Grasping affordance: a window onto social cognition

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Introduction

Although perception and action have been widely investigated on the assumption that they can be completely accounted for by focusing on single individuals, several cognitive neuroscientists, experimental and developmental psychologists and philosophers have recently argued for the need to take a social perspective on perceptual, motor and cognitive activities. Indeed, over the last few years more and more theoretical and empirical papers have been devoted to find out the neural and cognitive processes underpinning basic social phenomena such as joint attention (Campbell, 2002; Eilan, 2005; Heal, 2005; Tomasello & Haberl, 2003) and joint action (Carpenter, 2009; Knoblich & Jordan, 2002, 2003; Pacherie, 2010; Tollefsen, 2005; Tomasello *et al.*, 2005) in development as well as in everyday adult life.

The discovery of mirror neurons has shown that the very same cortical substrates are activated when actions are both executed and perceived in others (for a review see Rizzolatti & Sinigaglia, 2008, 2010). This indicates that a neurally instantiated mechanism for coupling action and perception mediates our capacity to share motor goals and motor intentions with others (Gallese, 2006; Sinigaglia, 2009). Progress has been made by researchers in investigating the different levels of real-time social interactions by studying how mechanisms of sharing attention and action might subserve joint attention and action (Knoblich & Sebanz, 2008; Pacherie & Dokic, 2006; Shepherd *et al.*, 2009) and how these low-level sensori-motor mechanisms might contribute together with higher-level processes (including memory and mindreading) to shape our ability to attend and act jointly in sophisticated and flexible ways (Sebanz *et al.*, 2006).

However, little research has directly explored whether and to what extent sharing and joining attention and action could shape the perception of target objects as well as whether and to what extend object perception in social contexts, far from being a private business of single perceivers, it could tell us something about the mechanisms underlying the primary ways in which we interact with others. It is often forgotten that most of our attempts to join attention and action are object-related. It has been shown that the affective evaluation of objects can be influenced by the fact that the objects are jointly attended (Bayliss *et al.*, 2006) or that they are looked at by someone else with a happy or a disgusted expression (Bayliss *et al.*, 2007). But, beyond the preferences for some object or other, how, if at all, does our perception of objects change in a social context, at least at the basic level? Is it the case that the possibility for other individuals to act on an object modifies the way in which that object is given to us, starting from its affording features? How, if at all, do objectual affordances change in a given situation when they appear to be potential target of an action performed by another agent? And to what extent can such change shed light on the basic mechanisms of social engagement?

Our paper aims to tackle these questions by investigating how a social context might shape the perception of objectual affordances. There are four sections to come. In the first one we will move from a preliminary definition of the notion of affordance, as a relation between the features of a situation and the abilities of an individual, to look into the mechanisms that make a situation supporting or even demanding a given action. It is worth noting that in discussing affordance we will deal almost exclusively with basic abilities such as those related to grasping or manipulating objects. In the second section we will show that the graspability of an object can be modulated not only by the features of the situated object and the motor abilities of an individual but also by the

spatial relationship between the former and the latter. In particular, we will demonstrate that an object may be given as really graspable only when it falls within the actual reaching space of the individual. Put differently, the individuals' reaching space seems to be an enabling condition for the affordance relation, at least at the basic level.

The first two sections will look at affordance from the "solipsistic" perspective of a single, isolated individual. Nevertheless they will allow us to find out the motor format that is common to the affordance relation both when the affording objectual feature is close to an individual and when it appears to be ready-to-hand to someone else. Indeed, in the third section we will show that the grasping-like affordance relation is dependent not only on one's own actual reaching space but also on the reaching space of another individual. In other words, objects may be given as really graspable when they are actually reachable not only by a single individual, but also by any other potential co-actor. In the last section we will go into the theoretical implications of these findings. We will argue that the varying range of object graspability can be construed in terms of a space mirror mechanism that allows the observer to match the surrounding space of others with her own action space. Like the mirror mechanism for action, the space mirror mechanism is motor in nature. However, differently from the mirror mechanism for action, which mandatorily requires the observation of another individual actually performing a given motor act, the space mirror mechanism can be triggered by the sight of a potential actor, that is, of a living body embedded in a situation that supports or even demands a given set of motor acts.

Finally, we will conclude by suggesting that such a mirror mechanism not only helps us refining the notion of affordance but also provides us with a plausible and unitary account of the crucial building blocks for basic social interactions, shedding new light on the processes that ground our primary identification with others and our connectedness to them.

Looking for (a definition of) affordance

To get going, it will help to have before us a preliminary definition of affordance. As is well known, it is to Gibson (1979) that we owe the first explicit theory of affordance. According to Gibson, affordances are properties of the environment providing the observer with practical opportunities which she is able to perceive and use. Because of their pointing "both ways, to the environment and to the observer", affordances should not be construed in terms of just objective or subjective properties, nor should they be considered as purely physical or psychical in nature, since they cut across any dichotomy of this kind (Gibson 1979: 129).

Post-Gibson attempts to highlight what kind of properties affordances are have mainly assumed that affordances are dispositional properties of the environment that must be complemented by some dispositional properties (e.g. effectivities) of individuals (Michaels *et al.*, 2001; Shaw *et al.*, 1982; Turvey, 1992; Turvey *et al.*, 1981). More recently, however, Chemero (2001, 2003, 2009) has convincingly argued that affordances are not properties of the environment, even if relative to the observer, since they are not best conceived as properties at all; rather they are relations between the features of a situation and the abilities of an individual.

The reason to distinguish between properties and features is that to perceive a property of an object one must identify the object as such and know that this object has that property. On the contrary, to perceive an affordance, "there is no need to know anything about any particular entity" (Chemero 2009: 140). All that is necessary is the ability to perceive "that the situation as a whole has a certain feature, that the situation as a whole supports (perhaps demands) a certain kind of action" (Chemero 2009: 140). Likewise, as far as individual abilities are concerned, they cannot be construed in terms of dispositional properties: "There is something inherently normative about ability: individuals with abilities are supposed to behave in a particular way, and they may fail to do so. Dispositions, on the other hand, never fail; they simply are or not in the appropriate circumstances to become manifest" (Chemero 2003: 189). Last but not least, abilities are not only interconnected, but also hierarchically organized, given that all other abilities depend on more basic abilities, that is, in ultimate analysis, on primary motor abilities, and "no ability will be exercisable in situations in which a more basic ability on which it depends cannot be exercised" (Chemero 2003: 194).

According to the corresponding motor abilities, basic affordances may be subdivided into two main categories: grasping-like or micro-affordances (Ellis & Tucker, 2000), that is, the affordance relations where the situated features typically suggest or demand action involving object-centered interactions (e.g. hand- or mouth-grasping, manipulating, tearing, pulling, pressing, biting, kicking etc.), and walking-like or macro-affordances, that is, the affordances where the situated features suggest or demand action (e.g. walking, climbing, jumping, going up, going down, etc.) requiring motor abilities in locomotion or navigation. In the following we will focus on the first kind of basic affordances. It is not that there aren't enough studies on affordances of the second kind, starting from the classical Warren's (Warren, 1984) experiments on stair-climbing affordances. On the contrary, many have been the works on the subject and numerous the advances achieved (e.g. Creem-Regehr *et al.*, 2004; Witt *et al.*, 2004). However, for the purposes of our paper, it is the micro-affordances that turn out to be more relevant. As we will see, the specific situation features as well as the motor abilities they may suggest allow us not only to refine the notion of affordance but also to demonstrate how our primary ways of interacting with the surrounding world might highlight our basic forms of engagement with others.

Let us have a closer look at micro-affordance. Most empirical findings obtained with very different techniques appear to be in line with their relational nature. There are a number of behavioral studies demonstrating that the sight of something graspable immediately retrieves the appropriate set of hand-action possibilities, even in absence of both any effective interaction and also any intention to act (Craighero *et al.*, 1999). In particular, it has been shown that task-irrelevant object information (e.g. the left-right orientation of the handle of a mug) may facilitate the execution of left-right hand motor acts when the orientation of the affording part of the object (e.g. handle) is spatially aligned with the responding hand (Ellis & Tucker, 2000; Tucker & Ellis, 1998, 2001, 2004). An analogous compatibility effect between object orientation and motor act execution has been found by Phillips and Ward (2002). They presented participants with a visual manipulable object prime oriented towards or away from participants, or in a neutral position. The prime was followed by an imperative target requiring a response with the left or right hand, or a foot press. The results showed that seeing the oriented object handles facilitates the corresponding lateralized motor responses.

Neurophysiological and neuroimaging studies have provided these behavioral data with a neuronal counterpart, showing that specific parieto-frontal circuits are devoted to encoding the observed situation features in terms of one or more action potentialities both in monkeys and in humans. Perceiving affordance, in neurophysiological terms, implies that the same neurons must be able not only to encode the motor acts (e.g. hand-grasping) they control, but also to respond to the situated visual features supporting or even demanding those motor acts. Now, single cell recordings from the ventral premotor cortex (area F5) have shown the existence of a special class of visuo-motor neurons, namely *canonical neurons*. These neurons respond to the visual presentation of objects of different size and shape, even when the monkey was just fixating them without being required to grasp them (Jeannerod *et al.*, 1995; Murata *et al.*, 1997; Raos *et al.*, 2006; Rizzolatti *et al.*, 1988; Rizzolatti & Craighero, 2004; Umilta *et al.*, 2007). Very often, a strict congruence has been observed between the type of grip coded by a given neuron and the size and shape effective in triggering its visual response (Sakata *et al.*, 1995).

Similar results have been found in humans. An early PET study (Grafton *et al.*, 1997) showed that the observation of manipulable objects activated the left premotor cortex even in the absence of any motor output. Further fMRI studies demonstrated that observing graspable objects activates the left premotor cortex and the inferior parietal lobule (Chao & Martin, 2000) and that the degree of activation of this fronto-parietal circuit during the execution of a given hand grip co-varies with the hand grip afforded by the object features (Grezes *et al.*, 2003). More recently, Buccino et al. (Buccino *et al.*, 2009) adopted a TMS paradigm to investigate the excitability of the primary motor cortex while observing manipulable familiar objects, e.g. a mug. Interestingly enough, the handle of the objects could be broken, thus lessening the corresponding affordance. Their results showed that MEPs were larger only when the handle was complete, thus suggesting that the cortical motor system is critically involved not only in the detailed programming and on-line control at the level of elementary movements, but also in the processing of the features of the surrounding objects that enables us to perceive them in terms of actual possibilities for action, that is, as effectively graspable or not.

Taken together, these findings clearly indicate that the possibility for a situation feature to evoke a grasping-like motor behavior relies on the possibility of a sensori-motor coupling allowing any onlooker to map such a feature onto the motor possibilities belonging to her own motor repertoire. This holds both at the neural and at the behavioral level. All this, though, should not give rise to misunderstandings. Maintaining that micro-affordances are relations between features of situations and individual abilities which, as such, depend on the presence of a potential actor, and that affordance perception is by nature linked to and brought to the motor repertoire of such an actor, by no means amounts to reducing affordances to mere subjective projections onto the world. On the contrary, it is about acknowledging the real character of affordances, that is, acknowledging that they are part of the world we experience, and that their experience is nothing but one of the primary ways of our interactions with the surrounding environment.

Ready-to-hand: the space of affordance

Up to this point, we have considered the status and characteristics of the *relata* involved in the affordance relation. But what about the relation *per se*? Is it the case that a given situated feature

together with the corresponding motor ability are necessary and sufficient conditions for there to be something like an affordance relation?

Imagine you are before a mug on an otherwise empty table. According to the relational notion of affordance, it doesn't really matter whether what is in front of you is your favorite mug, or even just a mug. You don't need to recognize an object as such or to individuate its specific properties in order to experience a given feature of the situation as suggesting or even demanding a certain kind of action. In order that this may happen, it is enough for you to perceive that there is something graspable, with your hand (or your mouth), with a specific grip and not a different one, etc. It is about an immediate perception, which depends as much on the features of the situation as on your motor abilities – among which, at least from five months' age onwards, there certainly is grasping.

So far, so good. Or at least so it seems, given that it is natural to ask whether affordances of this kind depend just on the appropriateness of the motor abilities with respect to the features of the situation. In the case of our example, the question arises as to whether the graspability of what is before you (e.g. the handle of the mug, its upper part, the central body, etc.) depends uniquely on the situation (mug layout, handle orientation, the mug being empty or full, etc.) and on your ability to grasp, or whether, instead, it requires something more; that is, whether, for instance, for there to be something graspable and for it to be given to you as such, it is necessary for it to be and to be given to you as reachable.

In an elegant series of experiments Proffitt and colleagues have shown that the judgment of distance with respect to a given object varies according to the action capabilities of the individual. In particular, Witt et al. (2005) asked participants to estimate distances to targets as they did or did not hold a tool, with or without the purpose of reaching them. The targets were presented at the same distances in all the conditions. However, the perceived distances were lower when participants not only held the tool but also had the intention to use it in order to reach the presented targets. More recently, Linkenauger et al. (2009) investigated whether and to what extent the perceived distances may be scaled by the difficulty required to pick up an object. Participants were presented with tools with handle orientations that could either facilitate or impede to grasp with their dominant and non dominant hands. The results showed that right-handed (but not left-handed) participants estimated tools that were more difficult to grasp to be farther than tools that were easier to pick up. According to the authors, these findings "support the notion that the perception of spatial layout is action specific and is scaled by the body's abilities to perform intended actions" (Linkenauger *et al.* 2009: 1660).

If the perception of the distance with respect to a graspable target may be modulated by the easiness with which it can be grasped, what does it happen to the affordance relation when one manipulates the possibility for an agent to reach the objectual features that may evoke a given action such as a grasping action? In the above-mentioned experiments, Witt et al. (2005) manipulated the reachability by providing the participants with a tool allowing them to get to objects being otherwise beyond their reach. But Witt and colleagues were only interested in the effects that such manipulation could have on distance perception. However, if affordances have to be construed in terms of relations between features of a whole situation and individuals' abilities, and if what individuals "typically perceive is the affordance relation, and not the constituent *relata*"

(Chemero 2009: 147), it remains an open question, whether the affordance relation is always instantiated whenever the constituent *relata* appear to be mutually appropriate, or whether it depends on something else, on a further relation that is not constitutive of the affordance but makes it possible. In the case of micro-affordances, the question arises to as whether they are always instantiated by the existence of something graspable and the presence of a potential actor who is able to perceive it and to use it, or whether they are modulated by the possibility for the graspable features to be actually reached by the actor.

In order to assess whether and to what extent micro-affordances could be space-dependent, we used the paradigm of spatial alignment effect (Costantini *et al.*, 2010). This effect refers to a decrease of reaction times when the subject executes a motor act, which is congruent with that afforded by a seen object (Bub & Masson, 2010). We used three-dimensional (3D) stimuli which allowed us to give the participants the illusions of objects being located in the peripersonal space or in the extrapersonal space. Participants were instructed to replicate a grasping movement as soon as a task irrelevant go-signal appeared. The go signal was a 3D scene in which a mug, placed on a table, had the handle oriented toward the left or right, thus being congruent or incongruent with the executed grasping action.

In a first experiment the mug was located either within the observer's peripersonal (30 cm) or extrapersonal space (150 cm) (see figure 1a). The results showed that the spatial alignment effect occurred only when the mug was presented within the observer's peripersonal space.

Peripersonal space is usually defined as the space that encompasses the objects within reach – in contrast to the extrapersonal space that is described as the space including objects which are beyond our immediate reach and that one can get close to enough only by locomotion. According to this definition, the peripersonal space can be construed in two different ways, by putting the emphasis either on the nearness of the object, that is, on its mere distance from the agent, or on the reachability of the object, that is, on its really being ready-to-hand, respectively.

Please insert Fig 1 near here

The results from our first experiment did not allow us to disentangle these two notions of peripersonal space. Thus, to investigate whether the space-dependence of the affordance relation is just matter of distance or whether it has to do with the actual readiness-to-hand of the affording feature, we carried out a second experiment in which we divided the surrounding space of the participants in both a reachable and non-reachable sub-space by presenting the task irrelevant handled mug in front or beyond a near transparent panel, respectively (see figure 1b). The results showed that the spatial alignment effect occurred only when the mug was presented within the reaching space, that is, when the mug was literally ready-to-hand.

In a further series of experiments we used Transcranial Magnetic Stimulation (Cardellicchio *et al.*, forthcoming). We stimulated from the left primary motor cortex and we recorded motor evoked potentials (MEPs) from the right First Dorsal Interosseus (FDI) and Opponens Pollicis (OP) while participants observed a 3D room with a table and a mug placed on it. Like in the behavioral

experiments, objects were located either in the peripersonal or in the extra-personal space. We found that, when the presented object was located within the participants' peripersonal space, MEPs were higher in amplitude than when the very same object was presented outside the participants' peripersonal space.

Overall, our findings suggest that, at least for the micro-affordances, the relation of affordance depends on a further relation between its *relata*, that is, a spatial relation which is not constitutive of the distinctiveness of the affordance, but makes it possible. In order for something to be graspable with respect to an individual endowed with the appropriate motor abilities, it has to fall within her own peripersonal space – better, it has to be ready to her own hand.

It could be argued that such a spatial relation should be construed as a part of the situation features affording a grasping action. After all, the individual with suitable motor abilities is part of the situation as a whole. Why should this not be true also for the spatial relation between the individual and the surrounding things? Now, there is no doubt that the nearness of the affording feature to the individual is relative to the situation as a whole. However, this is not enough to consider that the spatial relation is but a feature of the situation among others. Indeed, one has to distinguish between the situation features which may suggest or even demand specific motor actions (such as grasping, manipulating, kicking, etc.) and the individual's peripersonal space that, as such, enables the situation features to evoke her own actions. The peripersonal space is relational in nature by definition. The above spatial relation shouldn't be construed in terms of a mere distance; rather, as our data also suggested, it refers to the readiness-to-hand of everything that is immediately reachable for an individual. Like the micro-affordances, such a readiness-to-hand is rooted in the individual's own motor repertoire and its extent depends on the extent of the individual's motor abilities.

All of this appears to be consistent with the notion that the peripersonal space evolved primarily to subserve action (Rizzolatti *et al.*, 1997). Indeed, converging evidence from monkey and human studies demonstrates that the defining property of peripersonal space consists in its action-relatedness. A detailed analysis of these studies is far beyond the scope of our paper. Nevertheless, it is worth mentioning here that single cell recordings from the premotor cortex (area F4) (Fogassi *et al.*, 1992; Gentilucci *et al.*, 1988; Graziano *et al.*, 1994) and the inferior parietal lobule (VIP area) (Colby *et al.*, 1993; Duhamel *et al.*, 1998) of the macaque brain have shown that the peripersonal space is mostly encoded by bimodal visuo-tactile neurons, whose visual receptive fields (vRFs) are in register with the corresponding tactile receptive fields, being anchored to various body parts (Graziano *et al.*, 1997).

Most of the F4 bimodal neurons have been demonstrated to discharge in association with arm reaching movements (Gentilucci *et al.*, 1988), thus suggesting that they are encoding the surrounding space in a motor format as a reaching space. As for the bimodal visuo-tactile parietal neurons, it has been shown that their vRFs of can be modified by tool actions (Iriki *et al.*, 1996; Ishibashi *et al.*, 2000). After few minutes of tool-using the vRFs located on the paw extended to encompass the tool, as if the latter was incorporated into the former. When the monkey stopped using the tool the vRFs returned to their previous extension, even if the animal continued to hold it.

Analogous results have been found in healthy (Maravita *et al.*, 2002; Serino *et al.*, 2007) and brain damaged humans. Line-bisection studies on patients with selective neglect for the hemi-space

close to (or far from) their body indicate that tool use might reduce or increase the neglect according to the status of the line to be bisected (reachable or out-of-reach) in relation to tool use (Ackroyd *et al.*, 2002; Berti & Frassinetti, 2000; Neppi-Mòdona *et al.*, 2007; Pegna *et al.*, 2001). A dynamical space re-mapping has been also found in patients with visuo-tactile extinction selectively confined to the space close to one hand. Several studies showed that the severity of the extinction can be modified by tool use, which extends the reach of hand actions (Farnè *et al.*, 2005; Farnè & Ladavas, 2000; Maravita *et al.*, 2001).

Ready both to your and to my hands: sharing affordance

We have so far been considering the relation of affordance by tacitly assuming that it pertains to the features of a situation and the abilities of a single individual. Of course, given a certain feature, all the individuals with the suitable motor abilities may become part of the corresponding affordance relation. But the question is whether the affordance relation might involve more than one individual at the same time, requiring a specific relation between them, or whether it has to be thought as it has been generally thought, that is, as a "private business" of a single individual with her own surrounding world, regardless of the presence of other potential co-actors. This question becomes particularly relevant in the light of our above-reviewed data on the spatial constraint of the micro-affordances. We act upon objects in a surrounding world inhabited not only by inanimate things but also by other living and acting bodies. Is the space for action of others somehow related to our own space? And if this is the case, what does it imply for the affordance relation and its perception?

There is evidence in non-human primates and humans that the observation of an action performed by another individual evokes in the observer's brain a motor activation similar to that endogenously generated during her own planning and execution of that action. Single cell recordings from the ventral premotor cortex (area F5) (Gallese *et al.*, 1996; Rizzolatti *et al.*, 1996) and the inferior parietal lobule (areas PF/PFG) (Fogassi *et al.*, 2005; Gallese *et al.*, 2002; Nelissen *et al.*, 2005; Rochat *et al.*, 2010; Rozzi *et al.*, 2008) of macaque monkeys revealed the existence of a set of motor neurons (*mirror neurons*) discharging both during the execution and the observation of goal-directed movements. The relevance of these findings stems from the fact that, for the first time, a neural mechanism directly matching action perception and action execution has been identified. Several studies demonstrated that the mirror mechanism goes far beyond the mere kinematic features of movement, since it occurs at the level of the motor goal-relatedness shared by the actively executed, seen (Umilta *et al.*, 2001) or heard (Kohler *et al.*, 2002) motor acts of someone else, even when these motor acts involve tool use requiring a different or even opposite sequence of movements (Rochat *et al.*, 2010; Umilta *et al.*, 2007).

The results of fMRI (Buccino *et al.*, 2001; Gazzola *et al.*, 2007a; Gazzola *et al.*, 2007b) and TMS (Cattaneo *et al.*, 2009) studies on humans showing that the activation of the mirror mechanism is modulated by the goal of the observed motor act regardless of the movements required to accomplish it are quite consistent. In particular, it has been shown that the mirror mechanism can be activated during the observation of grasping actions performed by human hand, a robot hand and a tool (Peeters *et al.*, 2009). Moreover, in humans the mirror mechanism can generalize motor goals also– like in the monkey– when relying on action sounds through the auditory channel (Gazzola *et*

al., 2006; Lewis *et al.*, 2005). A similar functional property was also revealed in congenitally blind patients (Ricciardi *et al.*, 2009).

Very recently it has been shown that the activation of the mirror mechanism might be differentially modulated by the location in space of the observed action, selectively responding to stimuli presented within either the observer's peripersonal or extrapersonal space. Indeed, Caggiano et al. (2009) recorded F5 mirror neurons both when the monkey was executing hand goal-directed motor acts (e.g. grasping) and when it was observing an experimenter performing the same motor acts in its own peripersonal and extrapersonal space. More than half of the tested F5 mirror neurons exhibited a selectivity for the monkey's peripersonal or extrapersonal space, while the remaining mirror neurons responded to the visual presentation of actions independently of their spatial location. In a further experiment, the visual responses of F5 mirror neurons to motor acts performed within the monkey's peripersonal space were measured as the frontal panel of the primate chair was closed, thus preventing the animal from reaching for anything close to its body. The result showed that about half of the space-selective F5 mirror neurons tested change their tuning after the closure of the panel: mirror neurons selective for the extrapersonal space started to discharge also when the observed action was performed close to the monkey but outside of its reach, while mirror neurons selective for the peripersonal space displayed an opposite pattern of discharge, ceasing to respond to the near actions once the frontal panel was closed. According to the authors, this indicates that space-sensitive mirror neurons may be sensitive to the peripersonal space as a reaching space and not to its purely metric, because it "changes its properties according to the possibility that the monkey will act" (Caggiano *et al.*, 2009: 404).

Even more interestingly for our purposes, single cell recordings have recently demonstrated that there are bimodal neurons located in the ventral intraparietal area (VIP) that respond not only to tactile or visual stimuli delivered within the peripersonal space of the monkey but also to visual stimuli presented within the peripersonal space of another individual facing it (Ishida *et al.*, 2009). The visual stimuli were presented at four spatial locations: (1) within 30 cm of the monkey's body surface (peripersonal space of monkey); (2) 30–60 cm; (3) 60–90 cm; and (4) 90–120 cm from the monkey's body surface. The position of the visual stimulus was modified slowly from 120 cm to 10 cm in front of the monkey and retraced again. In a further condition, an experimenter faced the monkey sitting in a chair at a constant distance of 120 cm: he was presented with a moving stick or waved is hand close to his own body parts. Most of the recorded visuo-tactile neurons typically exhibited visual RFs in register with the tactile ones and anchored on a single body part (face, forearm, hand, trunk, leg, etc.). They selectively respond to the visual stimuli delivered within the peripersonal space of the monkey close to the corresponding body part. However, a significant portion of VIP bimodal neurons exhibited both visuo-tactile RFs on the monkey's body and visual RFs close to the experimenter's body, selectively discharging when a visual stimulus was delivered at 120 cm from the monkey's body parts but close to the corresponding experimenter's body parts. When visual stimuli were presented at the same distance from the monkey but in the absence of the experimenter, the responses were weak or disappeared altogether. It is worth noting that some of these bimodal neurons exhibited significantly strong responses only within a space of about 30 cm from each body, but not in between these regions (60-90 cm), and "this strongly suggests that neurons coded only the peripersonal space of the monkey and the experimenter" (Ishida *et al.,* 2009).

These findings point not only to the possible space-dependence of the mirror mechanism for action, but also to the existence of a mirror mechanism mapping the peripersonal space of others onto the observer's own peripersonal space, at least in the visuo-tactile domain. With regard to the latter, it might follow that such a mapping does exist in the motor domain as well. In addition, like the peripersonal space in our previous studies carried out on single individuals (Costantini *et al.,* 2010), it could be at the basis of the relation of affordance in a social context. In other words: is the space constraint of the micro-affordances always directly and uniquely relative to one's own peripersonal space or might it be mediated by the peripersonal space of another individual?

To tackle this issue and to assess whether and to what extent the peripersonal space of others might really influence one's own space and action, we have further extended our previous studies by introducing an actor in the visual scene and investigating whether objectual features being outside the peripersonal space of the participants but within the peripersonal space of the actor might afford actions as measured by the spatial alignment effect (Costantini *et al.*, Submitted). As in the previous behavioral study, participants were asked to replicate a seen grasping motor act, with either their right or the left hand, on presentation of a task irrelevant go signal represented by a 3D scene with a mug placed on a table with its handle oriented towards the right or the left, thus being congruent or not with the executed grasping movements. The mug could be located either within the peripersonal (30 cm) or extrapersonal (150 cm) space of the participants. Differently from the previous study, however, in half of the trials an avatar was seated on a chair at the table, while in the other half a virtual non corporeal object (a cylinder) with the same volume as the avatar was "seated" on the chair (see figure 2).

Please insert Fig 2 near here

In agreement with our previous study we found that the spatial alignment effect occurs when the presented object falls within the peripersonal space of the participants. However, in this study we have further expanded this result by showing that the presence of a potential co-actor allows for a remapping of one's own peripersonal space, making an out of reach object literally ready-to-hand. Indeed, we found that the spatial alignment occurred also when the object was located outside the peripersonal space of the participants, but provided that it fell within the peripersonal space of the avatar. No spatial alignment effect was observed when the object was far from the participants but close to the virtual cylinder.

All of this suggests that the space constraint of the micro-affordances should not be construed only as relative to one's own peripersonal space, because the affordance relation can be mediated by the peripersonal space of another individual. According to our data, the situation features may evoke a motor behavior to the observer even when they are outside her own reaching space provided that they fall within the peripersonal space of a potential co-actor. Our proposal is that the extension of the space constraint of the affordance relation from an individual to another one is likely to be due to a space mirror mechanism that allows the individual to match others' surrounding space with her own peripersonal space, thus mapping others' action potentialities onto her own motor abilities. This seems to be consistent with the fact that, in the virtual cylinder

condition, the out of reach situation features did not evoke any action in the participants because of the lack of any potential co-actor who could reach and in case use them.

Possibly one may argue that the occurrence of the spatial alignment effect when the object was located in the surrounding space of the avatar could be induced merely by gaze-object relations rather than by a mirror based remapping of the avatar's peripersonal space onto the participants' own peripersonal space. Indeed, it has been shown that both observing an actor grasping an object and simply observing her facing it does recruit the sensory-motor system of the onlooker (Becchio *et al.*, 2008; Pierno *et al.*, 2006). Thus, the fact that in our experiment the avatar always faced the object could be construed as both a necessary and a sufficient condition for the recruitment of the participants' motor activation producing the space alignment effect.

To disentangle the mirror based space remapping from the effect of mere gaze-object relations we ran a second experiment. Like in the previous study (Costantini *et al.,* Submitted), we divided the surrounding space of the avatar in both a reachable and a non-reachable sub-space by presenting the task irrelevant handled mug in front or beyond a near transparent panel, respectively (see figure 2). We found that the spatial alignment effect occurred only when the affording object was actually reachable for the avatar, that is, when it was actually ready-at-hand. It is important to note that the panel was almost transparent, not preventing the sight of the object. This suggests that gaze-object relation, although being necessary, it is not sufficient *per se* for space remapping to occur.

Mirroring space

The above-reviewed studies are still at an early stage and of course require new experiments to be further corroborated. Nevertheless, they seem to be both empirically and theoretically relevant for two fields of research that have been classically considered as unrelated one to another, but that actually are strictly intertwined: affordance theory and social cognition.

As for the theory of affordance, our findings reveal that micro-affordances are space constrained, given that the affordance relation depends not only on the appropriateness of its *relata* (i.e. situation features and individual's abilities) but also on their spatial relationship. In other words, if the affordance relation requires that the right conditions be met, these conditions do not pertain only to the presence of a given feature and to the possible existence of an individual with the appropriate motor abilities, but also (and above all) to the readiness-to-hand of that feature to the individual. It could be argued that such a space constraint is somehow involved in the notion of affordance itself, especially in the case of micro-affordances, so that our data would be but further empirically supporting something already well known. Indeed, there is a great consensus on the fact that the reachability of something around us has to be construed as a preliminary condition of its graspability both at personal and sub-personal level (Jeannerod *et al.*, 1995; Rizzolatti & Sinigaglia, 2008).

There is no doubt on this point. However, the space constraint of the affordance relation turns out to be not so theoretically trivial as soon as one considers what is going on when more than one individual is engaged with the affording features of the situation. At issue here is not just the

mere possibility that more than one individual can become part of the affordance relation. The latter requires the possible existence of *at least* an individual with suitable motor abilities. Thus, the presence of more than one individual does not anyway represent a real challenge to the notion of affordance. Things are different, however, if the presence of more than one individual on the agent-side of the affordance relation impact on the power of objectual features to afford a motor behavior, thus forcing using to refine the conditions for affordances.

Indeed, according to our data (Costantini *et al.*, Submitted), the presence of a potential co-actor – even in the case in which she is a virtual one, like our avatar – does not simply imply an increase of the member on the agent-side of the affordance relation, but actually it may change the nature and range of the relation itself. The features of the situation may suggest an action to us if we are endowed with the appropriate motor abilities, provided that those features are ready to our hands. However, this space constraint does not only pertain to individuals embedded in their own situations alone, but also to individuals involved in a situation together with other potential co-actors. In this case, situation features that cannot be part of an affordance relation with a given individual, because they do not appear to be ready to her own hands, may still become part of that relation when there is at least a potential co-actor on the scene who is able to meet the right spatial conditions. What our findings suggest is that the situation features may afford our motor abilities either *directly*, when they fall within our own peripersonal space, thus resulting to be ready to our own hands, or *indirectly*, that is, by means of others, when the features fall within their own peripersonal space, thus resulting to be ready both to their own hands and *through* them also to our own hands.

Our being part of an affordance relation can therefore be mediated by the possibility for someone else to be part of that relation, and of course *vice versa*. This does not involve a mere proliferation of affordance relations. Rather, it indicates that this kind of relation can be much more articulated than previously thought. Indeed, our being part of an affordance relation can be mediated by others' being part of that relation. According to our proposal, such a mediation could be accounted for by the activation of a mirror space mechanism triggered by other living bodies embedded in situations that support or even demand a given set of motor acts. This mechanism allows us to match the surrounding space of other bodies with our own peripersonal space, thus mapping action potentialities of other bodies onto our own motor repertoire.

The mirror mechanism for the peripersonal space not only helps us refining the notion of affordance but also provides us with an action and perception matching mechanism shedding new light on the cognitive processes that ground our primary ways to interact with others. With regard to the latter, we have already mentioned the single cell recordings carried out by Ishida et al. (Ishida *et al.*, 2009) providing evidence for the existence in the macaque's brain of a mirror mechanism that allows the animal to map stimuli delivered within the peripersonal space of an experimenter onto its own peripersonal space – where this mapping was occurring in the visuo-tactile domain only. It is worth noting here that earlier neuropsychological (Sirigu *et al.*, 1991) and behavioral studies (Maravita *et al.*, 2002; Reed & Farah, 1995) showed that a visuo-tactile mapping mechanism can also be found in humans, at least at the level of bodily (or personal) space.

More recently, (Thomas *et al.*, 2006) have used a cueing paradigm to investigate the putative role of this mechanism in the processing of sensory events on one's own body or on other's body.

Cues were brief flashes of light at one of several locations on the other's body, while the target was a tactile stimulus delivered at either the same anatomical location on the participant's body as the preceding visual cue on the model (congruent) or a different location (incongruent). The results showed a significant congruency effect for anatomical body position, as participants were faster at detecting tactile stimuli on their own body when a visual stimulus was delivered at the same location on the body of another individual. Crucially, this effect was body-specific, not occurring when visual cues were delivered at a non-body object (e.g. an house). According to the authors, these findings suggest that the visual-tactile mechanism critical for mapping one's own bodily space might also be used for mapping the bodily space of others, thus providing an interpersonal bodily space representation that may be "a basic precursor" to "theory of mind" (Thomas *et al.,* 2006).

What do our data really add to these findings? First of all they extend to the peripersonal space what Thomas et al. (2006) have found for the bodily space, providing Ishida et al (2009) discovery of a mirror mechanism for space with a behavioral counterpart in humans. Second, and even more interestingly, our data extend to the motor domain what Thomas et al. (2006) and Ishida et al. (2009) have found in the visuo-tactile domain only.

The relevance of this point can be hardly overestimated. By claiming that the mirror mechanism for the peripersonal space has to be construed as primarily motor in nature we don't mean that this mechanism mandatorily requires the observation of an executed action to be triggered. Quite the opposite. Our study clearly indicates that there is no need for the participants to be witnessing of an action performed by someone else in order to map the surrounding space of another individual onto their own peripersonal space. The space mirror mechanism is motor in nature because of the motor and action-dependent nature of peripersonal space itself. Most of the above-reviewed studies on peripersonal space demonstrated that its range co-varies with the range of our motor actions, and our experiments show that this is true also for the peripersonal space of others, as it is only the actually reachable space of others that is mapped onto our own peripersonal space, that is, only the space which embraces what is really ready-to-their-own-hands.

Given the motor nature of the space mirror mechanism, what might its function (if any) be in social cognition? One way to answer this question may be to compare the mirror mechanism for the peripersonal space with the mirror mechanism for action.

It has been argued that, by directly matching the observed actions performed by others with the observer's own executable actions, the mirror mechanism enables her to immediately understand their motor behavior (Rizzolatti *et al.*, 2001; Rizzolatti & Sinigaglia, 2008). Observing an action performed by another individual evokes a motor activation in the observer's brain that is alike to that which occurs during the planning and effective execution of that action. The difference is that while in the latter case the motor activation becomes an overt action, in the former it remains at the stage of a potential action. Given that the sensory-motor direct matching proper to the mirror mechanism goes far beyond the mere kinematic features of movement, occurring at the level of motor goals and motor intentions, the mirror-based activation of a potential action allows the observer to share the motor goal-relatedness of that action with the agent. In virtue of this kind of sharing, the observer may understand the other's action *from the inside* as her own motor possibility and not just *from the outside* as an external event, which can be at most the target of a mere sensory experience (Rizzolatti & Sinigaglia, 2010).

Like the mirror mechanism for action, the mirror mechanism for the peripersonal space does not appear to be sensitive to the kinematics, being its range essentially action dependent. However, differently from the mirror mechanism for action, the mirror mechanism for the peripersonal space does not mandatorily require the observation of another individual actually performing a given action. It can be triggered just by the sight of a situated body potentially interacting with the surrounding things. Non-corporeal objects, embedded in the same situation, with same distance to the same surrounding things do not determine any space mirror activation. Thus, what the mirror mechanism for the peripersonal space actually matches is the space around the observed situated body with the observer's reachable space, that is, the space encompassing everything is really ready-to-her-own-hands.

The question arises as to what such a peripersonal space matching is for. Our proposal is that the mirror mechanism for the peripersonal space allows one to grasp another body as a living and acting body, as a body of an agent to whom the features of the situation may suggest or even demand a given motor action. In other words, it allows one to grasp another body as a set of motor potentialities that are actually ready-to-hand, whose range and effectiveness are dependent on and strictly intertwined with their own reachable space. Below and before the effective execution of an action by another individual, the mirror mechanism for the peripersonal space unveils the space of actions that are really possible for that individual given a certain situation, providing the observer with an immediate pre-comprehension of the effective realm of her own agency as well as of what she could be really do.

If all of this is right, the mirror mechanism for the peripersonal space appears to bridge the gap between the motor-based affordance perception and the mirror-based action understanding, playing a key role in understanding *from the inside* what another individual is really doing. Indeed, there is no doubt that the motor information relative to the various affording features of a situation may be critical for understanding others' motor actions, and even others' motor intentions (Fogassi *et al.,* 2005; Iacoboni *et al.,* 2005). And it is also true that it is only by means of the activation of the mirror mechanism for action that what the other is really doing can be understood as one's own motor possibility. To the best of our knowledge, however, though it is generally accepted that both mechanisms might be involved in others' action processing, it still is unclear how they are related one to another, especially how affordance perception might be capitalized by the mirror-based action understanding. According to our proposal, the mirror mechanism for the peripersonal space provides us with the space of the motor possibilities of others that are really ready-to-their-own-hands, thus making the information about the affording features of the situation actually useful for a preliminary understanding of what others could do given that situation. It is on this preliminary understanding that the mirror-based action understanding will take place, by identifying the kind of action another individual is really doing among all the motor possibilities belonging to the her own action space.

Concluding remarks

In this paper we aimed to show how the theoretical and empirical investigation of the affordance relation might provide us with a window onto the basic cognitive processes underlying the primary ways of social cognition. At first glance, it might seem rather odd to attempt to get insight into

social cognition by considering the relation of affordance with respect to its necessary and sufficient conditions. There is no doubt that taking paths which are little or not at all explored is often a guarantee of failure. Sometimes, though, by doing so one may happen to come across new and unexpected facts, which somehow force use to rethink some key notions that are normally taken for granted.

This seems to be case for the space constraint of the affordance relation. Indeed, our findings forced us to refine the classical notion of affordance, by highlighting that, at least at the basic level, the affordance may depend on the spatial relationship between the features of the situation and all the actors who could be involved in that situation. To this regard, it is worth noting that the fact that more than one individual might be involved in the same situation does not only imply the presence of more than one member on the agent-side of the affordance relation, but also (and above all) the reshaping of the nature and the range of the relation itself. What our experiments show is that the features of a situation may suggest or even demand a given action to us either *directly*, when they fall within our own peripersonal space, thus resulting to be ready to our own hands, or *indirectly*, when they fall within the peripersonal space of other individuals, thus resulting to be ready both to their own hands and *through* them also to our own hands.

Paradoxical as it may seem, the spatial constraint does not at all reduce the range of the affordance relation– if anything, it extends its applicability domain by means of a mirror mechanism which allows us to match the surrounding space of others with our own peripersonal space, thus mapping action potentialities of others onto our own motor repertoire. What is more, the fact that the affordance relation is not a private business of a single individual, but it relies on a mirror mechanism that allows one to share the space of her own action with others, highlights that the investigation of affordance mandatorily involves dealing with the cognitive processes underlying basic social cognition.

In this regard, it has been proposed that a "purely *sensory* mirror system […] would match perceptual events across bodies for sensory stimuli, in absence of observed or executed motor action", thus giving origin to an "interpersonal body representation" that "may reflect a first step towards the human ability to track the specific, detailed contents of other minds" (Thomas *et al.*, 2006: 327, 328). Without meaning to deny the relevance of a such mirror-based sensory mapping occurring at the level of bodily (personal) space, our data shows that a mirror-based mapping might occur also at the level of the peripersonal space, further, our data shows that this mapping is not purely sensory but motor in nature. This does not mean that the mirror mechanism for the peripersonal space requires the observation of an executed action to be activated. Quite the contrary. It can be triggered just by the sight of a situated body potentially interacting with the surrounding things. However, because of its motor format, the mirror mechanism for the peripersonal space allows one not only to localize the sensory stimuli around the body of others, but also (and above all) to grasp their body in terms of a set of motor potentialities.

Gallese and Sinigaglia (2010) have recently argued that our body is "primarily given to us as 'source' or 'power' for action, i.e., as the variety of motor potentialities" defining the horizon of the surrounding world in which we live (Gallese & Sinigaglia 2010: 746). Our findings suggest that not only our body but also the body of others is primarily experienced as a variety of motor potentialities, defining the horizon of the surrounding world in which they live. Like our own body,

the body of others is given to us as a situated body – as a body embedded in its own space which encompasses all the affording features, that is, all the motor potentialities that are effectively ready-to-hand.

In conclusion, by matching the surrounding space of the body of others with the action space of our own body, the space mirror mechanism provides us with an immediate pre-comprehension of their own body as an acting body as well as the effective range of their bodily agency. Such pre-comprehension appears to play a critical role in action understanding, at least at the basic level of the motor-based action and intention understanding, thus allowing to highlight the very first steps in our making sense of others as well as in our sharing a common world with them.

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Captions:

Fig 1: Exemplar of stimuli used in Costantini et al (2010)

Fig 2: Exemplar of stimuli used in Costantini et al (submitted)
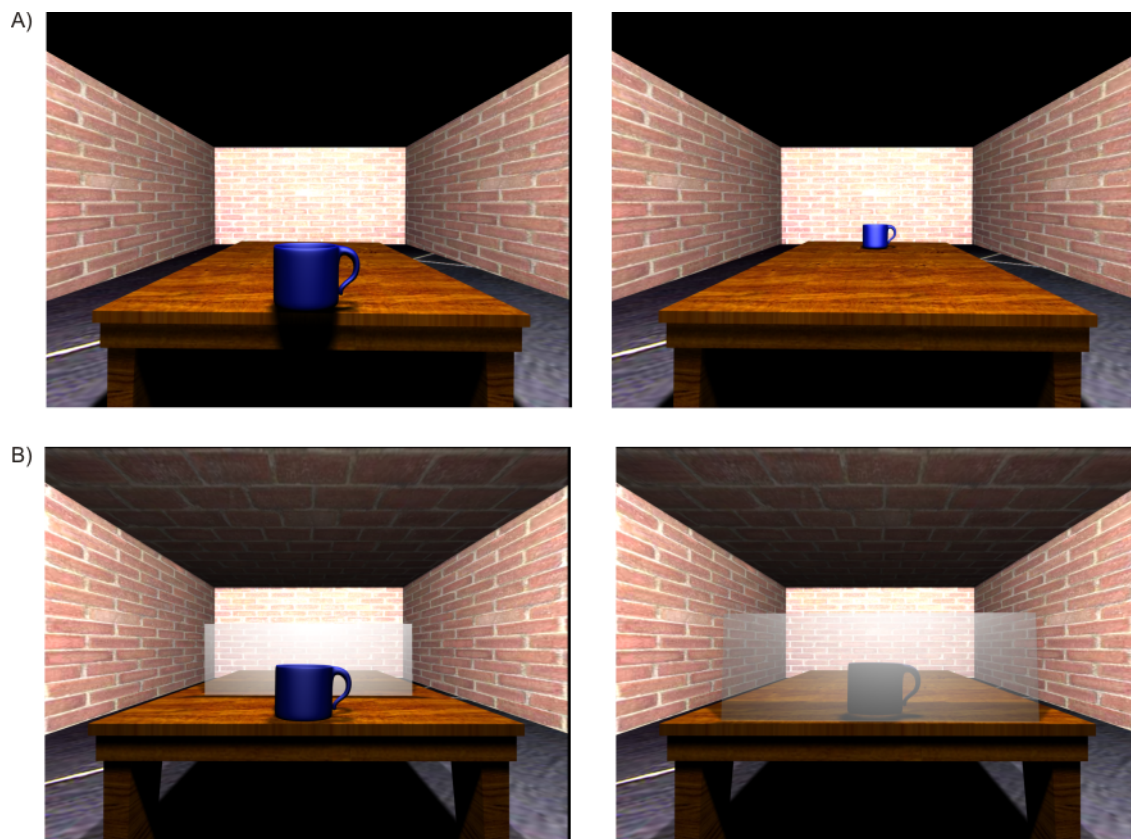
Fig. 1

A)

B)

Fig. 2