Vittorio Gallese

The Multimodal Nature of Visual Perception: Facts and Speculations.

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Introduction

> "Thus the perception in the mind of an onlooker, if it so constituted as to embrace what is going on in the agent, must itself possess a similar articulation. And hence the experience of agent A and the observant B must resemble each other". (Kurt Koffka 1924, 130-131)

In this paper I address visual perception and challenge the view that action and perception constitute two separate domains on the basis of a series of neuroscientific empirical findings on the functional properties of sensorimotor systems of non-human primates and humans. These findings – the facts – show that the motor system not only controls the execution of movements and actions, but it also plays a major role in perception and cognition. These data allow one to formulate a new account of the nature of visual perception and its bodily and neural constituents.

Perception and action have been traditionally considered as separate domains, each of them being underpinned by separate brain sectors. In primates, the sensory modality that is taken as paradigmatic for studying the mechanisms underlying perception is vision. Visual information is processed both serially and along parallel pathways. A particularly influential account of why there is parallel processing of visual information in the primate visual cortex was proposed by Ungerleider & Mishkin (1982). According to these authors the visual cortical areas are organized in two separate streams of visual information: a dorsal stream, which culminates in the inferior parietal lobule, and a ventral stream, which culminates in the inferior temporal cortex. According to this model the dorsal stream is responsible for perception of space, the ventral stream for object perception.

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A radically different view was advanced by Milner & Goodale (Goodale & Milner 1992; Milner & Goodale 1995). The fundamental functional difference between the dorsal and ventral stream, they propose, is not in the resulting percept (space vs. object), but in the output characteristics of the two cortical visual streams. The ventral stream would be fundamental for perception, while the dorsal stream would processes high order visual information for the control of action. According to ths model the dorsal stream is not involved in perception.

The division of cortical visual processing into two streams, however, is insufficient and leads to possible misunderstandings about the true nature of perceptual processes. In macaques there is solid evidence that visual processing is carried out along three distinct streams. Two of them include the parietal lobe, one includes the inferior temporal lobe. These three streams can be qualified as dorso-dorsal, ventro-dorsal and ventral streams, respectively. The dorso-dorsal stream contributes to the online control of action and has the characteristics suggested by Milner & Goodale when they describe their dorsal stream. In contrast, the dorso-ventral stream is responsible not only for the organization of actions directed towards objects, but also for space and action perception. It mediates also some aspects of object semantics. Finally, the ventral stream is responsible for the organization of actions following object categorization, and for object semantics (see Rizzolatti & Gallese 2006; Gallese 2007a).

For the sake of concision I focus here only on some aspects of the dorso-ventral stream and introduce and discuss a new model of the interplay between action, perception and cognition – embodied simulation, based on the empirical evidence reviewed in the first part of the paper. I posit that embodied simulation is a basic functional mechanism of the brain, instantiated by different populations of neurons distributed in different cortical networks. These different cortical networks, when instantiating embodied simulation, might serve different purposes, like the mapping of the space surrounding the body, the perception of manipulable objects, and the perception of others' actions, emotions and sensations. What is common among these different forms of simulation is neural reuse: the very same brain circuits allowing action in space and towards objects also participate in the perception of peripersonal space, objects and others' behaviors. I conclude by introducing some recent developments in relation to language, proposing that embodied simulation might instantiate a form of paradigmatic knowledge.

Motor Cognition and the Multimodal Nature of Vision

Observing the world is more complex than the mere activation of the visual brain. Vision is multimodal: it encompasses the activation of motor, somatosensory and emotion-related brain networks. Any intentional relation we might entertain with the external world has an intrinsic pragmatic nature, hence it always bears a motor content. Neuroscience shows us that cortical motor neurons also respond to visual, tactile and auditory stimuli. The same motor circuits that control the motor behavior of individuals also map the space around them, the objects at hand in that very same space, thus defining and shaping in motor terms their representational content (for a review, see Gallese 2000; Rizzolatti, Fogassi & Gallese 2000, 2001).

Whenever we look around, we are somehow aware of what is reachable and what is not, we can anticipate whether a falling object may hit us or not. We can calibrate the movement in space of our hand so as to be able to catch a fly. We can identify objects, locations in space where sounds may come from with a remarkable precision. All of these perceptual qualities are not the mere outcome of the *impression* exerted by the external world on our perceptual and cognitive systems. Neuroscience tells us a different story. These perceptual qualities depend upon the motor potentialities expressed by our situated body.

A peculiar example comes from the relationship between motor potentialities and spatial mapping, exemplified by macaque monkeys' ventral premotor area F4. This area is part of a parieto-premotor cortical network mapping specific sensory events in the space near the body onto the neural representation of arm and head motor acts. F4 neurons not only control orienting/avoidance movements of the head and reaching movements of the upper limb, they also respond to tactile stimuli applied to the same body parts whose movements they control, and to visual and auditory stimuli, provided they occur within the monkey's peripersonal space. F4 neurons' visual and auditory receptive fields are body-centered, that is, they are anchored to body parts and move along with them. Thus, perceiving a visual object or hearing a sound within peripersonal space evokes the motor simulation of the most appropriate actions towards that very same spatial location (Rizzolatti et al. 1997).

A putative human homologue of monkey area F4 was identified in the premotor cortex. Bremmer et al. (2001) demonstrated that the ventral region of the human premotor cortex responds to tactile stimuli applied to the face and to visual and auditory stimuli presented within its peripersonal space. Furthermore, repetitive transcranial magnetic stimulation (TMS) over the premotor cortex interferes with the processing of multisensory stimuli within the hand's peripersonal space. The cortical motor system both in non-human primates and humans maps the body's motor potentialities and such mapping enables the multisensory integration of self bodily-related stimuli affecting the body and its surrounding space.

Another instantiation of motor cognition comes from the so-called 'canonical neurons', originally discovered in macaques' premotor area F5. They discharge both during the grasping of objects with the hand and during their observation in absence of any detectable movement of the monkey (see Jeannerod et al. 1995;

Murata et al. 1997; Rizzolatti, Fogassi & Gallese 2000; Raos et al. 2006; Umiltà et al. 2007). In many canonical neurons a congruence is observed between the response during the execution of a specific type of grip, and the visual response to objects that, although differing in shape, nevertheless all afford the same type of grip (see Murata et al. 1997; Raos et al. 2006). Thus, the very same neuron controlling the hand action suitable to grasp small objects will also fire equally well to the mere observation of small objects like a small sphere, a small cone or a small cube. The objects' shapes are different but they all specify a similar type of grasping.

The function of F5 canonical grasping neurons cannot be defined in purely sensory or motor terms: canonical neurons process graspable objects in motor relationally-specified terms, as they map objects not in relation to their mere visual appearance, but in relation to the effect of the potential interaction with a situated potentially acting agent (Gallese 2000). This property qualifies as an intentional type of representation, although still fully within the functional architecture of the cortical motor system. Canonical neurons contribute to a multimodal representation of individual-object-relations, thus showing that the visual world is always also the horizon of our potential pragmatic relation to it (Gallese & Sinigaglia 2010).

The functionality of the motor system literally carves out a pragmatic *Umwelt*, dynamically surrounding our body. The profile of peripersonal space is not arbitrary: it maps and delimits a perceptual space expressing – and being constituted by – the motor potentialities of the body parts it surrounds. Similarly, manipulable objects are the potential target of intentional action and are mapped as such by the cortical motor system. An important component of the perceptual experience we make of objects is determined, constrained, and ultimately constituted by the limits posed by what our body can potentially do with them.

These results suggest that content is not exclusively confined to the propositional format of representation. Representational content cannot be fully explained without considering the ongoing modeling process of organisms as currently integrated with the objects to be represented, by intending them. This integration process between the representing organism and the represented objects is articulated in multiple fashions, e.g. by intending to explore it by moving the eyes, by walking towards it, by intending to hold it in the focus of attention, by intending to grasp it, and ultimately, by thinking about it (see Gallese 2000; Gallese & Metzinger 2003).

The same motor circuits that control the ongoing behavior of individuals within their environment also map distances, locations and objects in that very same environment, thus defining and shaping in motor terms their representational content. The way the visual world is represented by the motor system incorporates agents' idiosyncratic way of interacting with it. To put it simply, the producer and repository of representational content is not the brain per se, but the brain-body system, by means of its interactions with the world of which it is part.

Mirroring Mechanisms

The discovery of mirror neurons (MNs) in the brain of macaques (Gallese et al. 1996; Rizzolatti et al. 1996; Rizzolatti, Fogassi & Gallese 2001), and the subsequent discovery of mirror mechanisms (MMs) in the human brain (see Gallese et al. 2004; Rizzolatti & Sinigaglia 2010) suggest that a direct modality of access to the meaning of others' motor behavior is available, a modality that is different from the explicit attribution of propositional attitudes. MNs are motor neurons that not only respond to the execution of movements and actions, but also during their perception when executed by others. The relational character of behavior as mapped by the cortical motor system enables the appreciation of purpose without relying on explicit propositional inference.

The relation between purposeful actions and their outcomes was traditionally assumed to be largely independent of the motor processes and neural mechanisms underpinning action execution. Such processes and mechanisms would concern elementary motor features, such as joint displacements or muscle contractions. However, empirical evidence challenges this view: motor processes may involve motor representations of action outcomes (e.g., to grasp, to place, etc.), and not only kinematic or dynamic components of actions. This suggests that beliefs, desires, and intentions are neither primitive, nor the only bearers of intentionality in action. We do not necessarily need to meta-represent in propositional format the motor outcomes and intentions of others to understand them. Motor outcomes and motor intentions are part of the 'vocabulary' spoken by the motor system. In several occasions we do not explicitly ascribe intentions to others; we simply detect them. Indeed, I posited that bodily-formatted motor representation is enough to ground the directedness of an action to its outcome, not only during its execution but also during its observation when performed by others (Gallese 2000, 2003; see also Butterfill & Sinigaglia 2014).

The discovery of MNs gives us a new empirically founded notion of intersubjectivity connoted first and foremost as intercorporeality – the mutual resonance of intentionally meaningful sensorimotor behaviors. The ability to understand others as intentional agents does not exclusively depend on propositional competence, but it is in the first place dependent on the relational nature of action. According to this hypothesis, it is possible to directly understand others' basic actions by means of the motor equivalence between what others do and what the observer can do. Intercorporeality thus becomes the primordial source of knowledge that we have of others (Gallese 2003, 2007b; Gallese & Sinigaglia 2011).

Action, however, constitutes only one particular dimension of the rich and diverse experiences involved in interpersonal relations. Every interpersonal relation implies the sharing of a multiplicity of states, like the experience of emotions and sensations. As originally hypothesized by Goldman & Gallese (2000), solid empirical evidence demonstrates that the very same cortical areas activated during the subjective experience of emotions and sensations are also active when witnessing such emotions and sensations being experienced and expressed by others. A multiplicity of "mirroring" mechanisms are thus present in our brain. It was proposed that these mechanisms, thanks to the 'intentional attunement' they generate (Gallese 2006), allow intersubjective communication and a basic level of mutual implicit understanding. The functional architecture of embodied simulation seems to constitute a basic characteristic of our brain, making possible our rich and diversified intersubjective experiences, being at the basis of our capacity to empathize with others.

Embodied Simulation

MNs boosted a renewed interest in simulation theories and also suggested an embodied approach to simulation (Gallese 2003, 2007b, 2014). Embodied simulation aimed to account for basic social interactions by means of a neurobiologically plausible and theoretically unitary framework. According to the notion of simulation as reuse I am proposing, there is mental simulation just in case the same mental state or process that is used for one purpose is reused for another purpose (Hurley 2008; Gallese 2014; Gallese & Sinigaglia 2011; Gallese & Cuccio 2015). The main argument of the reuse view is that, in almost any story, all simulation type mindreading requires any resemblance of the mental states or processes between the simulator and the target to arise from the reuse of the simulator's own mental states or processes. At bottom it is mental reuse, not resemblance, that drives mindreading (Hurley 2008).

The notion of reuse entails a general principle of brain function. It has been applied to social cognition in general, and to language and conceptual thought in particular (Gallese & Lakoff 2005; Gallese 2008; Anderson 2010). By neural reuse, different brain areas participate in different functions through their dynamical engagement with different brain circuits. Furthermore, a given cognitive function can be supported by a variety of brain circuits; the newer in evolutionary terms a cognitive function is, the wider is the brain circuit underpinning it. Neural reuse not only enables the cortical motor system to process and integrate perceptual stimuli, hence instantiating novel cognitive functions, but also sheds new light on the phylogenesis and ontogenesis of the vicarious experiences characterizing human intersubjectivity.

Neuroscience shows that the line between what we call reality and imaginary and imagined worlds is much less sharp and clear than one might think (Gallese 2011). Indeed, experiencing an emotion and imagining it are both underpinned by the activation of partly identical brain circuits, although differently connected in these two different cognitive and phenomenal situations. Similarly, to see something and to imagine it, to act and to imagine acting, share the activation of partly common brain circuits. A recent high-density EEG study showed that the brain circuits that inhibit action execution are partly the same that allow us to imagine acting (Angelini et al. 2015). All these examples of dual activation patterns of the same brain circuits represent a further expression of embodied simulation and the related notion of neural reuse.

Embodied simulation theory does not aim to provide a general notion of mental simulation, nor a unitary account of the different stages involved in simulation type mindreading. Rather, it aims to explain the MM and related phenomena. Embodied simulation theory posits that the MM counts as implementing mental simulation processes primarily because brain and cognitive resources typically used for one purpose are reused for another purpose. For instance, the activation of parieto-premotor cortical networks, which typically serve the purpose of representing and accomplishing a single motor outcome, or a hierarchy of motor outcomes, might also serve the purpose of attributing the same motor outcome or motor intention to others. The same holds for emotions and sensations. The reuse of mental states and processes instantiated by embodied simulation is *constitutively* embodied. Alvin Goldman provided a very useful taxonomy of the different notions of embodiment. Accordingly, "embodied" means that body parts, bodily actions, or body representations play a crucial role in cognition. Note, however, that body representations might be interpreted in terms of mental representations either with a bodily content (i.e., representations of the body), or with a bodily format (Goldman & de Vignemont 2009; Goldman 2012).

Embodied simulation theory makes use of a notion of embodiment according to which mental states or processes are embodied because of their bodily format. Mental representations may differ not only because of their content but also because of their representational format. The bodily format of a mental representation constrains what such mental representation can represent, because of the bodily constraints posed by the specific configuration of the human body. I showed how this applies to space, objects and others' behaviors and experiences. A core claim of embodied simulation theory is that similar constraints apply both to the representations of one's own actions, emotions or sensations involved in actually acting and experiencing and also to the corresponding representations involved in observing someone else performing a given action or experiencing a given emotion or sensation. These constraints are similar because the representations have a common bodily format. Hence, embodied simulation is the reuse of mental states and processes involving representations that have a bodily format. The nature and the range of what can be achieved with embodied simulation is constrained by the bodily format of the representations involved. This doesn't necessarily entail that *all* forms of embodied cognition should be based on reuse. Indeed, the firing of a neuron or group of neurons in a premotor area as part of a plan of action or a motor command would certainly qualify as an instantiation of embodied cognition according to the bodily-format approach, but it wouldn't be an instance of reuse.

In sum, embodied simulation can provide a unified explanatory framework for different forms of visual perception. Our bodily acting and sensing nature appears to constitute the non-further-reducible basis upon which our experience of the world is built. In the final part of the paper I'd like to discuss the hypothesis that embodied simulation might play a role in linking brain, body and language.

Embodied Simulation and Language: The Paradigmatic Body

The embodied approach to human social cognition should in principle be able to explain how our bodily nature determines some of the key aspects identifying the uniqueness of human language, particularly in its most abstract forms. The question is open and empirical research must address this challenge in the coming years. In the meantime, at least at a purely speculative level, let us try to delineate a possible point of contact between the anthropogenic power of language and embodied simulation.

It is possible to connect the common pre-linguistic sphere to the linguistic one by showing that language, when it refers to the body in action, brings into play the neural resources normally used to move that very same body. Seeing someone performing an action, like grasping an object, and listening to or reading the linguistic description of that action lead to a similar motor simulation that activates some of the same regions of our cortical motor system, including those with mirror properties, normally activated when we do perform that action (see Gallese 2003, 2007b, 2008; Gallese & Lakoff 2005; Glenberg & Gallese 2012; Gallese & Cuccio 2015).

These data on the role of embodied simulation in understanding language broadly support the hypothesis that the bodily, sensory and motor dimensions play a constitutive role in language production and understanding. However, as argued elsewhere (see Gallese & Cuccio 2015), the relationship between language and body does not move along a single direction, because language offers us wholly human modalities of experiencing the corporeity of the body. Embodied simulation might well play a role in understanding language. Indeed, if one reversibly interferes with this process, for instance by means of transcranial-TMS stimulation, understanding of language is jeopardized. On the other hand, language allows us to fix and relive specific aspects of our bodily experience, by crystallizing and reliving experiences that are not topical, but become a paradigm, a model, for understanding others and us. The faculty of language is therefore, on one side, rooted in corporeity but, in turn, it changes and shapes our way of living bodily experiences.

I would like briefly to discuss the hypothetical role of embodied simulation as a way of accomplishing *paradigmatic knowledge,* in the light of the Aristotelian notion of *paradeigma* (Aristotle, 1981, 1992; for a lengthier formulation of this hypothesis, see Gallese 2013, Gallese & Cuccio 2015). Only the possession of language allows us to hypostatize and then relive segments of our experiences independently of the immediate physical context, or independently of specific physical stimuli. Because of language we can speak of natural kinds like human beings without referring in particular to any of the single individuals sharing the property of belonging to the human species. Language provides us with general meaning, valid for everybody but, at the same time, belonging to nobody.

According to Giorgio Agamben (2008) what holds "for everybody and nobody" is referable to the Greek notion of *paradeigma*, originally explored by Aristotle. The *paradeigma* is a type of argumentation that moves between individuals, according to a form of bipolar analogical knowledge. Agamben (2008, 23-24), radicalizing Aristotle's theses, proposes that the paradigm can only be conceived of by abandoning the dichotomy between individual and universal: the rule does not exist before the single cases to which it is applied. The rule is nothing but its own exhibition in the single cases themselves, which thus it renders intelligible. Linguistic rules derive from the suspension of the concrete denotative application.

The hypothesis I have proposed (Gallese 2013; Gallese & Cuccio 2015) is that the notion of *paradeigma* is a good model not only for the creation of linguistic rules but also for the definition of the embodied simulation mechanism. In this connection, simulation allows us, at a sensorimotor level, to hypostatize and reuse what holds "for everybody and nobody." What is the relation between embodied simulation and *paradeigma*? The *paradeigma* is a typical form of rhetorical reasoning: argumentation based on the *paradeigma* consists of the presentation by the orator of an exemplary case, based on a historical fact or a figment of the imagination, as in the case of fables. Argumentation based on the *paradeigma* does not claim universality. One case is sufficient, provided that it is particularly suitable, precisely exemplary, in relation to the context in which the argumentative discourse takes place. What is embodied simulation if not the suspension of the "concrete" application of a process? Let us think of when MNs are activated when observing actions performed by others; or of when canonical neurons are activated while we are looking at the keyboard of a computer thinking about what we want to write; or when cortical motor neurons are activated when we imagine ourselves writing on that keyboard. These responses of motor neurons manifest the activation of implicit knowledge, bodily motor knowledge expressing the motor potentialities of our body mapped by the motor system in terms of their motor outcomes. Part of the same neural network enabling us to perform singular and specific actions also serves the purpose of applying such personal knowledge when exposed to the actions of others. The bodily-formatted representation that allows me to grasp here and now a given object in a specific way, becomes a 'template' for grasping to map others' grasping actions. Reuse of motor knowledge, in the absence of the movement that realizes it as exemplified by embodied simulation is an example of "paradigmatic knowledge." According to the present hypothesis, embodied simulation allows us to naturalize the notion of paradigm, anchoring it at a level of sub-personal description, whose neural correlates we can study.

A further distinguishing feature of the *paradeigma* suggesting interesting links to embodied simulation consists of the fact that according to Aristotle it always proceeds from what is "best known and first for us" (Aristotle, 1981, Analytica posteriora II.19), or from what is for us most immediate and most easily accessible, because it is part of our baggage of experiences and knowledge. At a different level of analysis, all of these features also apply to ES. A condition for the simulation mechanism to be enacted by the observer is sharing a baggage of sensorimotor experiences and knowledge with the simulated target. Embodied simulation is enacted starting from what for us is "first", i.e. what for us is known and easily accessible in terms of motor potentialities and experiences. Sharing a repertoire of practices, experiences and sensations is therefore an essential condition, since only by starting from what is well known to us is it possible to identify analogies between our actions and others'. We understand the other starting from our own bodily experience, which is what is "best known and first for us", again using Aristotle's words. On the basis of this knowledge we identify similar elements in our experiences as well as in those of others. Our experiences are therefore the measure from which we understand others and their experiences. Embodied simulation underpinning our experience is also a *paradeigma* from which we can understand what we observe in others and draw inferences from it for others and for ourselves (Gallese & Cuccio 2015).

Conclusions

In this article I proposed a multimodal notion of visual perception, linking it to motor cognition. I discussed embodied simulation as a functional mechanism potentially capable of unifying several forms of neural reuse, serving several aspects of our cognitive life. By means of embodied simulation a new understanding of intersubjectivity can benefit from a bottom-up study and characterization of the non-propositional and non-meta-representational aspects of social cognition (see Gallese, 2003, 2007b).

I also proposed that embodied simulation seems to be able to naturalize the notion of paradigm, one of the features making language reflexivity possible, thus contributing to "create" the human. The display of the rule, the paradigm, exhibited in each individual case of actual occurrence, no matter if its display occurs when the action is performed, observed, or imagined, accomplishes its ruling role because of preexisting biological norms and constraints, which make it possible. Being a subject entails being a body that learns to express itself and to express its world thanks to the paradigm – embodied simulation – that allows one to go beyond the body while remaining anchored to it. Our openness to the world is constituted and made possible by a motor system predisposing and allowing us to adapt our daily and contingent pragmatic relationships with the world against the background of a prefigured but highly flexible plan of motor intentionality. Such a plan provides its coordination to any single contingent modality of relation with the world, in which it continues to actualize itself. Functional processes like embodied simulation, which are not uniquely human, likely scaffold specific aspects of human social cognition.

Summary

Observing the world is a more complex enterprise than the mere activation of the 'visual brain', because it implies a multimodal notion of vision. Neuroscientific evidence from non-human primates and humans is summarized and discussed, with particular emphasis on space, objects, actions, emotions and sensation. It is argued that vision also encompasses the activation of motor, somatosensory and limbic parts of the brain, within the broader notion of the intrinsic pragmatic nature of our relations with the world. This empirical evidence will be used to discuss the notion of embodied simulation, here proposed as a new model of visual perception and cognition and potentially capable of showing how to link language to our bodily nature.
Keywords: Action, cognition, embodied simulation, mirror neurons, multimodal integration, perception.

Zusammenfassung

Das Beobachten der Welt ist ein komplexeres Unternehmen als die bloße Aktivierung des „visuellen Gehirns", weil es einen multimodalen Begriff von Sehen einschließt. Neurowissenschaftliche Forschungsnachweise von nicht-menschlichen Primaten und von Menschen werden zusammengefasst und, mit einem besonderen Schwerpunkt auf Raum, Gegenstände, Handlungen, Emotionen und Sinneswahrnehmung, besprochen. Es wird behauptet, dass Sehen – innerhalb der breiteren Auffassung von der wesenhaft pragmatischen Beschaffenheit unserer Beziehungen zur Welt - auch die Aktivierung der motorischen, der somato-sensorischen und limbischen Teile des Gehirns umfasst. Auf Basis dieser empirischen Belege wird der Begriff der verkörperten Nachahmung erörtert, der hier als neues Modell der visuellen Wahrnehmung und Erkennung vorgestellt wird und der potentiell in der Lage ist zu zeigen, wie Sprache mit unserer Körperlichkeit verknüpft werden kann.

Schlüsselwörter: Handlung, Erkennung, verkörperte Simulation, Spiegelneuronen, multimodale Integration, Wahrnehmung.

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Vittorio Gallese is full Professor of Physiology at the Dept. of Neuroscience of the University of Parma, Adjunct Senior Research Scholar at the Dept. of Art History and Archeology, Columbia University, New York, USA and Professor in Experimental Aesthetics at the Institute of Philosophy of the University of London, U.K. Neuroscientist, among his main scientific contributions is the discovery of mirror neurons together with his colleagues in Parma, and the proposal of a new model of perception and intersubjectivity: embodied simulation theory. He is the author of more than 230 scientific articles published in international journals and books, the author of two books and editor of a further three.
Address: Dept. of Neuroscience, University of Parma, Via Volturno 39, 43121 Parma, Italy.
E-mail: vittorio.gallese@unipr.it