech (Buccino et al., 2004).

Activation of the inferior frontal cortex was found also during overt and covert production of gestures (Bonda, Petrides, Frey, & Evans, 1995; Parsons et al., 1995; Decety et al., 1994), especially during mental rotations necessary for hand recognition (Parsons et al., 1995), during mental imagery of grasping movements (Decety et al., 1994, Grafton, Arbib, Fadiga, & Rizzolatti, 1996a; Grafton, Fagg, Woods, & Arbib, 1996b), during preparation of finger movements on the basis of a copied movement (Krams et al., 1998), during imagery and performance of visually guided movements (Binkofski et al., 2000; Toni, Rushworth, & Passingham, 2001), and during imitation of distal movements (Iacoboni et al., 1999). Since Broca's area is activated by the production/observation of speech as well as by the execution/observation of hand/arm gestures, it is possible that the two systems controlling hand and mouth interact in the same area. Specifically, Gentilucci, Bernardis, Crisi, & Dalla Volta (2006) hypothesized that Broca's area is also involved in translating aspects of activated representations of arm gestures into mouth articulation gestures. These aspects may concern the goal (Buccino et al., 2001; Buccino et al., 2004) and/or the intention of actions.

In sum, the role of Broca's area seems to be strictly linked to how actions are structured, hence to the organization of sequences of motor acts to achieve a goal. However, the role of this areas does not seem to be to code a specific aspect of action, such as for instance the single motor act. More plausibly, since Broca's area is involved in a great number of domains, this area likely operates at the general level of organization of hierarchical structures (language, action, but also music as discussed by Fadiga, Craighero, & D'Ausilio, 2009). It is possible then that Broca's area is part of a larger network, which is involved in many processes classified as "mirror".

The role of Broca's area could be to give a "syntactic" structure of actions, which is the "empty" structure which is fulfilled with the contribution of other areas in specifying for instance a specific goal, sequence of motor acts, agent, target object, kinematics of actions and muscles involved.

2. Between facilitation and interference

As seen in chapter 1, a huge amount of studies provides evidence in favor of claims about the involvement of the motor system during language processing. Part of these studies focused on the neural correlates of motor resonance, that is they aimed at showing *which* areas are involved in processing action-language. At the same time, several studies have focused on *how* the motor system is modulated: this was made possible mainly by behavioral and kinematics measures, as well as with TMS paradigms where a certain temporal resolution is possible. However, the direction of how the system is modulated is not coherent nor agreed across different studies; some studies found facilitation effects whereas other found interference effects, leaving unsolved the question. A possible explanation is that, even in continuity of approach and sometimes of techniques, these studies substantially differ from the point of view of experimental procedures, tasks, measures. A review of some of these results will be helpful, since the thesis mainly focuses on how the motor system is modulated when action-related language is presented..

2.1 Facilitation and interference in TMS studies

With respect to imaging studies, TMS (Transcranial Magnetic Stimulation) studies allow scholars a deeper understanding of how the somatotopic modulation of motor areas is involved in language processing. This is mainly due to the possibility to capture effects with a higher temporal resolution and precision due to the good spatial resolution.

Despite these advantages of TMS, this technique is equivalent to others in depending largely on the modalities of stimulus presentation and on the task required to participants. In addition, the time-course of TMS-induced effects is largely dependent on the exact timing of TMS stimulation. Specifically, for single-pulse TMS (the most common paradigm used in the studies we are reviewing) the time of stimulation with respect to stimuli onset and offset is crucial, and it is even more crucial for linguistic stimuli. Finally, a critical aspect of the experimental procedure is constituted by the decision between the use of a passive task (e.g. silent reading) or of an active task (e.g. a concurrent motor response required together with motor stimulation)

2.1.1 Facilitatory effects during a production task

A first study reporting facilitatory effects was performed by Oliveri et al.(2004). In this study, two different kinds of stimulation were combined, single- and paired-pulse TMS over the left primary motor cortex (M1) to test the hypothesis that M1 is activated during the retrieval of words (nouns and verbs) associated with specific actions. As discussed by the authors, single-pulse TMS is an useful technique to both measure and modulate the neural activity in the motor cortex. In fact, TMS stimulation acts at the level of corticospinal excitability. This modulation can be measured through the simultaneous recording of motor-evoked potentials (MEPs) in peripheral muscles chosen as targets.

However, the authors chose to couple this stimulation with a paired-pulse TMS. Paired-pulse stimulation is useful to overcome some difficulties in interpreting data from single-pulse MEPs measures.

According to Oliveri and colleagues, “In paired-pulse TMS, a conditioning stimulus (CS) below the threshold intensity needed to elicit an MEP is followed at short interstimulus intervals (ISIs) by a suprathreshold test stimulus (TS). At ISIs of 1–5 msec, the CS results in MEP inhibition, while longer ISIs of 7–20 msec produce MEP facilitation. This modulation of MEP size takes place at the cortical level and is thought to reflect the activation of separate populations of inhibitory and excitatory cortical interneurons without affecting spinal circuits. Therefore, paired-pulse TMS provides a reliable index of motor cortical activation.” (p. 375)

Single-pulse and paired-pulse TMS were applied while participants performed a transformation task, that is they produced action-related and non-action verbs (e.g., “To throw” vs. “To ignore”) and nouns (e.g., “ball” vs. “cloud”). MEPs induced by TMS were recorded from the right first dorsal interosseous muscle. The task was designed as follows: first, a linguistic stimulus was presented (a verb, a noun) then after 250 ms the word disappeared replaced by a symbolic cue. This cue indicated what kind of transformation the participants had to perform: producing the word in singular or plural form in the case of nouns, producing the word in third-person or plural for verbs.

The results showed that the activity in the motor cortex increased for actions words as compared with non-action words. However, no difference between grammatical categories (i.e. nouns and verbs) was found. Interestingly, an effect of TMS condition was present. Specifically, processing of action-related words – as compared to non-action words - induced greater facilitation of MEPs only at the ISI of 10 ms .

For what concerns the timing, these effect were obtained applying the stimulation 500 ms after stimulus onset. Crucially, the increase of motor cortex excitability was found applying TMS 500 ms after stimulus onset, that is 250 ms after the appearance of a symbolic cue which acted as instruction for the task. In sum, the facilitatory effect was dependent on the type of stimulation and was present for action words regardless of grammatical category.

Given the paradigm used, the effects found can be classified as purely facilitatory. However, this kind of study differs from others since it uses a production task. In that case, access to the semantic content of action words was limited to a window of 250 ms, in which participants had to prepare for the following task, mainly recognizing whether the word was a verb or noun. This kind of task stressed, on the one side, the distinction between nouns and verbs, but on the other did not require participants to access a deeper comprehension of word meaning. In this sense, the data are not completely comparable to other experiments using linguistic tasks or motor tasks.

In addition, what seems problematic about this study is that the final facilitatory effects were found in a rather specific hand muscle (FDI), but linguistic stimuli were not classified on motor criteria, such as for example effector, goal, kinematics. The only distinction was grammatical (nouns-verbs) and just partially action-related, being very broad. Kicking has a broad congruence with throw being an action verb, but the two actions largely differ for what concerns effectors and action organization. In this sense, the facilitation observed was possibly due to the sum of multiple factors. Similar confounds were present for nouns, which described object with dissimilar characteristics.

A possible explanation would be that action words triggered a motor activation at a very general level, thus facilitating the production task under specific conditions. The study does not allow us to disentangle whether this was due to specific aspects of the verbs and nouns used. A further explanation could refer to the timing of the experimental procedure: first, a general motor activation is induced by action words – which are then easy to access and take in memory – which then is translated in a facilitatory effect after TMS. This would result by the sum of an unspecific activation which is maintained by TMS over a threshold which is detectable on MEPs recordings. This activation primed the consequent "motor" task of producing a word. This is consistent with the timing of the effect which arose 500 ms after stimulus onset. However, the timing is not easily comparable with other studies: effective processing of the word is probably only for the first 250 ms.

Summing up, this study showed interesting facilitation effects, however they do not fully contribute to disentangle whether and how the activation of motor aspects of action-related words contributes to comprehension and then production of those nouns.

2.1.2 Facilitatory effects induced during a lexical-decision task

A facilitation effect is reported also by Pulvermüller, Hauk, & Ilmoniemi(2005), in another TMS study. The authors used in this case a lexical decision task, where participants were requested to respond with a lip movement only to words and refraining from moving with pseudo-words. Words were arm-related and hand-related words, like "pick" or "kick". Words and pseudo-words were presented for 100 ms and TMS was delivered 150 ms after stimulus onset. A single pulse TMS was applied on different sites: arm or leg area of the left primary motor cortex (M1). In addition, the right motor area for leg and hand, and a sham stimulation, were used as control condition.

With respect to the Oliveri et al.'s study the timing of the stimulation is quite different, TMS occurring presumably during the phase of lexical-semantic access to word meaning. In addition, the stimulation is site-specific accordingly to the verbs selected as stimuli: since arm and leg words were used, arm and leg sites in the dominant hemisphere were stimulated. In addition, only a single pulse TMS was applied and no MEPs were recorded as a measure of motor facilitation of arm or leg muscles. As a measure of facilitation the accuracy and latency of mouth responses were recorded and analysed.

Furthermore, a different selection of stimuli was made: whereas Oliveri and colleagues classified words as action or non-action words, and grammatically as nouns or verbs, in this study Pulvermüller and colleagues used action-related categories. That is, words were grammatically distinguished by pseudo-words, but they were internally divided into arm and leg-related words. Yet, no fine-grained distinction was made with respect to the effector used or the goal (arm actions can evoke different uses of the hand, whilst foot actions probably do not). In addition, no distinction is mentioned for other grammatical categories.

Results showed that TMS on the left arm area led to faster lexical decision times with arm words, whereas leg area TMS led to faster RTs with leg words. Facilitation effects were not found in control conditions, when TMS was applied in the right hemisphere and during sham stimulation.

As suggested by Papeo and colleagues (2009), it is possible that in this case TMS pulse acted as a semantic prime, thus facilitating the lexical decision task in a way that was specific for stimulation site. However, responses to arm-words slowed down mouth responses, in according with an interference effect due to the proximity of arm-face areas. This suggests that the effects of arm vs. leg words are not comparable, while they produce effect into the action-category itself. That is, arm responses may be slower depending on the kind of motor task, so that the facilitation effects emerged later. However, a possible confound in reading these data is given by the fact that a mouth recording was made and no MEPs data were collected (since the stimulation was above threshold). In this sense it is hard to disambiguate how the facilitation effects on RTs are mouth-dependent or indicate a pure facilitation of the motor task (or interference only related to arm-words).

Finally, even if RTs were collected, this study is hardly comparable with behavioral studies implying the same measure. This is in reason of the TMS effect which appeared to be different depending on the representation of arm-leg-mouth in the motor cortex. Further, the effect seems to be variable in short times, becoming a facilitation effect only in the late phases of movement execution (bearing in mind that no motor effect was measured on arm and leg muscles). Would this effect be suppressed by using different stimulation intensities, or would this interference-becoming-facilitation be confirmed? An useful suggestion is certainly that the observed facilitation effects emerge very early after stimulus onset, probably occurring during the lexical-semantic processing of words. This emerges even in presence of a lexical task which did not directly imply deeper semantic understanding of words. This confirms that at early stages of word processing only some aspects of action emerge, such as for instance the effector used to perform an action.

2.1.3 Late facilitatory effects on semantic and syllabic tasks

In a recent experiment Papeo, Vallesi, Isaja, & Rumiati(2009) used TMS on the primary motor cortex to verify at which stage of semantic processing motor effects occur, revealing facilitatory effects. Stimuli were hand and non-hand actions, presented in the first singular person ("I stir" vs "I think"). Words were classified on the action category, but also taking into account the use of different effectors (not only hand) for actions verbs..

The authors used single-pulse TMS (supra-threshold) over the hand area of M1, in order to elicit and record MEPs from the right FDI muscle. The timing of stimulus delivery was varied in three experiments, with delays of 170 ms, 350 ms and 500 ms post-stimulus, according to different stages (lexical, semantic, post-conceptual stages) of language processing. In addition, two tasks were performed: in the first semantic task participants were required to decide whether the presented word was action-related or not (so explicitly referring to action); in the second, a syllabic segmentation task, which presumably was independent of deep language processing. Together with MEPs, RTs and accuracy were measured.

Results showed that participants' performance was faster and more accurate when processing action verbs with respect to non-action verbs in the experiments were a semantic decision was required. However, a specific modulation of M1 activity was revealed only when stimulation was delivered late, that is 500 ms after stimulus onset. Activity in M1 as revealed by MEPs recording increased with action words and decreased with non-action words. In addition, a specific effect for hand-words was observed, being only M1 hand area stimulated.

The claim of the authors is that these results, while confirming that language and motor system interact, demonstrate that this interaction occurs only when more abstract conceptual representations are activated. In this sense low-level motor programs are not activated. In addition, they suggest that the decreased activity in M1 observed with a TMS delay of 350 ms may be the effect of an inhibition of motor processes that were not required by the task, suggesting a strategic use of the motor system. In this sense a facilitation effect is claimed to explain the results at 500 ms, and an inhibition at 350 ms. The general conclusion of the authors is that these data can be accounted by a motor imagery explanation, in which it is not M1 which activates motor resonance during lexical-semantic processing, but on the contrary it is the motor activation at post-conceptual levels that activates M1.

A potential confound in these data is given by the pool of verbs used as stimuli. First, they were distinguished only in action and non-action verbs, with a sub-category of hand-verbs and non-hand verbs. The categorization between action and non-action is stressed by the kind of semantic task used: participants in fact were asked to decide whether a verb was action-related or not. Furthermore, the sub-category of action verbs is composed as hand-verbs vs. all that is not hand verb. In fact, there we find foot actions ("walk"), whole body actions ("dance"), very complex actions in which the hand is also involved ("crawl"). As noted for other studies, there is not a clear semantic distinction between actions, neither following semantic criteria nor motor related ones, such as effector, goal or typical kinematics. Altogether, this potentially limits the interpretation of the present data, since the claimed no-effect in M1 could have been due not to an effective absence of effect, but to the competition of more effects which did not lead to a visible modulation of MEPs. The facilitation of M1 observed at 500 ms post-stimulus would be then not the only effect on this area – as stated by authors – by the final effect of a more complex process. In other words, the final facilitation effect is the result of previous competing effects due to the activation of very different motor programs. We should also remark that MEPs were recorded from a single hand muscle (FDI), typically involved in proximal movements: again no control was made in order to avoid this confound, since not every hand verb involved this muscle and a large part of non-hand actions did not involve this muscle. The data discussed in the first part of this chapter from imaging studies about the somatotopic organization induce us to be very cautious when experiments do not take into account the significant differences into the general "action" category. And consequently the different levels of action organization and hence understanding at which an action or action verb is processed.

It is worth noting that verbs were used in the first person. This is interesting as this is a quite neglected aspect in discussing the presence of facilitation or interference effects. To me, this is on the contrary one of the crucial aspects to disentangle these effects. The first person pronouns (hence a "I do") perspective is not automatically a first person perspective. In fact, reading a sentence were an "I" is involved could be seen as more external with respect to sentences using "You", pronoun which directly calls the participant into action. Hence, this external perspective could induce no or little and thus less detectable motor effects. This aspect will be discussed in the experimental chapters.

Finally, authors of this study assumed that an involvement of the motor system during the very first stages of linguistic processing is detectable measuring M1's activity and reaction times. This assumption is based on the idea that low-level motor programs should be activated, but it does not take into account the fact that it is possible that a similar effect is present in the premotor cortex. A similar involvement of an area with a more abstract coding of action and action goals is shown by a study performed by Tettamanti et al. (2005), where no activity in M1 was detected, whilst PMC activity was. This could explain the late effect and it is coherent with the semantic task required. A possible strategy for subjects is to distinguish between action and non-action verbs using the typical goal of an action and hence its effects. This would induce a more abstract coding which is not linked to low-level aspects such as the effector, hence the potential involvement of premotor cortex. This effect could be present in early stages of action processing, being however not fully detectable by this task. When the effect of M1 emerges, it is a late effect, which – as precisely authors state – could follow word understanding. In this sense, the timing of processing would go from the more general (goal) to the more specific (effector), which is not coded automatically and *per se* but depending on action effects.

In conclusion, it is possible that both an interference turning into facilitation effect is here detected, but also that a different timing of involvement of different motor areas is active.

2.1.4 Interference effects during a passive task

In contrast with these studies which generally found facilitation effects, a TMS study by Buccino et al. (2005) showed an interference effect.

Single-pulse TMS was delivered in distinct experimental sessions either on the hand and foot/leg motor area in the left hemisphere. These areas were stimulated (with an intensity of 120 % of the motor threshold) while participants listened to sentences describing hand or foot actions. As controls, an equivalent number of abstract sentences was used. Action sentences described actions performed with the hand or the foot on an appropriate object, in the third-person form but omitting the personal pronoun (e.g., “cuciva la gonna”, “he sewed the skirt”). All abstract content sentences expressed an abstract action on an appropriate object (e.g., “amava la patria”, “he loved his land”). All verbs were formed by three syllables and were conjugated in the third person of the past tense. The use of past tense allowed to build up the verb by adding the suffix “va” to the verbal stem. The same stimuli were acoustically presented in blocks of 45 sentences (hand OR foot OR abstract) repeated in two experimental sessions, the two sessions differing for stimulation site.

TMS stimuli were given at the end of the second syllable of the verb, hence before the participants had access to the predicate of the verb.

MEPs were recorded from hand (right opponens pollicis OP, first dorsal interosseus FDI) and foot (tibialis anterior and gastrocnemius) muscles. This timing of stimulation was chosen to correspond to 500-700 ms after sentence onset, thus allowing participants to fully process and understand the verb, even without the specification of the object. In this sense hearing “cuci-“ before TMS stimulation would be sufficient to understand the verb (hence activating some motor aspects, such for instance the effector), whereas the second part “-va la gonna” would specify the action.

Participants were instructed just to listen carefully to sentences: no explicit motor or lexical response was required.

Results showed an effector-specific modulation of MEPs recorded from hand and foot muscles. That is, MEPs recorded from hand muscles were modulated by listening to hand-action sentences, while MEPs recorded from foot-muscles were modulated by listening to foot-action sentences. The modulation is interpreted as an interference effect, since MEPs amplitude was reduced. Authors' claim is that a specific modulation of different sectors of the motor cortex is involved in processing hand- or foot-related sentences, probably depending on a specific modulation of the mirror neuron system. For hand muscles, no significant interaction between sentences and muscle is reported, while for foot muscle only the *tibialis anterior* was significantly affected by sentence type.

These interference-like data appear in contrast with the results of previous TMS studies performed similarly stimulating M1. A partial explanation for the difference with other TMS studies relies on the pool of stimuli used, since a clear distinction between hand-related and foot-related verbs is made. In addition, verbs were not presented in the infinitive form, but in the form of third-person past tense, which likely activated more specific aspects of action (such as the agent, the time of action). The presence of the object does not seem to be the major difference, since it was presented at the end of the sentence, while TMS stimulation and MEPs recording occurred before object presentation. In this sense, if effector-related motor programs were active, these programs could be (i) multiple and partially incomplete (i.e. all the possible configurations of the hand to sew present in the motor repertoire) or (ii) rely on the typical movements used to sew. The two possibilities are probably equally possible, since as said the effect occurred early in sentence processing. However, both for hand- and foot-verbs, some actions are more typically coded with a specific sequence of movements (even in absence of the object) like the already cited “sew”, while other actions open a wider range of possible movements (like “cut”). This is not superfluous, since activating different motor programs likely activates different muscles normally used to execute them.

Another critical element is the use of the third person and of the past tense. The use of past tense is perfectly justified by the paradigm, but it is possible that this induced a different modulation as if the present tense was used. More crucially, the use of the third person likely induced a framework different from the one activated if another person or the infinitive form were used. Specifically, the interference effect could rely on the activation of an external perspective, were the modulation of the motor cortex is different from the one obtained by inducing a first-person perspective. This external perspective is reinforced by the use of the past tense, and supported by the absence of an explicit task.

On the contrary, Buccino and colleagues explain this interference effect comparing it with the results obtained with action observation, where an increase of MEPs amplitude is obtained. Buccino's claim is that action observation is inherently richer than listening to simple sentences, considered as agent and context neutral. In this sense action observation directly activated only one specific motor program correspondent to the observed action, whereas language would activate a global understanding of the action, linked to a sub-threshold activation of multiple motor schemata. These motor schemata likely inhibited each other, then producing the interference effect. This explanation is certainly plausible, however it does not clarify why this interference effect emerges. Yet, it does not clarify the degree of effector-specificity of the modulation: is it just the superficial activation of the effector or the activation of some other aspects like for instance the typical use of that effector, the kinematics and so on? The blocked designed used, where each type of verb was presented alone, supports the idea that the effector-specificity depends on the explicit strategy of subjects to use the effector to distinguish among different kinds of verbs.

The presentation in blocks together with the use of the third person likely induced a general frame for each block: on the one side, the "hand" or "foot" or "abstract" frame, on the other side the activation of an observational point of view. If this is true, the two contributed to generate the interference effect. If subjects activated, for example, the effector hand this would pre-activate the correspondent M1 sector *before* the verb and TMS stimulation. Then, verb understanding would rely on this pre-activation, so that it is unlikely that a more specific processing of the effector was not present. Probably, some aspects of typical effector use were also activated, and this specificity lead to the recorded interference effects. In this sense the spread of activated motor programs was probably larger for hand actions (seen the internal difference among the verbs used) and more limited for foot actions. This is supported by the fact that hand-actions did not show a muscle-specific modulation, while a modulation for only one muscle was present for foot-actions (specifically the muscle involved in actual performance of the foot-actions). Foot actions were – as discussed – more specific and the same verbs were repeated more often.

The interference effect then would arise when M1 effector-specific activation is modulated by the activation of possible motor programs of the presented actions. In other terms, if motor resonance occurred, this depended on specific aspects of actions (effector use, typical movements, goals) which were not controlled in this study. Hence, no specific prediction on which of these aspects were active is possible. The coding of some of these aspects – for instance action goals – do not involve directly M1: it is arguable then that the findings of this study probably depend not only on the activation of low-level motor programs, but by the activation of action goals which engage the premotor cortex (and probably parietal areas). This would support that the early modulation of the motor system is not due to an imagery process, but it is effectively part of language understanding, since goals are a substantial part of action meaning. Indeed, the modulation is induced by a deep processing of semantics aspects of action sentences.

Since no actual movement was required, it is not possible to have information on which phase of motor planning or execution would be affected if motor responses were required. In fact, the presence of motor responses likely induces a limitation in potential motor programs activated during sentence processing. Some of the questions emerged in this discussion are partially clarified by a behavioral experiment performed by the same authors. I will discuss of behavioral and kinematics results in the next section of this chapter.

Summing up, the TMS studies we reviewed seem hardly comparable, but suggest that a specific timing of facilitation – interference effects is crucial. In addition, type of stimuli and task seem to deeply influence the emergence of the two effects.

It seems possible that interference effect arises earlier, then evolving in a facilitation effect once the sentence is completely processed. This would explain the differences in timing obtained in these TMS experiments. It is worth noting, however, that it is possible that the two effects, interference and facilitation, are equally present in different phases of sentence processing. Whereas the first interference is produced by a deep semantic processing, the facilitation effect is induced once the sentence is completely disambiguated and just a specific motor program is active. This would explain well-known compatibility effects such as the Action-sentence compatibility effect. In this sense the way stimuli and experiments are designed is crucial: for instance, an ambiguous use of infinitive verbs can be disambiguated by the context of response or by the motor response. In this sense it is more likely that a motor resonance depending on one specific motor program arises in these cases, so inducing facilitation. On the contrary, when motor processes are more ambiguous they cannot be all processed in deep terms, so that necessarily motor resonance must rely (i) on a typical motor program depending on general goals, or (ii) on an incomplete resonance effector-dependent, with no other specificity. It is unlikely that (ii) would affect a deep understanding of sentence meaning, being less useful in the actual use of language in social context (and with more costs).

2.2 Modulation of the motor system during overt motor behavior: reaction times and kinematics

Similarly to TMS studies, an increasing amount of behavioral studies has focused on interference and facilitation effects during language processing. Iwill review in this chapter some examples, which are useful to discuss this issue at a behavioral level. Together with purely behavioral experiments I review kinematics experiments, which are particularly useful: first, they are comparable with the studies I will present in chapter 3 and 4; second, they give us additional information on the timing of the modulation of the motor system, following specific phases of movement planning and execution.

2.2.1 .The ACE effect

A well-known facilitation effect is surely the so-called ACE, Action-sentence Compatibility Effect. This effect was originally reported by Glenberg and Kaschack (2002), then replicated and extended by several studies assuming the embodied cognition point of view. Even not fully physiologically explained this is an interesting example of facilitation effects directly measured by movement execution.

In the original study by Glenberg and Kaschack participants were required to perform a sensibility judgment about sentences implying a specific movement direction. The implied movement direction was equally divided: half of the sentences implied a movement of the arm toward the body, half a movement of the arm away from the body. Participants responded by moving the arm away or toward the body to press two buttons, in a body-centered system of response.

Sentences were both abstract ("Liz told you the story") and concrete ("Andy gave you the pizza") descriptive sentences. In addition, the imperative form was presented. To cover all the possible syntactic constructions of English, the descriptive sentences presented both the double-object construction ("Andy gave you the pizza") and the dative construction "Andy gave the pizza to you"). The use of the personal pronoun YOU, which could be either agent or recipient of the action, directly called the participant into action (this aspect will be discussed in more detail in chapter 5). The dependent variable was the time it took to participants to read the sentence and release a central button (starting position) to reach the button to make the sensibility judgment. This measure is then a sum of reading time plus sensibility judgment, but not only. This time includes also movement planning while reading sentences. The three aspects are surely interacting, so that planning a movement away or towards likely affects the task more than a simple button-press with no other movement execution. From a strictly motor point of view, then, the focus is on movement planning and on its very early effects on movement execution (button release).

The results showed a compatibility effect both for concrete and abstract sentences, and for the imperative form as well. That is, participants were faster in responding to sentences whose implied motion was compatible with actual movement direction. Responding to a sentence like “You gave Andy the book” was then faster when responding moving away from the body (like in the act of “giving”) than responding in the opposite direction. The same was true for sentences where YOU was receiving and the movement was towards the body.

The facilitation arises then from the congruency between movement embedded in a sentence and movement direction, mediated by the typical motor schema we use: giving something implies moving away from the body, while receiving implies a movement towards our body. Interestingly, this is true also for abstract sentences like “Liz told you the story”, which the authors claim to be grounded in bodily experience as the concrete sentences are.

Reading these data from the point of view of motor control gives us some hints to compare them with other experiments.

First, given the body-centered set-up of the experiment, it is likely that when reading sentences participants automatically pre-activated the hand. Second, reading sentences implying movement directions modulated hand activation by means of activating typical motor programs of moving away or toward the body. It is plausible that this activation of the two motor programs was induced by the specific setting in which the experiment took place: in other words, reading “Andy gave you the pizza” can be seen as the motor program of Andy moving away from his body, or as Andy moving towards your body. Since the response system was strictly body-centered the second motor program was reinforced, being a movement towards *your* body. The facilitation effect is coherent with this hypothesis, supported also by the fact that in a control experiment using a different response configuration (the index being already in position on the button away or toward) the authors found a very little evidence of ACE.

The facilitation effect probably relies on the activation of hand-related motor programs away or toward the body, but as stated also by the authors not at the level of detailed motor planning. The effect was produced by the sentence as a whole and occurred later with respect to the effects we saw in the TMS studies. However, since judgment time is a “late” measure, being itself an effect of different processes, a discussion of the ACE in terms of timing and in comparison with other techniques is hard to make. It is worth noting, however, that into the debate on ACE a significant contribution has been made by Borregine & Kaschack (2006), who verified the presence of the effect with auditory stimuli, using a go-no go paradigm and different delays with respect to sentence onset (50, 500 or 1000 ms). They showed, using a reduced version of the original sentences, that the ACE is a very short-living effect: 50 ms are sufficient for the facilitation to disappear. Indeed, the effect tends to modify itself till reversing, even not significantly, with augmented delays of go-signal after sentence onset. A difference of this study is that the measured dependent variable was a sum of reading time and movement time, that is the time it took participants to read the sentence, decide if responding or not and then move to the button away or toward on a keyboard. The conclusion of the authors is that the ACE is present only when the response movement occurs during sentence processing, so that the magnitude of the effect is maximal and significant at 50 ms delay (150 ms the difference mismatch RT – match RT), decreasing and modifying, but not significantly, over time.

It is possible that the paradigm elaborated by Borregine and Kaschack captured the last part of the ACE effect on movement execution, but failing in investigating how and when the effect changes. In fact, it is not clear *when* the effect disappears and how fast the magnitude decreases.

A further criticism to the ACE as an effective measure of motor resonance, and in general of motor effects of language processing, has been made recently by Fischer & Zwaan (2008). Since the original effect was found both on concrete and abstract sentences, Fischer & Zwaan hypothesized that two factors were active in inducing the final compatibility effect:

- an action-specific motor resonance, evoked by individual words or word combinations
- a more general motor resonance evoked by the linguistic construction.

According to these authors, the ACE on concrete sentences would be the result of an interaction of the two factors. In particular, the responsible for the second form of resonance could be the dative construction used in some sentences, that implied a motor schema away-toward associated with a particular linguistic construction. This is coherent with what we discussed about the ACE as a facilitation effect. In addition, they suggest that the second form of resonance is responsible for the effect on abstract sentences. This will be taken into account in the chapter 5 of this thesis, were a revision and extension of the ACE is made using French sentences.

In sum, the ACE is an interesting example of compatibility/facilitation effects, but with some major criticisms that we need to take into account. Overall, also these data confirm that motor resonance is a very complex phenomenon with large contextual dependencies.

2.2.2 The ACE revised: the Linguistic Focus Hypothesis

Recently, Zwaan and colleagues (Zwaan & Taylor, 2006 Taylor & Zwaan, 2008; Zwaan, Taylor & De Boer, 2010) aimed at extending and at the same time specifying the ACE with a different paradigm, with the general aim to demonstrate the plausibility of a proposal of Linguistic Focus Hypothesis (LFH). A brief discussion of this works will be helpful to complete the discussion on the ACE, as preliminary to chapter 5.

According to the LFH motor resonance may arise in correspondence with any part of a sentence (not only a verb, but also pronouns, adverbs etc) which disambiguate the meaning of an action. That is, the linguistic focus must be on action in order to produce motor resonance.

This has been verified using a reading-by-rotating paradigm: participants read sentences by turning a knob, being each sentence divided in segments. This allowed to verify which segment induced motor effects on the rotation movement.

Taylor and Zwaan (2008) verified whether motor resonance was influenced by the adverbs used in sentences, being a specification of how the action was performed. Examples of stimuli are “He sat/next to/a lamp/which he/turned on/quickly” and “Behind the/TV, he/grabbed the/cable/which he/unscrewed/quickly”. The first involved a clockwise movement, the second a counterclockwise movement. Manipulating the rotating direction match and mismatch conditions were produced – similarly to the original ACE. The prediction was that as long as the action is within linguistic focus, then motor resonance occurs. However, as soon as the focus shifts the simulation shifts along with it. In this sense LFH makes very precise predictions in where to localize facilitated motor processes during language comprehension.

Indeed this prediction was confirmed by the results of this study. In fact, recording reading times, they showed a match advantage which is present not only in reading the segment containing the verb but also when the focus shifts to the adverb. A control experiment using agent-modifying adverbs (e.g. happily, nervously) demonstrated that the facilitation effect is no longer present when the linguistic focus is no longer on action but on the agent. This excluded the possible confound given by a spread of the effect from the verb segment to others. However, these data confirm the facilitation effect with a very specific paradigm, thus supporting the idea that the ACE does really depend on spatial constraints which radically influence its development. Valuably, these data show that the facilitation effect is tied to the elements of a sentence which specify the action but that the effect is not restricted to the verb.

2.2.3 Interference effects during semantic tasks

A contribution to the facilitation-interference issue has been given by another series of similar experiments performed by Buccino et al. (2005), Sato et al. (2008), Scorolli & Borghi (2007). I will review these studies together since they all focus on effector-dependent effects.

Buccino and colleagues performed a behavioral experiment with the same pool of sentences used in the TMS experiment described above. In this second experiment participants were required to respond either with the hand or foot to concrete verbs, and to refrain from moving in case of abstract verbs. As go signal a circle on a computer screen changed color from red to green in correspondence with the second syllable of the verb, replicating the timing of TMS stimulation. A group of participants responded pressing a key with the hand, while another responded pressing a key with the foot. Results on RTs showed an interference effect compatible with the MEPs recorded in the first experiment: RTs were slower when the hand responded to hand verbs, and similarly RTs were slower when the foot responded to foot-verbs. The data thus confirm the effects found in the first experiment, adding a behavioral measure. However, the design was slightly different so it is not fully comparable. First, the verbs were presented randomly (exp 2) and not in blocks (exp 1), but participants responded with only one effector, either the hand or the foot. Second, the effector-related properties of the stimuli were highly stressed, given the random presentation of all the types of verbs: the use of the body and specifically of one effector is part of what distinguishes concrete and abstract verbs. Third, the timing of the go-signal is slightly different from the one used in TMS, so that RTs measures and MEPs probably focus on two consequent phases but not on the same phase.

This considered, it is worth noting that the interference results are confirmed by a behavioral measure. This can be explained again as due to the activation of competing verb-related motor programs, which in turn interfered with the actual motor program used to respond. However, the very simple movement used and the absence of any other recording than RT does not clarify at which stage of motor planning/execution the interference effect arises, so that the previous criticism we made are still unsolved.

In a follow-up study by the same group (Sato et al., 2008), the task-dependency of the interference effect was investigated. In three experiments a go-no go paradigm was used. Participants were required to respond with their right hand to action verbs, related to the hand ("to applaud"), the foot ("to walk") or to abstract content ("to love"). Verbs were presented in the infinitive form. Stimuli were presented acoustically or visually, to different groups. The experimental manipulation regarded both the task and the delivery of the go-signal.

In experiment 1, they used a semantic task with an early delivery of the go-signal. Participants responded pressing a knob with the hand to concrete verbs, and refrained from moving with abstract verbs. The distinction concrete-abstract was considered as a deep semantic processing of the verb. The foot was not used in this case as effector. A group of participants responded to stimuli presented acoustically: the go-signal (a red-to-green circle) was delivered in correspondence with the isolation point (i.e. the disambiguation point) of the verb, that is during verb processing. The second group responded to stimuli presented in written form. In this case the go-signal (color change) was delivered 150 ms after verb onset, which is considered a sufficient time to fully understand the verb.

In experiment 2, a delayed go-signal was delivered. For the auditory modality, the go-signal appeared either at the isolation point (early delivery) or 1000 ms after the isolation point (delayed delivery). In the visual modality, the go-signal appeared either 150 ms (early delivery) or 1150 ms (delayed delivery) after the onset of the verb. The task was the same as in experiment 1.

In experiment 3 the task focused on lexical decision: participants were required to give a response when the stimulus was a word and to refrain from moving when the stimulus was a nonsense word. Participants gave again their response moving the index finger to press a knob. The stimuli were presented only in the visual modality, with the go-signal delivered 150 ms after verb onset.

Results on RTs showed that different effects were obtained manipulating the task and the delivery of the go-signal.

In experiment 1, slower responses were found for hand-related verbs as compared to foot-related verbs. The effect was present in the two modalities, with the difference that responses in the visual presentation were slower than in the auditory one. On average, this difference between modalities was of 120 ms (significantly). Indeed, this did not affect the magnitude of the effect which was similar in the two modalities.

In experiment 2, the early go-signal confirmed the difference between verb types and modalities, while the delayed go-signal made these differences disappear.

In experiment 3, though an early go-signal was used, no effect of verb type was found with a lexical decision task.

The claim of the authors is that the difference between different tasks confirms that the task used in behavioral experiments is crucial to induce interference or facilitation effects (or no effects at all).

When a rather deep semantic processing is required, then the interference effect is found. Using a lexical-decision task did not affect the motor response. However, the effect remains untested on foot responses and on more complex motor tasks, thus leaving unsolved the question on which stage of motor planning is affected. Similarly, the lexical-decision task was not tested for a delayed delivery of the go-signal: would the timing be coherent with a “late” ACE effect?

What remains a possible confound is the use of verbs in the infinitive form, were little information is given, so leaving ambiguous the action. In this context, where participants had to make a fast semantic decision (at the IP or 150 after onset) and effector-related verbs were randomly presented, it is implausible that the verb activated a great variety of related motor programs. It is more plausible that the most typical motor program is activated, thus interfering with the actual motor program used to respond with the hand. This is coherent with the recorded values of RTs. Other measures like kinematics could allow to disentangle the nature of this effect: this is the focus of chapter 3.

A further extension of the results obtained by Buccino et al. (2005) was performed in a study by Scorolli & Borghi (2007). The authors presented a combination of nouns and verbs referring to hand, mouth and foot actions. Nouns and verbs were presented with pairs of nouns and verbs, referring either to hand and mouth actions (e.g. to unwrap vs to suck the sweet) or to hand and foot actions (e.g. to throw vs kick the ball). Participants were also presented with an equal number of non-sensible pairs and they were required to decide whether the combination made sense or not. Half of them responded by saying “yes” into a microphone, whereas the other half responded by pressing a pedal. They were asked to refrain from responding in case of nonsense combinations. Results showed that a facilitation effect was present on RTs in response to mouth and foot-related sentences as compared to hand-related sentences in case of congruency between the effectors – mouth and foot – involved in the motor response and in the sentence. The task is more similar to the one used by Glenberg and Kaschack (2002) than to the one by Buccino et al. (2005) and by Sato et al. (2005). In this sense it is a deep semantic decision task, probably deeper than the one used as concrete-abstract decision. But it is a late semantic task. In fact, the verb was presented for 200 ms, then it was substituted by the noun and then participants were asked to respond whether the combination made sense or not. In this sense, the recording RTs relied both on verb processing and nouns processing alone, and *then* in processing their combination. This could have slowed down RTs then delaying the motor effect, making the facilitation effect plausible but ambiguous about the undergoing motor processes. Then, it is possible that with a different paradigm with earlier response would have induced interference effects similar to the ones presented by the group of Buccino. The results are however in line with a linguistic focus approach: the nouns is effectively the part of pairs which disambiguates the meaning. In this sense, it is possible that a first effect is due to verb comprehension which remains for the nouns and then appears in the motor response. However, seen the short life of similar effects recorded with other techniques, it is plausible that the effect observed by Scorolli & Borghi is due to the final effects of a previous motor activation which changes differently according to the phases of linguistic processing and motor planning. Yet, given the difference between the two motor tasks used, the verbal production of YES and pressing a pedal, the two are unlikely to be similarly affected. Asymmetric results obtained for hand and foot actions, where foot sentences are faster not only with the pedal but also with the microphone, are probably result of this confound. But the two responses are asymmetric also given the fact that hand and mouth are strictly interconnected (see for a review, Gentilucci, Dalla Volta, & Gianelli, 2008), and their representation in the motor cortex are proximal and partially overlapped. On the contrary, foot actions and foot responses are mainly independent by other effectors. Since this aspect was not taken into account the available data do not allow us to go further on this considerations.

2.2.4 Modulation of the motor system at different stages of verb processing

A kinematic study by Boulenger et al.(2006) investigated the fine-grained kinematics of reaching movements executed during or immediately before language processing, giving information useful to clarify the direction and the evolution of motor resonance as detectable in overt motor behaviors. Two experiments constituted the study. In the first experiment participants were requested to perform a reaching movement and a letter string was presented right after movement onset. In the second experiment participants performed the reaching movement after letter string presentation, since the presentation was used as go-signal. That is, in the first experiment participants performed the reaching movement during language processing, so that an effect on motor planning is not possible. In the second experiment language processing occurred at the same time of motor planning.

Stimuli consisted of 42 verbs (all in the infinitive form) describing actions performed hand/arm, leg and mouth/face, and 42 nouns, describing concrete entities (e.g. stars) that cannot be manipulated. The pool was completed by an equivalent number of pseudo-verbs and pseudo-nouns. Subjects were required to perform a lexical decision task, which is not supposed to induce a deep understanding of verbs and nouns. The procedure was as follows: participants seated with the hand in pinch position, then required (after a visual go-signal) to leave the position in order to reach and grasp a cylindrical object in front of them. Leaving the starting position triggered stimulus presentation. Participants were then required to decide if the presented string was a word or a pseudo-word: in case of a word they had to carry on the movement, otherwise they had to stop the movement and come back to the starting position. The kinematics of this reaching-grasping movement was recorded.

In the second experiment the same stimuli were presented, but the go-signal corresponded to the letter string. In case of a word, participants had to reach and grasp the object, in case of a pseudo-word they simply had to lift the hand on the starting position.

The results showed that action verbs significantly affected overt motor behavior as compared to nouns. In the first experiment, when the lexical and motor tasks were executed in parallel, processing action verbs interfered with the concurrent reaching movement. This was evident in early kinematic parameters, namely the peak of wrist acceleration, which occurred later and was smaller. This is a signal of initial muscular contractions, but no other parameter was significantly modulated. This is interpreted by the authors as an early interference effect detectable about 200 ms after movement onset.

In experiment 2, the same words facilitated movement execution when processed before movement onset. This effect became evident 550-580 ms after word onset, and the effect was again detectable in wrist peak acceleration and namely in the latency of this peak. The effect was more pronounced for hand/arm verbs, which corresponded to the effector used in the motor task. However, this effect was not significant, and the experiment was not explicitly designed to make this effect emerge.

Since no other kinematic parameter, but wrist peak acceleration, was significant it is hard to state that in experiment 1 movement planning was interfered by the lexical task. For instance, no effect on wrist peak velocity was detected, while peak velocity is a crucial parameter for movement planning, which would give much more information about how motor planning and/or execution is interfered. Seen the data from Buccino and colleagues (who used similarly verbs in the infinitive form) it is unlikely that a simple lexical decision task involved a deep semantic processing of the presented verbs. Thus, it is unlikely that the interference effect arose from a deep involvement of the motor system. However, the involvement is undoubted and confirms to be very praecox. At the same time, it is plausible that this involvement was not enough to affect deeply movement planning and execution, as showed by the absence of clear effector-specific effects. It is possible that this relies also in the presentation of the infinitive form of verbs, which is ambiguous and as stated before relies probably on a very schematic and general definition of action. That is, a general motor program related to the verb was activated, but incompletely leading to a short-living interference effect which just transiently competed for resources with movement planning. It is worth noting that participants were always required to start the reaching movement, in other words the hand was always pre-activated and ready to perform the reaching movement. Then, it is implausible that this repeated movement can be deeply interfered by a verb presented at movement onset – this partially explains the absence of modulation of peak velocity in experiment 1. The modulation of the acceleration peak is then probably linked to a form of on-line interference on movement execution, which does not involve movement planning. Probably processing verbs led to an unspecific motor activation which transiently interfered movement execution.

In experiment 2, participants, similarly, always responded with the hand. However, in one case the reaching movement was started and completed, in the other this movement never started, depending on the presence of a word or a pseudo-word. But similarly an effect on wrist peak acceleration was detected. Since presumably verb processing occurred before movement planning, then it is plausible that this effect on acceleration is effectively the product of an effect on movement planning and not on on-line execution. That is, the hand was similarly pre-activated but in a very unspecific manner which did not plan before word onset the reaching or the lifting movement. Then, once the word is processed, the motor activation supports movement planning and execution. However, the delay at which the effect emerges, and then disappear after the acceleration peak, does not fully support the idea that movement planning is deeply affected. Again, it is possible that – despite the lexical task – a form of semantic processing of the verb is automatically activated, but this did not involve specific aspects (effector, goal etc) of action which are more likely to emerge with more complex tasks.

Nevertheless, these data are interesting in supporting the idea that even in lexical tasks the motor system is involved – as denied by other authors like Buccino and his group. Similar results using the same paradigm were obtained by Nazir et al. (2008), while Boulenger et al. (2008) extended these results using a combined EEG and kinematics paradigm, showing that even displaying subliminally action words interferes with motor planning.

But summing up, the effective involvement of the motor system, and the degree of involvement, depending on stimuli, linguistic and motor task, remains unsolved. The same can be said for what concerns the debated issue of interference/facilitation effects. Some answers to these and other questions (and new questions) are discussed in the experimental part of this thesis.

3. Language-specific modulation of overt motor behavior

This study[2] was designed in order to disentangle the time course of the motor effects produced by linguistic stimuli, namely action verbs with different goals. In addition, the aim was to investigate whether overt actions with different degrees of complexity are differently affected by linguistic stimuli depending on the aspect they share or not with the linguistic actions (e.g. effector, goals, kinematics). The results of previous neurophysiological and behavioral studies suggested that processingof verbs related to different bodily effectors relies on corresponding somatotopic activations in motor cortex. The present behavioral study aimed at further investigating this issue by determining whether and, in affirmative case, at which stage of motor planning and execution effector-related action verbs influence different actions executed with either the same or a different effector.

[2] This study was performed in collaboration with Riccardo Dalla Volta, Cristina Campione, Maurizio Gentilucci, Università di Parma, Dipartimento di Neuroscienze – Sezione di Fisiologia. The paper is published as Dalla Volta, R., Gianelli C., Campione G.C., & Gentilucci M. (2009). Action word understanding and overt motor behavior. Exp Brain Res, 196(3), 403-12.

3.1. Introduction

As shown, a large amount of neurophysiological and behavioral results suggest that language processing activates motor areas, depending on the semantic content of the word/sentence presented.

In particular, neuroimaging studies have shown that action-related linguistic material such as sentences describing actions or visual presentation of single action-words activate the motor cortex in a somatotopic manner (Hauk, Johnsrude, & Pulvermüller, 2004; Pulvermüller, Härle, & Hummel, 2001; Tettamanti et al. 2005). ERP (Shtyrov, Hauk, & Pulvermüller,2004) and MEG (Pulvermüller and Shtyrov 2006) studies confirmed that action-words related to different effectors activate specific loci in the brain and this activation occurs early after stimulus presentation. Similarly, in a TMS study Buccino et al. (2005) found interference effects of the listening/reading of effector-related action verbs on MEPs recorded from muscles of the corresponding effector. Altogether, these results are in agreement with the assumptions of the Semantic Somatotopy Model proposed by Pulvermüller (see Pulvermüller,2005; for a review, Hauk, Shtyrov, & Pulvermüller, 2008). The model predicts that processing verbs implying actions with the use of a specific effector activate the corresponding cortical areas which control those actions when actually performed. The model assumes that the relation between verbs and motor areas is properly semantic and it is clearly involved in language comprehension.

In this line, behavioral studies (Buccino et al., 2005; Sato, Mengarelli, Riggio, Gallese, & Buccino, 2008) showed that a semantic decision on effector-related action verbs interferes with RTs of simple motor responses (i.e. pressing a key) executed with the same effector. The authors interpreted these results as due to the fact that the listener/reader automatically activated the motor program(s) related to the verb in order to understand its meaning. These motor program(s) interfered with the pressing-the-key movement executed with the same effector, slowing down RTs. However, the authors did not report whether the interference affected the time to pressing-the-key beginning or also the actual execution of the movement. In other words, it is unclear which phase of the movement, planning or execution, the action verb interfered with. In addition, Buccino and colleagues used a rather unspecific motor task, focusing on the effector used to perform it, without taking into account that actions (i.e. reaching-grasping) could be differently modulated with respect to simple movements (i.e. pressing a key).

In a kinematic study, Boulenger at al. (2006) found that processing action verbs interfered with a concurrent reaching movement when the word was presented after movement onset. By contrast, the same words facilitated reaching movements when processed just before movement onset. The action verbs induced variation in the acceleration peak of the actual reach occurring about 200 ms after movement onset; this suggests that an incomplete activation of the verb-related motor program, probably involved in language comprehension, affected the initial execution of the actual action. The activation was incomplete likely because it was inhibited by the planning of the actual action. In fact, a covert activation of the entire motor program related to the verb, i.e. a complete activation, would have affected successive kinematic landmarks like peak velocity. Peak velocity (i.e. the last kinematic landmark of the ballistic phase) is the main parameter resulted from the planning of the action. It is greatly affect by the external factors under which the movement is executed; for example, peak velocity of arm transitive actions is greatly influenced by extrinsic and intrinsic target-object properties (Gentilucci, Toni, Chieffi, & Pavesi, 1994; Jeannerod, 1988). Consequently it can be more susceptible to effects of covert activation of verb-related programs. In addition, the movement phase successive to peak velocity (the deceleration phase) is mainly executed under visual control and the kinematic parameters poorly reflect the results of movement planning. Consequently, the deceleration phase can be poorly affected by the verb-related action planning.

An aborted (i.e. incomplete) activation of a motor program in response to action verb presentation unlikely reaches the threshold for a deep comprehension of the verb meaning. For example, unspecific motor activation of the hand after presentation of hand-related verbs affects the beginning of the action, but this is not sufficient to conclude that the meaning of the word has been completely and deeply understood. In contrast, a complete activation of a motor program likely reaches the threshold for comprehension of the verb meaning because it contributes to understand the goal of the action. Indeed, the goal of the action can be completely understood only when the consequences and the effects of the action are recognized; this necessarily requires movement parameterization, i.e. how to reach the final state of that action (see below). We assume that movement parameterization is the activation of those kinematic rules, which govern that action, rather than the modulation of kinematic parameters as a function of contingent conditions. For example, the kinematic rules governing the reach action establish how the arm kinematics is modulated as a function of extrinsic and intrinsic object properties (Gentilucci et al., 1994). The fact that the meaning of a word can affect the kinematic rules of an action executed simultaneously to word presentation is supported by experimental evidence. Gentilucci and colleagues showed that the automatic reading of verbs (Gentilucci, 2003) and adjectives (Gentilucci and Gangitano 1998; Gentilucci, Benuzzi, Bertolani, Daprati, & Gangitano, 2000) modified the kinematics of another action congruently with word meaning.

The presents study aims at determining whether the semantic decision on effector-related action verbs influences, and at which stage of motor control, actions executed with the same or different effector. Action verbs were selected depending on the effector used to typically perform those actions. All actions involved the hand or the food: the hand actions involved the use of one acting hand, while normally foot actions involved the two feet and generally the entire body moving. Participants were required to toexecute actions with their right hand or foot in response to presentation of action-related verbs since the interaction between actions (i.e. verb-related actions and actual actions) rather than between actions and simple movements (i.e. verb-related actions and pressing-a-key) allowed to determine better the degree of motor activation in language processing. The basis assumption of this work is that the complete activation of action programs related to a verb is a necessary (even if not sufficient) condition to effectively understand the full meaning of that verb. Complete activation of action program(s) in response to verb presentation (i.e. programs in in which movement is parameterized) should affect the main kinematic parameter of another action, i.e. peak velocity. In contrast, incomplete motor activation should affect only the initial phase of the action, for example peak acceleration as observed by Boulenger et al. (2006). Indeed, incomplete activation could be easily blocked by the control of the actual action. This was verified in experiments 1 and 2 in which we used, as previously Sato et al. (2008) did, a go – no go paradigm requiring participants to execute intransitive (i.e. internally driven, experiment 1) and transitive (i.e. acted upon an object, experiment 2) actions in response to verb presentation. We required the execution of transitive as well as intransitive actions because, usually, the actions related to verbs can be guided by objects as well as they could be internally driven. Then, in experiment 3 we used a paradigm of effector-choice in order to verify whether the semantic decision on effector-related verbs also influenced the initial activation of the effector used to execute the action.

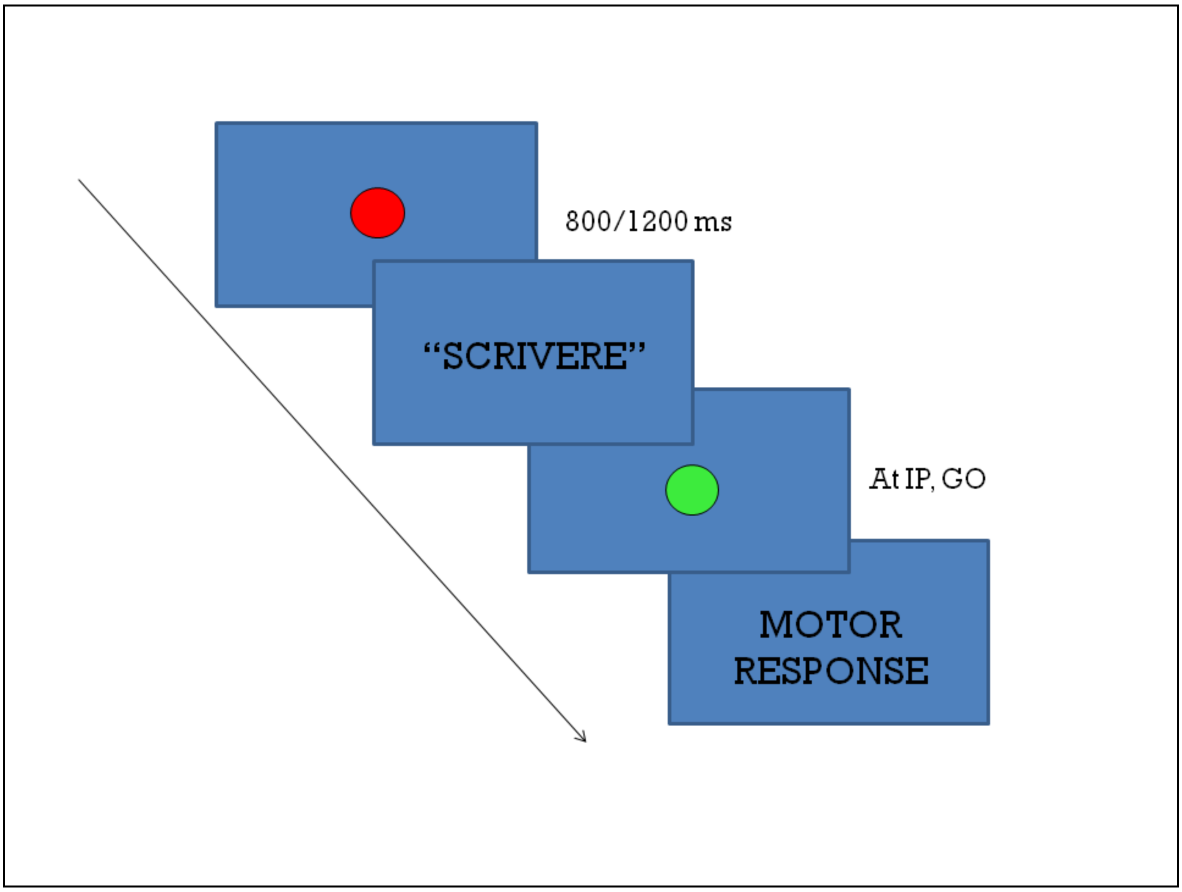

Fig 1 Experimental procedures followed in the three experiments

3.2 Experiment 1

Experiment 1 aimed at determining whether the semantic decision on effector-related action verbs interfered with an internally driven (intransitive, i.e. whose final state is internally established) action executed with the same effector. All actions involved by the verbs showed a typical goal (i.e. writing), whereas the overt action performed did not show an external goal and did not involve acting with the environment or an object.

3.2.1 Methods

Participants

Sixteen (7 females and 9 males, aged 20-27 years) right-handed (according to the Edinburgh Inventory; Oldfield, 1971) volunteers participated in experiment 1. All of them were naïve to the purpose of the experiment. The Ethics Committee of the Medical Faculty of the University of Parma approved the study.

Apparatus, stimuli and procedure

The participants sat in front of a table on which their hand was placed in pinch position. The stimuli were thirty Italian verbs in the infinitive form: ten verbs expressed hand-related actions (e.g. “to sign”), ten expressed foot-related actions (e.g. “to walk”), and ten expressed an abstract content (e.g. “to think”). They were the same used in the study by Sato et al. (2008) and were matched for syllable number, word length and lexical frequency (see Appendix for details). All the verbs were acoustically presented through a pair of headphones (BEHRINGER hps 3000). Each verb was recorded from an Italian native male speaker and digitized in an individual sound file at a sampling rate of 32-kHz with 16-bit quantization recording by means of the software SASLAB (Avisoft). For each sound file, the isolation point (Marslen-Wilson, 1990) was detected on the stimulus spectrogram using the Praat software (Institute of Phonetic Sciences - University of Amsterdam). This procedure allowed us to determine the precise time when the verb could be correctly identified. The three verb categories were matched for duration (average values: 1.40, 1.41 and 1.39 s for hand-related, foot-related and abstract verbs, respectively) and for interval between the beginning of the acoustic presentation and the isolation point of the verb (average values were 0.68, 0.68 and 0.64 s for hand-related, foot-related and abstract verbs, respectively). The participants were instructed to listen carefully to the verbs and either to execute an internally driven action (see below), as fast and accurately as possible when the verb expressed a concrete action, or to refrain from responding when the verb expressed an abstract content (go – no go paradigm). Each trial started with a red circle (diameter of 6 cm) presented at the center of a 17 inches PC monitor distant 80 cm from the participant. After a variable delay of 800-1200 ms (in order to avoid a response habituation), a verb was acoustically presented. When the color of the circle changed from red to green in coincidence with the isolation point of the word the participants were required to open their right thumb and index finger by an arbitrary amount; however, they were required to maintain this amount constant through all the experimental session. The thirty verbs were quasi-randomly presented in a single experimental session.

Data recording and analysis

Movements of the participant's right hand were recorded using the 3D-optoelectronic SMART system (BTS Bioengineering, Milano, Italy). This system consists of six video cameras detecting infrared reflecting markers (spheres of 5-mm diameter) at a sampling rate of 120 Hz. Spatial resolution of the system is 0.3 mm. Recorded data were filtered using a linear smoothing low pass filter, i.e. a triangular filter where each value was the weighted mean computed over 5 samples (window duration 33.3 ms).

We used two markers attached on the tip of the index finger and the thumb. We analyzed the time course of the distance between the two markers placed on the two fingertips in order to study the finger opening. We measured the following parameters: time to response beginning (TRB, i.e. the time from the isolation point to the beginning of finger opening), peak velocity of finger opening, time to peak velocity of finger opening, maximal finger aperture and time to maximal finger aperture. We chose to analyze peak velocity of finger opening since we aimed at verifying whether the main and temporally central parameter of this act was affected by the parameterization of the action related to the verb.

The first frame when the variation in distance between the two fingertips was greater than 0.3 mm (spatial resolution of the system) in two consecutive frames was considered the beginning of finger opening, whereas the first frame when the variation in distance between the two fingertips was less than 0.3 mm in five consecutive frames was considered the end of the finger opening.

Data Analysis

For each dependent variable of each parameter, we calculated the skewness (SK) and its confidence interval (95%, CI) in order to test whether the distribution was normal. Then, ANOVA was carried out on the mean values. The within-subjects variable was effector-related verb (hand vs foot). Since multiple comparisons were performed, we applied the Bonferroni adjustment to the P-values for significance testing. Consequently, the significance level was fixed at P=0.01. For each significant variable and interaction we calculated also the effect size (η^2). Only the parameters that reached significance are discussed in detail, the other measures are reported in Appendix.

3.2.2. Results

TRB was not affected by the effector-related verbs (mean value: 411.0 ms), whereas peak velocity of finger opening was (the distributions of the dependent variables were normal, $F(1,15)=9.0$, $P<.01$, $\eta^2 = 0.4$). The movement was slower in response to hand-related verbs than foot-related verbs (Fig.1). The mean values of time to peak velocity of finger opening and time to maximal finger aperture were 80.7 and 260.3 ms, respectively; that is peak velocity of finger opening approximately occurred at 31.0% of the total time of finger opening. No other parameter reached significance.

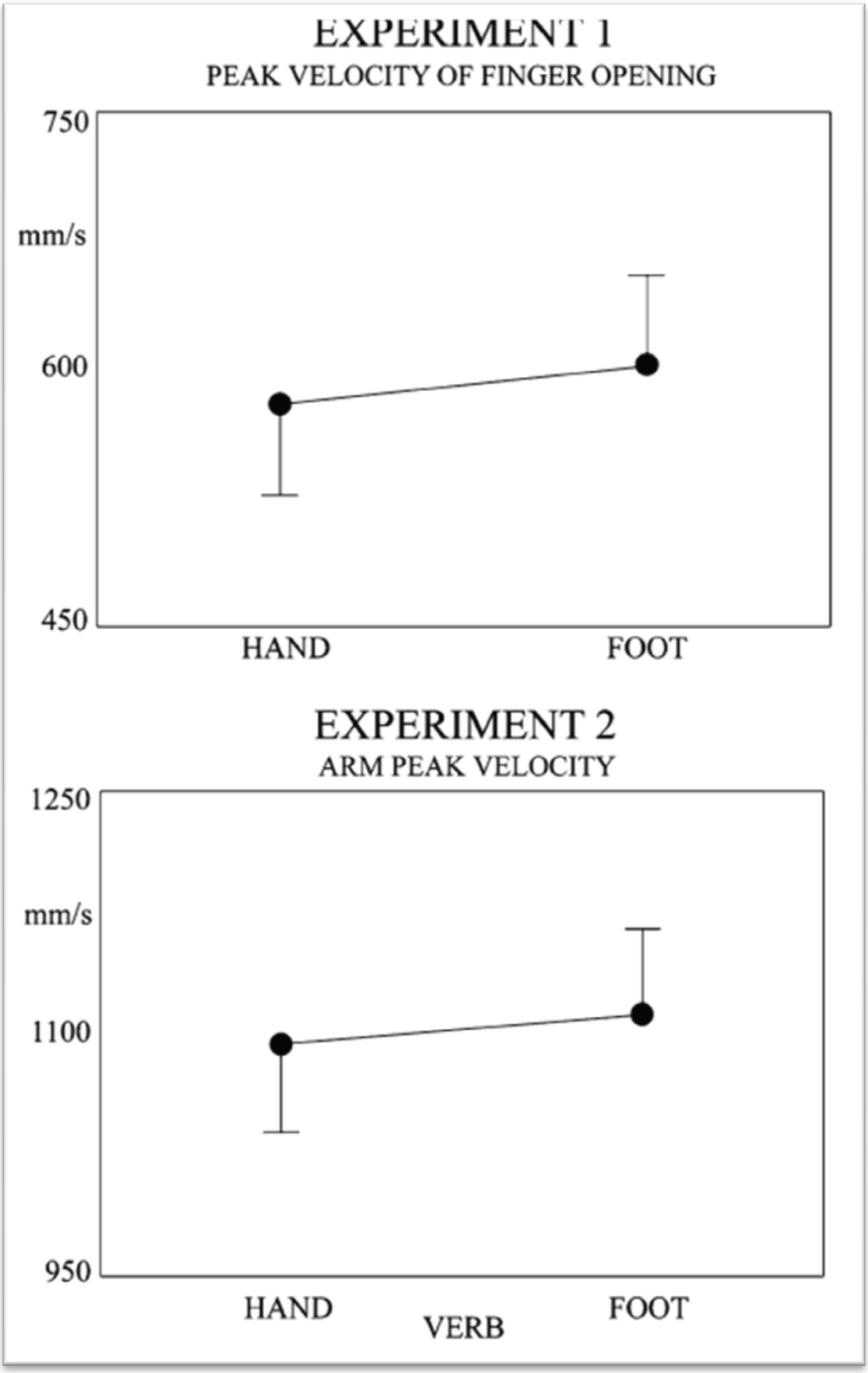

Fig.2 Effects of the processing of hand-related and foot-related verbs on peak velocity of finger opening in Experiment 1 and peak velocity of arm during reaching-grasping in Experiment 2. Bars are SE.

3.3 Experiment 2

Experiment 2 aimed at determining whether in the same semantic task used in experiment 1 effector-related action verbs interfered with an externally driven (transitive, i.e. acted upon an object) action executed with the same effector. In this case the overt action is given of a goal, in which a specific chain of motor acts is activated: reaching to grasp and object, take and replace it. The sequence is quite complex, so that it is supposed to involve a more complex motor planning, which could be less or differently modulated by linguistic stimuli.

3.3.1 Methods

Participants

Fifteen (9 females and 6 males, aged 20-25 years) right-handed (according to the Edinburgh Inventory; Oldfield, 1971) volunteers participated in the experiment.

Apparatus, stimuli and procedure

Apparatus, stimuli and procedure were the same as in experiment 1. When the color of the circle presented on the PC monitor, changed from red to green in coincidence with the isolation point of the word the participants were required to execute two actions in sequence that consisted in reaching-grasping and removing with their right thumb and index finger, a transparent (Plexiglas) cylinder (diameter of 6 cm and height of 2 cm) attached on the PC monitor in correspondence of the red/green circle by means of a light magnet. The height of the cylinder center from the table (on which the participant's hand was placed in pinch position) was 26 cm, whereas the 3D distance of the cylinder center from the fingertips was 36 cm. The cylinder center and the participant's fingertips were aligned along the participant's midsagittal plane. The thirty verbs were quasi-randomly presented during the experimental session.

Data recording and analysis

Movement recording was the same as that in experiment 1. We used three markers attached to the tip of the index finger, the thumb, and to the wrist of the participant's right hand in order to study the kinematics of the reaching-grasping action. We analyzed the time course of the distance between the two markers placed on the two fingertips to study the grasp. The grasp time course starts with the hand in pinch position, and is constituted by a finger opening phase till a maximum (maximal finger aperture) followed by a phase of finger closing on the object (Jeannerod, 1988). The measured grasp parameters were the following: TRB of grasp, grasp time, maximal finger aperture, and time to maximal finger aperture. The kinematics of the marker placed on the wrist was used to study the reach. The measured reach parameters were the following: TRB of reach, reach time, reach peak velocity and time to reach peak velocity. We chose to analyze maximal finger aperture and reach peak velocity since we aimed at verifying whether the main and temporally central parameters of the grasp and reach were affected by the parameterization of the action related to the verb. The methods to calculate beginning and end of reaching-grasping is described elsewhere (Barbieri et al. 2007).

Data analysis

Data analysis performed on the reach and grasp kinematic parameters was the same as in experiment 1. We applied the Bonferroni adjustment to the P-values and, consequently, the significance level was fixed at $P = 0.006$. Only the parameters that reached significance are discussed in detail, the other measures are reported in Appendix.

3.3.2. Results

TRBs of reach and grasp (i.e. the times from the isolation point to the beginning of the reach and the grasp: 389.0 and 432.0 ms, respectively) were not affected by the effector-related verbs, whereas reach peak velocity was (the distributions of the dependent variables were normal), $F(1, 14)=11.3$, $P=.005$, $\eta^2=0.5$. As in experiment 1, the hand movement was interfered by the hand-related verbs (Fig.1). The mean values of time to reach peak velocity and reach time were 249.2 and 648.8 ms, respectively; that is reach peak velocity approximately occurred at 38.4% of the total time of reach. No other parameter reached significance. The finding that the grasp was not affected by the effector-related verbs can be explained by considering that the grasp requires greater attentional resources in the control of the finger opening/closing as compared to the control of the arm during approaching the target. Consequently, the attentional request could make the finger control refractory to interference of the actions activated by the effector-related verbs.

3.4 Experiment 3

In Experiments 1 and 2, the peak velocities of finger opening and reach, which occurred at 31–38% of the movement execution, were influenced by the semantic decision on abstract and concrete verbs. They were interfered by hand-related action verbs. The fact that the main parameter of the action, i.e. peak velocity, was affected suggests that the activation of the motor program elicited by action verbs was complete. The activated program interfered with the parameterization of the velocity of the actual action. However, the beginning of the action, i.e. TRB, was not affected by the activation of the verb-related motor program. We reasoned that the parameterization of a movement follows a first phase of effector activation, which occurs before action beginning. The finding that the effects of a possible reciprocal influence between effector activations (hand vs. hand and hand vs. foot) was not observed at movement onset can be explained by the fact that only the hand was actually moved in both the experiments. Consequently, the hand could be already activated at trial onset and could be less sensitive to the influence of the activation of the effector related to the action verb. To solve this problem, we designed Experiment 3 in which we used an experimental paradigm that required the choice of the effector used for the response. In such a way, either the hand or the foot could be actually moved in the same experimental session. Thus, an activation of both hand and foot at trial onset, i.e. before verb presentation, was unlikely, and this could allow reciprocal influence between activation of the actually moving effector and that related to the action verb.

3.4.1 Methods

Participants

Fifteen (8 females and 7 males, aged 22-28 years) right-handed (according to the Edinburgh Inventory; Oldfield, 1971) volunteers participated in the experiment.

Apparatus, stimuli and procedure

Apparatus was the same as in experiments 1 and 2. The participants placed their right hand in prone position on the table and their right foot on a low basement. We presented the concrete verbs only, but the presentation was the same as in experiments 1 and 2. The participants were required to respond to the verbs by lifting the tip of either their right index finger or their right foot by an arbitrary amount, but constant through the experimental session, like in experiment 1. Specifically, the index finger was extended while the hand palm rested on the table or the foot was extended while the heel rested on the basement. In one block of the same experimental session the participants were required to respond to the hand-related verbs with their hand and to respond to the foot-related verbs with their foot (compatible condition), whereas in the other block the effector use was reversed, i.e. they responded to the hand-related verbs with their foot and responded to the foot-related verbs with their hand (incompatible condition, effector-choice paradigm).

This paradigm of effector-choice substituted the go-no go task of the first two experiments. This allowed a direct comparison of foot and hand verbs, but without the constraint of having always one effector (namely the hand) pre-activated has being the only one used in the motor response. Using both the foot and hand we forced participants to process action verbs focusing on the effector and at the same time we increased the possibilityprobability to have a modulation of the effector used for the motor response. The two blocks were counterbalanced across participants. In each block 10 concrete verbs (5 hand-related verbs and 5 foot-related verbs) were quasi-randomly presented. In each block the verbs were different and were counterbalanced across compatible and incompatible blocks presented to the participants.

Data recording and analysis

Movement recording was the same as in experiments 1 and 2. We used four markers: two markers were attached to the tip of the index finger and on the tip of the foot of the participants. The other two markers were placed on the table plane and on the basement. They were aligned with the markers attached on the effector tips and were used as reference points. We analyzed the time course of the distance between the marker placed on the tip of the effector (either index finger or foot) and the corresponding reference marker. The measured kinematic parameters were the following: TRB of the effector (either the index finger or the foot), peak velocity of effector lifting, time to peak velocity of effector lifting, maximal effector height, and time to maximal effector height. The method to calculate beginning and end of the effector lifting was the same as in experiment 1.

Data analysis

ANOVAs were performed on the mean values of the measured kinematic parameters. The within-subjects variables were the following: effector (hand vs foot) and effector-related verb (hand-related verb vs foot-related verb). In all analyses, paired comparisons were performed using the Newman-Keuls procedure. We applied the Bonferroni adjustment to the P-values as in experiments 1 and 2: the significance level was fixed at P=0.005. The other analyses were the same as in experiments 1 and 2. Only the parameters that reached significance are discussed in detail, the other measures are reported in Appendix.

3.4.2 Results

TRB (i.e. the time from the isolation point to the beginning of the effector lifting) was affected by the interaction between effector and effector-related verb (the distributions of the dependent variables were normal, $F(1,14)=24.9$, $P<.001$, $\eta^2=0.6$, Fig.2). A facilitation effect of the effector-related verbs on the choice of the effector was observed in the compatible condition. Specifically, the post-hoc analysis showed that the hand-related verbs induced a decrease in TRB of the hand responses and conversely foot-related verbs induced a decrease in TRB of the foot responses (Fig.2). In contrast, in accordance with the results of experiments 1 and 2, the kinematics of the hand and the foot lifting were interfered by the hand-related and foot-related verbs, respectively. Peak velocity of effector lifting (the distributions of the dependent variables were normal, $F(1,14)=27.1$, $P<.001$, $\eta^2=0.7$) and maximal effector height (the distributions of the dependent variables were normal, $F(1, 14)=23.9$, $P<.001$, $\eta^2=0.6$) were affected by the interaction between effector and effector-related verb. Post-hoc analyses showed that the two parameters were interfered when the foot moved in response to foot-related verbs, and conversely, when the hand moved in response to hand-related verbs (compatible conditions; Fig.2). Maximal height was also affected by effector ($F(1,14)=142.8$, $P<.00001$; $\eta^2=0.9$). It was greater when lifting the foot than the index finger (Fig.2).

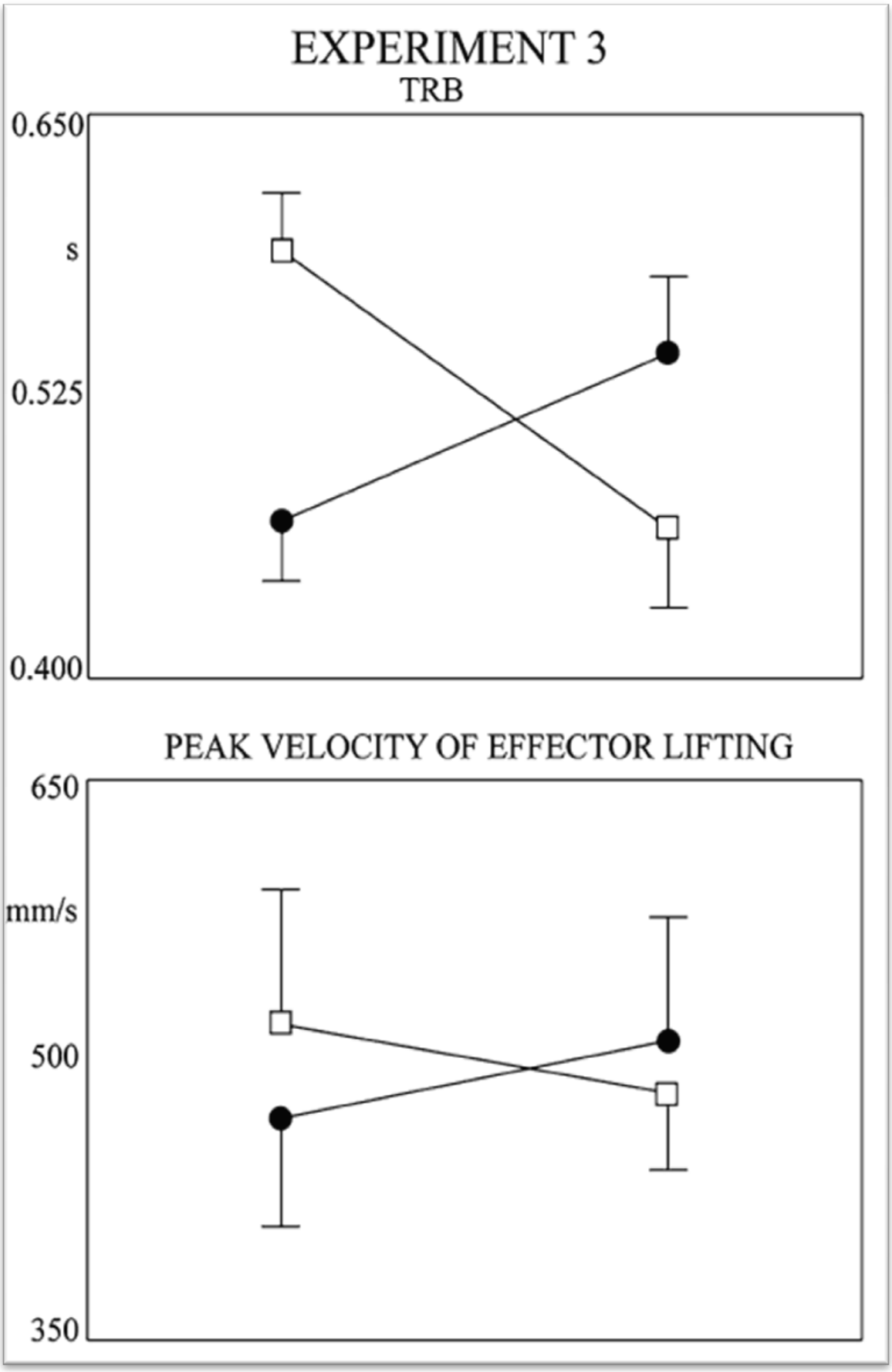

Fig. 3 Effect of hand-related and foot-related verbs respectively on the kinematics in Experiment 3. *TRB* time to response beginning. Foot movements correspond to white squares, hand movements to black circles.Bars are SE.

3.5 Discussion

The results of the present study show that, in a semantic task, manual intransitive and transitive actions executed in response to acoustical presentation of hand-related verbs slowed down in comparison with presentation of foot-related verbs. According to Buccino and colleagues (Buccino et al., 2005, Sato et al., 2008) these data can be interpreted as activations of manual motor programs in response to hand-related verb presentation, which interfered with manual responses. Since peak velocity was affected, the hypothesis about a complete activation of motor programs related to verbs can be supported (see “Introduction”). The verb-related motor program was completed, and it interfered with the parameterization of the actual action velocity.

Effects of the verb-activated motor program on the reach final phase (deceleration phase) were not found probably because the execution of this phase is mainly under visual control of the spatial relationships between hand and target (Jeannerod, 1988) and consequently less susceptible to influence due to the planning of another movement, i.e. the verb-related motor program. The results of the present study differ from those of the study by Boulenger et al. (2006) in that an interference effect was found only initially in the latter, whereas in the central part (30-40%) of the execution in the present one. This can be explained by the fact that a semantic task was required in the present study, whereas a lexical task was required in the study by Boulenger et al. It is likely that the semantic task required a complete activation of the verb-related action in order to understand completely the verb meaning, whereas the lexical task did not require any access to the specific meaning and content of the verb: it required just to understand whether the letter string was a word or a pseudo-word. This could induce an incomplete activation of the verb-related action, which was easily blocked by the actual action before the activation reached the threshold for complete comprehension of the word meaning. This incomplete activation may also explain why the authors failed to find a significant difference between the effects of verbs related to hand actions and verbs related to non-hand actions. In other words, the incomplete hand activation induced weak interference, which was not significantly different from possible weak effects induced by the activation of other effectors. In agreement with the data by Boulenger et al., the results of the present study show that the verb-related motor program facilitated the initial activation of the actual action. The facilitation effect observed on TRB can depend on the fact that initially the parameterization of the actual action is *in fieri* and consequently the verb-related motor program contributes to the activation of those muscles, which are involved in both the verb-related and the actual action programs. Only once completed, the program of the actual action competes with the verb-related motor program. This initial facilitation seems to be at odds with the data by Scorolli and Borghi (2007) who found, on the contrary, facilitation at the end of presentation of sentences related to actions. However, this facilitation might be due to rebound consequent to the fact that the participants were required to start moving after presentation of the noun predicate of the action verb, i.e. when possible interference effects were suppressed (see chapter 2 for an extensive discussion of this issue). Why should the complete covert activation of motor programs related to verbs be necessary to understand their full meaning? We proposed that in order to understand the exact meaning of an action verb, the goal of the action related to the verb should be understood. In turn, in order to understand the goal, the consequences of the action should be represented; this necessarily requires movement parameterization. For an example, in order to understand the verb "to grasp" the goal of the action should be understood, i.e. "to take possession" of an object, but to this purpose also the consequences of the action should be represented: an object held in the hand and how to reach this final state. In other words, the type of interaction of the hand with the object should be activated (the affordance, Barbieri, Buonocore, Bernardis, Dalla Volta, & Gentilucci, 2007) and this implies the activation of the kinematic parameterization of the verb-related action. However, the actions related to verb meaning can be multiple: for an example “to write” can activate programs of writing either using a pen or a PC keyboard. However, writing with a pen or a keyboard share the same goal, which informs all the meaning of the action. What is different it is the single sequence of movement we use to accomplish it. We propose that the most habitual action is activated. However the activation of multiple programs cannot be excluded *a priori*, although it is unlikely. In fact, if different programs are tentatively activated the activation should be incomplete because the simultaneous parameterization of different movements executed with the same effector is impossible. Our data rule out the possibility of incomplete activations. Consequently, only one program, probably the most typical and habitual one, was activated.

In our case, the congruence between effector-related verb and effector actually used was reinforced by the fact that hand-action verbs were selected as mainly describing unimanual actions. However, stimuli were not specifically balanced for this aspect, so we can just make some general considerations on this point.

A possibility is that different use of the effector during the overt motor response (i.e. involvement of the other hand during bimanual tasks) would have likely affected movement parameterization and execution in a different way. For instance, presenting unimanual and bimanual action verbs would have induceinduced different motor activations and hence differently affect the execution of bimanual and/or unimanual reaching tasks, depending on the different use of the effector. In this case, more fine-grained kinematics aspects of action would have been activated. However, we hypothesized that what induces motor effects is the overall goal, with a complete activation of motor programs related to the action-related linguistic stimuli. In this sense, bimanual or unimanual actions may share their overall goal, but not the fine-grained aspects of the motor act which compose them. In this sense, it is reasonable that what effectively modulates the motor planning and execution is the final goal (i.e. the distal aspects of action representation in the terms of Hommel et al., 2001) rather than the more proximal aspects.

In this sense, presenting bimanual action verbs and asking for unimanual motor responses, or the reverse, could be an interesting study to investigate the different effect of goals and effector parameterization on overt motor responses.

Take for instance the case of “grasping” with the overall goal of “taking possession of an object”. Grasping may be possible with one hand and with two hands as well. In this sense, the two actions would have a broad congruence in terms of goal, while differing for the kinematic aspects of action. This is particularly true in cases, like ours, in which the verbs are presented in infinitive form and without any cue on the object – grasping would be then interpreted depending on the required motor response.

If it is the goal which affects the motor behavior, then we should expect that presenting only bimanual or only unimanual verbs in contrast with foot verbs, and requesting a congruent motor response (i.e. reaching-grasping with one or two hands), likely would induce a modulation of the actual action depending on the overall goal and on a typical motor parameter associated with it. On the contrary, presenting bimanual and unimanual verbs together and requesting to respond with a congruent or incongruent response, probably would activate more fine-grained distinctions in which the goal itself is modulated depending on the typical kinematics through which it is accomplished. Experiments following this line would help to disentangle the contribution of proximal and distal aspects of action in producing effects of action-language on motor behavior. As in our study, the effect wouldwill be stronger in the reaching phase, which is also known to be differentiated depending on the subsequent motor acts: reaching to grasp with one hand is not the same motor act as reaching to grasp with two hands. This aspect will be more deeply discussed in the next chapter.

The results of our study are also relevant for the actual debate about the role of processes of motor resonance during language comprehension.

In summary, two hypotheses are debated: the first assumes that language understanding completely relies on symbolic, amodal mental representations (e.g., Fodor 1975). Following this approach, the meaning of language derives from an arbitrary correspondence between abstract symbols and their corresponding extensions in the world. According to this view (the ‘disembodied’ hypothesis, see Mahon and Caramazza, 2008) motor activations accompanying language understanding are completely irrelevant for semantic analysis. They are consequent to processes similar to those leading the “Pavlovian dog to salivate when it hears the bell” (Mahon and Caramazza, 2008) and are automatically elicited in conditions similar to those produced in S-states, as defined by Jeannerod (2001). The second hypothesis (‘embodied’ hypothesis) assumes that language understanding does rely on processes of embodiment (Lakoff, 1987; Glenberg, 1997; Barsalou, 1999; Pulvermüller, 2002; Zwaan, 2004; Gallese and Lakoff, 2005; Zwaan and Taylor, 2006). Based on this view, language understanding implies the involvement of the same neural systems used to perceive or to act. This is in agreement with the assumptions of the Semantic Somatotopy Model proposed by Pulvermüller (see Pulvermüller 2005; for a review, Hauk et al. 2008). Together with these two radical approaches, the debate has been recently enriched by new intermediate positions. On one side, Mahon and Caramazza (2008) assume that motor representations can access and contribute to the full representation of a concept (the grounding by interaction hypothesis). On the other side, Fischer and Zwaan (2008) gave the provisional conclusion that the current research demonstrates that “motor resonance results in a deeper, higher resolution, comprehension” of a concept, so that motor resonance at least enhances comprehension of language. However, Mahon and Caramazza (2008) postulate higher level for amodal conceptual representations as compared to motor representations, whereas Fischer and Zwaan (2008) postulate that the motor representations are complementary to concept and language understanding.

In the present study, we found that the activation of the action program related to the verb was complete: this suggests that the goal and the consequences of the action were understood. This is in favor of the hypothesis that the activation was involved in fully understanding the meaning of the verb. In addition, the effects of the action program(s) related to the verb were visible at the beginning of the execution of the action, i.e. 450 ms after verb presentation. This time is compatible with the activation of motor programs nearly simultaneously to verb presentation and their successive interaction before completion. This early activation supports the idea that the observed effect is not a by-product of motor imagery occurred in the post-understanding stages of linguistic processing. A late imagery would probably affect also the last part of the reaching phase and the grasping component (in experiment 2) as well. This was not the case. On the contrary, early reaching parameters were affected: this supports the idea that the activation of language-induced motor processes preceded or was at least accompanied the phase of motor planning of the motor response. Furthermore, our stimuli were simple verbs in the infinitive form: they are unlikely to induce very fine grained processes of motor imagery, since we did not provide an agent, and object, a context to deeper interpret the verb. That is why we hypothesized that the typical goal and motor program associated with a verb in our motor repertoire is activated. Moreover, the motor program is activated from the perspective of an agent, since no other element was provided to discriminate this aspect. This makes our stimuli very different from an image or a video, which provide an external observation of an action, condition that probably induces a different activation of motor processes, in being more locally constrained. The same can be said for the lack of a direct object: the presence of an object would have likely induced the activation of more specific kinematics depending on the characteristics of the object. In this case probably other phases of movement could have been affected.

Similarly, an automatic spreading activation similar to a Pavlovian process without any specific utilization of the motor representation, as proposed by the ‘disembodied’ hypothesis (see Mahon and Caramazza, 2008), should be liable to extinction. This was not observed. Consequently, we suggest that the motor activation is involved in language understanding. This is in agreement with neurological data showing that pathological changes in frontal areas due to motor neuron disease produced deficits more pronounced in comprehension and production of verbs than nouns (Bak, O'Donovan, Xuereb, Boniface, & Hodges, 2001). Our data indicate that the motor activation is used to understand the goal of the action related to the verb, by means of representations of the consequences of the action. This is in favor of the hypothesis that the relation between verbs and motor areas is properly semantic and it is involved in language comprehension.

3.6 Conclusions and general discussion

In this first study I showed that the activation of motor processes during language comprehension is at least double-folded and relies on different aspects of action organization.

First, it can be involved in a more superficial understanding of the verb, related for instance to the effector typically used to perform that action. This relationship between motor areas controlling the effector (i.e. hand or foot) emerges at a semantic, but rather unspecific level. That is, the effector involves the semantics of an action, but does not disentangle other aspect of actions such as for instance how we commonly perform them using a given effector. At this level, writing or cooking are similar in involving the hand as effector, but they largely differ for the use of that hand.

However, we know well that they are inherently different, so that writing involves specific muscles and cooking others. In this sense, we can identify a deeper semantic level, where , different kinds of hand-actions differ for what concerns their goal, and consequently for the way we perform those actions and coordinate movements in order to accomplish that goal and produce some effects on the world. At this level we can also consider the social modulation of goals, thus considering how social interactions can be described by (action) language, for instance depending on action sequences implying the presence of others as we are going to discuss in chapter 4. This deeper understanding is often crucial from the point of view of social interaction: as stated before, "observing" an action linguistically implies processing different aspects of an action, depending on the context, on our goals, on our needs to perform (actually or linguistically) other actions to respond. In this sense, the motor activation contributes to this full understanding, thus leading to comprehend the goal of the action, and the final effects of it depending on the way it is performed. In addition, this process is definitely fast and occurs at the very first stages of language processing. In this sense, it cannot be a by-product of other processes, but it is effectively part of them. This confirms it as a process with a social function and relevance, since it occurs depending on the context of interaction, for example the context in which a verb is used. This process contributes to define language itself as a form of action: our words and sentences produce concrete, motor effects on the people we are interacting with. We use some aspects of action to act linguistically, by activating effectors, action goals, and, as I will show later, perspectives. In this sense, language is crucial in its function to help us to share actions with other people, not at the level of abstract cognitive representations, but at the level of the motor experience.

Our data suggest that, together with the goal of an action, the motor programs to perform that action are activated. This is not in contrast with our proposal that what is linguistically translated is the goal of the action. In fact, even if the goal is hierarchically more general than the kinematics of action, the way (*how)* we perform an action is crucial to pursue the specific goal of a that action. As said before, the actions of writing with a pen or with a keyboard share the goal to "write a letter" and the effector we use, but *how* we accomplish that goal is different. In this sense, the kinematics aspects of action are fundamental to identify the goal, and this is part both of our bodily experience, being the agents of an action and having this action in our motor repertoire, and of our social (linguistic) experience. This is certainly true for the simple actions described in the verbs from this study, and for all the stimuli this thesis used. We all share the basic experience of grasping or of writing. However, in our everyday life we often perform very complex and skilled actions, at different degrees of ability. In this sense, several unsolved pointspojnts remain:

- Does the linguistic description of skilled actions (from the fluent use of technology to dancing) activate motor processes similarly to the basic actions of our motor repertoire? That is, do they activate fine-grained motor aspects or more general aspects (i.e. goals but not the fine-grained kinematics)? Do they activate the former only for the people having an expertise of those actions?
- At the level of motor effects, do these actions affect only experts or also novices? If using skilled actions as responses, are they more or less interfered with respect to simple actions such as reaching and grasping an object?

All these points are still unsolved and constitute a possible future development in this field. This first study I report suggests that linguistic stimuli differently affect motor planning and execution according to the linguistic task and to the motor task used as response. That is, motor aspects of linguistic described actions interact with some parameters of different overt actions. I will show in the next experiment how other aspects of action organization similarly interact.

In this way we expect to give account of how we can linguistically manage actions, and linguistically "act" as suggested above: we can have a linguistic experience of actions we have never performed and similarly we experience actions of which we do not have a linguistic description or name. In the case of linguistic experience of actions never performed, we can have a certain degree of understanding of different aspects of that action, but probably not the fine-grained kinematics of the way to perform it. Think of the situation of a friend who is describing her last match as kick-boxer describing and naming her single moves, and you never performed it and maybe neither saw a match. She can linguistically describe her experience so that you can at least partially understand.

The contrary is true as well: we can have the bodily experience of an action, hence of its kinematics, but we have not the linguistic experience of it – since our language does not provide an exact verb to describe it. In some cases other linguistic devices (i.e. adverbs) or constructions (paraphrases) allow us to communicate and explain that action. Alternatively, we can refer to other languages in which the exact term is used.

Summing up, in all the situations described above we have experiences, bodily experiences, in which our body and brain is continuously involved in interaction with other actors, humans or not, and this leads constantly to a redefinition of what is experience and what is "action" for us. Language contributes in modeling our experience, and in being modeled by experience itself, in a process of translation from the one to the other. For this reason, other aspects than goals can be stressed and become more relevant: this is the case of perspective, as we will see in the next section of this work.

4. The perspective of the agent and action chain organization

This second study has been designed in order to examine the interplay between the role of motor perspective (agent) and action organization in motor chains, verifying its behavioral effect on an overt action required as response. As stated in the Introduction, we aim at determining how language is capable to translate some aspects of action organization and to investigate the behavioral effects and possibly the functional role of the re-activation of these aspects during language processing. In this sense, we demonstrated in the first study that the goal of an action can be linguistically re-activated, modulating a motor response. Moreover, the action goal, expressed by language, seems to modulate early motor planning and just marginally action execution. We demonstrated also that other aspects of actions – such as for example the effector – can be similarly activated depending on the context, the task and the kind of motor response. In this sense, we postulated that different levels of linguistic action understanding affect an overt action, depending on the aspects of an action activated in a specific context. This is true for our first experiments, where the effect vary depending on the task, and it is true as well during our daily interactions. My assumption is that a linguistic motor activation is not only part of the semantic content of a word, but has a complementary role in making language itself a form of action.

This second study [3]moves from the first and aims aimsat deepening how goals can be translated in language. We assume that language encodes goals at different levels: not only at the very general level of goals as abstract entities, but at the specific level of goals

[3] This study was performed in collaboration with Anna M. Borghi, Università di Bologna. The paper is submitted as Gianelli, C., Borghi, A.M., I grasp, You give. When language translates actions. (submitted to Language and Cognition).

as concrete entities relying on sequences of motor acts or simple actions. For instance, the action of "giving" would not be coded only for its goal, but also for the motor sequence it involves (e.g. reaching-grasping an object and then reaching another person to give it, moving the hand away from the body). In addition, we investigated the role of motor perspective taking: does taking my perspective or the perspective of another person vary the motor effects of a verb? In addition, does assuming a specific perspective interact with goal-dependent action organization?

4.1 Introduction

The basic assumption of our study, in keeping with the embodied and grounded cognition views (Barsalou, 2008; Fisher & Zwaan, 2008; Rueschermeyer, Pfeiffer, & Bekkering, 2009), is that the activation of the motor and sensorimotor cortices during language processing is not just a side-effect but effectively contributes to language comprehension. The majority of previous studies have focused on whether words activate their sensorimotor referents, without taking into account the different degree of specificity conveyed for instance by an infinitive verb with respect to a complete sentence. Namely, none of the previous studies has sufficiently taken into account how motor activation are s modulated depending on the perspective induced by the linguistic stimulus. The novelty of this study consists in focusing on how action sentences can translate the relationship between self and others (humans or not, such as objects) and how these relationships may reflected in detectable motor effects. If I hear or read "You gave him a pen", I do not only refer to the action I can perform with my hand. The action of giving implies a relationship both with an object and with another agent, and this very fact results in a specific action organization which includes an overall goal (the other person should obtain an object) and at least two different motor acts, grasping an object and giving it to someone else. This study investigates specifically how and to what extent the action organization resulting from the interplay of different goals and different kinds of relationship with objects is translated in language, and has a coherent behavioural effect.

Goal-relatedness of action has recently received much attention, both from a theoretical and from an experimental point of view. As recently stated, goals are defined in terms of “value for the system” (Gallese, 2009). In our interpretation, goals cannot be reduced just to the final end state of an action, or to the intention of a subject; rather they are what stands for the “value” of an action. Broadly considered, the notion of value can refer to the social value, to the value for an individual in a given situation, or it can reflect the value of a single motor act (sub-goals) with respect to the action in which it is embedded. This open definition of goal allows us to treat action organization at a very general level, where goals can be dynamically modulated through the structure of actions in motor chains. The proposal of motor chains was first advanced in the framework of monkey studies. Fogassi et al. (2005) found, for instance, that some neurons fired when monkeys performed the act of grasping when bringing an object to the mouth, others fired when grasping was embedded with the action of bringing an object to a container. Similar effects were recorded for action execution and observation. The notion of motor chains was used to explain the effect of these parietal neurons firing differently depending on whether a single motor act (e.g. grasping) was embedded in two motor chains characterized by two different goals. The idea that actions have a chained organization has been then extended to humans, with an imaging study by Iacoboni et al. (2005). The functional relevance of motor chains has been then revealed by study on autistic spectrum disorders (Cattaneo et al., 2007; Fabbri-Destro, Cattaneo, Boria, & Rizzolatti, 2009; Boria et al., 2009). These results show that a mechanism of motor chains constitutes one of the basic structures of the motor system. A chain of motor acts is informed by the final goal of action; motor acts are organised in the chain so that each of them depends on the successive and all depend on the last. Goals characterize both single motor acts and actions as a whole.

Of course, action organization cannot be reduced to the motor acts which compose it. Specifically, an action implies at least one actor, either human or not. An actor can assume dynamically all the possible roles provided by a given situation: he/she can be agent, patient, subject or object of the action, depending on the relations which are activated by that specific action. Both goals and actors represent important constitutive parts of the action as a whole. We hypothesize that language is capable to translate the interplay between goals and actors, and that this information is re-activated when discourses or simple sentences are processed.

This study has been designed in order to examine this interplay verifying its behavioural effect on an overt action required as response. To this aim we constructed very simple sentences composed by a pronoun and a verb, with the intent to disentangle the contribution of the two components (agent perspective, action organization).

Personal pronouns (such as I, You, He) have at least a double role: they allow us to understand who is performing an action (the agent) and if there is someone else (e.g., object, patient) involved in the action. Telling somebody a story starting with I or with He can be very different as it might change perspective, hence to emphasize some aspects of a situation while neglecting others. The perspective we adopt while understanding language is of crucial importance in the development of social interactions. Curiously, however, pronouns have not been extensively investigated in the recent studies focusing on the motor grounding of language. Therefore we can rely only on a few linguistic studies (MacWhinney 2005) and on some studies on action observation (Jackson, Meltzoff, & Decety, 2006; Vogt, Taylor, & Hopkins, 2003; Schütz-Bosbach, Mancini, Aglioti, & Haggard, 2006; Gianelli, Dalla Volta, Barbieri, & Gentilucci, 2008; Bruzzo, Borghi, &

Ghirlanda, 2008), which differently underline the crucial role of perspective, in particular of our own perspective.

Overall, these studies mainly rely on the visual perspective (egocentric vs. allocentric perspective), while our work focuses on perspective as induced by linguistic pronouns. This is a crucial point: static pictures or videos, and certainly direct observation as well, directly convey a specific perspective, using the body of the "observer" as reference. Language contains a double potentiality : first, to use linguistic devices to convey perspective (e.g. pronouns), second, to use these devices to re-articulate perspective just linguistically. "I" is not strictly a fist person perspective, "You" can be a first person as well depending on the way reading/listening are located into a specific interaction. The same distinction between external and internal perspectives fails to give a complete account of how language can build up perspectives. Furthermore, it fails in giving account of how we can embody our motor perspective from different points of view.

Our study aims at opening this field of investigation, starting by studying the different motor effects produced by the personal pronouns.

Namely, we used the three singular personal pronouns, I You and He/She (io, tu, egli), in Italian. The complementary issue of goals and motor chains has been addressed selecting two categories of verbs, that we called *action verbs* and *interaction verbs* (AVs, IVs) (e.g., grasp vs. give), which differ according to various dimensions. First, the two categories differ for the relations they describe and involve: in one case the direct relation subject-object, in the other the at least triadic relation subject-object-other subject. Second, they differ for how these relations imply different goals: AVs are actions which may stand alone and whose final goal might be the manipulation of the object, whilst IVs directly imply the interaction with another person. Third, they differ as to the organization in motor chains: AVs and IVs share the motor act of reaching-grasping an object, while they differ for the last act of the sequence, the one which determines all the others, which might imply or not the presence of another person. Thus, even if the first motor act is common, it is embedded within two different goals. If chained organization is reflected in language, then the kinematics parameters of the motor acts should differ according to the kind of verb.

Two different hypotheses can be advanced.

The first is that language structure reflects the action structure. If this is the case, then while reading simple pronoun-verb pairs we should activate more the first person pronoun, corresponding to our own perspective. Therefore, we should either find an advantage of the first person perspective (typically associated with "I") or no modulation due to perspective at all, as while reading we would be able to simulate all perspectives in the same way. More specifically, the "I" pronoun would be the one which is mostly modulated by the difference between action and interaction verbs.

A second possibility is that when we understand a sentence we reactivate an inter-subjective situation, such as for example a conversational framework. This could happen even if in our study word pairs were presented in a written rather than in an acoustic form. If an inter-subjective framework is activated, this would mean not only that language builds on the action structure, but that it also modifies and constrains it. If this is the case, then we predict a modulation of the 2nd person pronoun ("YOU"), followed by the 1st person pronoun ("I"), and no modulation of the third person perspective, given that in a conversation the 3rd person perspective is typically the most external. It is true that the 1st person is not used to refer to us (in quality of listener), but the 3rd person typically is not involved in the conversation at all, whereas the person speaking in 1st person necessarily is. Therefore, we predict a modulation of the different action goals (AVs and IVs) referred to the perspective which is directly advocated in a conversation (YOU), a less marked modulation with the “I” perspective and no modulation with the He perspective.

In our experiment participants were required to grasp an object while reading a sentence (see figure 1). This allowed us to investigate the development of the effect of sentence processing on the overt action of grasping (which has its own goal, of course), through the analysis of its fine-grained kinematics aspects, which are much more informative than simple RTs. Our aim was to disentangle the final effects of the two components, pronouns and verbs, and at the same time to understand how their effects are combined producing a modulation of various phases of movement kinematics.

4.2 Methods

Participants

Twelve women, aged 18-28, participated in this study. All participants were right-handed, native Italian speakers and reported normal or corrected-to-normal vision. All were naive as to the purpose of the experiment and gave their informed consent to the experiment.

Procedure

The experiment took place in a sound-proof room. Participants sat in front of a laptop, whose LCD monitor was set on a temporal resolution of 60 Hz. The distance between hand and monitor was of 60 cm. Participants started placing their right hand on the table in a pinch position. The target of the subsequent reaching-grasping movement was a mouse, placed in line with the hand of the participant, at a distance of 33 cm. The final position for the mouse movement was set at 50 cm. The hand movement was performed on the right of the laptop, at a distance of 5 cm. This allowed participants to easily perform the movement and look at the video.

Stimuli

Stimuli consisted of 10 Italian verbs referring to manual actions (see "Appendix", table 2). We selected five proper "action" verbs, which involved a direct relation subject-object (e.g., *to grasp)* and five inter-action verbs, involving at least a relation subject-object-subject (e.g., *to give*). Sixteen students evaluated these verbs on two 7 point scales, one aimed to rate how much the verbs implied a relation subject-object, the other how much the verbs involved another person. An ANOVA performed on the mean ratings (considering 2 types of verbs and 2 type of ratings) showed a significant interaction (F (1,15) =15, 2, MSe = 21.39, p=.001) between verb type and rating. As predicted, "action" verbs obtained higher values as referred to the object, whilst "interaction" verbs obtained higher values in the subject. Two other independent groups of ten students evaluated the same verbs on two 7 point scales for concreteness and abstractness. An ANOVA performed on the mean ratings (considering 2 types of verbs and 2 scales) showed that in general our verbs were evaluated as more concrete (F (1,9) = 22.296, MSe = 14.16, p= .001), as we expected since we focused on choosing verbs with a specific action-relatedness. A significant interaction of verb type and scale was also detected (F(1, 9)=25.857, MSe = 29.93, p = .001). The evaluation of IVs tends to be constant along the two scales, (M = 4.36 vs M = 3.82), whereas AVs tend to be evaluated higher in the concrete scale (M= 5.8 vs M = 2.88). However, a post hoc test revealed that AVs and IVs do not significantly differ in the abstractness scale, but they differ only in the concreteness scale. This was expected, since we selected AVs as specifically related to object interaction and manipulation, whereas IVs imply a relation with another subject which can be considered as more abstract. Furthermore, IVs are often related to abstract sentences or expressions, which could explain a tendency to associate them with more abstract contexts.

For each verb we identified the isolation point (IP), intended as the minimum part of the verb required to understand it and to differentiate it from other verbs with similar root. Verbs were then balanced for syllables, length, isolation point duration, and frequency.

Each verb was presented in written form in three singular persons (I, YOU (2nd person), He/She) of the Italian past tense. In Italian the pronoun is often omitted, as the verb contains information on the person. In our case, using both the pronoun and the past tense, we obtained a double reference to the agent. The final set of stimuli comprised 10 verbs, each presented once in each of the three persons. We inserted also 10 catch-trials, i.e. verbs in the same tense as the others but incorrect for the correspondence verb-subject, e.g., “io portava”: in this case the explicit subject is a first person pronoun while the verb refers to the third person. With catch-trials participants were required to refrain from completing the movement. We obtained then a single block of 40 trials.

Experimental design

Each trial started with a fixation cross (1000 ms). Then the pronoun was shown for 500 ms, followed by IP of the verb (e.g., “prend”) displayed for 500 ms. Subjects were required to pay attention to both the pronoun and the verb, and once they recognised the verb they had to start moving as fast as possible to reach for and grasp the mouse in front of them. During the movement the verb was completed with its suffix (e.g., “evo”) (500 ms). This time was sufficient to accomplish the movement at about the same time in which the complete sentence “io prendevo” (I took) was presented (time limit of 500 ms). Participants held the hand on the mouse till they decided whether the sentence was correct or not. If correct, they had to click on the left button and then move the mouse to the final position. Otherwise, they had to refrain from moving.

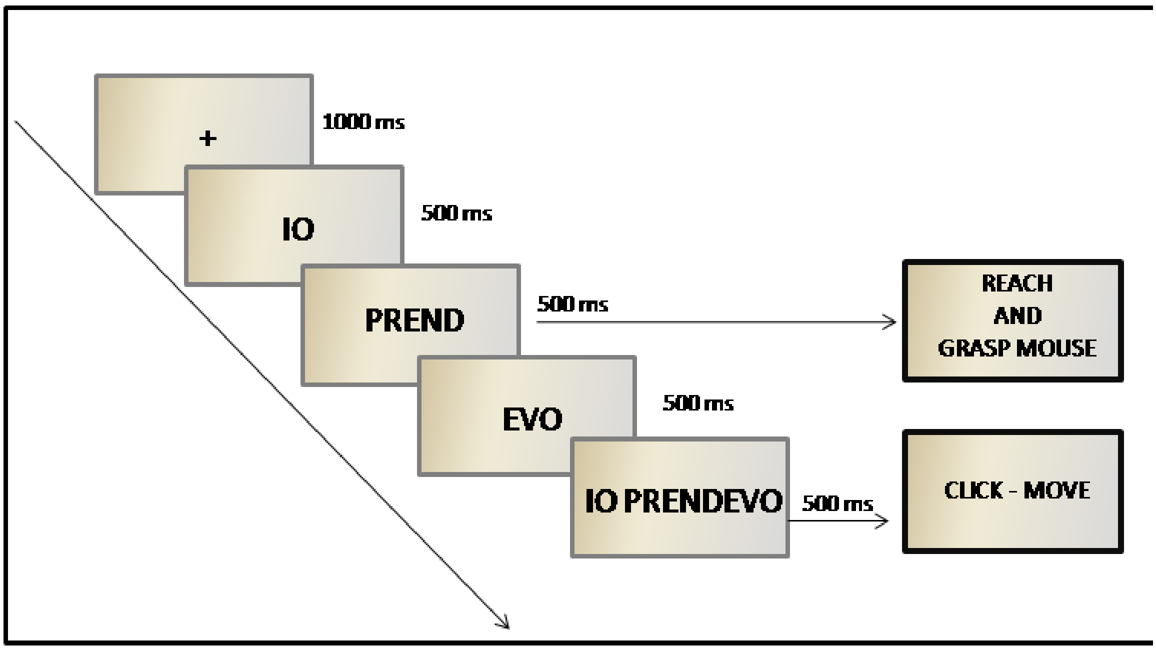

Fig. 1 Experimental procedure

Data recording and Kinematic Analysis

Movements of the participant's right hand were recorded using the 3D-optoelectronic

SMART system (BTS Bioengineering, Milano, Italy). The SMART system consists of three video cameras detecting infrared reflecting markers at a sampling rate of 60 Hz. Spatial resolution of the system was768x576 pixel. Recorded data were filtered using a moving average filter. We used three markers, one applied on the wrist, and the other two on the nail of the index and of the thumb finger respectively.

We considered two components of movement, reaching and grasping, and for each of them we identified different parameters. We avoided considering the act of giving/placing of the mouse due to the high variability of the performed movements.

For the reaching component we analyzed the behavior of the marker placed on the wrist. We considered two types of parameters, one concerning times and the other velocity and acceleration. For the first, we measured reach time, time to peak velocity, time to peak acceleration, % of time to peak velocity (with respect to the reach time), % of time to peak acceleration. Since percentage is normalized with respect to the total reach time, this measure can be informative as to the distribution and homogeneity of movement. For the second, we analyzed the latency of velocity and acceleration peaks.

To analyze the grasp component we considered the time course of the distance between the two markers posed on the index and on the thumb finger. We considered the following parameters: grasp time, peak velocity of finger opening, maximal finger aperture, time to maximal finger aperture and percentage of time to maximal finger aperture. We divided movement components following (Gianelli et al., 2008) using similar rules and conventions to define the various parameters.

Data analysis

ANOVAs were conducted on the mean values of participants' reaching-grasping and mouse-moving parameters, considering as within-subjects variables Verb (AV vs. IV) and Pronouns (I, YOU, HE). For each significant parameter we calculated also the effect size (η^2). Only the significant parameters are reported and discussed.

4.3 Results

Reaching component

During the act of reaching we observed a significant interaction Verb-Pronoun in the percentage of time to peak velocity, F (2,22) = 6.48; MSe = 12.85; p <.006, η^2= 0.4. This measure consists of the normalized value of the time to reach wrist peak velocity, with respect to the total reaching time. As it can be seen in Figure 2, whereas AVs and IVs did not differ when preceded by the pronoun HE (48.5 % vs. 49%) and differed only slightly when preceded by I (49% vs. 51.7%), they clearly differed with the pronouns YOU (47% vs. 52%). These percentages correspond to a mean reach time of 720 ms and to a mean time to peak velocity of 356 ms.

The data suggest that the effect of modulation occurs early during the actual movement and is evident in a range of 300-350 ms after stimuli presentation. Moreover, we know that peak velocity is the main parameter which is defined in movement planning and it is susceptible to be affected by the various factors (Dalla Volta, Gianelli, Campione, & Gentilucci, 2009, Gentilucci, Negrotti, & Gangitano, 1997) under which the movement is executed. Consequently, slower times in reaching this peak can be related to a greater influence of the stimuli in the very first stages of action planning and execution. The very fact that the modulation of the motor system due to the combination of pronouns and verbs occurs early suggests that the activation of the motor system is not a by-product but is part of the comprehension process.

The results indicate a specific contribution of YOU in modulating kinematics parameters in the reaching component, whereas the I perspective does not modulate them in a significant way. The absent or little effect produced by HE confirms it as an “external perspective”, which differs from the others also from the point of view of its neural substrates. The specific pattern induced for AVs and IVs by YOU is consistent with an agent motor perspective, as activated in a conversational framework by the pronoun YOU.

In order to disentangle the specific contribution of the I and YOU pronouns we performed on the same parameters a 2x2 ANOVA in which the two Verbs (AVs vs IVs) and only two Pronouns (I vs. YOU) were considered as within-subjects variables.

The significant effect of verb type in the acceleration peak confirms that responses to AVs require less time than to IVs, $F(1,11) = 8.26$, $MSe = 46022.74$, $p<.015$, $\eta^2=0.2$. This confirms our hypothesis that the two kinds of verbs activate a different chain and encode a different goal. Notably, we also found a significant interaction in percentage of time to peak velocity: $F(1, 11) = 1.33$, $MSe = 14$, $p<.007$, $\eta^2 = 0.5$). As revealed by post-hoc Newman-Keuls test, responses to IVs required less time than responses to AVs when preceded by YOU ($p <.04$). This interaction suggests that the perspective of the agent is entailed by the pronoun YOU, and it confirms the differential modulation of the two pronouns on the verbs. More specifically, it suggests that since the very first stages of movement execution, AVs imply focusing on the person which performs the action, referred to as YOU, whereas IVs imply focusing on the relation between agents. Thus, the modulation on the actual action does not rely on verbs or pronouns *per se*, but it significantly depends on the combination of the two, as we predicted.

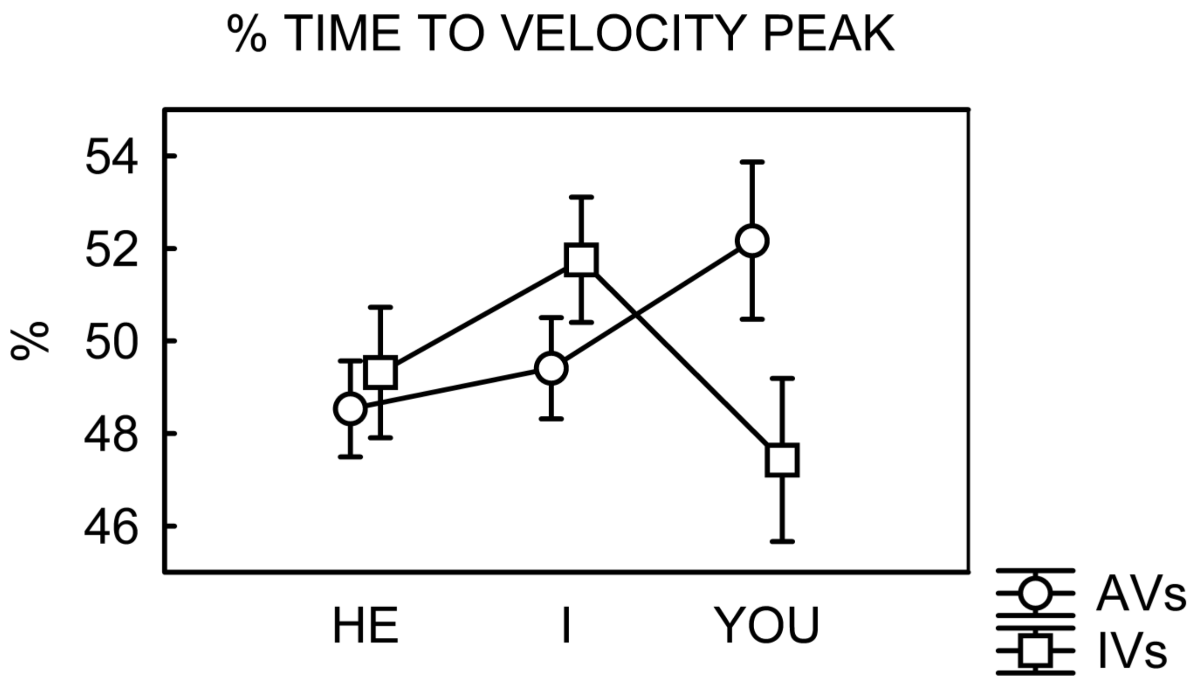

Fig. 2 % of Time to peak velocity, effect interaction between perspective and verb type. Bars are SE.

Grasping Component

The ANOVA on time to maximal finger aperture, the time between finger opening and the maximal aperture before closing on the object to effectively grasp it, did not reach significance, ($F(2,22) = 2,08$, $MSe = 3113$, $p =. 148$). Consider that our main predictions concerned reaching rather than grasping. Namely, we did not expect grasping to be greatly affected by our stimuli, due to the fact that events such as maximal finger aperture occur later in time while we expected very early effects. Even if the ANOVA did not reach significance, Figure 3 clearly shows that AVs and IVs differ mostly when preceded by the pronoun YOU.

In analogy with what we did while analysing the reaching also for the grasping component we performed a further ANOVA in which we eliminated HE and focused on the role played by I and YOU in modulating AVs and IVs. This is allowed because the grasping component is less susceptible to be interfered by external components, such as the linguistic stimuli, since it is mainly dependent on object properties and it is under visuo-motor control. The ANOVA on the time to maximal finger aperture revealed an interaction Verb-Pronoun, F (1,11) = 8.00, MSe = 777.19, p<.016, η^2= 0.2. As it can be seen in Figure 3, the effect was mainly due to longer times of YOU (M = 491 ms) with respect to I (M = 441 ms) with IVs (post-hoc p<.003). No difference was detected between I and YOU with AVs.

This result reveals that the interplay between factors tends to modify in the time course of movement execution. Differently from the reaching component, in the grasping one the activation of different chains for AVs and IVs acquires relevance. To resume: in the analysis on reaching component we found that in percentage of time to peak velocity responses to AVs required more time than responses to IVs when preceded by YOU; in addition, AVs were faster than IVs. The pattern was exactly reversed in the analysis on the grasping component (see Figure 3). This is perfectly coherent with our predictions. Namely, the sequence related to AVs effectively ends with grasping, whereas the one related to IVs continues as it involves the interaction with another person. In this sense grasping is the final motor act for AVs, so that motor planning and execution is mainly focused on accomplishing it. On the contrary, grasping in IVs depends on another act (that of giving something to somebody else). Thus grasping has value just as an intermediate motor act which allows taking possession of the object in order to interact with another person. Further, consider that the modulation is present with the pronoun YOU, not with the pronouns He or I: this suggests that the role of agent is taken when the YOU pronoun is used.

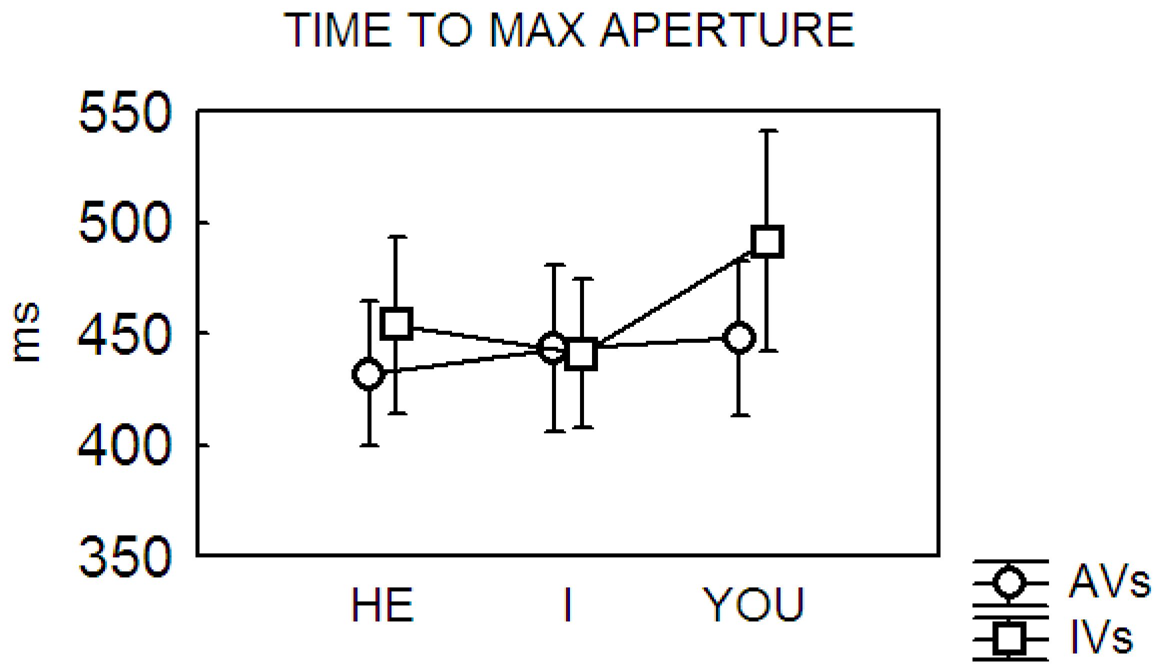

Fig. 3 Time to maximal finger aperture, effect interaction between perspective and verb type. Bars are SE.

4.4 Discussion

The results of the kinematic analysis in our study show the presence of distinct motor patterns as influenced both by the perspective elicited by the pronouns and the motor chains. Our results clearly indicate that the effect of linguistic stimuli is articulated and that it intervenes very early in movement execution. This confirms the kinematic data from our first study, and hence the hypothesis of a precocious and fundamental role for the motor system in language comprehension. Further, this effect of motor resonance is again showed to impact in particular on the motor programming of a response movement, as demonstrated by the different patterns of time distribution in the reaching and grasping component. As discussed in the previous chapter, the presence of these early effects on motor planning are unlikely due to processes of late motor imagery. In this specific case, another point is in favour of the conclusion that motor processes are active before or at least together with language understanding. That is, as mentioned above, we hypothesised that the mechanisms through which we linguistically experience action and motor perspective relies but also partially differ from the ones of action observation. This can explain the reason why we found a clear modulation only for the YOU pronoun.

The data on the reaching component allow us to disentangle the effect of the perspectives induced by the pronouns YOU, I and HE: the latter did not modulate movement execution when combined with the two categories of verbs. This suggests that the perspective elicited while reading the pronoun HE is more abstract and external, so that the motor effects of language processing disappear. Interestingly, this seems to be true for the I perspective as well. Namely, the role of agent is taken when the YOU pronoun is used. In this condition it appears that the participant is called directly into action.

The data on reaching and grasping confirm that, even if subjects performed the motor response always in the same way on the same objects, the two components are differentially modulated by linguistic stimuli. This shows that our sentences affect the entire motor planning. The way the motor planning is affected is undoubtedly interesting, since both perspective and chain organization are involved.

In reaching execution, our data show a strong effect of the YOU perspective in modulating both action and interaction verbs, and this pattern is strongly present in all our subjects. The effect of the I perspective is still present in 9/12 of our subjects, however its magnitude seems weaker. The motor pattern activated by YOU both with AVs and IVs fits well our hypothesis about the organization of actions in motor chains. In fact, IVs have a shorter time to velocity peak, so that conversely the deceleration phase is longer. This is coherent (Gentilucci et al., 1997) with evidence on motor planning and control of a sequence of motor acts: an increasing accuracy in interaction with the object influences arm velocity profiles by decreasing peak velocity and lengthening the deceleration phase. In this sense the current motor act is influenced by the requests of the successive act. AVs do not imply any particular request of accuracy since there is not a second motor act to plan: namely, the action ends with the grasping of the object. This is not the case for IVs where more accuracy is requested in order to interact with the object: namely, the object should be grasped and given to somebody else. One could speculate that participants are particularly accurate also due to the fact that IVs do not simply involve a further motor act compared to AVs, but that they also involve a social dimension, guaranteed by the virtual presence of a recipient. However, our data do not allow us to definitively solve this issue.

The specificity of YOU is substantially confirmed by the results in the grasping component. In fact, also in this case with IVs the time to maximal finger aperture is longer with YOU than with I; probably due to a request of accuracy. This confirms that YOU mostly activates the perspective of the agent and a proper motor simulation: when reading YOU we are directly called into action, we are expected to be agents and we have to strategically understand what we are supposed to do or have done.

The action is understood as the action having value for the agent, who is directly performing the action and hence has control on its organization. This is consistent with the previous studies where the strongest compatibility/facilitation effects (Glenberg & Kaschak, 2002) are obtained with sentences using YOU or with the infinitive form of the verbs, where the perspective activated is necessarily the one of the agent. One important theoretical implication of our work is that it reveals that the perspective induced by the pronoun strongly affects the motor system. That is, language affects the motor system activating a specific perspective. This could give us some hints to solve the long-standing debate on interference/facilitation in literature on language and motor grounding. Namely, some studies found evidence of an interference when the same effector used for the motor response was implied by the sentence, others found facilitation (for a discussion see Dalla Volta, Gianelli, Campione, & Gentilucci, 2009). So far it has been argued that a possible solution to this problem can be found by analysing in detail the time course of language processing. Our results suggest that another possible explanation for contradictory results can be found taking into account the different pronouns used in sentence, and hence the perspective they activated. Namely, the pronoun YOU, which as we have seen leads to the adoption of the agent perspective, typically produced a facilitation effect , whereas an interference effect is typically found when the first or the third person pronouns are used.

Overall, our results support our hypothesis that language comprehension activates an inter-subjective framework. This suggests that the perspective elicited while reading the pronoun HE is more abstract and external, so that the motor effects of language processing disappear. Interestingly, this seems to be true for the I perspective as well. Namely, the role of agent is taken when the YOU pronoun is used. In this condition it appears that the participants is called directly into action and then they re-activate the motor pattern of an action from the point of view of the agent. “I” and “HE” constitute external and “observational” perspectives but at different degrees. In an inter-subjective framework, as for example in a conversation, the use of the pronoun I normally refers to the presence of a speaker who is reporting the action from his/her point of view, whereas we (i.e. the readers) are recruited as recipients of his/her speech. In the case of the pronoun HE, a radically external perspective is assumed. Consider for instance a situation in which we and another person are talking of the actions of a third person: his/her perspective does not involve us directly.

To summarise: our study reveals that the perspective expressed by a sentence influences the kinematics parameters of an overt response movement. Importantly, the adoption of a given frame of reference has a very precocious effect as it differently impacts even the very early stages of movements planning and execution.

A further novelty of our results consists in suggesting that the chained organization that characterizes the motor system is translated by language. Namely, we found that, when the agent perspective was taken (with the YOU pronoun), motor programming was accomplished earlier with AVs than with IVs. This might be due to the different length of the motor chains related to the two verbs: compared to AVs, IVs imply a further motor act, that of giving somebody the object.

To conclude, our results support the hypothesis that while comprehending language we activate an inter-subjective framework. The adoption of this frame of reference has a very precocious effect as it differently impacts even the early stages of movements planning and execution. The activation of a conversational framework has an interesting theoretical implication. Even if our study clearly shows that action organization (e.g., the motor chains) is reflected in language, language imposes its own constraints on the way actions are conceived, giving relevance to the YOU pronoun in taking the agent's perspective, at least in the specific experimental setting here used. It is probable that using other settings and adding more cues to define perspective would induce the activation of different points of view, mediated not only by pronouns but also by nouns and other linguistic devices. This will be discussed in detail in the following study.

4.5 Conclusions and general discussion

The data from this second study confirmed that understanding simple sentences involves the motor system, affecting in particular the phase of motor planning and consequently the first stages of action execution. In addition, it gave us additional information on how goals are translated and coded in language.

This study differed from the first for the way linguistic stimuli were composed: while in the first experiment we presented verbs in the infinitive form, here we presented simple sentence were an agent was implied (pronouns) and the verb was declined accordingly. In this sense, the first study presented verbs in a form which is probably less susceptible to induce fine-grained modifications on action kinematics. Specifically, modifications depending on how the action is internally construed and planned with respect to internal and external constraints. This is consistent with our proposal that different levels of verb meaning can be activated, hence influencing action execution. For instance, the infinitive form of verbs does not explicit *who* is the agent performing the action. Probably participants rely on their own perspective on action, so assuming their selves as directly the agents. Alternatively, another possible strategy could be for participants to assume the action verbs from an external perspective, being the observers of that action. The data from the first study did not allow us to disentangle which kind of perspective was used. But presenting a pronoun directly establishes a point of view on action: our second study demonstrates that it is the perspective induced by YOU which produces effectively behavioural and kinematics effects. This finding has interesting implications: namely, in this light previous data from our and other study can be discussed, considering that the motor effects we obtain are dependent on the way we build up stimuli and present a context of interaction.

Two major, unsolved, points remain:

- As regards to stimuli, all the sentences we used presented one agent and did not involve an explicit recipient. That is, no "me" sentences were included, for instance for IVs sentences where a YOU would be offering to ME, or a HE offering to ME. Of course the use of these sentences induces different interactional frameworks, for which it should be verified if the primacy of YOU perspective remains or not. A manipulation in this regard could allow studying to what extent language is capable to re-build perspective in a way that differs from the one of visual observation. Our last study partially covers this unsolved point, by comparing different types of transferring sentences.
- As regards to the motor response, we used as in many other experiment, a strictly body-centred system of response. This likely induced the same self-centred setting also for the linguistic stimuli. A further development could be to manipulate the participant's position and/or their motor response in order to disentangle the effects of language when different spatial positions are implied – positions were the motor system of a potential agent is implied. For example, a simple manipulation could be to require participants a reach-to-receive responses: that is reaching the hand of another person in order to receive something that is being "offered", "given" and so on.

These elements could thus affect both the perspective elicited by pronouns and the motor effects they determine, supporting the hypothesis of a differentiation between linguistic and "real" action observation and experience of action. This differentiation would mainly rely on the way the same processes are implied and used.

In the study here reported the context and perspective on interaction is mainly given by the pronoun, supported by the fact that in Italian also the verb elicits the agent. Consequently, the re-activation of chains of motor acts depends on this perspective, since we found a motor pattern coherent for the two types of verbs/actions only in the case of YOU. An open question remains whether the manipulation of motor-perspective taking can produce differential effects. For instance, which differences in performance would emerge if we present linguistically another agent (another pronoun, a name) or we just leave it supposed (as in our interaction-verbs sentences)? This is the aspect we will investigate in the next chapter.

5. When perspective is not (completely) embodied

In the previous study we demonstrated that activating a specific perspective on action (i.e. by means of pronouns) contributes to modulate a subsequent motor response. Interestingly, our study showed that pronouns articulate in a peculiar manner the structure of linguistic perspective, thus differing from action observation.

Specifically, we suggested that only written sentences using YOU as pronoun directly involve the participants as agents, so inducing stronger motor effects. On the contrary, using different pronouns produced no or little motor effects, as happened using sentences with HE or I in the agent position. However, our data did not completely rule out the possibility that motor effects were present in the last two cases (mainly for I), but relying on a different, observational, framework that our task was not capable to detect. To verify whether and how it is possible to manipulate motor-perspective taking we performed a third study, focused on perspective and its effect during linguistic action comprehension.[4]

[4] This study was performed in collaboration with Alessandro Farné and Alice C. Roy. The paper is in preparation, and is going to be submitted as Gianelli, C., Farné, A., Roy, A., When perspective is not embodied.

5.1 Introduction

Being the agent of an action is one of our basic experiences and this is intimately linked to our experience of having a perspective, a point of view on the world. However, quite often we are not allowed to have experiences in a first-person perspective, but only through 'devices' that shift our point of view. Language provides a huge amount of this kind of devices, through which we can describe and observe actions stressing some aspects or neglecting others. Pronouns are a good example of our ability to shift perspective in a way that is very important for our social interactions. The more we are able to grasp different aspects of actions and situations, the more we are socially able to interact with other people. As stated before, hearing a sentence like "You gave him the book" remind us of the very simple action of giving, of movements we perform every day. We know the goal of the action, we know the final state (the book is passed from a person to another), we perfectly know how to perform that action. In a straight-forward view of motor resonance, this action would automatically activate the correspondent action, the effector hand, and probably the kinematics used to accomplish that goal. However, we have to take into account that processing some "motor" aspects is not enough to bring to detectable motor effects. As stated recently by Zwaan and colleagues (Taylor & Zwaan, 2008), other parts than the typical verbs, adverbs, can induce motor resonance, in acting to disambiguate the meaning of the action and hence of the sentence. In this sense, a crucial role is assumed by the use of specific pronouns, or in other cases of nouns.

We assume that pronouns are specialized linguistic devices used to activate a specific perspective on action. Try to read these two sentences "You gave him a book" and "Lisa gave him a book". The two actions describe the same action of giving, and the effects are the same: a book was given by one person to another. But the role of the agent is taken by a different person, hence activating a different perspective. In the first case, the use of a personal pronoun, You, activates for the reader a more internal perspective, while the use of a personal noun, Lisa, activates the perspective of an external agent. The issue of linguistic perspective has not been extensively investigated in the field of embodied cognition, whilst some linguistic studies have addressed this question (MacWhinney, 2005). A recent study by Brunyé, Ditman, Mahoney, Augustyn, & Taylor (2009) investigated the issue of perspective as induced by pronouns, by using a picture verification task. Verbal stimuli consisted of descriptive sentences referring to events (e.g. "I am slicing the tomato"). Sentences were composed by a pronouns subject (I am, You are, He is), a verb (e.g. slicing, ironing, taping) and a direct object (the tomato, the pants, the package). Visual stimuli consisted of event images (four for each experimental description) depicting the same actions in four conditions: performed and seen from an external or internal perspective, not performed from an external or internal perspective. In each trial participants read a sentence and then had to verify whether a presented image corresponded or not with the previous action. Picture verification reaction times and accuracy were recorded. Results showed that description pronouns and picture perspective interacted: faster verification times for internal relative to external perspective when the descriptive sentence used the pronoun You or the pronoun I. In the case of He this effect is not replicated, then an external perspective is taken. In a second experiment sentences were preceded by a brief description aimed at contextualizing the sentences. Results in the verification task showed that in this case only sentences using You induced an internal perspective. Authors explain this effect with the fact that the ambiguity of sentences like "I am slicing the tomato" induced participants to use an internal perspective. When the ambiguity is clarified by the use of contextual descriptions, then the external perspective is adopted. They conclude, then, that only the use of You induces in readers an internal and embodied perspective.

The fact that perspective is still an open issue for embodied approaches to language processing is confirmed by a recent statement by Zwaan (2009), who defined perspective as a challenge for embodied theories of language comprehension. Our study moves from the same idea that it is not enough to demonstrate that “give” activates early the motor program of giving: we have to demonstrate how this effect is modulated by specific context, possibly taking into account that sentences are not produced alone, but they are part of our social interactions.

This is not restricted to verbal language: quite often our gestures are body-centered with respect to the body of the speaking person. Interestingly, in the case of sign languages there is evidence that verbs are generally represented through signs that are gestured in reference to the body signer even if he is not the agent of the action. The only exception concerns transfer verbs that indeed have agreement with the agent of the transfer and are thus not sign in reference to the signer’s body (see Meir,2002; Meir, Padden, Aronoff, & Sandler, 2007, who used Israeli Sign Language as an example). Interestingly, studies on anosognosia (Marcel et al., 2004, for a review see also Fotopoulou 2010) showed that presenting questions in the 1st or in the 3rd person perspectives influences the motor awareness of these patient and thus the way they report their motor abilities.

Could we, then, manipulate perspective and modulate the motor effects of action sentences? To answer this question we decided to start from a well-known effect, probably one of the most tested effects of embodied cognition: the Action-sentence compatibility effect.

This effect was first discovered by Glenberg and Kaschak (2002), who reported faster responses when direction embedded in a sentence was congruent with response movement direction, using sentences like “You gave the pizza to Andy” or “Andy gave you the pizza”. This compatibility effect was induced in a strictly body-centred set up: participants responded with a movement to press a button away or towards their body. In this sense, the results suggest that participants read “giving” as “moving away from their body” in a context like “You gave the pizza to Andy”, and the contrary for the sentences in which they were recipient of the action. The effect has been then widely studied and reported in various conditions: written or auditory presentation (Borregine & Kaschack, 2006), with different tasks (sensibility judgment, silent reading) and response devices (buttons, keyboards, knots as the in the paradigm of reading-by-rotation used in Zwann's group). A recent contribution to ACE paradigms has been introduced by Zwaan and colleagues (Zwaan & Taylor, 2006 Taylor & Zwaan, 2008; Zwaan, Taylor & De Boer, 2010). In these studies the paradigm of reading-by-rotation has been introduced to test the so-called Linguistic Focus Hypothesis (LFH). According to LFH, motor resonance may arise in correspondence with any part of a sentence (not only a verb, but also pronouns, adverbs etc) which disambiguate the meaning of action (see chapter 2 for a detailed discussion). During these studies participants read sentences by turning a knob, being each sentence divided in segments. This allowed to verify which segment induced motor effect on the rotation movement. Zwaan and colleagues investigated, then, the emergence of compatibility effects with faster reading times (that is, rotating-reading is faster) in case of congruence between rotation direction (clockwise or counterclockwise) and movement direction embedded in sentence.

Each of these studies stressed different aspects of the effect, but all confirmed that it emerges typically as a facilitatory effect, which appears early during or immediately after sentence presentation(until 50 ms after sentence disappearance according to Borregine and Kaschask, 2006) and tends to reverse with later delays (500 ms, but not significantly according to the same authors).

However, none of these studies has explicitly focused on perspective, both in sentences and in relation with the body-centred setting of experiments. We assume that the emergence of the ACE effect is not independent not only from the task used but also from the specific setting we design to allow participants' response. Specifically, our idea is that what is fundamental is the interplay between the situation described by sentences (from a specific point of view) and participants' position and hence their response direction. The position of the body of the participant(for example, compatible with giving or not) influences her ability to read sentences from a specific perspective. This study, by involving away and toward movements, is the only in my thesis which allows to verify whether proximal or distal movements are differently affected by linguistic stimuli. Moreover, seen our data from chapter 4, we cannot take for granted that the participants is always and necessarily activating her perspective, hence positioning herself in the linguistic situation. We predicted that manipulating this body-self positioning in real and linguistic space would induce different motor effects during a typical ACE task, hence modifying the emergence of the compatibility effect itself.

We can hypothesise at least two possibilities: first, participants could rely only on their body, being unable to take another perspective at a motor level, reducing or cancelling the ACE effect; second, participants could shift their perspective also at a motor level, thus reproducing the ACE effect. In the first case, the only body-self dissociation would be induced at an abstract level, with no or little involvement of motor areas, so not affecting motor responses (i.e., no ACE). Alternatively, body and self could be dissociated also at a motor level, so that the experience of being agent could be transferred and re-activated just linguistically. In this sense, participants would have a linguist bodily experience of the sentence we are presenting, that is what would induce the ACE effect.

To answer to these complex questions we performed three experiments.

In the first experiment we aimed at replicating the ACE effect with French sentences, using transfer sentences similar to those originally used by Glenberg and Kaschack. The aim of this experiment was twofold: to confirm the ACE in French, since cultural independence of this effect is neither demonstrated nor obvious, and then to provide a baseline of the effect for the following experiments. As in the original experiment, all the sentences used the pronoun YOU, both as the agent or the recipient of actions, thus directly involving the participants as being called into action . The participants' task, as in the original paradigm, required participants to evaluate the sensibility of the sentences by moving a joystick away or towards their body.

The second experiment introduced a manipulation of perspective as mediated by nouns: we replaced YOU by the introduction of two external actors, Louis and Léa, proposed as the two actors of the sentences. We then asked participants to perform the same sensibility task by taking the perspective of one of the two actors depending on participant gender. This was supposed to induce a perspective shift, possibly modifying the ACE effect.

A third experiment used the same sentences of experiment two, but adding more information about the two inter-actors, namely their spatial position. We expected that this additional information would facilitate motor perspective taking, thus favouring the emergence of an ACE effect, possibly in specific spatial positions.

5.2 Experiment 1

In this experiment we aimed at replicating the ACE using "YOU" as pronouns, a condition in which the participant is directly the agent or recipient and effectively called into a dyadic action. In addition, we verified the presence of the effect across a different linguistic structure, namely different dative constructions in French with respect to English.

5.2.1 Methods

Participants

Thirty-two students of Lyon University participated in experiment 1. All participants were right-handed, native French speakers and reported normal or corrected-to-normal vision. All were naive as to the purpose of the experiment and gave their informed consent to participate to the study that was approved by the Inserm Ethics Committee.

Stimuli

The original set of stimuli by Glenberg and Kaschak (2002) has been modified in order to identify the structure of sentences. We followed then the work by Borregine and Kaschak (2006), where a first selection of the stimuli was made (e.g. imperative sentences were eliminated). Stimuli consisted of transfer sentences, implying the action of giving/receiving something, either concrete or abstract (see “Appendix” for a complete list of stimuli). Sentences were composed by a noun/personal pronoun to indicate agent/recipient of action, a verb in the past tense and a noun to indicate the object transferred. The final set of stimuli in French comprised: 40 sentences in the form "You gave something to someone" (“Tu as donné quelque chose à Louis”) divided into 20 abstract and 20 concrete sentences, and 40 sentences in the form "Someone gave you something" (“Louis t’a donné quelque chose”), divided into 20 abstract and 20 concrete sentences. The set was completed by 40 non-sense sentences of the first form (abstract and concrete), and 40 non-sense sentences in the second form. The stimuli were presented in written form and were randomly repeated into 2 blocks, for a total of 320 trials.

Procedure

The experiment took place in a sound-attenuated room. Participants sat in front of a computer screen holding with their right hand a joystick in face of them. The distance between head of participant and the screen was of 70 cm.

Each trial started with a fixation cross, then a sentence was presented until response of the participant, with a time limit of 5000 ms to start moving the joystick. Participants were instructed to read the sentence and to move a joystick (away or towards the body) to respond as to whether the sentence made sense or not, as soon as they could. Each participant was randomly assigned to one of two possible conditions, starting with a response away for YES and towards for NO, or the reverse. The response was registered each time the participant reached a predetermined threshold of the joystick displacement, thus measuring the 'reading time' (I.e., the time between sentence onset and beginning of movement, as in G & K's definition) and movement time (i.e., the time between the beginning and the end of the movement). The sentence disappeared once the threshold was passed.

Data analysis

Data on reading times for each participant were analyzed and times beyond ± 2,5 standard deviation from average reading time were trimmed for each condition. Final movement direction was checked for each trial, to verify the accuracy of participants' movements (i.e. that they did not start moving in a direction and then change). We applied a repeated measures ANOVA to the mean reading times of the participants, with role in sentence (agent/recipient), type of verb (abstract/concrete), and movement direction (away/toward) as within-subject variables. The effect size was also calculated for each significant variable (η^2).

5.2.2 Results

The data on reading times (RTs) showed a main effect of verb type, that is reading concrete sentences was significantly faster than abstract sentences ($F(1,31)=41.73$, $p <.0001$, $\eta^2=0.7$). Interestingly, a main effect of role in sentence was also present ($F(1,31)=6.81$, $p< .02$, $\eta^2=0.1$): when YOU was agent then reading times were slower compared to when it was recipient. Crucially, the interaction ROLE X MOVEMENT was significant ($F(1,31)=4.52$, $p < .042$, $\eta^2= 0.1$), that is the ACE effect was present. However, we observed a specific pattern of compatibility effect for French sentences. A Newman-Keuls post hoc comparison confirmed that compatibility was not distributed along all conditions. In particular, the compatibility was significant for the AGENT condition ($p < .04$), where away responses were faster than toward ones. In addition, toward responses seemed to be more likely to be influenced by the sentence, since toward responses for recipient were significantly faster than those for AGENT ($p < .005$).

In order to disentangle the contribution of concrete and abstract sentences, we performed additional analyses where each type of verb was evaluated separately. Differently from previous studies, where the separate analysis did not produce any effect, in our case the ACE effect was present and significant also when considering concrete verbs separately. Specifically, the ACE interaction ($F(1,31)= 6.02$, $p < .020$, $\eta^2= 0.2$) relied on a compatibility effect for the AGENT condition, away responses being faster than toward responses. In addition, no effect was present for the recipient condition. A main effect of ROLE was also present, with AGENT sentences being generally slower. No significant effect was detected for the abstract sentences analysis.

Summarizing, the ACE effect is generally confirmed with French sentences, but with a specific pattern of compatibility. The effect is significantly present only for the "receiving" condition, where YOU in sentence is receiving something and the movement of the joystick is toward the body. No or little effect is present for the other compatible condition. A further analysis showed that this effect was mainly due to the contribution of concrete verbs.

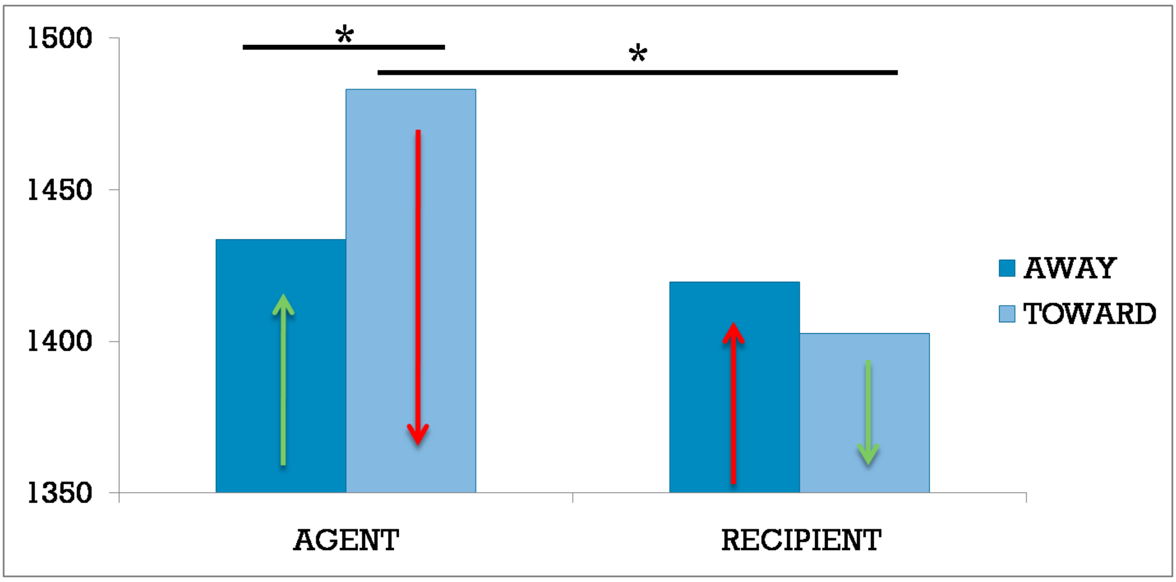

Fig. 1 The pattern of the ACE effect in French as revealed by experiment 1. The arrows indicate sentence direction. The green arrows correspond to the compatible conditions, agent-away and recipient-toward. The red arrows correspond to the incompatible conditions.

5.3 Experiment 2

In the second experiment the sentences from experiment one were modified introducing the names of LOUIS and LEA as actors of a dyadic transfer interaction, in the form “Louis gives x to Léa”. We asked participants to change perspective (third person) and perform the task as if they were one of the two actors (Louis for males, Léa for females).

5.3.1 Methods

Participants

Thirty-four students of Lyon University participated in experiment 2. All participants were right-handed, native French speakers and reported normal or corrected-to-normal vision. All were naive as to the purpose of the experiment and gave their informed consent to the experiment that was approved by the Inserm Ethics Committee.

Stimuli

The set of stimuli of experiment 1 was manipulated, introducing two external actors, Louis and Léa. The pronoun YOU was then eliminated, so that the participant was no longer directly called into action and the perspective on action was modified. The structure and number of stimuli were otherwise unchanged, as well as the procedures.

Procedure

The procedure was the same as in experiment 1. In addition, we asked participants to change perspective (third person) and perform the task as if they were one of the two actors.

At the end of the experimental session each participant filled a questionnaire in order to self-evaluate their performance during the perspective-taking and sensibility judgment task. A list of 16 affirmations about the task were presented and each participant was required to indicate her agreement on a horizontal line, where the extreme left indicated "I do not agree at all" and the extreme right indicated "I completely agree". The responses for each item were then transformed in a 1-10 scale and analyzed.

Data analysis

Data on reading times only for correct responses were analyzed for each participant and times beyond ± 2,5 standard deviation from average reading time were trimmed for each condition. Final movement direction was checked for each trial, to verify the accuracy of participants' movements (i.e. that they did not start moving in a direction and then change). We applied a repeated measures ANOVA to the mean reading times of the participants, with role in sentence (agent/recipient), type of verb (abstract/concrete), and movement direction (away/toward) as within-subject variables. The effect size was also calculated for each significant variable (η^2).

5.3.2 Results

The data from this experiment confirmed a significant effect of verb type, concrete verbs bringing to faster responses than abstract verbs ($F(1,33)= 8.76$, $p<.006$, $\eta^2= 0.6$). However, the ACE interaction of ROLE and MOVEMENT was not significant($F(1,33)= 3.043$, $p< .09$). Since neither a main effect of ROLE or other factors were present, it appears clear that the absence of ACE-like compatibility effects was well distributed over all the conditions. It is worth noting, however, that there is a trend of an inverse pattern of the classical ACE: in fact, there is a trend to have faster responses for the RECIPIENT-AWAY and AGENT-TOWARD conditions.

As indicated both by the average RTs and by the self-report at the end of the experiment, participants correctly performed the perspective-taking tasks. With respect to the first experiment, in fact, RTs increased indicating that it took longer for participants to read the sentences because they were also performing the perspective taking task together with the sensibility judgment. No additional source for this delay was present. This is supported by the results of the questionnaire filled by participants. In particular, the crucial items for the perspective taking task indicate that participants correctly understood the task and performed it. We need to acknowledge that our questionnaire was not specifically designed to test the individual differences in the perspective taking task. Thus, we did not verify the strategy performed by each single subject to correctly perform the task. However, their final reports state that our participants correctly performed the task, or at least explicitly reported so. Indeed, future studies probably should rely on questionnaire more specifically designed to test the perspective taking attitude for each participant and then correlate it with the RTs.

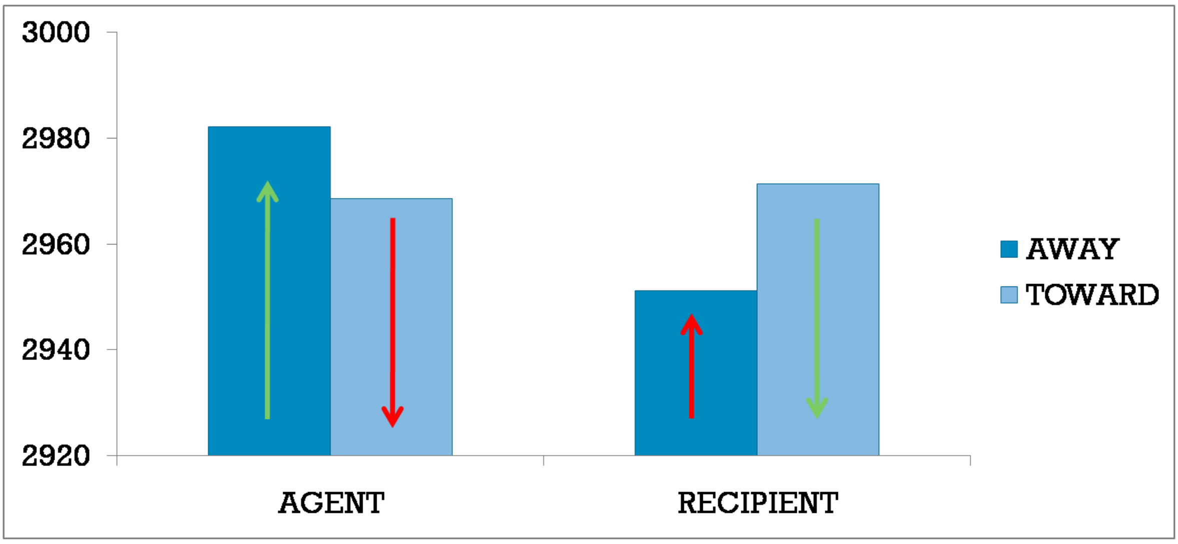

Fig.2 Absence of the ACE effect in experiment 2. Conventions as in experiment 1.

5.4 Experiment 3

The first experiment confirmed the ACE in French, with a major sensitivity for the 'toward' movement direction. The second experiment revealed no significant ACE when participants were required to take a third person's perspective. These findings suggest that motor effects of language processing are constrained: dissociating the spatial position of the participant from her third person perspective actually makes the ACE disappear. This finding opens the question of the possible role played in ACE by the space-related, in addition to agency-related information. Following this rationale, we next tested the hypothesis that adding spatial information to the perspective-taking manipulation would (re)create the conditions for the ACE to appear. This was verified in the third experiment.

5.4.1 Methods

Participants

Thirty-four students of Lyon University participated in experiment 3. All participants were right-handed, native French speakers and reported normal or corrected-to-normal vision. All were naive as to the purpose of the experiment and gave their informed consent to the experiment that was approved by the Inserm Ethics Committee.

Stimuli

The set of stimuli of experiment 2 was maintained. In order to induce perspective taking also from a given spatial point of view, each trial started with the presentation of the spatial position of Louis and Léa, as shown in figure 3, which was left visible on the screen for the entire block. The names “Louis” and “Léa” were presented within a circle on the right or on the left of the sentence. The circle position on the screen was task irrelevant. . The left position was supposed to induce the frame of “giving”, the right position of “receiving”. Stimuli were divided into four blocks, which randomly presented one spatial position R-L or L-R for Louis/Léa and one of the two directions of movement. The final design comprised then 2 spatial positions (left/right), 2 roles in sentence (agent/recipient), 2 verbs (abstract/concrete), and 2 movement directions.

Procedure

The procedure was the same as in experiment 2. Participants were instructed to pay attention to the spatial position of Louis/Léa, which appeared before the sentence, and then to read the sentence and to perform the task from the point of view of the assigned actor.

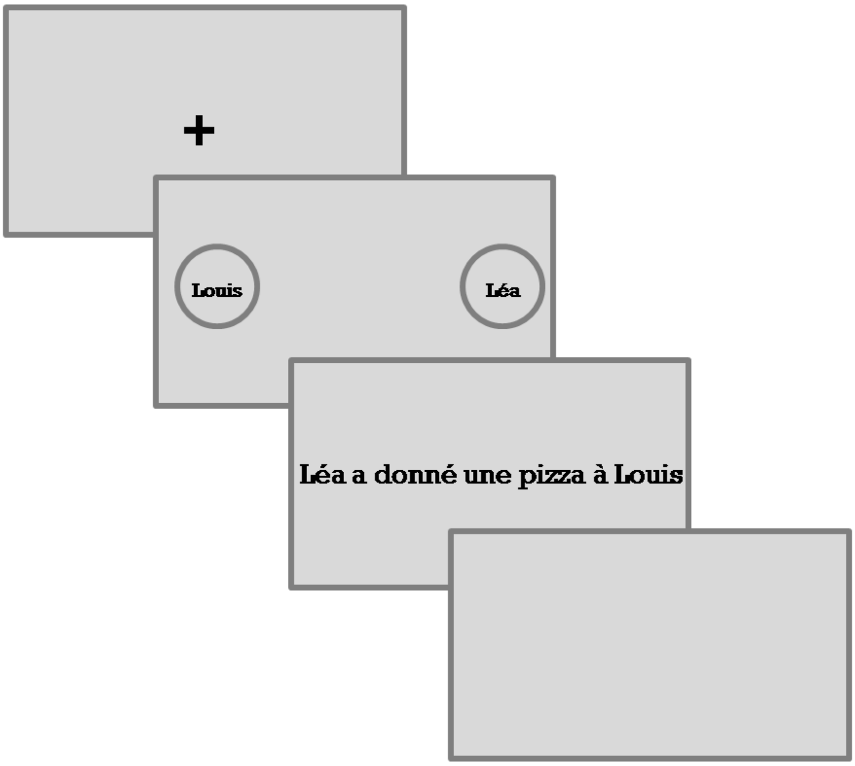

Fig. 3 Procedure used in experiment 3, adding the spatial position of the two actors

Data analysis

Data on reading times only for correct responses were analyzed for each participant and times beyond ± 2,5 standard deviation from average reading time were trimmed for each condition. Final movement direction was checked for each trial, to verify the accuracy of participants' movements (i.e. that they did not start moving in a direction and then change). We applied a repeated measures ANOVA to the mean reading times of the participants, with spatial position (left/right), role in sentence (agent/recipient), type of verb (abstract/concrete), and movement direction (away/toward) as within-subject variables. The effect size was also calculated for each significant variable (η^2).

5.4.2 Results

The data from reading times confirmed a main effect of verb type, with concrete verbs generally faster than abstract verbs ($F(1,33)=32.53$, $p < 0.0001$, $\eta^2 = 0.5$). No other significant main effect was detected. Spatial position (right/left) revealed a marginally significant effect ($F(1,33)= 3.63$, $p< .066$, $\eta^2 = 0.1$), right spatial position tending to be associated with faster reading times. Crucially, the interaction SPATIAL POSITION X ROLE X MOVEMENT was significant ($F\ (1, 33) = 4.08$, $p <.033$, $\eta^2 = 0.05$). Newman-Keuls post hoc test revealed a compatibility effect in the case of RIGHT spatial position. Specifically, in the AGENT condition, away responses were faster than the toward ones ($p < 0.01$). This confirms the stronger compatibility effect for agents compared to recipient we found in the first experiment. For the LEFT spatial position, an inverse pattern was observed. Whilst the compatibility disappears for the AGENT condition, it was significant for the recipient, but with an inversion: away movements were faster than toward ones ($p< 0.002$). In addition, also the toward movement confirmed itself as more sensitive, since it was significantly faster for agent than for recipient ($p <.002$). Across the two spatial positions, only RECIPIENT – toward responses differed significantly ($p<.004$), with faster reading times in the right than in the left position.

Data from the questionnaire confirmed that participants report to have correctly understood and performed the perspective taking task. With respect to the spatial position of the two actors, participants did not report to be actually influenced by this additional cue. More specifically, participants did not report an explicit preference for the left or right spatial position to perform the perspective task: this supports the idea that the effect we obtain is not a by-product of an explicit strategy performed by participants. The potential criticism about the fact that we did not verify the perspective taking strategy for each participant may be the same as discussed above. However, the fact that we did not find any significant report of an explicit preference between left and right positions allows us to discuss our results in terms of how the motor effects of language are constrained by a successful perspective taking task. Future studies, however, should test more specifically for the individual differences and maybe transfer our task into specific populations with known impairments in (spatial) perspective taking task.

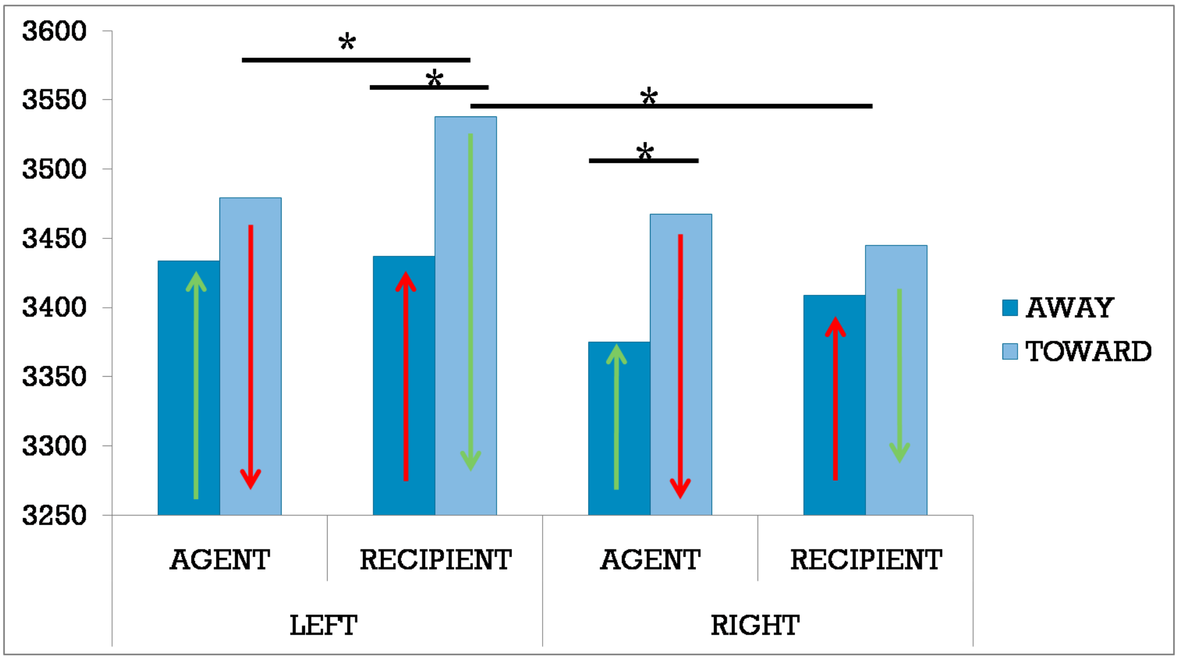

Fig. 4 Presence of the ACE effect on RTs in the left and right spatial position in Experiment 3. Conventions as in figures 1 and 2.

5.5 Discussion

The data from the three experiments we performed give us different insights on how a classic compatibility effect, the ACE, can be modulated through different tasks. Overall, our results suggest that the effect is not as much as automatic and mandatory as it was supposed to be, but rather a flexible effect, which crucially depends on the interactional context that sentences describe.

The aim of the first experiment was to firstly replicate the presence of ACE using French sentences. This was confirmed, and the findings additionally showed a specific pattern for French sentences. The compatibility effect was present only for the AGENT condition, with away responses faster than the toward ones. In addition, our data show significant differences between the away and toward movement, with toward responses being more sensible to the action embedded in sentence. This suggests that proximal and distal movements are differently sensitive to the modulation offered by linguistic stimuli.

A further analysis showed that these effects are mainly due to the contribution of concrete verbs. This is confirmed by the main effect of verb type, that we obtain differently from the original study by Glenberg and Kaschack (2002). Overall, the effect we obtained for the concrete verbs was stronger than the original one for these conditions. This suggests that the elaboration of concrete sentences is different from the abstract ones, possibly because they rely on different strategies of reading to understand whether the sentence makes sense or not. It is possible that the French structure for donation ("Louis t'a donné quelque chose" vs "Tu a donné quelque chose à Louis") influenced reading times in this sense. However, data on the presence of the ACE effect on abstract verbs are still controversial, so it is possible that both a differential effect of concrete verbs, strongly embodied and experience-related, and a specific effect of sentence form in French is present. A similar explanation, based on the syntactic structure of donation in English, has been advanced by Fisher & Zwann (2008), precisely to explain the ACE effect on abstract sentences. The fact that we do not confirm this effect for abstract sentence in French supports this idea. In the second experiment we asked participants to shift perspective by introducing two external actors and asking them to perform the task "as if they were" one of the two. Our aim was to test whether the presence of the ACE can be modulated depending on the perspective assumed during the sensibility judgment task. We reasoned as follow: the use of pronoun HE is supposed to produce no motor effects (see our Chapter 4), and using the names of two actors is comparable to inducing a third person perspective. However, it is possible that the motor effects could be re-instantiated by asking participants to shift their perspective and take the point of view of another actor during the experiment. Our results ruled out this possibility, since the motor effects and namely the ACE were absent when perspective was manipulated alone. The data suggest that the first-person perspective is necessary to induce an ACE effect, so that the mere presence of two actors does not induce an action framework compatible with participant's position. Perspective-taking did not occur at a motor level, since participants were unable to shift their bodily position in the space of action created by the sentence. This suggested that the ACE effect could be again induced by adding supporting spatial information that allows each participant to take a ‘spatial’ perspective at a motor level: this was the aim of the third experiment.

Data from this experiment effectively confirmed that by adding a spatial anchor to perspective taking can affect the motor level, producing an ACE similar to that obtained in experiment one for French sentences. Interestingly, our data additionally show a different pattern for the right and left spatial position.

In the case of the right perspective, the pattern of the ACE as present in experiment 1 is reproduced. On the contrary, the left perspective was associated with an inverse ACE pattern. This is undoubtedly an interesting and intriguing data, since we show not only that we can manipulate participant’s perspective inducing an ACE effect, but also that this tends to vary with the spatial location.

One possible explanation can be found in the study by Borregine and Kaschak (2006), where it has been already documented that timing is crucial to obtain the ACE effect as we know it: already 50 ms of delay can make it disappear, and then tend to modify or reverse it. Since reading times were numerically, although not significantly, slower for the left position, it is possible that the ACE is actually modified in reason of a delay in the response. However, this would not explain why the effect is reversed. A further explanation could be that the left position is effectively considered as a “giving” position and this interferes with the actual movement execution instead of facilitating it. Again, this could explain a right-left difference in reading times, but does not clarify why this does interact with the role in sentence.

Considering our previous data, we can hypothesize that we re-install a first-person perspective only in the right condition, whereas the perspective in the left condition remained an external one, where we cannot induce a first-person perspective taking, This would explain the interference pattern present in the reverse effect we observe. In this sense, the presence of another actor on the left did induced a stronger third person-perspective frame, so that it interfered instead of facilitating, and did not produce any effect for the role in sentence. This could be due to a specific right-left bias (Chatterjee, 2002; Maas, Suitner, Favaretto, & Cignacchi, 2009) according to which we tend to attribute agency to actors placed on the left. As confirmation, the reversed effect is significantly present only for the object role (both with abstract and concrete verbs), which is unrelated to the left spatial position. On the contrary, the left position is strongly associated with agency, in this case an external agency which is hard to interfere.

In this sense, the right perspective is easier to be manipulated, since participants can first change their perspective and place their body in the space of interaction described by the sentence, and then perform the task as if they were effectively someone else. This induced the ACE effect, with exactly the same pattern of the basic version of the experiment.

Overall, our data show that even a simple and well acknowledged effect such as the ACE is really quite flexible. This suggests that the motor effects of language processing are constrained by the perspective of a specific agent with a specific body position in space. When the body of the participant is the only reference for movements, then simple perspective taking does induce no motor effects. By adding a spatial anchor to perspective taking the motor effects reappear (under specific constraints) suggesting that spatially localizing ourselves allows to embody somebody else's perspective.

5.6 Conclusions and general discussion

In this study we focused on perspective and its motor effects during linguistic comprehension. The results confirmed that the presence of the pronouns YOU induces directly and strongly a first person perspective on action, depending on the interactional and inter-subjective framework that is activated. This confirms previous data on the action-sentence compatibility effect, but adds information highlights in more detail the specific relevance of language itself in manipulating perspective with respect, for instance, to action observation. Our study shows that it is ispossible to manipulate perspective by introducing external actors and adding to a sensibility judgment a perspective-taking task.

Interestingly, it is not sufficient to introduce external actors and ask participants to perform actions as if they were one of these actors, in order to induce a motor effect. In this sense the roles of agent and recipient in our sentences are nothing but syntactical roles that need to be filled in order to produce motor effects. In the case of simple perspective-taking this does not happen and our participants rely on more abstract strategies to perform the task. They cannot act as someone else because their perspective on action is too external and no reference is present to place themselves in the space of the action described by the sentence. In this sense, this condition is equal to the one of simple linguistic observation of actions, where the focus is not on the agent, but probably on the effect of the action as interaction between two agents.

What is fundamental in our data is that this no-effect is not stable and given: we can manipulate third person perspective in order to reproduce a typical ACE effect. This is made possible by adding a spatial anchor to the perspective taking task, thus allowing participants to take their own motor perspective on the action described in sentences. This confirms that sentence with a third person perspective can induce, under specific constraints, motor effects. This is of great importance in our general discussion about the social and functional aspects of motor resonance. Simply inducing motor resonance each time there is YOU in a sentence, and inducing nothing with HE, would be just an automatic and rather unspecific effect. On the contrary, showing that the effect depends on the context of interaction and on perspective, suggests that this motor resonance adapts itself to the ongoing (social) situation. In this sense perspective can be activated together with other motor aspects of action: motor chains in our second study, motion direction and the relation with another person in the third study. This contributes to what I defined in my first study as the “deep” understanding of action, which is a crucial aspect of our social ability to interact with others. Language supports this ability, by being highly flexible and capable to translate very fine-grained aspects of action organization. Crucially, this last study showed also that language re-articulates perspective and other aspects of action organization in a peculiar manner.

6. General Discussion

The general aim of the thesis was to investigate how and to what extent action organization can be translated in language, and consequently which aspects of action interact with overt motor behavior. .This issue is still very debated in literature, mainly as far as the specific contribution of motor processes to language understanding – or better to linguistic understanding of action. – is concerned. .Large part of the studies did not systematically focus on specific aspects of action organization in order to investigate their translation in language, being more interested in low-level motor effects such as effector-relatedness of action. Furthermore, they mainly relied on the hypothesis of a similarity of involvement of motor processes during language and observation/execution, thus not investigating whether language has its own peculiar way to "describe" action or not. Even if comparable, my thesis shows that these processes probably do not completely overlap.

6.1 Experimental evidences on the linguistic translation of action

The first study was designed in order to disentangle the time course of the motor effects produced by linguistic stimuli, namely action verbs with different goals. In addition, the aim was to investigate whether overt actions with different degrees of complexity are differently affected by linguistic stimuli depending on the aspect they share or not with the linguistic actions (e.g. effector, goals, kinematics). The results of previous neurophysiological and behavioral studies suggested that processing of verbs related to different bodily effectors relies on corresponding somatotopic activations in motor cortex. The present behavioral study aimed at further investigating this issue by determining whether and, in affirmative case, at which stage of motor planning and execution effector-related action verbs influence different actions executed with either the same or a different effector.

Three kinematics experiments were performed aiming at investigating whether and, in affirmative case, at which stage, of motor planning and execution effector-related action verbs influence different actions executed with either the same or a different effector. Results demonstrate that the goal of an action can be linguistically re-activated, modulating a motor response. Moreover, the action goal, expressed by language, seems to influence early motor planning and just marginally action execution. This study demonstrated also that other aspects of actions – such as for example the effector – can be similarly activated depending on the context, the task and the kind of motor response. In this sense, different levels of linguistic action understanding affect an overt action, depending on the aspects activated in a specific context.

Our results suggest that the involvement of the motor system during language processing is at least double-folded and is connected to the possibility to linguistically translate aspects of action organization.

At a first level, the involvement can be on a more superficial understanding of action verbs: at this level it can be linked for instance to the effector typically used to perform the action described by a verb.

The relationship between motor areas controlling the effector (i.e. hand or foot) emerges at a semantic, but rather unspecific level. That is, activating the effector clearly involves part of the semantics of an action, but does not disentangle other aspects. For instance, it does not rely on how we commonly perform actions using that given effector. At this level, hand-related verbs emerge for difference with respect to foot-related verbs.

Furthermore, writing or cooking are similar in involving the hand as effector, but they largely differ for the use of that hand. However, we know well that they are inherently different, so that writing involves specific muscles and cooking others. In this sense, we can identify a deeper semantic level, where different kinds of hand-actions differ for their goals, and consequently for the way we perform those actions and coordinate movements in order to accomplish our aims and produce some effects on the world. At this level we can also consider the social modulation of goals, thus considering how social interactions can be described by (action) language, for instance depending on action sequences implying the presence of others. This deeper understanding is often crucial from the point of view of social interaction: as stated before, "observing" an action linguistically implies processing different aspects of an action, depending on the context, on our goals, on our needs to perform (actually or linguistically) other actions to respond. In this sense, the activation of motor areas contributes to this full understanding, thus leading to comprehend the goal of the actions, and their final effects depending on the way the action is performed. In addition, this process is definitely fast and occurs at the very first stages of language processing. In this sense, it is unlikely a by-product of other processes, but it is effectively part of them. This confirms it as a process with a social function and relevance, since it occurs depending on the context of interaction, for example the context in which a verb is used. .Furthermore, our stimuli were simple verbs in the infinitive form: they are unlikely to induce very fine grained processes of motor imagery, since we did not provide an agent, and object, a context to deeper interpret the verb. That is why we hypothesized that the typical goal and motor program associated with a verb in our motor repertoire is activated. Moreover, the motor program is activated from the perspective of an agent, since no other element was provided to discriminate this aspect. This makes our stimuli very different from an image or a video, which provide an external observation of an action, condition that probably induces a different activation of motor processes, in being more locally constrained. The same can be said for the lack of a direct object: the presence of an object would have likely induced the activation of more specific kinematics depending on the characteristics of the object. In this case probably other phases of movement could have been affected.

Our data suggest that, together with the goal of an action, the motor programs to perform that action are activated. This is not in contrast with our proposal that what is linguistically translated is the goal of the action. In fact, even if the goal is hierarchically more general than the kinematics of action, the way (how) we perform an action is crucial to pursue a specific goal. As said before, the actions of writing with a pen or with a keyboard share the goal to “write a letter” and the effector we use, but how we accomplished that goal is different. In this sense, the kinematics aspects of action are fundamental to identify the goal, and this is part of our bodily experience of being the agents of an action and having this action in our motor repertoire. Nevertheless it is part of our social (linguistic) experience. This is certainly true for the simple actions described in the verbs from this study, and for all the stimuli used in this thesis. We all share the basic experience of grasping or of writing. However, in our everyday life we often perform very complex and skilled actions, starting from different degrees of ability. We can experience just linguistically actions we've never performed, as we are able to understand different aspects of that action, but probably not the fine-grained kinematics of the way to perform it. Think of a situation in which a friend is describing her last match as kick-boxer describing and naming her single moves, and you never performed it and maybe neither saw a match. She can linguistically describe her experience so that you can at least partially understand. The contrary is true as well: we can have the bodily experience of an action, hence of its kinematics, but we have not the linguistic experience of it – since our language does not provide an exact verb to describe it. In some cases other linguistic devices (i.e. adverbs) or constructions (paraphrases) allow us to communicate and explain that action. Alternatively, we can refer to other languages in which the exact term is used.

Summing up, in all the situations described above we have experiences, bodily experiences, in which our body and brain is continuously involved in interaction with other actors, humans or not, and this leads constantly to a redefinition of what is experience and what is "action" for us. Language contributes in modeling our experience, and in being modeled by experience itself, in a process of translation from the one to the other. For this reason, other aspects than goals can be stressed and become more relevant: this is the case of perspective, issue discussed in chapter 4 and 5.

In chapter 4, I presented a second study performed with the aim to examine the interplay between the role of motor perspective (agent) and action organization in motor chains, verifying its behavioral effect on an overt actions required as response. This second kinematics study aimed at deepening how goal can be translated in language, using as stimuli simple sentences composed by a pronoun (I, You, He/She) and a verb. The basic assumption is that language encodes goals at different levels: not only at the very general level of goals as abstract entities, but at the specific level of goals as concrete entities relying on sequences of motor acts or simple actions. Results showed that the perspective activated by the pronoun You reflects the motor pattern of the "agent" combined with the chain structure of the verb. These data suggest that the motor system is early modulated by linguistic elements inducing a specific perspective,: the one of the agent. The data from this second study confirmed that understanding simple sentences involves the motor system, affecting in particular the phase of motor planning and consequently the first stages of action execution. In addition, it gave us additional information on how goals are translated and coded in language.

This study differed from the first for the way linguistic stimuli were composed: while in the first experiment we presented verbs in the infinitive form, here we presented simple sentence were an agent was implied (pronouns) and the verb was declined accordingly.

In this sense, the first study presented verbs in a form which is probably less susceptible to induce fine-grained modifications on action kinematics. Specifically, modifications depending on how the action is internally construed and planned with respect to internal and external constraints. This is consistent with our proposal that different levels of verb meaning can be activated, hence influencing action execution. For instance, the infinitive form of verbs does not state explicitly who is the agent performing the action. Probably participants rely on their own perspective on action, so assuming their selves as directly the agents. Alternatively, another possible strategy could be for participants to assume the action verbs from an external perspective, being the observers of that action. The data from the first study did not allow us to disentangle which kind of perspective was used. But presenting a pronoun directly establishes a point of view on action: our second study demonstrates that it is the perspective induced by YOU which produces effectively behavioural and kinematic effects. This finding has interesting implications: namely, in this light previous data from our and other study can be discussed, considering that the motor effects we obtain are dependent on the way we build up stimuli and present a context of interaction.

In the study here reported the context and perspective on interaction is mainly given by the pronoun, supported by the fact that in Italian also the verb elicits the agent. Consequently, the re-activation of chains of motor acts depends on this perspective, since we found a motor pattern coherent for the two type of verbs/actions only in the case of YOU. Our results suggest that while comprehending language we activate an inter-subjective framework. The adoption of this frame of reference has a very precocious effect as it differently impacts even the early stages of movements planning and execution. The activation of a conversational framework has an interesting theoretical implication. Even if our study clearly shows that action organization (e.g., the motor chains) is reflected in language, language imposes its own constraints on the way actions are conceived, giving relevance to the YOU pronoun in taking the agent's perspective, at least in the specific experimental setting here used. It is probable that using other settings and adding more cues to define perspective would induce the activation of different points of view, mediated not only by pronouns but also by nouns and other linguistic devices. This will be discussed in detail in the following study.

An open question remains whether the manipulation of this interactional framework and hence of motor-perspective taking can produce differential effects. For instance, which differences in performance would emerge if we present linguistically another agent (another pronoun, a name) or we just leave is supposed (as in our interaction-verbs sentences)? This is the aspect investigated in chapter 5.

In chapter 5, the issue of perspective is specifically investigated, focusing on its role in language comprehension. In particular, this study aimed at determining how a specific perspective (induced for example by a personal pronoun) modulates motor behaviour during and after language processing. A classical paradigm to induce a compatibility effect (the Action-sentence compatibility effect) has been used to this aim. In three behavioural experiments we investigated how the ACE is modulated by taking first or third person perspective. Results from these experiments showed that the ACE effect occurs only when a first-person perspective is activated by the sentences used as stimuli. This is true when using the pronoun YOU (experiment 1), but not when using an external actor in sentences, even asking participants to take the perspective of that actor (experiment 2). However, the first-person perspective is re-activated, and hence the ACE, when a spatial perspective is given. This suggests that the motor effects of language processing are constrained by the perspective of a specific agent with a specific body and position in space. If no other additional frames of reference are present, then, subjects are unable to take effectively (on a motor level) another perspective on action and they probably rely on more abstract processes for language comprehension.

The results confirmed that the presence of the pronouns YOU induces directly and strongly a first person perspective on action. This further corroborated previous data on the action-sentence compatibility effect. However, it is possible to manipulate perspective by introducing external actors and adding to the sensibility judgment a perspective-taking task.

Interestingly, introducing an external actor does not induce motor effects and it is not sufficient to ask participants to perform actions as if they were one of these actors. In this sense the roles of agent and recipient in our sentences are nothing but syntactical roles that need to be filled in order to produce motor effects. In the case of simple perspective-taking this does not happen and our participants rely on more abstract strategies to perform the task. They cannot act as someone else because their perspective on action is too external and no reference is present to place themselves in the space of the action described by the sentence. In this sense, this condition is equal to the one of simple linguistic observation of actions, where the focus is not on the agent, but probably on the effect of the action as interaction between two agents.

What is fundamental in our data is that this no-effect is not stable and given: we can manipulate third person perspective in order to reproduce a typical ACE effect. This is made possible by adding a spatial anchor to the perspective taking task, thus allowing participants to take their own motor perspective on the action described in sentences. This confirms that sentence with a third person perspective can induce, under specific constraints, motor effects. This is of great importance in our general discussion about the social and functional aspects of motor resonance. Simply inducing motor resonance each time there is YOU in a sentence, and inducing nothing with HE, would be just an automatic and rather unspecific effect. On the contrary, showing that the effect depends on the context of interaction and on perspective, suggests that this motor resonance adapts itself to the ongoing (social) situation. In this sense perspective can be activated together with other motor aspects of action: motor chains in our second study, motion direction and the relation with another person in the third study. This contributes to what we have defined in our first study as the "deep" understanding of action, which is a crucial aspect of our social ability to interact with others. Language supports this ability, by being highly flexible and capable to translate very fine-grained aspects of action organization.

Overall, the studies I presented suggest that language has a peculiar manner to re-articulate action organization. This process contributes to define language itself as a form of action: our words and sentences produce concrete, motor effects on the people we are interacting with. We use some aspects of action to act linguistically, by activating effectors, action goals, and perspectives. In this sense, language is crucial in its function to help us to share actions with other people, not at the level of abstract cognitive representations, but at the level of the motor experience.

Interestingly, I suggested throughout the thesis that probably the idea of a similarity between action observation and linguistic actions processing should be revised. Specifically, the investigation of the role played by introducing and or manipulating perspective-related aspects of linguistic processing showed that language acts in a peculiar way to articulate points of view on action. This is a crucial point: static pictures or videos, and certainly direct observation as well, directly convey a specific perspective, using the body of the "observer" as reference. Language opens two possibilities: first, to use linguistic devices to convey perspective (e.g. pronouns); second, to use these devices to re-articulate perspective just linguistically. "I" is not strictly a fist person perspective, "You" can be a first person as well depending on the way reading/listening are located into a specific interaction. The same distinction between external and internal perspectives fails to give a complete account of how language can build up perspectives. Furthermore, it fails in giving account of how we can embody our motor perspective from different points of view.

In conclusion, the data from this work suggest that a further investigation of how language translates actions should take into account that it is not a perfect translation, but a passage that adds and modifies action itself.

Overall, the data from our thesis contribute to disentangle several aspects of how action organization is translated in language, and then reactivated during language processing producing detectable motor effects. This constitutes a new contribution to the field, adding lacking information on how specific aspects such as goal and perspective are linguistically described. In addition, these studies offer a new point of view to understand the functional implications of the involvement of the motor system during language comprehension, specifically from the point of view of our social interactions. In particular, I suggest to revise the role of language not as a poor description of actions, but as an active form of action itself. However, I am aware of the fact that the effective functional role of the motor system needs to be investigated more deeply and with other techniques to build up a more general and coherent definition of the contribution of the motor system to meaning processes.

I believe that an approach considering the translation between different aspects of action through various domains (execution, observation, language) can be very fruitful. A point in favour of this approach is that assuming different translations at different levels necessarily implies the assumption that not one, but several areas contribute to this translation. This prevents to assume a reductionist approach in which separate areas contribute to separate and independent functions. That is, it is unlikely that the single M1 – relatively low-level area – contributes to language understanding, but it is surely plausible that other areas (premotor cortex, Broca'area, probably parietal sectors connected to motor chains) which normally contribute to action representation are active also during language processing. This is plausible given also the fact that normally we do not process single verbs or sentences, but entire dialogues or longer descriptions or narrations, as we do not observe single grasping actions separated by an interactional context. Indeed, since I proposed also a revision of the respective positions of language, action execution and observation, also these processes of translation need to be reconsidered.

This approach in terms of a productive translation is undoubtedly new and useful to discuss the open issues in the study of the involvement of the motor system during language processing, as detectable through motor effects or not. To conclude, I will briefly summarize some open questions that future research could focus on.

1. Is even processing action verbs or simple sentences influenced by the social context in which their processing occurs? That is, may the presence of other people (supposed or real) induce a modulation of language processing due to a differential involvement of the motor system? An effective modulation would imply a stronger functional link between activation of the motor system and social understanding of language. A point in favour of this functional link is given by the fact that we already showed that language is capable to manipulate the perspective assumed by a listener/reader. Understanding a sentence is critical as part of our social interactions, then an hypothesis is that the motor system plays a crucial role in enhancing our social comprehension of language. Of course, a definitive demonstration would come by extending these results to more complex descriptions or narrations as involved in more ecological contexts.

2. Does processing of more complex narrations and descriptions rely on the same processes elicited by simple sentences and single components such as verbs? Our hypothesis is, of course, that the same processes are active in all these cases. However, I have already demonstrated that not only verbs but also other aspects of linguistic actions are connected with a specific activation of the motor system. More, I demonstrated that this activation can be modulated and is not completely automatic. In this sense, it is plausible that during complex language

processing – that is, the everyday processing - these processes rely on a principle of economy in which the motor activation is modulated in relation with other concurrent tasks. Specifically, this could be connected to the exact timing of this activation: an early activation of the motor system during narration or dialogue processing would make it very plausible an effective contribution of the motor system to understanding processing, that is giving a strong confirmation of our previous results. It is in fact implausible to explain similar results in terms of motor imagery post-understanding. A critical point is then to elaborate paradigms capable to detect the language-motor system relations using complex linguistic stimuli.

3. Does manipulating the syntax of real/linguistic actions modulate the activity of the motor system? That is, may we manipulate the general level of syntax that logically precedes the fulfilment of its empty roles (with goals, agents, subjects, object, effectors, etc), hence manipulate how the successive stages are elaborated? This manipulation would be possibly really fruitful in comparing different linguistic or motor expertises (technical language, specialized language, infants vs adults, etc) and to assume a cross-cultural comparative approach. In fact, it is possible that languages implying a different order of the syntactic roles imply a different manner of processing these elements. Perspective itself could be influenced by languages presenting the personal pronoun or not, or presenting the agent at the end of the sentence and not at the beginning (as partially discussed for the ACE). In addition, it would be useful to compare different languages, verbal language gestures but also music or visual language, to detect if a similar syntax is used. The involvement of the Broca's area in several tasks related to these domains seems to confirm this hypothesis, which however needs to be clarified and deepened.

4. Which are effectively the neural substrates of these processes?

In the introduction I suggested that a strong candidate to be the neural substrate of effects of motor resonance and/or simulation could be the mirror neurons system. This position assumed a continuity among execution, observation and language, but I nevertheless introduced a note of caution being when discussing the position of some authors stating a complete overlap of these three situations.

The studies I presented showed that language actively translates (into) action, manipulating for instance perspective in a way that partially differs from actual action observation. That is, motor processes are still active, but the cues activating them seem to differ and seem to differ according to a specific intersubjective framework, being the framework in which language is developed. For these reasons, a further investigation is needed to clarify whether and how the motor processes and areas involve in action language are the same or differ from the ones involved in observation and execution. A possibility is that the same areas are involved, but in different networks which determine the behavioural patterns. For example, it is possible that language needs to rely more the action observation on the first perspective, on the perspective of the self. Future studies will investigate this aspect. A consequence of these results is that we need to reconsider the potential role of mirror mechanism active in motor resonance and simulation. Indeed, we should reconsider the definition of motor resonance itself. In fact, we showed that – at least in some specific cases – the motor resonance does not act as it would have been expected depending on studies on action observation. In fact, on the basis of these studies one could predict that all the perspectives on action share the same motor processes. This was clearly not true, and we found that a proper motor simulation is present only when the reader is directly called into action as an agent. These results induce to reconsider both the relationship between language and action observation and the nature of motor resonance itself. Further research should investigate how aspects such as the self-other distinction may play a role and which are the effective neural processes underlying the behavioural effects we observed. Consequently, the notion of embodiment should be re-framed and re-articulated.

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APPENDIX

CHAPTER 3

Table 1, Stimuli used in the three experiments

Name	Category	Letters	Syllables	IP (s)	AD (s)	LF	Translation
Stappare	Hand-related	8	3	0.72	1.4	0	To uncap
Svitare	Hand-related	7	3	0.57	1.28	0	To unscrew
Timbrare	Hand-related	8	3	0.51	1.21	1.21	To stamp
Rammendare	Hand-related	10	4	1.01	1.8	0.3	To mend
Sbottonare	Hand-related	10	4	0.85	1.68	0	To unbutton
Correre	Foot-related	7	3	0.52	1.12	58.18	To run
Camminare	Foot-related	9	4	0.56	1.35	28.18	To walk
Calpestare	Foot-related	10	4	0.87	1.6	1.82	To trample
Marciare	Foot-related	8	3	0.65	1.34	3.33	To walk
Inciampare	Foot-related	10	4	0.85	1.61	0.91	To stumble
Calciare	Foot-related	8	3	0.62	1.33	0.91	To kick
Saltellare	Foot-related	10	4	0.86	1.5	0.61	To jump
Pattinare	Foot-related	9	4	0.67	1.4	0.3	To skate
Pedalare	Foot-related	8	4	0.5	1.28	2.73	To pedal
Zoppicare	Foot-related	9	4	0.75	1.58	0	To hobble
Amare	Abstract	5	3	0.32	0.97	26.97	To love
Odiare	Abstract	6	3	0.41	1.2	1.82	To hate
Godere	Abstract	6	3	0.38	1.05	16.06	To enjoy
Scordare	Abstract	8	3	0.74	1.46	2.42	To forget
Temere	Abstract	6	3	0.38	1.16	13.64	To fear
Meditare	Abstract	8	4	0.69	1.44	1.82	To meditate
Contemplare	Abstract	11	4	0.99	1.75	3.94	To contemplate
Ammirare	Abstract	8	4	0.76	1.49	13.33	To admire
Sopportare	Abstract	10	4	1	1.72	20	To bear
Approvare	Abstract	9	4	0.77	1.66	10.91	To approve

IP isolation points (s), *AD* acoustic duration (s), *LF* lexical frequency

EXPERIMENT 1 – Finger Opening	HAND VERBS	FOOT VERBS
Time to Finger Peak Velocity	78,66	78,07
Grasp Time	546,52	537,74
Time to Maximal Finger Aperture	258,28	246,66
Maximal Finger Aperture	93,70	95,02
	406,02	404,77

TRB		

EXPERIMENT 2 – Reaching-grasping	**HAND VERBS**	**FOOT VERBS**
Reach Time	655,831	641,4073
Time to Arm Peak Velocity	245,4051	253,831
Maximal Finger Aperture	90,69137	90,36716
Arm Peak Velocity	1112,527	1126,797
TRB	391,5092	405,2377

EXPERIMENT 3 – Effector lifting	**HAND VERBS – HAND RESP**	**FOOT VERBS – FOOT RESP**	**HAND VERBS- FOOT RESP**	**FOOT VERBS – HAND RESP**
Time to Peak Velocity	252,03	285,16	217,76	271,49
Maximal Effector Height	0,07114	0,125456	0,07496	0,13025
Time to Maximal Effector Height				
Peak Velocity	439,51	426,652	494,7355	451,2515
TRB	523,9394	468,7636	536,6872	562,7155

CHAPTER 4
Table 1, Stimuli used in the experiment, with English translation

STIMULI					
VERB ITALIAN	**VERB TYPE**	***First person***	***Second Person***	***Third Person***	**VERB ENGLISH**
Afferrare	AV	*Io afferravo*	*Tu afferravi*	*Egli afferrava*	To grasp
Alzare	AV	*Io alzavo*	*Tu alzavi*	*Egli alzava*	To raise
Portare	AV	*Io portavo*	*Tu portavi*	*Egli portava*	To carry
Prendere	AV	*Io prendevo*	*Tu prendevi*	*Egli prendeva*	To take
Sollevare	AV	*Io sollevavo*	*Tu sollevavi*	*Egli sollevava*	To lift up
Consegnare	IV	*Io consegnavo*	*Tu consegnavi*	*Egli consegnava*	To deliver
Dare	IV	*Io davo*	*Tu davi*	*Egli dava*	To give
Offrire	IV	*Io offrivo*	*Tu offrivi*	*Egli offriva*	To offer
Porgere	IV	*Io porgevo*	*Tu porgevi*	*Egli porgeva*	To hand
Scambiare	IV	*Io scambiavo*	*Tu scambiavi*	*Egli scambiava*	To exchange

CHAPTER 5

Table 1, Stimuli used in experiment 1

1	Tu as adressé un courrier à Léa
2	Tu as cédé ta place à Léa
3	Tu as chanté une chanson à Léa
4	Tu as communiqué le message à Léa
5	Tu as confié ton secret à Léa
6	Tu as consacré du temps à Léa
7	Tu as déclaré son amour à Léa
8	Tu as délégué ses tâches à Léa
9	Tu as dispensé ses conseils à Léa
10	Tu as donné sa chance à Léa
11	Tu as écrit une lettre à Louis
12	Tu as envoyé un baiser à Louis
13	Tu as exposé ses raisons à Louis
14	Tu as exprimé son amitié à Louis
15	Tu as jeté un sort à Louis
16	Tu as lancé une idée à Louis
17	Tu as présenté sa démission à Louis
18	Tu as raconté une histoire à Louis
19	Tu as transféré la responsabilité à Louis
20	Tu as transmis les consignes à Louis
21	Louis t'a adressé un courrier
22	Louis t'a cédé sa place
23	Louis t'a chanté une chanson
24	Louis t'a communiqué le message
25	Louis t'a confié son secret
26	Louis t'a consacré du temps
27	Louis t'a déclaré son amour
28	Louis t'a délégué ses tâches
29	Louis t'a dispensé ses conseils
30	Louis t'a donné une chance
31	Léa t'a écrit une lettre
32	Léa t'a envoyé un baiser
33	Léa t'a exposé ses raisons
34	Léa t'a exprimé son amitié
35	Léa t'a jeté un sort
36	Léa t'a lancé une idée
37	Léa t'a présenté sa démission
38	Léa t'a raconté une histoire
39	Léa t'a transféré la responsabilité
40	Léa t'a transmis les consignes
41	Tu as adressé une vague à Léa

42	Tu as cédé son nez à Léa
43	Tu as chanté une cuisine à Léa
44	Tu as communiqué la prison à Léa
45	Tu as confié ses seuils à Léa
46	Tu as consacré du tempête à Léa
47	Tu as déclaré son mouvement à Léa
48	Tu as délégué ses phrases à Léa
49	Tu as dispensé ses villages à Léa
50	Tu as donné une race à Léa
51	Tu as écrit une viande à Louis
52	Tu as envoyé un genou à Louis
53	Tu as exposé ses maisons à Louis
54	Tu as exprimé sa chemise à Louis
55	Tu as jeté un cinéma à Louis
56	Tu as lancé une église à Louis
57	Tu as présenté sa cheminée à Louis
58	Tu as raconté une fille à Louis
59	Tu as transféré la boussole à Louis
60	Tu as transmis les résidents à Louis
61	Louis t'a adressé une vague
62	Louis t'a cédé son nez
63	Louis t'a chanté une cuisine
64	Louis t'a communiqué la prison
65	Louis t'a confié ses seuils
66	Louis t'a consacré du tempête
67	Louis t'a déclaré son mouvement
68	Louis t'a délégué ses phrases
69	Louis t'a dispensé ses villages
70	Louis t'a donné une race
71	Léa t'a écrit une viande
72	Léa t'a envoyé un genou
73	Léa t'a exposé ses maisons
74	Léa t'a exprimé sa chemise
75	Léa t'a jeté un cinéma
76	Léa t'a lancé une église
77	Léa t'a présenté sa cheminée
78	Léa t'a raconté une fille
79	Léa t'a transféré la boussole
80	Léa t'a transmis les résidents
81	Tu as apporté une bouteille à Louis
82	Tu as assené un coup à Louis
83	Tu as attribué une médaille à Louis
84	Tu as confié la clé à Louis
85	Tu as consigné un message à Louis
86	Tu as donné un livre à Louis
87	Tu as envoyé un paquet à Louis

88	Tu as fourni les draps à Louis
89	Tu as lancé la balle à Louis
90	Tu as légué son appartement à Louis
91	Tu as livré une pizza à Léa
92	Tu as montré une photo à Léa
93	Tu as offert un cadeau à Léa
94	Tu as passé le plateau à Léa
95	Tu as porté des fleurs à Léa
96	Tu as prêté sa voiture à Léa
97	Tu as rendu sa veste à Léa
98	Tu as servi du thé à Léa
99	Tu as vendu des cigarettes à Léa
100	Tu as versé de l'eau à Léa
101	Léa t'a apporté une bouteille
102	Léa t'a assené un coup
103	Léa t'a attribué une médaille
104	Léa t'a confié la clé
105	Léa t'a consigné un message
106	Léa t'a donné un livre
107	Léa t'a envoyé un paquet
108	Léa t'a fourni les draps
109	Léa t'a lancé la balle
110	Léa t'a légué son appartement
111	Louis t'a livré une pizza
112	Louis t'a montré une photo
113	Louis t'a offert un cadeau
114	Louis t'a passé le plateau
115	Louis t'a porté des fleurs
116	Louis t'a prêté sa voiture
117	Louis t'a rendu sa veste
118	Louis t'a servi du thé
119	Louis t'a vendu des cigarettes
120	Louis t'a versé de l'eau
121	Tu as apporté une nation à Léa
122	Tu as assené un canard à Léa
123	Tu as attribué une honte à Léa
124	Tu as confié la cohérence à Léa
125	Tu as consigné un retard à Léa
126	Tu as donné un livre à Léa
127	Tu as envoyé un appartement àLéa
128	Tu as fourni la lune à Léa
129	Tu as lancé le crocodile à Léa
130	Tu as légué sa nature à Léa
131	Tu as livré un ciel à Louis
132	Tu as montré un rêve à Louis
133	Tu as offert une conscience à Louis

134	Tu as passé la bouche à Louis
135	Tu as porté des déserts à Louis
136	Tu as prêté sa naissance à Louis
137	Tu as rendu son courage à Louis
138	Tu as servi du remord à Louis
139	Tu as vendu des doutes à Louis
140	Tu as versé de l'obéissance à Louis
141	Léa t'a apporté une nation
142	Léa t'a assené un canard
143	Léa t'a attribué une honte
144	Léa t'a confié la cohérence
145	Léa t'a consigné un retard
146	Léa t'a donné une intelligence
147	Léa t'a envoyé un appartement
148	Léa t'a fourni la lune
149	Léa t'a lancé le crocodile
150	Léa t'a légué sa nature
151	Louis t'a livré un ciel
152	Louis t'a montré un rêve
153	Louis t'a offert une conscience
154	Louis t'a passé la bouche
155	Louis t'a porté des déserts
156	Louis t'a prêté sa naissance
157	Louis t'a rendu son courage
158	Louis t'a servi du remord
159	Louis t'a vendu des doutes
160	Louis t'a versé de l'obéissance

Table 2, Stimuli used in experiments 2 and 3

1	Louis a adressé un courrier à Léa
2	Louis a cédé sa place à Léa
3	Louis a chanté une chanson à Léa
4	Louis a communiqué le message à Léa
5	Louis a confié son secret à Léa
6	Louis a consacré du temps à Léa
7	Louis a déclaré son amour à Léa
8	Louis a délégué ses tâches à Léa
9	Louis a dispensé ses conseils à Léa
10	Louis a donné une chance à Léa
11	Louis a écrit une lettre à Léa
12	Louis a envoyé un baiser à Léa
13	Louis a exposé ses raisons à Léa
14	Louis a exprimé son amitié à Léa
15	Louis a jeté un sort à Léa
16	Louis a lancé une idée à Léa
17	Louis a présenté sa démission à Léa
18	Louis a raconté une histoire à Léa
19	Louis a transféré la responsabilité à Léa
20	Louis a transmis les consignes à Léa
21	Léa a adressé un courrier à Louis
22	Léa a cédé sa place à Louis
23	Léa a chanté une chanson à Louis
24	Léa a communiqué le message à Louis
25	Léa a confié son secret à Louis
26	Léa a consacré du temps à Louis
27	Léa a déclaré son amour à Louis
28	Léa a délégué ses tâches à Louis
29	Léa a dispensé ses conseils à Louis
30	Léa a donné une chance à Louis
31	Léa a écrit une lettre à Louis
32	Léa a envoyé un baiser à Louis
33	Léa a exposé ses raisons à Louis
34	Léa a exprimé son amitié à Louis
35	Léa a jeté un sort à Louis
36	Léa a lancé une idée à Louis
37	Léa a présenté sa démission à Louis
38	Léa a raconté une histoire à Louis
39	Léa a transféré la responsabilité à Louis
40	Léa a transmis les consignes à Louis
41	Louis a adressé une vague à Léa
42	Louis a cédé son nez à Léa
43	Louis a chanté une cuisine à Léa
44	Louis a communiqué la prison à Léa

45	Louis a confié ses seuils à Léa
46	Louis a consacré du tempête à Léa
47	Louis a déclaré son mouvement à Léa
48	Louis a délégué ses phrases à Léa
49	Louis a dispensé ses villages à Léa
50	Louis a donné une race à Léa
51	Louis a écrit une viande à Léa
52	Louis a envoyé un genou à Léa
53	Louis a exposé ses maisons à Léa
54	Louis a exprimé sa chemise à Léa
55	Louis a jeté un cinéma à Léa
56	Louis a lancé une église à Léa
57	Louis a présenté sa cheminée à Léa
58	Louis a raconté une fille à Léa
59	Louis a transféré la boussole à Léa
60	Louis a transmis les résidents à Léa
61	Léa a adressé une vague à Louis
62	Léa a cédé son nez à Louis
63	Léa a chanté une cuisine à Louis
64	Léa a communiqué la prison à Louis
65	Léa a confié ses seuils à Louis
66	Léa a consacré du tempête à Louis
67	Léa a déclaré son mouvement à Louis
68	Léa a délégué ses phrases à Louis
69	Léa a dispensé ses villages à Louis
70	Léa a donné une race à Louis
71	Léa a écrit une viande à Louis
72	Léa a envoyé un genou à Louis
73	Léa a exposé ses maisons à Louis
74	Léa a exprimé sa chemise à Louis
75	Léa a jeté un cinéma à Louis
76	Léa a lancé une église à Louis
77	Léa a présenté sa cheminée à Louis
78	Léa a raconté une fille à Louis
79	Léa a transféré la boussole à Louis
80	Léa a transmis les résidents à Louis
81	Louis a apporté une bouteille à Léa
82	Louis a assené un coup à Léa
83	Louis a attribué une médaille à Léa
84	Louis a confié la clé à Léa
85	Louis a consigné un message à Léa
86	Louis a donné un livre à Léa
87	Louis a envoyé un paquet à Léa
88	Louis a fourni les draps à Léa
89	Louis a lancé la balle à Léa
90	Louis a légué son appartement à Léa

91	Louis a livré une pizza à Léa
92	Louis a montré une photo à Léa
93	Louis a offert un cadeau à Léa
94	Louis a passé le plateau à Léa
95	Louis a porté des fleurs à Léa
96	Louis a prêté sa voiture à Léa
97	Louis a rendu sa veste à Léa
98	Louis a servi du thé à Léa
99	Louis a vendu des cigarettes à Léa
100	Louis a versé de l'eau à Léa
101	Léa a apporté une bouteille à Louis
102	Léa a assené un coup à Louis
103	Léa a attribué une médaille à Louis
104	Léa a confié la clé à Louis
105	Léa a consigné un message à Louis
106	Léa a donné un livre à Louis
107	Léa a envoyé un paquet à Louis
108	Léa a fourni les draps à Louis
109	Léa a lancé la balle à Louis
110	Léa a légué son appartement à Louis
111	Léa a livré une pizza à Louis
112	Léa a montré une photo à Louis
113	Léa a offert un cadeau à Louis
114	Léa a passé le plateau à Louis
115	Léa a porté des fleurs à Louis
116	Léa a prêté sa voiture à Louis
117	Léa a rendu sa veste à Louis
118	Léa a servi du thé à Louis
119	Léa a vendu des cigarettes à Louis
120	Léa a versé de l'eau à Louis
121	Louis a apporté une nation à Léa
122	Louis a assené un canard à Léa
123	Louis a attribué une honte à Léa
124	Louis a confié la cohérence à Léa
125	Louis a consigné un retard à Léa
126	Louis a donné un livre à Léa
127	Louis a envoyé un appartement à Léa
128	Louis a fourni la lune à Léa
129	Louis a lancé le crocodile à Léa
130	Louis a légué sa nature à Léa
131	Louis a livré un ciel à Léa
132	Louis a montré un rêve à Léa
133	Louis a offert une conscience à Léa
134	Louis a passé la bouche à Léa
135	Louis a porté des déserts à Léa
136	Louis a prêté sa naissance à Léa

137	Louis a rendu son courage à Léa
138	Louis a servi du remord à Léa
139	Louis a vendu des doutes à Léa
140	Louis a versé de l'obéissance à Léa
141	Léa a apporté une nation à Louis
142	Léa a assené un canard à Louis
143	Léa a attribué une honte à Louis
144	Léa a confié la cohérence à Louis
145	Léa a consigné un retard à Louis
146	Léa a donné une intelligence à Louis
147	Léa a envoyé un appartement à Louis
148	Léa a fourni la lune à Louis
149	Léa a lancé le crocodile à Louis
150	Léa a légué sa nature à Louis
151	Léa a livré un ciel à Louis
152	Léa a montré un rêve à Louis
153	Léa a offert une conscience à Louis
154	Léa a passé la bouche à Louis
155	Léa a porté des déserts à Louis
156	Léa a prêté sa naissance à Louis
157	Léa a rendu son courage à Louis
158	Léa a servi du remord à Louis
159	Léa a vendu des doutes à Louis
160	Léa a versé de l'obéissance à Louis