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INVESTIGATING THE RELATION BETWEEN OBJECT AFFORDANCES, SPATIAL COMPATIBILITY AND HUMAN-ROBOT INTERACTION

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Introduction

In their everyday life, humans interact with a multitude of objects. The ability to interact properly is made possible by their knowledge of the object properties and how they must be manipulated in order to implement actions consistent with the person's will. Gibson (1979) coined the term affordance, understood as the instrumental property of the environment that allows the individual to know how to act. In the first theorization of the term by Gibson, we find his definition: *"The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill. The verb to afford is found in the dictionary, the noun affordance is not. I have made it up. I mean by it something that refers to both the environment and the animal in a way that no existing term does. It implies the complementarity of the animal and the environment."* (Gibson, 1979, p. 127). According to this theory, the individual is immersed in an environment that gives him information on how to act. The term affordance was then evolved and refined until the definition of the term "micro affordance" by Ellis and Tucker (2000). Micro affordances point to the implications of the motor system when perceiving an object. In fact, according to this definition there would be internal representations that mediate the perception of the object and a direct association between vision and action, where the perception of objects is not only related to the semantic knowledge of their characteristics. The association of vision and action would evoke representations of an action when you see a specific object, this activation would also depend on the intentions of the individual. The authors came to this theorization after a multitude of experimental observations where subjects were faster in recognizing an object orientation when its handle was in the same position as the response. However, there is still no unilateral agreement on the effects observed by Tucker and Ellis, and many studies tend to see spatial compatibility effects toward the functional part of an object as governed by spatial encoding mechanisms, and are therefore not necessarily related to motor components regarding the actions that are potentially achievable with the object being observed.

Many studies have shown that it is not easy to dissociate spatial encoding effects from spatial compatibility effects related to the affordances of an object.

Examples of criticisms to the affordance theory used to explain these phenomena stem from Cho and Proctor ‘s (2010) studies, in which the authors have shown how the compatibility effect found by Tucker and Ellis is primarily due to spatial encoding and not to the motor intentions of the subjects. In their studies they have shown how the response mode does not affect the spatial encoding effects, as a result there is no link between object affordance and motor system.

The objection often raised by the affordance critics concerns the fact that the stimuli used in the experiments are usually asymmetric and, given this asymmetry, what is being observed is a spatial encoding effect.

In the experiments presented in the second chapter of this work, we will try to clarify whether the affordance effects can be attributed to the activation of objects affordance or they are due to a generic spatial encoding effect.

Many studies have shown how the visual perception of an object is influenced by it being seen when manipulated by another individual. The influence of the presence of another person manipulating the object is understood as a proof of the activation of a motor simulation mechanism related to actions that can be accomplished with the object. The presence of such mechanisms demonstrates that the objects are perceived according to their functional properties and are linked to motor mechanisms, so that object encoding does not only concern aspects related to spatial perception, but to our own and other people's motor intentions. In the third chapter of this work we have made three experiments to evaluate how the vision of hands approaching an object can be used to clarify whether the effects usually observed are due to the spatial encoding of the stimuli or to objects affordance.

Chapter 4 lists the results of an experiment that aims at clarifying the mechanisms involving the affordance of pairs of objects and the perception of motor intentions in robotic agents.

Experimental evidence has shown how the presentation context modulates the affordance effects. E.g., presenting an object together with another object, with which complementary actions can be made, makes it easier to recognize the pair of objects. Even in this case there seem to be links between the observer's visual perception and their motor system. There is a strong preference for the active object of the pair, the one with which more refined movements are performed, and that is used on the passive object. Even in the case of objects shown in pairs, the literature shows evidences that the performance of those recognition tasks is modulated by the presentation of other individuals manipulating the objects. (Laverick, Wulff, Honisch, Chua, Wing & Rotshtein,2015).

It has been proposed (Gallese & Sinigaglia, 2011) that individuals are able to understand the intentions of other individuals by means of motor simulation mechanisms. During the observation of another individual acting, it is possible to understand the outcome of the actions, and therefore their intentions. This happens because we can represent internally the movements we are observing, and thus understand what will happen shortly thereafter. These motor simulation mechanisms are easily explained during the interaction between human beings, but it has to be clarified how a human being perceives and internalizes the intentions of a robotic agent. In fact, while we can easily recognize ourselves in another human being because of having similar body features, with the same biological motor constraints; it is unclear how the actions of a robot and consequently its intentions can be perceived automatically. To clarify the underlying mechanisms of a possible human-machine interaction we have investigated to what extent two robotic hands are perceived, and their influence on motor simulation mechanisms involving pairs of objects that can be used together. In our experiment we asked the subjects to classify pairs of objects semantically, by manipulating the pair composition and position of the objects to suggest a possible action for the experimental subjects. Prior to the presentation of the experimental stimuli we presented human hands and robotic hands images to evaluate the effects that these may have on the perception of the objects presented afterwards. Our hypothesis is that, if the humans show mechanisms of motor simulation with robotic hands, then it is possible that similar interactions to those typically found among human beings occur during the interaction with a robotic agent.

Chapter 1: How the human brain perceives objects, space and other agents

1.1 Affordances

James Jerome Gibson, in 1979, was the first psychologist who introduced the term "affordance" to describe the possible actions that the environment offers to animals, suggesting that we can perceive the world as opportunities for action. The physical properties of the object (such as, shape, orientation, size and so on) determine the object affordances, and the action capabilities of the agent shape them. For example, a cup affords a two-hand power grip for a child, while the same cup only affords a one-hand grip to an adult. Furthermore, the perception of affordance is influenced by the action context in which an object is presented. Seeing a spoon next to a cup affords a stirring action; while a spoon next to a bowl will afford an eating action. Earlier researches show that the presence of a hand interacting with an object triggers or primes possible actions (e.g., Kumar, Riddoch, & Humphreys, 2013; Kumar, Yoon, & Humphreys, 2012).

As a consequence, the concept of affordance given by Gibson can be extended up to include the presence of a hand as an additional affordance cue to afford a corresponding motor response.

Gibson, always in 1979, suggested the idea that affordances are comprehended directly without the requirement to interact with the object – thus proposing a direct link between perception and action. Consequently, the physical properties of the object itself, i.e. its affordance, automatically create a motor response, even in the case of no-necessity of motor response. The mean used for measuring the affordance is stimulus-response compatibility paradigms (Michaels, 1988). In this case people view graspable objects, e.g. cups, and they must make fast responses to the properties of objects (for example, the vertical orientation of an object). Compatibility effects, as index of the affordance perception, are observed especially when the task-irrelevant orientation of a graspable object, as the previously mentioned cups for example, matches the response hand.

In a 1998 seminal research, Tucker and Ellis presented pictures of graspable objects with the object handle pointing towards the left or the right. Participants had to determine, by pressing left-right keys, if the object was upright or inverted. Results showed that responses were faster when they were compatible with the task-irrelevant orientation of the object's handle (e.g., the handle pointed to the right). This result was taken as an indication that a motor response was automatically activated by the position of the task-irrelevant handles. Afterwards, Tucker and Ellis (2000) coined the term micro-affordances to define these effects, however, in the next chapters of this thesis we will only use the term affordance to designate these effects.

Symes, Ellis and Tucker (2007) declared that the task-irrelevant orientation of an object, rather than its visually salient area, was at the basis of the observed affordance effect. To support these theses, the authors used artificial graspable 3D cylinders, oriented to either the left or to the right. It is important to underline that these objects had not been previously linked with any action procedure. The participants had to make semantic decisions about the texture of the object pressing either the left or the right button. When the object orientation corresponded to the response hand, responses were significantly faster. Interestingly, this effect was independent of whether attention was clued to the nearest or farthest visually salient area of the cylinder. Symes et al. argued that the observed compatibility effect reflects affordances rather than attentional processing of the most salient or behaviorally relevant feature of an object. Several other studies have demonstrated that affordance compatibility effects may occur even when the object itself is task-irrelevant (e.g., responding to an imperative target superimposed on an object (Phillips & Ward, 2002; Xu, Humphreys, & Heinke, 2015), or regardless of which part of the object is attended by the participant (Vainio, Ellis, & Tucker, 2007).

The results reported above are consistent with the view according to which affordance effects are evoked automatically, even when irrelevant to the task. Starting from these studies, converging evidence has shown that the observation of graspable objects automatically activates action representations in corresponding motor areas, even in cases where no hand response actually needs to be made (Di Pellegrino, Rafal, & Tipper, 2005; Grafton, Fadiga, Arbib, & Rizzolatti, 1997; Grezes, Tucker, Armony, Ellis, & Passingham, 2003; Phillips & Ward, 2002; Riddoch, Humphreys, Edwards, Baker, & Willson, 2003; Tucker & Ellis, 1998;). However, recent evidence has cast doubt on the automatic perception of affordance as suggested by Gibson (Borghi & Riggio, 2015; Thill, Caligiore, Borghi, Ziemke, & Baldassarre, 2013;van Elk, van Schie, & Bekkering, 2014). Instead, there is growing evidence that affordance effects are sensitive to the task and the context. For example, affordance compatibility effects were absent when participants had to make color decisions (Pellicano, Iani, Borghi, Rubichi, & Nicoletti, 2010; Tipper, Paul, & Hayes, 2006). Tipper et al. (2006) suggested that the occurrence of compatibility effects require attention to be directed toward action-relevant object properties such as object orientation or size, while attention to action-unrelated features acts against the activation of affordance-related responses (Vainio et al., 2007).

Affordance perception is also influenced by contextual factors such as the location of the object in space (e.g., Costantini, Ambrosini, Tieri, Sinigaglia, & Committeri, 2010), the ownership of the object (Constable, Kritikos, & Bayliss, 2011), the presence of another person (Cardellicchio, Sinigaglia, & Costantini, 2013), the presence of other objects (Borghi, Flumini, Natraj, & Wheaton, 2012), and contextual information about the action such as the presentation of a congruent or incongruent hand grip approaching an object (Yoon & Humphreys, 2005). Taken together, the reviewed studies indicate that affordance perception is not automatic per se; while affordances may be influenced by the task and contextual information.

It has been suggested that tools bias attention based on the visual asymmetry created by the position of the handle, and this attentional capture towards the handle, the most salient part of an object, generates the motor response (Anderson et al., 2002; see also Cho & Proctor, 2010). In particular, the handle of a tool rather than its functional end seems to bias visual attention (Matheson et al., 2014; Roberts & Humphreys, 2011). Using electroencephalography (EEG), Matheson, Newman, Satel and Mcmullen.(2014) showed that the handle of a tool triggered an early visual attentional response in the extra striate visual cortex, and argued that this early response is presumably elicited before a motor response when motor-related areas are activated (Goslin, Dixon, Fischer, Cangelosi, & Ellis, 2012).

A somewhat different approach to investigate attentional capture by tools comes from Handy and colleagues (Handy, Grafton, Shrof Ketay & Cazzaniga , 2003; Handy & Tipper, 2007). In their EEG study (Handy et al., 2003); the participants had to respond, by pressing a button, to a target superimposed over a graspable or a non-graspable tool. The authors found early visual attentional response (using event related potentials) to task-irrelevant tools compared to non-tools when presented in the right visual field (i.e., the appropriate location for action). Handy et al. (2003) concluded that tools capture attention and argued for right visual field dominance in visual motor processing.

Further support for attentional capture by tools comes from neuropsychological studies with patients suffering from visual extinction. Visual extinction is a neuropsychological attention disorder impairs the recognition of multiple items in the environment. Patients frequently fail to detect a contralesional stimulus when an ipsilesional stimulus appears simultaneously, but they are able to detect a single contralesional stimulus when presented alone (Driver & Vuilleumier, 2001; Karnath, 1988). Di Pellegrino Rafal and Tipper (2005) presented cups with different handle orientations to parietal patients with visual extinction after right parietal brain damage. Patients reported the contralesional cup more often when the handle afforded a left-hand rather than a right-hand grasp. The authors proposed that action-relevant object features automatically capture visual attention by activating corresponding motor representations. Hence, patients with parietal lesions are unable to perceive object affordances in the environment.

A link between affordance and attention can be also observed with pairs of objects affording a mutual action. Presenting single objects in an action relationship next to another object, for example a cup and a teapot, modulates affordance, extending the notion of affordance beyond effects offered by single objects.

1.2 Affordances and spatial compatibility

Some actions are afforded by specific objects (Gibson, 1979) and they are determined both by the object shape and the actor's physical abilities. The actor has the possibility to choose from a repertoire of a multitude of actions (Warren, 1988), e.g., if the actor has both hands occupied by a cumbersome object, he/she can open a door with the elbow in a simple way.

Supporters of the object affordance view have extended this concept to key press response tasks involving pictures of real objects (Tucker & Ellis, 1998). Tucker and Ellis (1998) were the first to use this kind of task. Specifically, they showed participants with photographs of objects with a graspable part oriented to the left or to the right (i.e. a frying pan with the handle pointing to the left). Participants were asked to respond if the object orientation was upright or inverted, by pressing one of two buttons with the right or left index finger.. They found that responses were faster when they were compatible with the position of the object's handle. Specifically, right responses were faster when the graspable part of the object pointed to the right as compared to when it pointed to the left. The observation of a compatibility effect between the response and the handle of the object depicted in the photo was attributed to the action-related properties of the object automatically evoking the action most suited to interact with it. However, as pointed out by the same authors, the observed effect could also be due to the activation of a spatially defined response code based on the coding of the object's handle. In other words, the effect could be interpreted as a Simon effect based on stimulus-response compatibility.

In stimulus-response compatibility paradigm, the participants give faster responses based on one of the stimulus features. The SRC effect refers to a relative advantage of some mapping between stimulus and response (Alluisi & Warm, 1990). In the simplest case, a stimulus-response compatibility effect can be obtained by assigning left responses to left stimuli, and right responses to right stimuli. In this case, neither of these answers would be favored, but both would be in the optimal position. As for the stimulus-response compatibility is not so much the absolute position that matters more, but the relative one (Umiltà & Nicoletti, 1990). In the stimulus-response compatibility effect, it is more important the stimuli location than the position of the effectors used to respond. Congruent mappings remain faster even in conditions in which a subject responds with their hands crossed (Anzola, Bertoloni, Butchtel & Rizzolatti, 1977). One of the most studied effects is the Simon effect. The Simon effect is similar to the stroop interference effect, except for the fact that that the overlapping between the dimension related to the stimulus and the dimension related to the response, rather than between two dimensions of the stimulus (Kornblum, 1994). A typical demonstration of the Simon effect can be obtained by asking the subjects, sitting in front of a computer monitor, to discriminate the color stimuli, which may appear red or blue, pushing a right or left button to indicate the color of the stimulus. The participants' responses are typically quicker when the stimuli appear in the half screen corresponding to the response. E.g.: if they have to respond by pressing on the right when the stimulus is red, they will be faster when the red stimulus appears to the right rather than to the left.

To test this alternative account , they ran a second experiment in which participants were required to respond using the index and middle fingers of the same hand. In this condition, no compatibility effect emerged, hence supporting their hypothesis.

However, there are a number of studies that criticize the explanation according to which the effect observed by Tucker and Ellis could be attributable to the automatic activation of motor affordances. For instance, Phillips and Ward (2002) found results that speak again the automatic nature of these effects. They showed participants with an image of a frying pan with its handle oriented to the right or to the left at various stimulus onset asynchronies (SOAs) prior to the onset of the stimulus to which they had to respond. They found a compatibility effect between the side of the response and the side of the frying pan's handle with increasing SOAs. The observation of an effect increasing with response time was interpreted as an indication that affordance effects are not automatic. In a second experiment, participants were required to respond by crossing their hands so that with the right hand they pressed the left button and vice versa. Again they found a compatibility effect between the side of the response and the side of the frying pan's handle and the effect was even larger than in Experiment 1. This result led the authors to the conclusion that the handle positioned on the left does not automatically activate a left hand response. Finally, in Experiment 3 they required participants to respond using their feet, and even in this case they found a compatibility effect. Since the effect is not attributable to the specific effector, it is not possible to affirm that affordance effects are due to the potentiation of the action most suited to interact with an object.

Cho and Proctor (2010) tested the grasping affordance and spatial coding accounts using pictures of graspable objects. The researchers asked participants to discriminate the color of the objects (e.g., a frying pan) or of the circle stimuli presented to the right or the left of the fixation point. Responses were made with the left and right index finger of each hand or with the index or middle finger of the right hand. In all cases, the effects were greater when the subjects gave responses using the index and middle finger of the same hand. Cho and Proctor (2010) study showed no evidence for the grasping affordance view.

Cho and Proctor , in their work of 2010, asked the subjects in the first experiment to perform a Simon task, using the classic red and green spots, or silhouette o frying pans which color varied from green to red. They asked their subjects to answer using both hands, or with the index and middle fingers of the same hand. The results showed that the Simon effect occurs either when the task is performed by discriminating the color of the objects or when they respond using one or two hands, excluding, according to the authors, the possibility that there is an involvement of the motor system in the activation of the affordances, and therefore it is a mere spatial codes activation. In their second experiment , they asked the subjects to discriminate if the pan handle was facing up or down, the other comparison stimuli were represented by a handle without the body of the pan, or a dashed line providing an outline in the shape of the pan handle. Also in this case they did not find significant differences in the conditions "between hand" and "within hand", confirming their hypotheses about the first experiment results , that is the existence of a "location coding account".

Pappas (2014) compared the subjects' performance on discriminating object orientation (upright vs inverted) using silhouettes or photographs depicting real object; the results showed significant effect in within and between hand condition with silhouette, and only significant effect in hand condition with pictures of real objects. Pappas concluded that there were different mechanisms underlying these two different effects: a Simon effect with silhouettes and an affordance effect with photographs.

Pellicano, Iani, Borghi, Rubichi and Nicoletti (2010) studied the affordance effect using pictures of torches oriented horizontally with a left or right graspable part. The authors varied the active and passive state of the objects showed either in an active state (the torch was switched on) or in a passive one (the torch was switched off). This object stimulus was chosen because it has two relevant portions: a graspable part that is congruent with a grasp with either the left or the right hand and a goal-directed portion, that is, the portion that is involved in executing a function,

which is spatially defined. In their first experiment they required participants to discriminate the color of the torches, whereas in their second experiment they required them to discriminate the upright vs. inverted orientation of the torches. In Experiment 1 they found a compatibility effect based on the direction of the goal-directed portion of the torch irrespective of the object's state (active or passive), while in Experiment 2 effect they found a compatibility effect based on the graspable part of the object only in the active-state condition. The authors concluded that *"these results also suggest that affordances do not appear to be automatic but, rather, seem to depend on the extent to which the task requires detailed processing of shape. Furthermore, they are selectively activated if the functional meaning of tools is made very salient"* (p. 2200).

Cho and Proctor (2013) suggested that the results from Pellicano and colleagues could be better explained by a feature asymmetry account. Specifically, they supposed that the participants may have attended to the vertical position of the strips on the torch to make the upright inverted judgments and consequently they could have coded the row of the strips as left or right. Furthermore, Song, Chen and Proctor (2014) found that the effect tended to become stronger when the handled part of the torches used by Pellicano et al. (2010) was removed. These results support the location coding account, because the removal of the handle makes the stimuli more unbalanced in left right asymmetry, and this asymmetry is even more evident when the torches are depicted in an active state. According to the affordance activation account, the removal of the handle should lead to the disappearance of affordance effects because the handle tip of an object is the main source of these effects.

1.3 Neurocognitive model of affordances

Affordances are related to theories regarding the link between perception and action. Some of the neural substrates that support the theories that involve this link are the tool network (Lewis, 2006), the action observation network (Grafton, 2009) and the mirror neuron system (Rizzolatti & Fogassi, 2014). The difference between these systems is based on the different way they focus attention on different aspects of the relation between perception and action.. The tool network focus is on the tool used by an agent, and the action needed to accomplish a proper action with the tool. Differently from the tool network, the action observation network and the mirror neuron system focus on how we observe other people's action to learn the proper use of an object and to know their intentions.

For the tool network, tools are a special category of objects (Creem-Regehr & Lee, 2005) that activates a distributed left-lateralized network composed by the premotor cortex (PMC) for the planning of tool related actions, the posterior middle temporal gyrus (pTMG) for the semantic knowledge of the tools and of their motion, and the posterior parietal cortex for the representation of tool skills (Beauchamp & Martin, 2007; Grezes & Decety, 2001; Lewis, 2006; Orban & Caruana, 2014). Creem-Regehr and Lee (2005) proposed that the activation of the dorsal and ventral visual streams is due to the fact that tools can be processed for what they are and for how the can be used

(Chao & Martin, 2000; Goodale & Milner, 1992; Johnson-Frey, 2004; Noppeney, 2008). Gibson's affordance concept (1979) relates to the automatic activation of pre-motor and parietal cortex (dorsal areas) when an individual is seeing the tools, these areas are indeed involved in reaching and grasping objects (Jeannerod, Arbib, Rizzolatti & Sakata, 1995). The dorsal motor-related activations reflect the neural correlations of Gibson's affordance concept (Orban and Caruana, 2014), while the visual properties of the tools such as, size, orientation, shape and graspabilty are responsible for the perception of affordances. These object's features are encoded by the inferior parietal lobule, IPL (Maranes, Bonini & Fogassi, 2014).

Tool Network is linked to tool use (Frey, 2007), and Binkofski and Buxbaum (2013) proposed that semantic and sensory motor representations are both involved in tool use. Left-lateralized parieto-frontal networks are both activated by viewing and using tools (Lewis, 2006). These regions, in macacque, contain mirror neurons and these neurons discharge when an action is viewed passively and when an individual performs the same goal directed action (Gallese, Fadiga, Fogassi & Rizzolatti, 1992).

The link between visual perception and the perceived potential action of a tool is automatically activated by the tool network.

Differently from the tool network, the action observation network is automatically activated during the observation of other people's action (Caspers, Zilles, Laird & Eickhoff, 2010). It is possible to consider action observation network in association with action understanding by action simulation based on mirror neuron system (Grafton, 2009). Observing another individual's action can activate simulation processes, these processes depend on the type of observed action, type of action could be different in the sense of goal directed versus body related actions. The action observation network is composed by a bilaterally distributed network including the inferior temporal gyrus (IFG) the PMC ,the superior temporal sulcus and the IPL (Grafton, 2009).

The action observation network overlaps with the areas involved in executing goal-directed actions (Grafton,2009).

Understanding other people's action is possible because of the existence of shared neural representation in the action observation network (Rizzolatti & Craighero, 2004). Somatotopic PMC and IPL are activated during the observation of goal-directed actions, and this is a simulation test that supports a direct match between action observation and action execution (Buccino et al., 2001). The activation of PMC and IPL, part of the action observation network is influenced by the motor repertoire of the observer, humans cortex are differently activated by the vision of a human vs a non-human performing an action (Buccino, Binkofski & Riggio, 2004) and also a role is played by the familiarity with a specific action . The action observation network can provide explanation on action understanding, however, for more complicated actions involving the use of tools, the activation of other areas beyond action observation network may be necessary (Grafton, 2009).

The third system mentioned earlier is the mirror neuron system. The Mirror Neuron System is the most powerful neural system explaining how humans can understand other humans' actions. Mirror neurons have been discovered in the monkeys' pre motor cortex (di Pellegrino et al., 1992; Gallese et al., 1996) and in the monkeys' anterior intraparietal area (Fogassi et. Al, 2005). Mirror neurons respond when the researcher performs a goal-directed action and the monkey performs a similar action. The mirroring mechanism that consists in a direct matching between action performance and action observation is present also in humans and it has been taken to be the neurophysiological substrate that sustain action and intention understanding (Rizzolatti, Fogassi & Gallese, 2001 ; for reviews, see Fabbri-Destro & Rizzolatti, 2008; Rizzolatti & Fogassi, 2014; Rizzolatti & Sinigaglia, 2010; Rizzolatti & Craighero, 2004; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996; Turella, Pierno, Tubaldi, & Castiello, 2009). Our brain represents an observed action in the same way it represents our own actions. This mechanism consents a map to our motor representation and other people's actions and their intentions. Studies have demonstrated that mirror neuron system are also associated with imitation learning (e.g., Rizzolatti & Craighero, 2004; Rizzolatti et al., 2001; Jeannerod, 1994). While the affordance concept is related to action perception and sensorimotor representation elicited by the observation of graspable objects, the functioning of mirror neuron system is based on the observation of other people's actions and intentions (Buccino et al., 2004; Iacoboni et al., 2005; Ortigue, Sinigaglia, Rizzolatti, & Grafton, 2010; Perry & Bentin, 2009).

Bach, Nicholson and Hudson (2014) proposed an alternative framework for action understanding and prediction, the affordance matching hypothesis. According to these authors, action understanding is based on the knowledge of the object function and on the awareness that it can be used. In this way, action understanding and action prediction are due to the ability to match predicted and observed actions. Observing a typical action made with a typical object helps detecting other people's intentions. According to Bach et al., the role of mirror neurons is to confirm a previously predicted action, mediated by canonical mirror neurons, canonical mirror neurons that are activated both by seeing an object and by actions performed by others (Bonini, Maranesi, Livi, Fogassi, & Rizzolatti, 2014; Uithol & Maranesi, 2014).

The relation between affordance and mirror neurons is still unclear and further investigation is required to clarify how different neural network interact while observing an object and imitating other people's actions (Thill et al., 2013).

1.4 Paired-object affordance effect

There is substantial evidence of a facilitation in perception and attention when an individual sees two objects that relate to the same action (cup and teapot), if compared to when they see objects that do not relate to the same action (cup and a fork) (Borghi et al., 2012; Humphreys, Wulff, Yoon, & Riddoch, 2010; Laverick et al., 2015; McNair & Harris, 2014; Riddoch et al., 2003; Roberts & Humphreys, 2011; Wulff & Humphreys, 2013; Wulff, Laverick, Humphreys, Wing, & Rotshtein, 2015 ; Yoon, Humphreys, & Riddoch, 2010;;).

Riddoch, Humphreys, Hickman, Clift and Colin (2006) found that recovery from visual extinction in fronto-parietal patients is possible when the object orientation between the left and the right stimulus implies a functional relation, for example a teapot and a cup facing each other, than when two objects are not facing each other. Based on this evidence, Riddoch and colleagues concluded that the affordance for action improved the extinction. It seems that action relations between objects influence visual attention in an implicit way (Riddoch et al., 2003, 2006). When there is a functional relation between objects, these objects are automatically joined together as an "action unit", and the attentional bias in visual extinction patients can be overcome because attention moves from the ipsilateral side of the lesion to the location of the two objects. When two objects are linked by a functional relation, the pair is composed by an active and a passive object (Riddoch et al, 2006); the active object is the object actively used in the action and the passive one is passively held during the action. In the error trials, where patients reported only one object, patients reported only the active objects rather than the passive ones, when the passive were oriented for action, ignoring the location in space of the objects (Wulff & Humpreys, 2015, 2013).

Recovery from visual extinction occurred with unfamiliar object pairs indicating that the effect is based on action relation and not on the familiarity with the action (Riddoch et al., 2006). Humphreys et al., (2010) examined the modulation of the affordance effect with paired object by the perspective in which the object are presented and the way the objects are grasped for a proper action. The authors used photographs of objects being grasped by hand in an incongruent or congruent position. They manipulated the perspective of the person holding the object showing a first person perspective or a third person perspective. When the objects were positioned for action patients showed lesser visual extinction than when they were not. Furthermore, recovery from extinction was stronger when objects were held in the same position used premorbily by the patients. The effect was stronger when patients saw the objects from a first person perspective rather than from a third person one. The effect on perception and attention are also reported for healthy participants (e.g., Adamo & Ferber, 2009; Green & Hummel, 2006; Bach, Knoblich, Gunter, Friederici, & Prinz, 2005; McNair & Harris, 2014;

Roberts & Humphreys, 2011; Xu, Humphreis & Heike , 2015; Yoon et al., 2010). In a study by Bach,Knoblich, Gunter, Friederici, and Prinz (2005), the participants were slower making action decisions about object pairs when the objects were incorrectly collocated for action than when they were collocated correctly (Bach et al., 2005).

Some evidence of affordance effects was found using attentional blink paradigm. In attentional blink paradigm two target elements (referred to as T1 and T2) are presented within a stream of successive distracters, participants must identify both of the targets. Participants often fail to identify T2 if presented from 100 ms to 500 ms after T1. Attentional blink reflect the competition between T1 and T2 for attentional resources. When a participant attends to T1 and consolidates it into working memory he/she cannot have attentional resources for the processing of T2 (Olivers & Nieuwenhuis, 2006).

Using the attentional blink procedure to measure the allocation of visual attention (Raymond, Shapiro, & Arnell, 1992), Adamo and Ferber (2009) and McNair and Harris (2014) showed reduced attentional blink when the two objects formed a functional pair; even in this case it seems that functional relations between objects drive attentional selection. The active object role and the importance of its location emerge in several studies. It is possible to define an object as active when the object is actively used with the dominant hand during a proper action, while the passive one is the object held with the non-dominant hand. For example when we pour water in a glass we take the bottle with our dominant hand and use the non-dominant hand to hold the glass. More complex movements are made with the dominant hand and in the manipulation of active objects, while the manipulation of passive objects requires less refined movements. As in the studies with patients, also tests with healthy participants showed a preferential bias towards the active object rather than the passive one (Wulff et al., 2015; Laverick et al., 2015; Xu et al., 2015; McNair & Harris, 2014; Roberts & Humphreys, 2011; Roberts & Humphreys, 2010). Overall, performance is better when the active object is congruent with the position of the subject’s dominant hand (Laverick et al., 2015; Roberts & Humphreys, 2011 ; Xu et al., 2015; Yoon et al., 2010). This result suggests that affordance perception is modulated by hand-object compatibility. The effect of hand-object compatibility is one of the starting points of this thesis: we have manipulated object compatibility and object position to test if the activation of affordance information about the object is affected by the brief presentation of a biological and non-biological prime.

In a study participants were slower making action decisions about object pairs when the objects were incorrectly collocated for action than when they were collocated correctly (Bach et al., 2005). As in the studies with patients, also the tests with healthy participants show a preferential bias towards the active object rather than the passive one (Laverick et al., 2015; McNair & Harris, 2014; Roberts & Humphreys, 2011; Roberts & Humphreys, 2010; Wulff et al., 2015; Xu et al., 2015;). These studies showed that performance is better when the active object is congruent with the position of the subject's dominant hand (Laverick et al., 2015; Roberts & Humphreys, 2011; Xu et al., 2015; Yoon et al., 2010). In this thesis, we will use the term "paired-object affordance effect" (Yoon, Humphreys & Riddoch; 2003) to refer to this performance advantage.

According to Humphreys, Romani, Olson, Riddoch and Duncan (2016), the paired-object affordance affect might reflect two components: a visual response to the visual familiarity of the object pair and a motor response to the possibility to make an action with the object pair. The effects of action relation be due to the statistical learning of the spatial relations between objects (Humphreys & Riddoch, 2007). The co-occurrence of objects that are usually used together improve perceptual grouping and the perceptual report of the stimuli, for example in Humphreys et al., 2010 patients with spatial bias show less extinction. Extinction is reduced both in first person view and in third person view, however in the first person view affordance effect are stronger (Humphreys et al., 2010), these findings suggest that the effect aren't solely due to a visual effect but a motor based component is crucial in the object pair affordance.

Roberts and Humphreys (2010) found that visually responsive areas in the brain showed increased activity when action related objects were presented. The activity in these brain regions is typically linked to object processing (Goodale & Milner, 1992). Kumar,Yoon and Humphreys (2012) found activity over the motor cortex when participants viewed a hand grasping an object in a congruent way compared when a incongruent hand grasp was showed to the subjects. Mu rhythm activity over motor regions desynchronization was increased for congruent compared with incongruent grasp conditions (Kumar, Riddoch, Humphrey, 2013); increasing desynchronization is consistent with a motor response to the stimuli.

Overall, the results described above suggest that the perception of affordances is modulated by hand-object compatibility and object position. These two factors will be the topic of investigation of the next two chapters.

1.5 The link between affordances and human-robot interaction

Social robotics aims at designing artificial agents that can interact with people in their daily lives. In this perspective these robots should be part of human's social environment. Social acceptation of robot as partners is a fundamental milestone to realize this aim. The difference between a social robot and simple automata is in the quality of interaction. An individual in interaction with simple automata interacts with an interface to access the function supported by the automata. On the contrary, interactions with a social robot are natural interactions, similar to those with other human agents.

In human-human interaction, the individuals show an ability to interpret other humans' actions and intentions. When an individual sees someone grasping a cup, the individual does not see solely the grasping movements but also infers the action's goal. Although robots can be humanoid, their kinematics still remains different from human kinematics. However, evidence of activation of the mirror neuron system when observing robot was found (Gazzola, Rizzolatti, Wicker & Keysers, 2007).

Natural interaction is sustained by underlying mechanisms regarding social cognition in the human mind. One of the fundamentals aspects of social cognition is the understanding of other agents' actions. Humans developed mechanisms such as the theory of mind or simulate mechanisms that allow action understanding (Rizzolatti, Fogassi & Gallese, 2001). The theory of mind postulates that understanding actions is based on a higher order mechanism referenced to other people's mental states. To explain an agent's behavior, one refers to the agent's mental states such as their desires or intentions. The simulation theory (Gallese & Goldman, 1998.) argues that when an individual observes an action made by another agent, the individual automatically simulates similar actions in their own cognitive system; this simulation mechanism should allow the individual to represent the action and understand the other individual's intention. The metalizing theory can be considered more explicit and reflective, on the other hand the simulation theory can be considered more implicit and automatic (Schilbach et al., 2013).

A potential neural system supporting the simulation theory is the mirror neuron system (Gazzola, Aziz – Zadeh, & Keysers, 2006; Rizzolatti & Craighero, 2004). Mirror neurons are thought to be involved in action understanding (Umiltà et al., 2001) and action imitation (Brass, Bekkering, & Prinz ,2001; Wohlschlänger & Bekkering, 2002). The ability to internally simulate observed actions in order to infer associated action goals is believed to provide a common ground between interacting agents. In joint action is recommended to make a complementary action to achieve a common goal (Sebanz, Bekkering & Knoblich, 2006), in this case the imitation regards only the action goal and not the proper action to achieve the goal.

Understanding action goals of an agent does not mean that the observed actor is perceived as an intentional agent. The perception of an intentional agent requires a mental representation similar to the mechanism proposed by the theory of mind. There is the possibility that the simulation theory and the theory of mind are both at work in the human's brain.

In human-robot interactions imitating goals is important. Robots have a different body and the question is what human beings can imitate to understand action goals. Bekkering, Wohlschlanger and

Gattis (2000) found that humans prefer to imitate the goal of a goal-directed action rather than imitating the specific movement to achieve the goal. In their study, the authors asked participants to imitate an actor's movement as if looking in a mirror. The actor sit facing the subjects and made movements with either his left or right hand to touch his ear with a contralateral or an ipsilateral movement. Results indicated that partcipants tended to sacrifice the correct movement trajectory to achieve the correct target (the correct ear); this strategy allowed them to minimize the number of errors.

This form of imitation is referred as emulation rather than simulation. The theory of Goal Directed Imitation (GOADI, Gattis, & Bekkering, 2003) holds that imitation is based on the identification of action goals and on the organization of action goals into hierarchical structures. GOADI is verified in human-human interactions. Bao and Cujpers (2017) partially extended GOADI to human-robot interaction. The authors found that the subjects can easily imitate the movement of a robot in a similar way to how they can imitate a human, but some perplexities remain, due to the different peculiarity in human vs robot movement. Wykowska, Chellali, Al-Amin and Müller (2014) tested if observing a robot hand or a cartoon human's hands performing two types of movement, such as grasping or pointing, would elicit similar action representations in the human brain. The authors tested the difference with a perceptual task, more precisely a visual search of a target defined by either size or luminance, and a movement task of grasping and pointing. Wykowska et al. (2014) found similar results both with robot hands and human cartoon hands.

Anelli, Borghi and Nicoletti (2012) tested with a visuomotor paradigm the discrimination of biological vs non-biological hand grasping dangerous objects. The subjects of the experiment were more sensible to dangerous objects when they saw human than when they saw a robotic hand in the same condition. Results show that humans can easily embody a human hand and that there are limits in the embodiment of a robotic hand.

Some interesting observations derives from the rubber hand illusion (Botvinick & Cohen, 1998). In the rubber hand illusion, the subjects are seated in front of a table, where there is a rubber hand. On the table is positioned a mirror between the rubber hand and the subject's left hand so as to block the view of the real hand. So, the subject from his position can see the rubber hand but not his left hand. The experiment consists of two phases. At the preliminary stage the subject's left hand, which is hidden, is stimulated with a brush, and at the same time the rubber hand that is seen by the subject is stimulated with a brush.

The purpose of this preliminary phase is to induce a conflict between the visual and tactile perceptions,

to highlight if these would lead to a change of the proprioceptive perception of the subject, so that he was deluded that his arm was in a different position than its real one that is in the opposite position.

In the second phase of the experiment, to quantify the degree of modulation, the subject is prompted to slide the right hand index finger on a ruler placed on the table until it is in the same position perceived of the left hand index finger, which is always kept in the same position throughout the duration of the experiment. The data showed a localization error of the subject's arm towards the rubber hand, which increases with increasing of the preliminary stimulation. This effect refers to the ability of the human brain to incorporate a fictitious limb inside its bodily experience.

Caspar et al (2015) found a "*robotic hand illusion*" with a robotic hand, demonstrating that it is possible to instill an ownership and agency sensation using a robotic hand. Human-robot interaction will be the focus of Chapter 4 in which we will present an experiment aimed at investigating the relationship between the paired-object affordance effect and motor primes that can represent by a human or a robotic hand.

Chapter 2: Comparing affordance and response compatibility effects

2.1 Introduction

The perception of objects influences motor behavior even when an interaction with objects is not required. Studies that investigate on this interaction between perception and action relate to a stimulus-response compatibility (SRC) effects (Proctor & Vu 2006). The spatial SRC effect consists in a faster and more accurate response when there is a compatibility between stimulus and response than when stimulus and response do not correspond (Alluisi & Warm, 1990). When the spatial code for stimuli and response correspond, the response selection is faster (Proctor & Reeve, 1990).

Spatial SRC is independent from the task and is present also when the subjects must use left or right responses based on a non-spatial feature of the stimuli such as color, or shape. SRC consists in faster reaction time when the location of the stimulus matches with the correct response location, than when the two positions do not correspond; this effect is called Simon effect (Simon, 1990; Pellicano, Iani, Rubichi, et al., 2010; Proctor & Vu, 2006). The Simon effect is attributed to the activation of the spatial response code corresponding to the spatial stimulus code, due to the matching of the spatial dimensions representation of stimulus and response (Baroni, Pellicano, Lugli, Nicoletti & Proctor, 2010; Kornblum, Hasbroucq, & Osman, 1990).

Another interpretation of SRC effects was made by Michaels (1988, 1993): the interpretation of SRC effects is based on the activation of motor affordances that appear when humans interact with stimuli in a rich visual interaction context. The affordance account postulates that everyday actions are controlled by relations between an observer's action systems and the observed situation (Chemero, 2009).

Tucker and Ellis (1998) tested the affordance hypothesis employing pictures of graspable objects. The stimuli of graspable objects were presented centrally, with their graspable part on the left or on the right. Subjects had to discriminate the orientation of the object depicted (upwards vs downwards) by pressing the left or right button with their right or left index. The results clearly showed that the subjects were faster when the graspable part of the object was in correspondence with the response position (i.e. affordance compatibility effect) . It should be noted that the location of the graspable part of the object is irrelevant to the main task (discrimination between upward and downward orientation). Tucker and Ellis attributed this effect to the motor affordance evoked by the presence of the graspable part of the object.

The stimuli of Tucker and Ellis (1998) consisted in objects with a large graspable part which created an unbalanced image of the object with a more perceptual salient part in correspondence of the graspable part of the object. Tucker and Ellis run a control experiment where subjects had to respond with their right hand index and middle finger; the aim of the experiment being to determine if the effect found was attributable to an affordance effect account or to a location coding account. The results showed that with responses made by the right hand, with index and middle finger the effect wasn't present, and this result is in line with the affordance activation account. However, median Rt data showed a handle to finger compatibility effect, supporting the location account.

Tucker and Ellis (1998) proposed that the affordance derives from handle to hand compatibility, the object asymmetries generating a left-right spatial code (Goslin, Dixon, Fischer, Cangelosi, & Ellis, 2012). In this theory, the left-right code is generated by a graspable object and consists in the activation of motor patterns compatible with the handle position. Recently, the grasping affordance was defined as the action of using objects for a specific purpose with functional gestures and is distinguished from the volumetric gestures, which are generally used to pick up objects (Bub, Masson, & Cree, 2008; Mizelle, Kelly, & Wheaton, 2013).

In 2010 Cho and Proctor found results in contrast with Tucker and Ellis (1998). Participants had to perform a location-based task and an object-based Simon task. In the location-based task a circle could appear in the left or in the right of the screen while in the object based Simon task the object was a frying pan presented centrally with the handle located in the left or in the right of the screen. The participants gave responses only with their right hand using their index or middle finger (within hand condition) or with right vs left index (between hand condition) and had to discriminate the color or the upward orientation of the stimulus. In location-based tasks a Simon effect occurred for both between and within hand condition, while in the object-based task it happened only for the between hand condition. Pellicano and colleagues (Pellicano et al., 2010) have tried to clarify the difference between the affordance effect and the Simon effect using electric torches as a stimuli. The stimuli used by Pellicano and colleagues were characterized by two distinct ends, on the one hand the torches had an handle, and therefore their graspable part, on the other hand the torches showed their "goal-directed portion" (let it) that consisted of the torch lens, the part from which the beam of light comes out during the typical use of the object.

In the first experiment they asked the subjects to discriminate the color of torches that ranged from green to blue. In addition, the torches could be presented in an active state, that is, turned on, or in a passive state, that is turned off. This manipulation was chosen by the authors to disassociate the graspable part of the object from the goal-directed portion of the object. The results show that the subjects were faster when the response hand corresponded to the torch lens, that is, the salient part for the object goal, while no effect was found for the responses in which the graspable part of the object corresponded with the response side. The authors concluded that, when discrimination does not involve the use of the object, and it is also not closely linked to a functional property of the object such as color discrimination, it is likely to observe effects that may be attributed to the spatial compatibility, which is typical of the Simon effect.

In a second experiment they asked the experimental subjects to discriminate the orientation of the torches, which could be presented up or downward. In this case, discrimination was made on the basis of a series of strips placed on the torch handle.

In this experiment, the reaction times are generally shorter than those recorded in experiment 1. In addition, the authors found that the stimulus-response effect was faster when the side of the torch handle corresponded with the response side. This effect of compatibility between the response side and the handle of the object was evident in the trials in which the torches were turned on, and therefore in an active state. The authors concluded that in a task where it is necessary to process the shape of the object, and then access the its functional properties, a matching effect occurs depending on the affordances and on the possibilities to use the object, while if the task does not relate to characteristics closely related to the object function, a Simon effect occurs, as in the color discrimination of Experiment 1.

These results show how visually presented objects can trigger an internal simulation as suggested by the embodied simulation hypotheses (Jeannerod, 2007).

A criticism to Pellicano and colleagues' hypotheses comes from a study by Song, Chen and Proctor (2014). The main criticism of the authors concerns the stimuli used by Pellicano and colleagues, as the torches would not be symmetrical horizontal stimuli, and therefore the results of Pellicano and colleagues would not be attributable to the affordances of the torches but to a generic spatial encoding effect between stimulus and response.

In fact, the torches could be asymmetrical due to the presence of the handle and the strips on the body of the torch, which were to identify the orientation of the object, but at the same time caused an unbalance of the stimulus to the right or to the left, especially in the condition in which the torches were turned on. In a first experiment, the researchers replicated Pellicano and colleagues' results, using the same stimuli. In a second experiment they eliminated the torch handle and maintained the same number of strips on the torch body. In this case, Song and colleagues found a spatial stimulus-response matching effect in trial where the torch was turned on, but having removed the torch handle, the compatibility effect could not be due to the affordances of the object but it has to be considered due to the horizontal asymmetry of the stimulus. In experiment 3, the authors further modified the stimuli. In the first half of the test they showed torches with symmetrical stripes on their body, and in the other half, torches having asymmetrical stripes as in previous experiments. In this case the results clearly show that the decision of the subjects is influenced by the asymmetry of the strips on the body of the torch that create horizontal asymmetry to the right or to the left. Indeed, in tests where the stimulus had a smaller number of strips on its body, symmetrically balanced, no stimulus-response effect was found, neither toward the torch body side, nor toward the torch bulb.

In the experiments presented below, we will try to further clarify whether spatial matching effects, with objects in different functional states, are attributable to the effect of simple spatial compatibility between stimulus and response (location coding account) , or to the activation of affordance information concerning action-related motor mechanisms toward the torches.

To do this, we used the same type of torches used by Pellicano and colleagues in their first study (2010), but requesting the subjects to discriminate their size, i.e. to distinguish between longer and shorter torches, in Experiments 1 and 2. Additionally, in Experiment 3 we asked the subjects to discriminate the torches according to their size on a vertical axis, in order to evaluate whether the phenomenon also exists with discriminations not related to the horizontal axis. It is important for the study is that the stripes on the body of the torches were removed, since these are no longer essential for length discrimination and may create asymmetry in the stimulus. To evaluate the difference between affordance and Simon effects, it was decided to position the stimuli differently. In the first experiment, they were centered considering the entire image of the torch with its beam of light, while in the second experiment the stimuli were centered, taking as reference the torch body, ignoring the protrusion of the beam of light, which, in fact, creates a glimpse asymmetry in the stimulus from the opposite side to torch handle. This chapter is the result of collaboration with Dr. Antonello Pellicano PhD[1].

[1] This study was conducted in collaboration with the University of Aachen. Data for Experiment 1 were collected at the University of Aachen while data for Experiments 2 and 3 were collected at the University of Modena and Reggio Emilia.

2.2 Experiment 1

The aim of the experiment was to replicate the findings of Pellicano and colleagues (2010). The horizontal visual asymmetry within the object structure were removed according to Pellicano et al. (2010), in the passive state the object was symmetrically centered to the body midline, its goal-directed tip was more salient than the opposite graspable tip, and could generate a compatibility effect in this direction. For active state objects, a visual asymmetry was induced in the direction of the handle tip of the object. This modified version of the original stimuli can shed light on previous results and clarify if the difference in reaction times was due to affordance effect or Simon effect.

2.2.1 Participants

Thirty-six undergraduate students (24 females; mean age = 25.1 years, SD = 5.12) participated voluntarily. All reported having normal or corrected to normal vision and were naive to the purpose of the study. They were all right-handed (86.72/100, SD = 16.41) as assessed with the Edinburgh Handedness Inventory (Oldfield, 1971). The local Ethics Committee of the Medical Faculty at RWTH Aachen University, Germany approved the study. Subjects received a monetary compensation for participation.

2.2.2 Stimuli, apparatus and procedure

The experiment took place in a dimly illuminated room. Stimulus presentation, response recording, and data collection were controlled with the E-Prime 2.0 software. Participants were seated facing a 19-inch LCD monitor, screen resolution 1280 X 1024, at a viewing distance of 58 cm. The stimuli, (see Figure 1), were greyscale pictures of an electric torch, depicted in an active state (switched-on, with a light beam projected out of the bulb side) or a passive state (switched-off, no light beam), and in two different lengths (i.e. short torch and long torch). The torches were 75 mm high; for the switched-on ones, the short and the long versions were 178 mm and 210 mm wide, respectively, whereas the switched-off torches were 140 mm and 170 mm wide. The stimuli were presented in eight different configurations: functional state (active vs. passive) x horizontal orientations (handle on the left vs. handle on the right) x torch lengths (long vs. short). Stimuli were centered on the screen and in relation to the picture frame. Thus, the passive state torches were also centered in relation to their body, whereas the active state torches had their body jutting laterally from the handle side (see Figure 1). The functional state features of the stimuli were presented in two separate blocks of trials. The order of the active and passive state blocks was counterbalanced between participants. Each object occurred equally often for the different combinations of experimental conditions with a randomized order for each participant. Responses were recorded by pressing the left- or the rightmost button of a 5-button PST serial response box (http://www.pstnet.com/) with the corresponding index finger. The box was centered on the vertical midline of the screen in front of the participant. Participants were instructed to respond as fast and accurately as possible to the length of the stimuli while ignoring their horizontal orientation and their functional state. Half the participants responded with the left button to the short torch and with the right button to the long torch; for the other half the mapping was opposite. After a practice block of 16 trials, participants were presented with two experimental blocks of 200 trials each, resulting in a total of 400 trials. Each trial started with a 500 ms blank screen, followed by a 1000 ms central fixation cross (5 mm x 5 mm) and the stimulus displayed for 1000 ms at the center of the screen. A 400 Hz tone was presented for 500 ms after an error or omission occurred. No feedback was provided for correct trials.

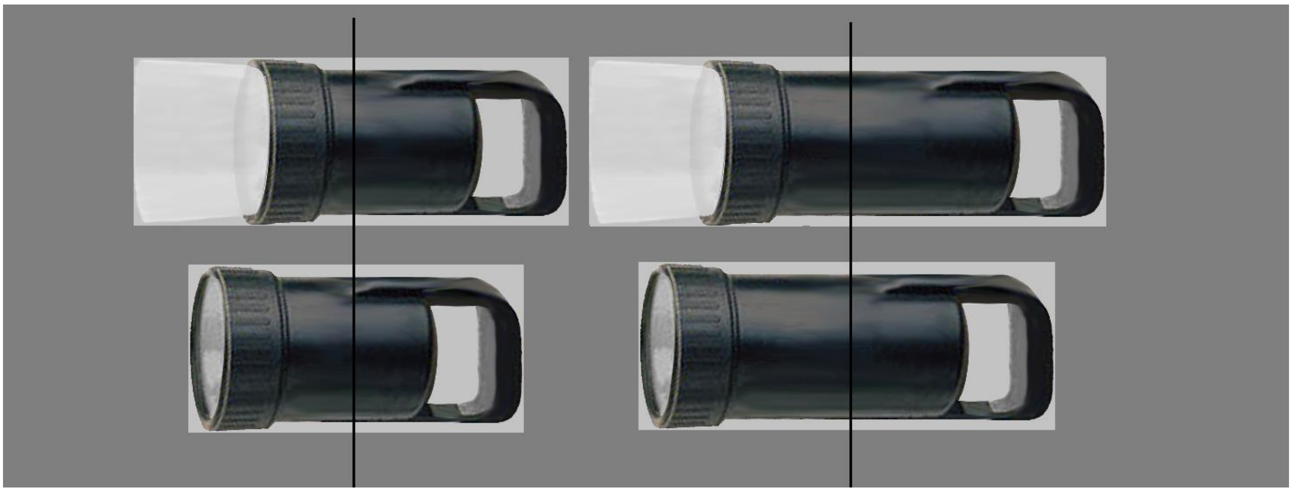

Figure 1*. Short torch switched on (top left); short torch switched off (bottom left); long torch switched on (top right); long torch switched off (bottom left). Stimuli were centred in relation to the entire image frame.*

2.2.3 Results and discussion

Omitted responses (0.40 %), RTs that were two standard deviations below (0.40 %) or above (3.97 %) each individual overall mean were excluded from the analyses, whereas errors (1.39 %) were analyzed separately. Mean correct reaction times (RTs) and arcsine-transformed error rates (ERs) were submitted to two repeated-measures ANOVAs with Functional state (active vs. passive) and Affordance Compatibility (affordance compatible vs. incompatible pairings) as within-subject factors. However, actual error percentages were reported for clarity's sake. The respective data are shown in Table 1. For the ERs, none of the factors reached significance, $F(1,35) < 1.3$. For RTs, the main effect of Functional state was significant, $F(1,35) = 32.95$, $p < .001$, $\eta^2_p = .48$ with faster performance for the passive state condition (463 ms) than for the active state condition (486 ms). The main effect of Affordance Compatibility was not significant, $F(1,35) = 0.31$, $p = .581$, $\eta^2_p = .01$ (475 vs. 474 ms for compatible and incompatible trials, respectively). However the Functional state x Affordance Compatibility interaction was significant, $F(1,35) = 12.21$, $p = .0013$, $\eta^2_p = .26$. Paired-sample t-tests showed that in the active state condition, the participants were 7 ms faster when the graspable tip and the response corresponded, compared to when they did not correspond, $t(35) = 2.22$, $p = .033$. In the passive state condition the pattern was opposite: RTs were 5 ms slower when the graspable tip of the torch corresponded to the response compared to when it did not, $t(35) = 2.189$, $p = .035$. Indeed, for the active state objects affordance compatibility between the graspable tips and the responses provided faster performance, whereas for the passive state objects performance was faster in case of compatibility between the goal-directed tips and the responses.

The results of Experiment 1 replicated those of Experiment 2 in Pellicano et al. (2010), showing a affordance compatibility effect in the active state condition. Furthermore, and differently from Pellicano et al. (2010), a significant spatial compatibility effect was observed in the passive state condition as a function of the orientation of the object's goal-directed tip. On the one hand, results were consistent with the view that in the active state condition information on the tool-use was highlighted, so that a grasping affordance was activated that favored the handle-to-hand corresponding pairings (i.e. affordance compatibility effect). On the other hand, however, in light of the fact that in the passive state condition compatibility with the opposite goal-directed tip was favored, results in both conditions are more easily explained in terms of changes in the perceptual saliency of the objects tips, in the two active/passive state conditions. In spite of the fact that the sources of horizontal visual asymmetry within the object structure were removed with respect to Pellicano et al. (2010), and that in passive state the object was symmetrically centered to the body midline, its goal-directed tip was judged as more salient than the opposite graspable tip, generating a compatibility effect in this direction. For active state objects, visual asymmetry was induced because of the handle tips left/right jutting displacement on the screen (as for the original Pellicano et al., 2010, Experiment 2). Given this asymmetry, a consequent spatial coding of stimulus orientation was produced, which ultimately generated a spatial compatibility (i.e. Simon-like) effect.

***Table 1**: Mean (Standard Deviation) of the Reaction Time (in ms) and ER (in %) for the affordance compatibility effect (handle orientation-to-response position compatible vs. incompatible pairings) in Experiment 1Note. The affordance compatibility effect is computed by subtracting reaction times (RTs) and error rates (ERs) in corresponding trials from RTs and ERs in non-corresponding trials. Asterisks denote significant differences.*

	Active state		Passive state	
	M	% ER	M	% ER
Compatible	483	1.4	465	1.5
Incompatible	490	1.5	460	1.1
Affordance Compatibility effect	7*	0.1	-5*	-0.4

2.3 Experiment 2

The aim of this experiment was to test if it is possible to observe a compatibility effect in the direction of the light bulb of the torch. Stimuli were centered in function of the body of the torch, ignoring the light bulb. This stimulus placement creates a horizontal asymmetry in the direction of the light bulb in the active state of the object.

2.3.1 Participants

Twenty undergraduate students (8 female; mean age = 20.50, SD = 2.62) participated voluntarily. All reported having normal or corrected to normal vision and were naive to the purpose of the study. They were all right-handed (94/100, SD = 9.27) assessed with the Edinburgh Handedness Inventory (Oldfield, 1971).

2.3.2 Stimuli, apparatus, and procedure

Stimuli, apparatus, and procedure in this experiment were identical to Experiment 1 but contrary to it, the stimuli were centered in relation to the body of the torch, ignoring the light beam. Thus, in the active state condition the image of the torch was unbalanced in the direction of the goal-directed tip (lens of the torch), which became the more salient part of the stimulus. In the passive state condition, instead, stimuli were symmetrically centered as for Experiment 1 (see figure 2).

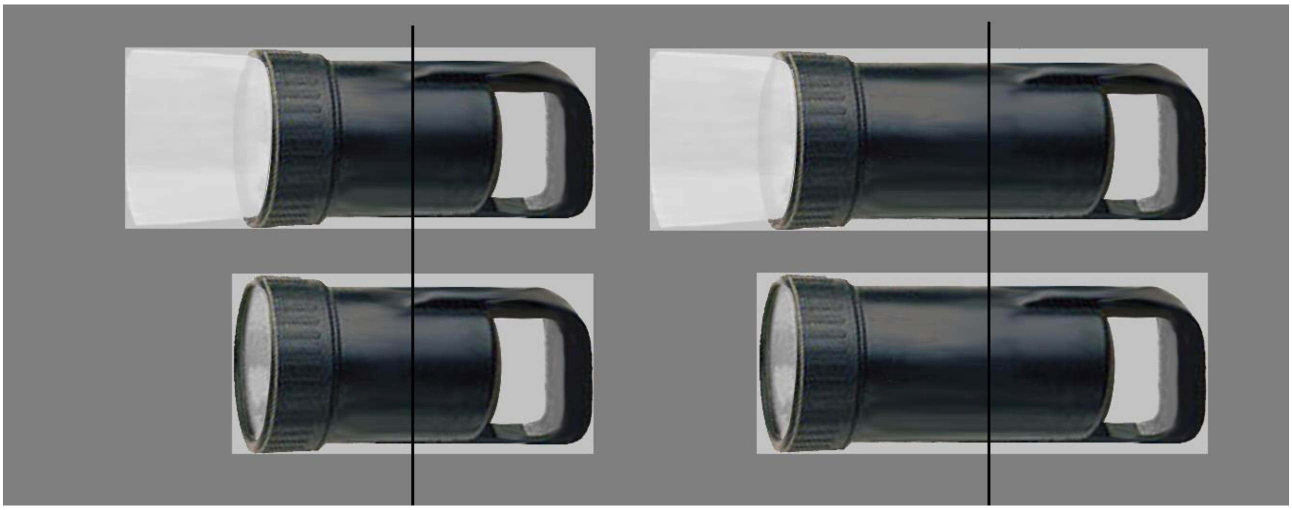

Figure 2. *short active state torch (top left); passive state short torch (bottom left); active state long torch (top right); passive state short torch (bottom right). Stimuli were centred in relation to the body of the torch.*

2.3.3 Results and discussion

Omitted responses (0.39 %), RTs that were two standard deviations below (0.15 %) or above (2.29 %) each individual overall mean were excluded from the analyses, whereas errors (1.74 %) were analyzed separately. Mean correct RTs and arcsine-transformed ERs were submitted to two repeated-measures ANOVAs with Functional State (active vs. passive) and Affordance compatibility (affordance compatible vs. incompatible pairings) as within-subject factors. The respective data are shown in Table 2.

For the RTs, the main effect of Functional state was significant, $F(1,19) = 22.11$, $p < .001$, $\eta^2_p = .54$, with faster RTs for the passive state condition (454 ms) than for the active state condition (475 ms).
The main effect of Affordance Compatibility was significant, $F(1,19) = 18.77$, $p < .001$, $\eta^2_p = 0.50$, with faster RTs for non-compatible button to graspable tip pairings (459 ms) with respect to compatible pairings (470 ms).
The Functional state x Compatibility interaction was significant, $F(1,19) = 33.85$, $p < .001$, $\eta^2_p = .64$. For the active state condition, paired sample t-test showed a reversed Affordance compatibility effect: a significant 19 ms advantage when the location of the graspable tip was opposite to the one of the response button, $t(19) = 6.54$, $p < .001$. No significant difference was found in the passive state condition, $t(19) = 0.918$, $p = .370$.
For the ERs, results showed a main effect of the Functional state of the torch, $F(1,19) = 4.81$, $p = .041$, $\eta^2_p = .20$. Participants made more errors in the active state condition (2.03%) than in the passive state condition (1.45%). Compatibility was also significant, $F(1,19) = 7.43$, $p = .013$, $\eta^2_p = .28$: Participants made more errors when the graspable tip of the torch was in the same location as the response button (2.25%) than when it was in the opposite location (1.23%).
The interaction between Functional state and Compatibility was marginally significant, $F(1,19) = 4.02$, $p = .059$, $\eta^2_p = .17$, displaying for the active state condition numerically higher ERs in the compatible (graspable tip-to-response button) condition (2.8%) respect to the incompatible condition (1.2%) .In Experiment 2 a reversed affordance compatibility effect was observed in the active state condition for both RTs and ERs. Contrary to Experiment 1, results display that when asymmetry on the horizontal axis was given by the goal-directed tip of the torch, a spatial compatibility effect was observed consistent with it. This result is fully in accordance with the location coding account of the stimulus response compatibility effect.

Table 2*: Mean (Standard Deviation) of the Reaction Time (in ms) and ER (in %) for the Affordance compatibility effect (handle orientation-to-response position compatible vs. incompatible pairings) Experiment 2 for the Active (leftmost panel) and Passive (rightmost panel) state conditions. Note. The Affordance compatibility effect is computed by subtracting reaction times (RTs) and error rates (ERs) in corresponding trials from RTs and ERs in non-corresponding trials. Asterisks denote significant differences.*

	Active state		Passive state	
	M	% ER	M	% ER
Compatible	485	2.8	455	1.6
Incompatible	466	1.2	453	1.2
Affordance Compatibility effect	-19*	-1.6*	-2	-0.4

2.4 Experiment 3

Experiment 3 intends to replicate Experiment 2 by employing discrimination of different visual features. It is possible that effect found in previous experiment was due to the specific discrimination on horizontal axis. The aim of this experiment was to test if the discrimination of height instead of length of the stimuli is sensible to horizontal asymmetry of the stimulus or if this type of discrimination made more salient affordance information than horizontal asymmetry.

2.4.1 Participants

Twenty undergraduate students (14 female; mean age = 23.20, SD = 3.53) participated voluntarily. All reported having normal or corrected to normal vision and were naive to the purpose of the study. They were all right-handed (90.40/100, SD = 7.41) as assessed with the Edinburgh Handedness Inventory (Oldfield, 1971).

2.4.2 Stimuli, apparatus, and procedure

Apparatus and procedure were identical to the ones used in Experiment 1 and 2.

As in the Experiment 2, the stimulus was centered in relation to the body of the torch, but stimulus sizes differed in height instead of length (i.e., small and big torches). In the active state (switched-on torches) the small torches were 175 mm wide x 75 mm high, whereas the big torches were 175 mm wide x 90 mm high. In the passive state condition (switched-off torches) the small torches were 140 mm wide x 75 mm high, and the big torches were 140 mm wide x 90 mm high. As for Experiment 2, the active state condition provided the stimuli to be asymmetric on the horizontal axis because of the goal-directed tips jutting more left- and rightwards. Conversely, the passive state condition provided symmetrically centered stimuli as for Experiment 1 and Experiment 2 (see Figure 3).

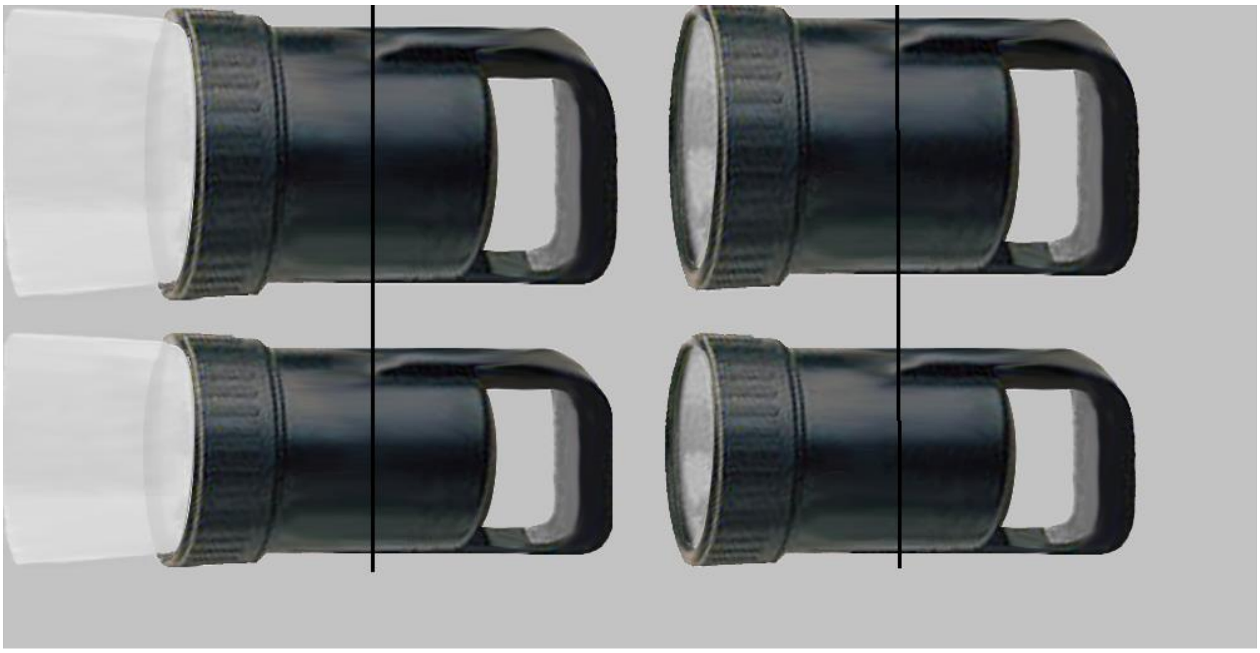

Figure 3 *Stimuli were centred as in experiment 2, in relation to the body of the torch. On top large in height torches and below the smallest.*

2.4.3 Results and discussion

Omitted responses (0.21 %), RTs that were two standard deviations below (0.25 %) or above (2.19 %) each individual overall mean were excluded from the analyses, whereas errors (3.00 %) were analyzed separately. Mean correct RTs and arcsine-transformed ERs were submitted to the same ANOVAs as the previous experiments. The respective data are shown in Table 3).

The main effect of Functional state was significant, $F(1,19) = 4.74$, $p < .042$, $\eta^2_p = .20$, with faster RTs in the passive state condition (449 ms) than in the active state condition (462 ms).

The main effect of Compatibility was significant, $F(1,19) = 20.95$, $p < .001$, $\eta^2_p = .52$, showing a reverse pattern with slower RTs when the graspable tip was in the same location of the response button (464ms) than when it was in the opposite location (448 ms).

The significant interaction between Functional state and Compatibility, $F(1,19) = 11.62$, $p =.003$, $\eta^2_p =.38$, specified that the reverse Affordance compatibility effect depended only on the active state condition: Paired sample t-test displayed performance being 22 ms slower when the location of the graspable tip of the stimulus and the location of the response button corresponded (473 ms) compared to when they did not correspond (451ms), $t(19) = 7.30$, $p < .001$; no significant difference was observed in the passive state condition, $t(19) = 1.898$, $p = .073$.

For the ERs, results showed a reversed main effect of Compatibility, $F(1,19) = 7.16$, $p =.015$, $\eta^2_p =.27$, where subjects made more errors when the graspable tip corresponded to the response position (3.3%), compared to when they did not correspond (1.9%). Neither other main effects nor interactions were significant, $Fs\ (1,19) < .29$.

The results of Experiment 3 replicated the results of Experiment 2, when a discrimination task was employed that did not involve the horizontal dimension. The participants were faster when the location of the response button corresponded with the more salient part of the stimulus, irrespective of its afforded graspabilty.

Table 3*: Mean (Standard Deviation) of the Reaction Time (in ms) and ER (in %) for the Affordance compatibility effect (handle orientation-to-response position compatible vs. incompatible pairings) in Experiment 3 for the Active (leftmost panel) and Passive (rightmost panel) state conditions. Note. The Affordance compatibility effect is computed by subtracting reaction times (RTs) and error rates (ERs) in compatible trials from RTs and ERs in incompatible trials. Asterisks denote significant differences.*

	Active state		Passive state	
	M	% ER	M	% ER
Compatible	473	3.40	454	3.20
Incompatible	451	1.65	445	2.10
Affordance Compatibility effect	-22*	-1.75	-9	-1.1

2.5 General discussion

The results of these experiments provide evidence against the affordance view in a spatial compatibility task involving simple key press and orientation of the object's handle. They allow us to conclude that, when the object's handle (the graspable part of the stimulus) does not provide any visual asymmetry on the horizontal axis that could interact with the response position, no affordance effect is observed.

Our findings seem to support the location coding account (Cho & Proctor, 2010, 2011, 2013; Lien et al.,2013, see also Proctor & Miles, 2014, for a review). Responses made by keypress are coded in terms of spatial locations and the effects observed are due to the dimensional overlap of the spatial codes between stimuli and response (Kornblum et al., 1990). The results of Experiment 1 show a affordance compatibility effect in the active state condition. Furthermore, a spatial compatibility effect was observed in the passive state condition as a function of the orientation of the object's goal-directed tip. It would seem that in the active state condition, information on the tool use was highlighted, so that a grasping affordance was activated favoring the affordance compatible trials. Nevertheless, in the passive state condition, the goal-directed tip was the salient part of stimuli in the horizontal asymmetry, and the founding of a compatibility effect in this direction are due to the perceptual saliency of the object and not on the affordance of the object.

In spite of the fact that the sources of horizontal visual asymmetry within the object structure were removed according to Pellicano et al. (2010), and that in the passive state the object was symmetrically centered to the body midline, its goal-directed tip was judged as more salient than the opposite graspable tip, generating a compatibility effect in this direction. For active state objects, visual asymmetry was induced because of the handle tips left/right jutting displacement on the screen (as for the original Pellicano et al., 2010, Experiment 2). Given this asymmetry, a consequent spatial coding of stimulus orientation was produced, which ultimately generated a spatial compatibility (i.e. Simon-like) effect.

In Experiment 2 we observed a reversed affordance compatibility effect in the active state condition for both RTs and ERs. The results show that it exists a spatial compatibility effect in the direction of the goal-directed tip of the torch, this result is due to the fact that the asymmetry on the horizontal axis was given by the goal directed tip of the torch. This result is fully in accordance with the location coding account of the affordance compatibility effect. In Experiment 3 we requested to the subjects to make discrimination on a vertical axis feature instead of the horizontal axis feature of the previous experiment. The results show that also in a discrimination of a vertical axis feature of the stimuli, the Simon effect due to an horizontal asymmetry of the stimuli is more salient than the affordance effect due to the handle part of the object. In this study we used visual stimuli depicting real objects to examine the nature of the spatial - stimulus response compatibility effect and affordance effect of the graspable part of the objects depicted. When the handle of an object stimulus matches with the side of the response, we can typically observe faster RTs than when the handle part of the object doesn’t match with the correct hand of response side. Our purpose was to clarify if this effect is due to object affordance (affordance effect account) or to the spatial coding of salient object parts due to asymmetry (location-coding account). A recent formulation of the affordance-activation account affirms that perceiving an object activates the motor simulation of the action consistent with its typical use, and the specific term is functional affordances (Bub et al., 2008; Mizelle et al., 2013). The activation of the grasp-to-use facilitates the pressing of the corresponding button, due to the activation of the right hand "grasp-to-use" action. In a different way, for the location coding account, faster RTs are due to the stimuli feature in the visual salience in terms of asymmetry, perceived by the vision with faster response when the asymmetry matches the side of the response. Our results seem to confirm the location coding account, after observing that the RTs were faster when the response was stronger on the asymmetrical side than when the handle of the object was on the same side of the subject's correct hand.

Chapter 3: The effect of contextual information on affordance effects

3.1 Introduction

A series of studies have shown that the effects described in the previous chapter are not only modulated by specific objects' features but also by the context within which actions are performed.

It is important to underline that these "affordance effects" are not only created by these object characteristics but they also involve the physical and social context in which the actions are performed (Gibson (1979). In fact, affordance effects are influenced by the observation of actions performed by other agents (e.g., Bach, Bayliss, & Tipper, 2010; Borghi et al., 2006; Ellis et al., 2013; Maranesi, Bonini, & Fogassi, 2014), by the specific context in which they are performed (e.g., Fini, Brass, & Committeri, 2015), and by the observer's possibility to interact with the observed object (e.g., Buccino et al., 2009; Cardellicchio, Sinigaglia, & Costantini, 2013; Costantini, Ambrosini, Tieri, Sinigaglia, & Committeri, 2010). The latter point was examined in a first behavioural study by Costantini et al. (2010). Their findings underlined that the hand response was favoured when they were congruent with the object handle orientation only when the object was perceived as falling within the participant's reachable space. Cardellicchio et al. (2013) in a follow-up TMS study stimulated the participants' left primary motor cortex letting them observe graspable and non-graspable objects within or outside their own reachable space. They found higher motor-evoked potentials (MEPs) for graspable objects in their reachable space compared to either a non-graspable object or a graspable object outside the reachable space. Buccino et al. (2009), with the same technique investigated the primary motor cortex excitability letting the participants observe objects which handles were intact or broken, finding that MEPs were stronger when the handle was intact. All these studies stress the importance played by contextual information in the emergence of affordance effects. Which information affects the observer? We believe that the studies conducted so far do not tell us which contextual information, among the multiple conflicting ones available, affects the observer's final behaviour.

The main aim of this study, given the remarks above, was to investigate the role of the various characteristics of the observed objects and of the physical context in affecting the performance. To this end, we conducted three experiments[2] in which participants had to discriminate whether a centrally-presented graspable object was upright or rotated. We assessed whether motor responses were affected by the irrelevant left-right orientation of the object's handle. In Experiment 1, the aim was to assess whether the motor systems takes into consideration the object potential graspability. The object could be presented alone (object-only condition) or grasped by a human hand (grasped-object condition). In addition, to assess whether the perceptual salience could affect the results (see the location coding account proposed by Cho and Proctor, 2010, 2011, 2013 discussed in Chapter 1), we included a condition in which we partially covered the object handle (masked-handle condition). If the activation of the motor system during object observation depends on the observer's opportunity of interacting with it, then a handle orientation effect should emerge in the object-only condition, which has faster response times when the responses are congruent with the right-left orientation of the object graspable part. Conversely, an object that is already held should not suggest motor actions that are compatible with a grasping action. As a consequence, handle orientation should not affect performance. However, it is possible that the observation of a hand holding the object activates action simulation. In this case, the affordance effect should be amplified in the grasped-object condition as compared to the object-alone condition. If affordance effects are due to perceptual asymmetry, then no difference should be evident between the grasped-object and the masked-handle conditions. Experiment 2 investigated whether the same results can be obtained when the hand does not grasp the object handle but lies close to it. Finally, Experiment 3 investigated whether the performance is affected when either a human hand or a geometrical shape is presented opposite to the handle side.

[2] Data of these experiments are currently under submission.

3.2 Experiment 1

Experiment 1 investigated if seeing an object grasped by a human hand activates the same motor information triggered by the observation of the object alone. To this end, the participants were requested to press one of two lateralized response keys according to the vertical orientation (i.e., upward or inverted) of a graspable object presented in the centre of the screen while ignoring the left-right orientation of its handle. In the object-alone condition the object had nothing next to it, while in the grasped-object condition the object was always presented with a human hand holding the handle. To exclude those differences between these two conditions could be due to differences in visual asymmetry and salience; we included a third condition in which the hand grasping the object was replaced with a grey square covering part of the object graspable part (masked-handle condition). In this way the stimulus presented the same perceptual asymmetry of the grasped-object condition.

If object's affordances are activated only if the observer is in the position to potentially act on the object (e.g., Costantini et al., 2010; Iani, Rubichi, Ferraro, Nicoletti, & Gallese, 2013), then, the affordance effect, that means faster responses when the response is on the same side as the object's handle, should emerge only in the object-only condition. On the other hand, if the observation of others performing actions facilitates the execution of the same actions by the observer (e.g., Borghi et al., 2006; Brass, Bekkering, & Prinz, 2001), then an affordance effect should emerge also in the grasped-object condition and, as a consequence of motor priming, should be greater. If this increased effect is due to the increased perceptual salience characterizing the grasped-object condition, a comparable increased effect should be evident also in the masked-handle condition.

3.2.1 Participants

Ninety undergraduate students (68 female; mean age = 20. years; SD = 1.49 years) from the University of Modena and Reggio Emilia took part in this experiment for course credit. All were right-handed, reported normal or corrected-to-normal vision, and were naïve as to the purpose of the experiment. All participants gave their written informed consent to participate to the study. Once selected, they were randomly assigned to one of three experimental conditions (i.e., object-only, grasped-object, and masked-handle conditions).

3.2.2 Stimuli, apparatus and procedure

The participants were sitting in a dimly lighted room, in front of a 19” monitor with a resolution of 640 x 480 pixels, at a distance of about 60 cm from the screen. E-Prime software system version 2.0 controlled stimuli presentation and response collection. The stimuli consisted of digital photographs of four different domestic objects (i.e., a watering can, a coffee pot, a jug and a kettle), presented in the centre of the screen. All images were rendered in grayscale and were of the same size (10.47 x 8.57°), irrespective of the size of the real objects. The objects could be presented upward or inverted (i.e., vertical orientation) with a leftward or rightward-oriented handle. In the object-only condition, the object handle was fully visible; in the grasped-object condition, the stimuli were shown as already held by a human hand (i.e., two women’s and two men’s hands; 3.82 x 4.78°); finally, in the masked-handle condition the handle was covered by a geometrical shape occupying about the same area that in the grasped-object condition was covered by the hand (3.82 x 5.72°) (see figure 4). In all the conditions in the trial, the participants were asked to respond according to the vertical orientation (upward or inverted) of the objects. The responses were given by pressing the “z” or “-“ keys of a standard Italian keyboard with the left and right index fingers, respectively. The subjects participated in a single session, individually. In all conditions, each trial began with a fixation point displayed at the centre of a black background for 1 s. Then the image of one object was displayed fin the centre of the screen for a maximum of 3000 ms or until the response occurred. In each test condition, half of the participants responded with a right key press ("-") to upward objects and with a left key press ("z") to inverted objects, whereas the other half experienced the opposite mapping. In the trials involving handle-response, the handle and the correct key were on the same side (e.g., handle on the right, correct response key on the right), whereas in the other trials, the handle was located on the opposite side with respect to the position of the correct response key (e.g., handle on the left, correct response key on the right). After a response was given, a blank screen was displayed for 600 ms. the instructions given to the participants emphasized both speed and accuracy. However, no feedback was provided. The experiment consisted in 8 practice trials and 3 experimental blocks of 64 trials each, for a total of 192 trials. For each combination was provided an equal number of trials, with the following variables: stimulus vertical orientation (upright vs. inverted), handle position (handle on the right vs. handle on the left) and, for the grasped-object condition only, type of hand (two women's and two men's hands).

Figure 3 *Stimuli used in experiment 1: a free affordable kettle; an already grasped kettle and a masked kettle.*

3.2.3 Results and Discussion

Practice trials, RTs faster or slower than two standard deviations from the participant's mean (4.3% of the total trials), and incorrect responses (3.5% of the total trials) were excluded.

In line with the previous studies (e.g., Iani et al., 2014), data were collapsed based on the compatibility between: Handle orientation and Response position (affordance compatible vs. affordance incompatible trials). The correct RTs were included in a repeated-measures Analysis of Variance (ANOVA) with Affordance compatibility and Object vertical orientation (upright vs. inverted) as within-participant factors, and Condition (object-only vs. grasped-object vs. masked-handle conditions) as a between-participants factor. Table 4 shows the processed data. Since we found no effect of type of hand, this factor was not included in the following analyses. When necessary, post-hoc comparisons were performed by using t-tests and by correcting the p-value for the number of comparisons.

	Object-only		**Masked-handle**		**Grasped-object**	
	Upright	*Inverted*	*Upright*	*Inverted*	*Upright*	*Inverted*
C	476 (54.1)	471 (49.2)	526 (69.3)	516 (63.2)	464 (57.0)	460 (58.3)
I	487 (48.3)	483 (53.3)	543 (67.3)	533 (53.6)	500 (64.0)	482 (62.0)
Affordance effect	11	12	18	17	36	22

Table 4. *Mean RTs (and standard error) in ms in the three experimental conditions of Experiment 1 as a function of object vertical orientation (upright and inverted) and affordance compatibility (compatible vs. incompatible). The affordance effect is computed as the difference in RTs between compatible and incompatible trials.*

Since the analysis showed a main effect of Object vertical orientation, $F(1,87) = 8.26$, $p < .01$, $\eta^2_p = 0.09$, with faster responses for inverted (491 ms) than for upright stimuli (499 ms), we performed separate analyses for upright and inverted objects. For upright objects, the analysis showed a main effect of Condition, $F(2,87) = 7.85$, $p < .001$, $\eta^2_p = 0.15$. Post-hoc comparisons showed that responses were the slowest in the masked-handle condition (534 ms, *p*s < .001), while they did not differ between the other two conditions (482 and 482 ms for the object-only and grasped-object conditions, respectively). The main effect of Affordance compatibility was also significant, $F(2,87) = 57.69$, $p < .001$, $\eta^2_p = 0.40$, but it was modulated by Condition, $F(2,87) = 6.92$, $p < .01$, $\eta^2_p = 0.14$. Affordance compatible responses were 11 ms faster than incompatible ones in the object-only condition, 18 ms faster in the masked-handle condition and 36 ms faster in the grasped-object conditions. Post-hoc comparisons showed that these effects were all significant and that the effect evident in the grasped-object condition differed from the effects evident in the object-only ($p = .002$) and masked-handle ($p = .03$) conditions. There was no difference between the object-only and the masked-handle conditions ($p = .94$).

For inverted objects, the analysis showed a main effect of Condition, $F(2,87) = 8.31$, $p < .001$, $\eta^2_p = 0.16$. Post-hoc comparisons showed that RTs were the slowest in the masked-handle condition (524 ms, *p*s < .001), while they did not differ between the grasped-object (471 ms) and object-only (477 ms) conditions. There were also a main effect of Affordance compatibility, $F(1,87) = 49.52$, $p < .001$, $\eta^2_p = 0.36$, with faster responses for compatible (482 ms) than for incompatible (489 ms) trials. The difference between handle-response corresponding and non-corresponding trials was 12 ms in the object-only condition, 17 ms in the masked-handle condition and 22 ms in the grasped-object condition. The interaction between Affordance compatibility and Condition did not reach significance, $p > .21$, $\eta^2_p = 0.03$.

Surprisingly, a significant affordance effect was present in all the conditions. The effect evident in the object-only condition was comparable in size to the effects reported in previous studies employing similar stimuli (e.g., Iani et al., 2011; Riggio et al., 2008). In line with the affordance view, these findings suggest that the horizontal orientation of the graspable part of an object affects performance, even if this information is task irrelevant. We may suggest two alternative explanations for the effect evident in the masked-handle condition. The first assumption is that the effect emerged because of the stimulus most salient part spatial coding. In fact, as in the object-only condition, the stimulus display was asymmetric, with the handle side being perceptually more salient than the other side of the object. The second assumption is that the effect emerged because of the activation of a motor affordance. Since RTs in this condition were slower than in the other two conditions, it is possible that the participants perceived the object as "incomplete" and perceptually completed it, thus producing the preconditions for the activation of a motor affordance (e.g., Grützner et al., 2010; Snodgrass & Feenan, 1990). The longer RTs evident in this condition could be due to these completion processes. However, the results of the present experiment do not allow us to discriminate between these two explanations.

It is important to underline that the effect was evident even when the objects were already grasped and was significantly stronger than in the other two conditions, when the objects were upright. Such a finding does not support the view that the activation of the motor system during the observation of an object depends on the real possibility of interacting with it. Rather, it seems to suggest that observing a human hand holding an object activates the motor simulation of the observed action (e.g., Borghi et al., 2006; Jannerod, 2001).

The observation that the handle orientation effect was significantly stronger in the grasped-object condition, as compared to the other two conditions only for the upright stimuli, allows us to exclude that the effect given by grasped objects is exclusively due to salience. If this were the case, the effect should not vary between upright and inverted objects, which are identical as regards salience/laterality.

3.3 Experiment 2

In Experiment 2 we assessed whether the increased effect found in Experiment 1 emerges even when the hand is located beside the object's handle, in a pose congruent with the action of grasping it.

3.3.1 Participants

Thirty new right-handed undergraduate students (21 female; mean age = 21.3; SD = 1.94 years), selected as before, took part in this experiment for course credit.

3.3.2 Stimuli, apparatus and procedure

Apparatus, stimuli and procedures were the same as in Experiment 1, except for the following new features: a human hand (two men and two women's hands) was always presented with the object. The hand displayed the same pose as in the grasped-object condition of Experiment 1, and it was presented on the same side of the handle, 5.7° from the centre of the object image (see figure 5).

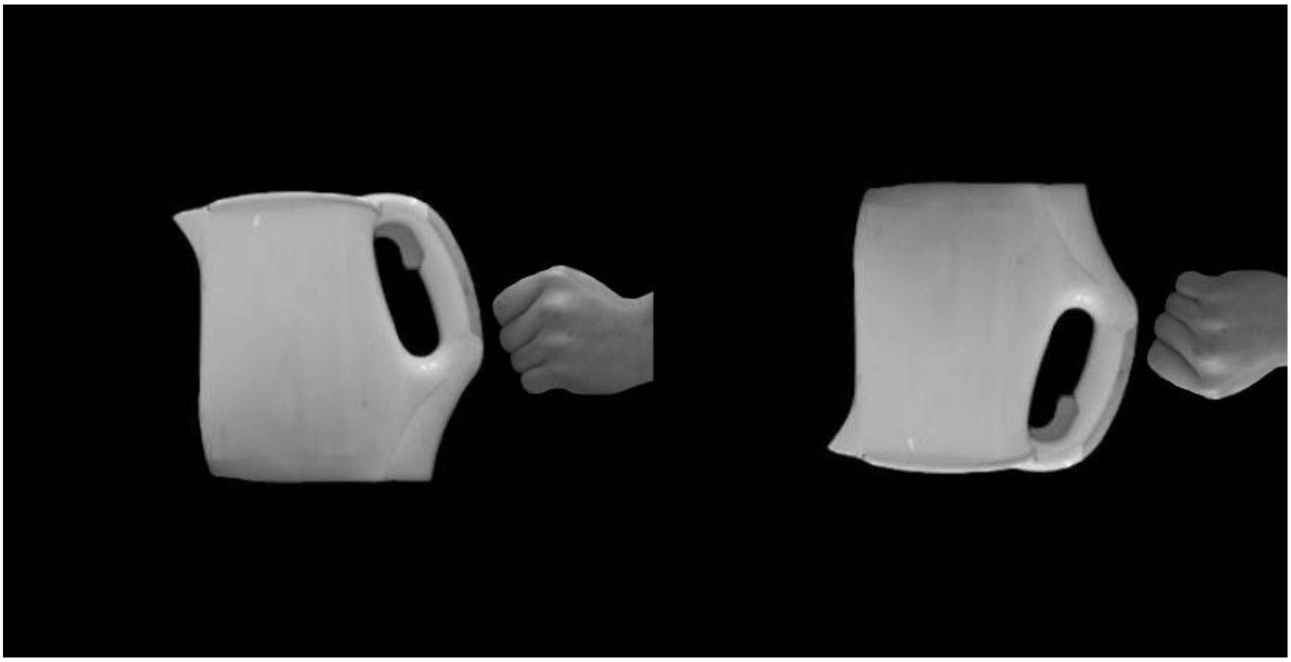

Figure 4 *Stimuli used in experiment 2 a kettle with an approaching hand and a reverse kettle with an approaching hand.*

The experiment consisted in 8 practice trials and 3 experimental blocks of 64 trials each, for a total of 192 trials. An equal number of trials were provided for each combination of the following variables: stimulus vertical orientation (upright vs. inverted), handle position (handle on the right vs. handle on the left) and type of hand (two women and two men's hands).

3.3.3 Results and Discussion

Practice trials, RTs faster or slower than two standard deviations from the participants' mean (4.3% of the total trials) and incorrect responses (3.7% of the total trials) were excluded from the analyses. Correct RTs were entered into a repeated-measures ANOVA with Affordance compatibility and Object vertical orientation as within-participant factors. Since the variable type of hand had no effect, this factor was not included in the analysis. The respective data are shown in Table 5.

	Upright	*Inverted*
C	478 (79.5)	473 (68.6)
I	509 (86.2)	503 (72.8)
Affordance effect	31	31

Table 5. *Mean RTs (and standard error) in ms in Experiment 2 as a function of object vertical orientation (upright and inverted) and affordance compatibility (compatible and incompatible). The affordance effect is computed as the difference in RTs between affordance compatible and incompatible trials.*

The analysis showed only a main effect of affordance compatibility, $F(1,29) = 45.33$, $p < .001$, $\eta^2_p = 0.61$, with 31 ms faster responses in compatible (475 ms) than in incompatible (506 ms) trials. No other effect or interaction reached significance (*F*s < 1).

3.4 Experiment 3

A hand can capture attention because of its biological nature (e.g., Morrisey & Rutherford, 2013). Hence, the effects observed when the hand was present in the previous two experiments could be explained as due to the presence of the biological nature of the stimulus rather than to the action primed by it. In addition, since the orientation of the hand was always congruent with the upward or downward orientation of the object, it is possible that the participants were influenced by the hand when discriminating object vertical orientation. Directing attention to the hand could then lead to the activation of a spatially compatible response (e.g. Cho & Proctor, 2010, 2011). To test these hypotheses, the object was always displayed along with a distractor positioned on the opposite side as the object handle in all the trials of this experiment. For half of the participants, the distractor was the human hand used in Experiment 2, while for the other half it was the same geometrical shape used in the masked-handle condition of Experiment 1. If the hand captures attention because of its biological nature, or because its orientation is informative for the task, then the responses should be significantly faster when compatible with its location and this effect should be larger as compared to when a geometrical shape is presented.

3.4.1 Participants

Sixty new right-handed undergraduate students (43 female, mean age = 21.6, SD = 1.98 years), selected as before, took part in this experiment for course credit.

3.4.2 Apparatus, stimuli and proceduresStimuli, apparatus and procedure

Apparatus, stimuli and procedures were the same as in the object-only condition of Experiment 1, except for the following features. The objects could be presented upward or inverted (i.e., vertical orientation) with a leftward or rightward-oriented handle. For half the participants a human hand was presented opposite to the object handle (i.e., the hand was on the left of the object when the handle pointed rightward), while for the other half a filled square was presented opposite to the object handle (i.e., the square was on the left of the object when the handle pointed rightward). The distance from the centre of the hand/square to the centre of the object was of 5.72°. As in the previous experiments, participants were asked to respond according to the vertical orientation (upward or inverted) of the objects (see figure 6).

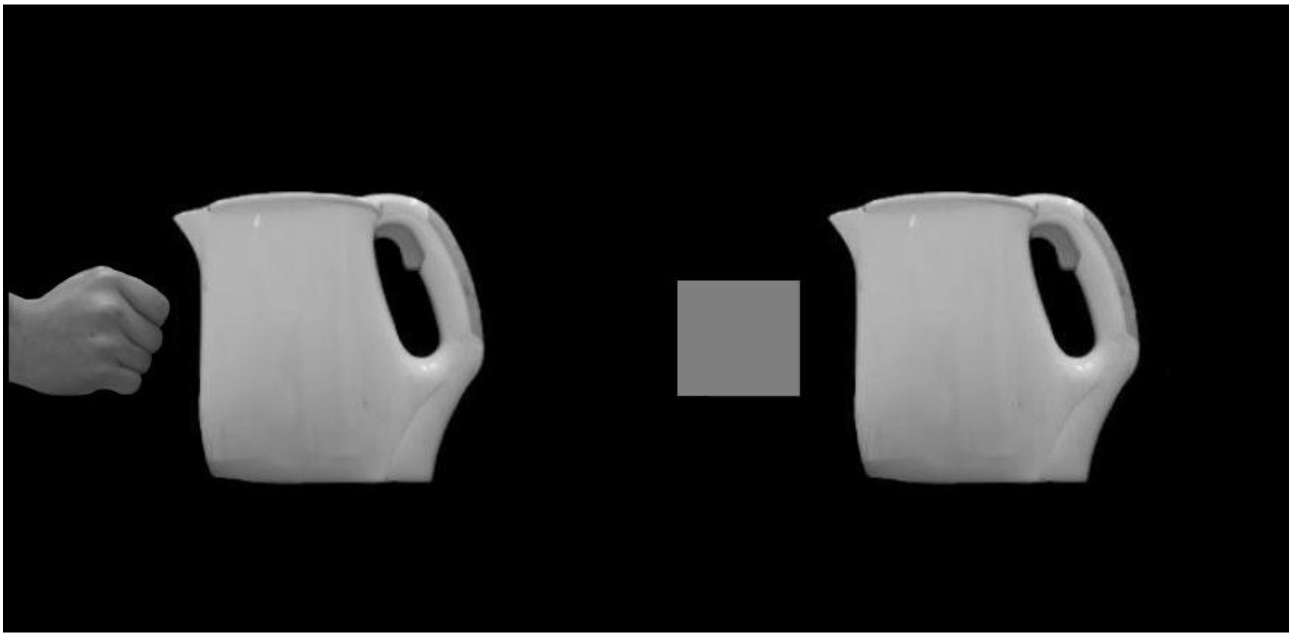

Figure 5 *Stimuli used in experiment 3 a kettle with a non-approaching hand and a kettle with a square opposite to the handle part.*

The experiment consisted in 8 practice trials and 3 experimental blocks of 64 trials each, for a total of 192 trials. An equal number of trials were provided for each combination of the following variables: stimulus vertical orientation (upright vs. inverted), handle position (handle on the right vs. handle on the left) and, for the opposite-hand condition only, type of hand (two males and two females).

3.4.3 Results and Discussion

Practice trials, RTs faster or slower than two standard deviations from the participant's mean (4.5% of the total trials) and incorrect responses (3.9% of the total trials) were excluded from the analyses. Correct RTs were included into a repeated-measure ANOVA with Affordance compatibility and Object vertical orientation as within-participant factors and Condition (opposite-hand vs. opposite-square condition) as between-participants factor. The respective data are shown in Table 6.

	Opposite hand		**Opposite square**	
	Upright	*Inverted*	*Upright*	*Inverted*
C	487 (82.3)	493 (82.4)	574 (88.1)	557 (67.2)
I	481 (80.4)	481 (79.5)	558 (87.5)	549 (66.9)
affordance effect	- 6	- 12	-16	-8

Table 6. *Mean RTs (and standard error) in ms in the two experimental conditions of Experiment 3 as a function of object vertical orientation (upright and inverted) and affordance compatibility (compatible vs. incompatible). The handle orientation effect is computed as the difference in RTs between compatible and incompatible trials.*

There was a main Condition effect, F (1,58) = 13.55, $p < .001$, $\eta^2_p = 0.19$, with faster RTs in the opposite-hand condition (485 ms) than in the opposite-square condition (559 ms). The main effect of Object vertical orientation did not reach significance ($p = .17$, $\eta^2_p = 0.03$), but it interacted with the Condition, $F(1,58) = 4.95$, $p < .05$, $\eta^2_p = 0.08$, with faster RTs for inverted than for upright objects in the opposite-square condition only. The main effect of Handle-response compatibility was significant, $F(1,58) = 17.14$, $p < .001$, $\eta^2_p = 0.23$, with faster RTs for non-corresponding (517 ms) than for corresponding (527 ms) trials. Hence, responses were faster when they were congruent with the position of the distractor presented along with the object. No difference between the square and the hand was evident, as indicated by the lack of the interaction between Handle-response compatibility and Condition, $F < 1$. The overall handle orientation effect was -12 ms for the square and -9 ms the hand. No other interaction reached significance (ps > .12).

3.5 General Discussion

The goal of the present work was twofold. In the first place we examined whether affordance effects in response to pictures of graspable objects emerged, even when these objects appeared as already grasped. Secondly, we assessed whether the effects observed could be explained by visual salience rather than to action potentiation mechanisms. The results obtained when the object was presented as graspable replicated those of previous studies (e.g., Tucker & Ellis, 1998; Iani et al., 2011): responses were faster when the handle was located on the same side of the responding hand. This result is usually interpreted as suggesting that object affordances automatically activate congruent motor responses (e.g. Tucker & Ellis, 1998). In contrast to our early suppositions, this advantage was evident also when the object appeared as already grasped and when its handle was partially covered. A greater effect shown when an upright object was already grasped seems to indicate that the observation of a human hand holding an object, especially when the latter is presented in its canonical orientation, activates a process of motor simulation, even though the observer is prevented from potentially grasping the object that is shown as already grasped by another hand. The results in Experiment 2 show that this action potentiation seems to occur even when the observed hand is simply located close to the object and displays a pose congruent with grasping it. Such behaviour could be fostered by the participants maintaining an egocentric perspective, so that the grasping hand was perceived as belonging to the self (e.g., Shmuelof & Zohary, 2008).

The results of the experiments reported in this chapter are in line with those of previous studies showing tha contextual action information presented along with an object affects the time taken to identify the object, and its typical use (Yoon & Humphreys, 2005) and leads to compatibility effects on grasping responses (Girardi, Lindemann, & Bekkering, 2010).

As previously stated, the results obtained in the masked-handle condition could involve the spatial coding of the stimulus more salient part and the perceptual completion of an “incomplete” object (e.g., Emmanouil & Ro, 2014; Grützner et al., 2010). The results of our research do not allow us to exclude one of these hypotheses; The longer RTs evident in this condition could be due to these completion processes. However, the results of the present experiment do not allow us to discriminate between these two explanations.

There is considerable increasing evidence supporting the idea of affordance effects in terms of spatial compatibility (e.g., Cho & Proctor, 2010, 2011; Lien et al., 2013). In order to determine whether the observed effects could be due to perceptual saliency bringing to spatial coding, in Experiment 3 we presented the object along with a distractor located on the opposite side of the object handle. We found that a distractor close to the object captured the participants' attention and the resulting location coding produced a Simon-like effect. However, the reversed effect as shown by the analyses, was not numerically comparable to the effects observed in Experiments 1 (grasped-object) and 2 (approaching hand. This made us safely exclude that the increased effect observed in the grasped-object condition of Experiments 1 and 2 could be explained solely in terms of spatial compatibility. Therefore, a hand congruent with the action of grasping an object activates the same action in the observer; differently the presence of a hand in a pose incongruent with a grasping response toward the object captures attention and affects performance in the same way as a non-biological stimulus (i.e., a geometrical shape). These findings reinforce the increasing experimental evidence indicating that both motor affordance and spatial compatibility mechanisms may contribute to the observed handle orientation effects in similar tasks (e.g., Iani et al., 2011; Kourtis & Vingerhoets, 2015; Pappas, 2014; Riggio et al. 2008; Saccone et al., 2016). Related to this point, Saccone, Churches, Szpak, and Nicholls (2016) asked participants to classify objects with a left- or right-oriented handle presented in upper or lower locations (Experiment 1), to discriminate their colour (Experiment 2) or to discriminate their vertical orientation (Experiment 3) by pressing two response buttons placed vertically one below the other. Differently from previous studies, in this specific study there was no explicit spatial relationship between the object's graspable part and the response buttons, as their position varied orthogonally. A vertical Simon effect, due to the compatibility between stimulus and response locations (upper or lower), was present in all three experiments. An affordance compatibility effect, due to the compatibility between object's handle (left or right) and hand of response (left or right) emerged only when the task required to recognize the object. These latter findings, as suggested by Saccone and colleagues, are clearly reconfirming the *affordance view* and suggest that affordance emerging in tasks in which the spatial relation between handle and response locations is explicit may result from an interaction between motor affordance and spatial compatibility mechanisms. Our results seem to be in line with this vies since they that contextual information may modulate which mechanism prevails and influences performance: a hand with a pose incongruent with a grasping response toward an object captures attention thus leading to the emergence of spatial compatibility effects. Differently, a hand with a pose congruent with the action of grasping an object handle is more likely to potentiate the same action in the observer.

Chapter 4: Effect of robotic agents on the activation of paired object affordance effects

4.1 Introduction

In the experiment presented in this Chapter, we used a modified version of the paradigm originally employed by Borghi, Flumini, Natraj and Wheaton (2012). In their experiment, the Authors manipulated the object presentation context by presenting pairs of objects that could or could not be used together next to biological stimuli composed of human hands that approached the objects in different ways. The participants had to press a key if the presented objects were linked by a specific function (such as a knife and butter), or by a spatial link, if the objects could usually be found in the same environment (such as a knife and a cup); they had to press another key if the objects were not connected to each other. To evaluate how a human-like biological stimulus could influence the presentation of objects, the authors showed alongside the pair of objects a hand approaching one object to move it (manipulation grasp), a hand that was catching one of the two objects (functional grasp) or a hand that was standing still next to the objects, while in a control condition no hand was shown beside the objects.

Results showed better performance when the objects were functionally linked as compared to when they were spatially linked. In addition, the presence of the hand influenced RTs: manipulation postures were processed slower when objects were functionally linked than when they were spatially linked. Similarly, functional postures were slower when objects were spatially linked.

According to the authors, these results could be interpreted as due to the activation of simulation mechanisms, so that for the participants it would be more difficult to simulate a manipulative action when the context suggests using the objects rather them manipulating them; on the other hand, when the context does not suggest any functional use, as in the spatial context, the motor system tries to make sense of the scene, slowing down RTs with the functional posture.

A recent study by Laverick, Wulff, Honisch, Chua, Wing, and Rotshtein (2015) has shown how objects belonging to a pair do not have the same role. In their experiment, participants were presented with a series of sequential objects. The participants's task was to indicate whether the object they were seeing was functionally related to the object that had preceded it. In addition, objects could be displayed alone or as grabbed by a hand that could show either a pose congruent with the use of the object or incongruent with the use of the object. The authors found that responses were faster when the active object preceded the passive object and when strong information was provided about the use of the object by showing it as grabbed by a hand in a use-compatible position. The difference between active and passive objects lies in the fact that the active object is the one actively used when performing a complementary action, while the passive one is usually only held by the hand. The facilitating effect observed with the active object suggests that we start from that object when trying to make sense of a live scene including objects with which an action can be performed. This difference lies in the fact that typically active objects are more closely related to the movements with which complementary actions are performed, so that the simulation mechanisms are more strongly activated. Based on the above reported evidence, it seems possible to propose that a biological stimulus can influence the perception of pairs of objects and suggest, in interaction with the presentation context, a possible action. It is an open question whether the same effects can be found when individuals observed actions performed or suggested by a robotic agent. Relevant to this point, Wykowska, Chellali, Mamun Al-Amin and Muller (2014) have shown how humans are equally influenced by the presentation of biological and robotic stimuli. Their purpose was to evaluate whether the observation of actions carried out by a robot leads to the same representation of the observation of actions carried out by a human being. To do so they asked the experimental participants to perform a visual search task of targets characterized by brightness and size. In each trial participants had to indicate whether or not the target stimulus was present. In each trial, prior to the visual search task, they were also required to perform a grasping or pointing movement by mimicking the movement that was shown either by a human hand or a robotic hand. According to the authors, in the case of the search for the stimulus that varies in size, grasping mechanisms would be activated, whereas in the case of the search for the brighter stimulus, the pointing mechanisms would be activated. Reaction times were faster in the trials in which participants had seen and made a movement congruent with the following visual search task, i.e. grasping movements make it easier to detect the stimulus that differs by size, while pointing movements make it easier to detect the stimulus that differs by brightness. Moreover, the effect did not seem to be modulated by the difference between robotic and human agents. The authors concluded that, given the similar effect obtained by human and robotic hands, it can be asserted that simulation mechanisms are activated even if a robotic agent, instead of a human being, is being observed.

Recently, Romano, Caffa, Hernandez-Arieta, Brugger, and Maravita (2015), by means of a modified version of the paradigm used to investigate the rubber hand illusion (Botvinick & Cohen 1998), showed that it is possible to induce a proprioceptive drift towards a robotic hand when the biological hand and the robotic hand move in visuo-motor congruency. However, in a study that involved the observation of robotic hands performing actions on dangerous objects, Anelli, Borghi and Nicoletti (2012) found higher resonance when a human hand was used as prime as compared to then a robotic hand prime was used. This result suggests that humans do not easily perceive a robot as a real agent, or that the human knowledge of perceiving pain tends to influence the possibility of embodying a robotic hand.

Another important aspect of human-robot interaction is the ability to understand the goal of an action made by a humanoid agent. Robot body and human body have different shapes and characteristics, and in human-robot interaction a crucial question is what human can simulate to understand the goal of a robot action. Bekkering, Wohlschlager and Gattis (2000) found that humans imitate goals of an action made by another human being instead of imitating the proper movement of a seen action. This form of emulation reflects the ability of humans to adapt their movement in the sense of imitating the final results of the action if the trajectory is complex or unusual. These results are really important, especially because the body of humans and robots is characterized by different constraints. E.g. a human being can easily understand the trajectory of grasping movements, because the biological movement is characterized by known biological constraints, Conversely, imitating the goal of action, and thus not following the movement, allows establishing a simple and natural interaction with an agent that has different biological constraints, and thus even more explicit knowledge can be used to quickly expose the purpose of action.

Taken together, the results of the studies investigating paired objects clearly show that humans are sensitive to object-related actions. Anyway, little is known about the effect of robotic primes on object categorization, that shed light on the simulation mechanism with non-human agents.

The aim of the present experiment was to examine if object categorization is affected by the nature of a prime (two human hands or two robotic hands). Specifically, we intended to evaluate whether the functional relation between a pair of objects and the position of the active object in the pair affects performance in the same way when either human or robotics hands are presented as primes. Square prime in this experiment serve as a baseline; indeed, squares are neutral primes that do not convey motor information, but in the present experiment they have the same dimension of the robot and human hand primes and the same duration, to allow us to control for the perceptual effect deriving from the brief presentation of the prime.

4.2 Experiment

4.2.1 Participants

Eighteen right-handed undergraduate students (9 female; mean age 19.5 ± 1.01 years) from the University of Modena and Reggio Emilia took part in the experiment for a partial fulfillment of course credit. They reported normal or corrected-to-normal vision and were naïve as to the purpose of the study. All participants gave their written informed consent to participate to the study.

4.2.2 Stimuli, apparatus and procedure

The experiment took place in a dimly lighted room. Participants sat in front of a 19” monitor at about 60 cm from the screen. Stimuli presentation and response collection were controlled by the E-Prime software system version 2.0. The prime stimuli consisted of digital photographs of two human male hands, two robotic hands or two filled squares. The two prime stimuli were presented on the centre of the screen, one 3 cm to the right and the other 3 cm to the left of the centre. The images were 8 cm x 11 cm. Stimuli consisted of digital photographs of two objects belonging to one of two contexts: the garage and the home. The two stimuli in the pair were presented one 3 cm to the left and the other 3 cm to the right of the centre of the screen. Each pair was always composed of an active object (i.e., the object that is actively manipulated during a specific action; for instance, a screwdriver) and a passive object (i.e., the object typically held during the action; for instance, a screw). Both objects belonged to the same context (home or garage) but they could be either functionally related (i.e., they could be used together to perform a meaningful action; functionally congruent objects) or not (functionally incongruent objects). For example, a bottle of water could be presented along with a glass. In this case, both objects belonged to the home context and could be used together (functionally congruent objects), with the bottle being the active object and the glass being the passive object. A glass could be presented along with a scissor. In this latter case, the scissor was the active object while the glass was the passive object. Differently from the pair of objects of the previous example, in this case, even though the objects belonged to the same context, they could not be used together to perform a meaningful action (functionally incongruent objects). Responses were emitted by pressing one of two response keys (“L” or “A”) on a standard Italian keyboard. Participants were tested individually in a single session lasting about 30 minutes. Each trial began with a fixation cross, displayed at the center of a black background for 500 ms. Then the prime stimuli (either two robotic hands, two human hands or two squares) were displayed for 200 ms, followed, after 100 ms, by the two object stimuli which were displayed for 3000 ms or until the response occurred. Participants were instructed to discriminate if the objects belonged to the home or to the garage by pressing one of two keys ("L" or "A"). Half of the participants responded with a right button press ("L") if the objects belonged to the home and with a left button press ("A") if they belonged to the garage in the first experimental block and with the inversed mapping in the second block. The remaining half responded with a right button press ("L") if the objects belonged to the garage and with a left button press ("A") if they belonged to the home in the first experimental block and with the inversed mapping in the second block. After a response was emitted, a black screen was displayed for 600 ms. Instructions emphasized both speed and accuracy of response. However, no feedback was provided. The experiment consisted of 2 experimental blocks. Each block was composed of 384 experimental trials and 10 trials practice trials. In each block, an equal number of trials was provided for each combination of the following variables: stimulus context (home and garage), active object's position (left and right), functional relation between objects (functionally congruent vs. functionally incongruent objects), and prime type (human hands, robotic hands, squares). The presentation of the stimuli was completely randomized.

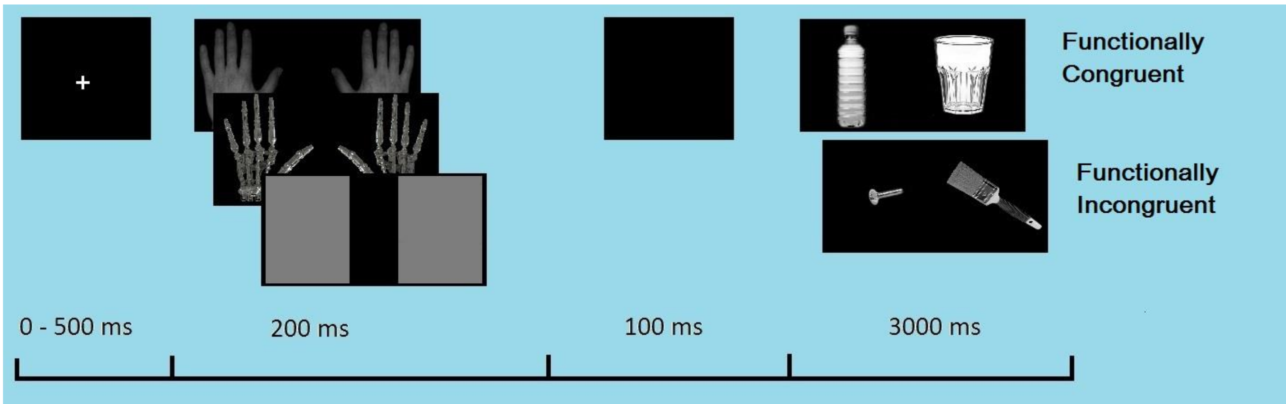

Figure 6 *Procedure. Note that prime image was showed in the same position of the following target objects.*

4.2.3 Results and discussion

Practice trials, RTs faster or slower than two standard deviations from the participant's mean (3.5% of the total trials) and incorrect responses (5% of the remaining trials) were excluded from the analyses. Correct RTs were entered into a repeated-measures Analysis of Variance (ANOVA) with active object's position (right vs. left), functional relation (functionally congruent vs. functionally incongruent objects), prime type (human hands vs. robotic hands vs. squares) and hand of response (right vs. left) as within-participant factors. The Greenhouse-Geisser correction was applied to account for sphericity violations. When necessary, post-hoc comparisons were performed by using t-tests and by correcting the p value for the number of comparisons.

The interaction between active object position and response position was significant, $F(1,17) = 9.61$, $p = .007$, $\eta^2_p = 0.36$. Right responses were significantly faster than left responses when the active object was on the right (583 ms) as compared to when it was on the left (593 ms), $t = 2.584$, $p = .019$. No difference was significant for left responses (active objects on the left: 590 ms; active object on the right: 594 ms), $p > .05$

The interaction between active object position, response position and functional relation was significant, $F(1,17) = 6.557$, $p = .02$, $\eta^2_p = 0.28$. The interaction between prime type, active object position and response position was also significant, $F(2,34) = 3.27$, $p = .05$, $\eta^2_p = 0.16$. Moreover, there were significant interactions involving prime type, active object position and functional relation, $F(2,34) = 3.79$ $p = .033$, $\eta^2_p = 0.18$, and involving response position, active object position and functional relation, $F(1,17) = 6.56$ $p = 0.020$ $\eta^2_p = 0.28$.

To better investigate the significant interaction involving the variable prime type, we performed separate analyses for the three different primes. No main effects or interactions reached significance when the primes stimuli were two human hands. Differently, when two robotic hands were presented as primes, the interactions between functional relation, active object position and response position reached significance, $F(1,17) = 5.41$, $p < .033$, $\eta^2_p = 0.24$. Post-hoc tests showed significant difference between responses with the right hand when the active object was on the right for functionally linked objects (579 ms) and responses with the right hand when the active object was on the left and objects were not functionally linked (600 ms), t = -2.323, p = 0.033. For left-hand responses there was a significant difference between compatible couples when the active object was on the left (574 ms) as compared to when it was on the right (605 ms) t = 3.553 p = 0.002. When squares were presented as primes there was only a significant interaction between response position and active object position, F (17,1) = 5.36 p = 0.033 η^2_p = 0.24; post-hoc comparisons showed that the only significant difference was evident for right responses with faster RTs when the active object was on the right (581 ms) as compared to when it was on the left (593 ms), t = -2.126 p = 0.048.

Robotic prime	**Right hand**		**Left hand**	
Functional relation	*Active right*	*Active left*	*Active right*	*Active left*
C	579 (22)	591 (23)	605 (22)	574(20)
NC	585 (26)	600 (26)	588 (25)	596 (26)

Table 7. *Mean RTs (and standard error) in ms in the three experimental conditions of Experiment as a function of object action congruence (congruent, non congruent) and hand of response position (left- right); active object position (left-right)*

Human Prime	**Right hand**		**Left hand**	
Functional relation	*Active right*	*Active left*	*Active right*	*Active left*
C	581(24)	591 (24)	590 (22)	596 (25)
NC	588(25)	590 (26)	588 (20)	598 (21)

Table 8. *Mean RTs (and standard error) in ms in the three experimental conditions of Experiment as a function of object action congruence (congruent, non congruent) and handof response position (left- right); active object position (left-right)*

Square prime	**Right hand**		**Left hand**	
Functional relation	*Active right*	*Active left*	*Active right*	*Active left*
C	574 (23)	595 (23)	599 (26)	594 (24)
NC	588 (29)	591 (25)	599 (25)	584 (24)

Table 9. *Mean RTs (and standard error) in ms in the three experimental conditions of Experiment as a function of object action congruence (congruent, non congruent) and hand of response position (left- right); active object position (left-right)*

The aim of this experiment was to investigate whether observing robotic hands, human hands or a pair of squares would elicit similar effects on the semantical discrimination of paired objects. To this aim, we required participants to press a button with their left or right index finger to categorize pairs of objects in function of the place in which they could typically found them. Object pairs were characterized by action-congruence and by the position of the active object of the pair. Our results confirmed previous findings of similar studies (e.g.,Laverick et al., 2015; Yoon, Humphreys, & Riddoch, 2010), with faster RTs when the active object and the response were spatially compatible and when the two objects could be used together. This result supports the view of a direct route from perception to action, because the active object is the object with a strong affordance for action and which is more strongly linked to the action repertoire than the passive object.

In our study we presented different types of primes. The overall analysis showed a significant interaction between prime type and the other experimental factors. Separate analyses by prime types allowed us to better clarify the differential effects exerted by this variable on performance. Specifically, the analyses showed that, when squares were presented as primes, responses were faster when the active object position matched the position of the response. This result may reflect a preference for active objects, which are the objects strongly characterized by affordances. Crucially, this effect was significant only for responses emitted with the right hand, the hand usually employed to manipulate the active object.

The robotic hand prime showed a more complex pattern of results, with a significant interaction involving active object position, hand of response and functional relation. This complex interaction seems to suggest that participants perceived robotics hands as hands that had the ability to act on the object to perform a proper action. To note, we did not tell participants whether the robotic hands could move or manipulate objects, but the presence of all the joints and the fingers as in human hands might have suggested to the participants that they were able to interact with objects, irrespective of the fact that they did not share with human hands either shape of colour.

The lack of effects when human hands were used as primes was surprising. Though, we think that there is a smoothing effect provided by the human hand. In this experiment we presented two hands and participants had to answer by using only one hand. It is possible that presenting two human hands might have prompt responses with both hands independently of all other experimental factors.

Overall, it seems that three different effects caused the observed results. First, when squares were presented as primes, performance was affected solely by the position of the active objects, while the functional relation between objects had no effect. Second, when robotic hands were presented as primes, performance was affected by the position of the active object position and by the compatibility between objects. It is possible that, due to the fact that the robotic hands had all the joints and the fingers of a real hand and could be perceived as able to interact with the objects, a simulation mechanism was activated. Third, when human hands were used as primes, performance was not affected by the experimental factors. It is possible that, because the real position of the participants' hands was the same as that of the hands used as primes, a simulation was activated that speeded up responses irrespective of all other variables. Such an explanation would be in line with the idea, already discussed in Chapter 1, that simulation mechanisms are implicit and reflexive, and based on the activation of the motoric representation that occurs when we observe another individual's action (Gallese & Goldman,1998 ; Gallese e Sinigaglia, 2011 ; Grafton, 2009).

In our study, the presence of two objects suggested a proper action when these objects were functionally related. While there are studies demonstrating that a robot agent can have an impact on human perception (e.g., Wykowska et al., 2014; Romano et al., 2015), Anelli et al. (2012) showed, in a task that involved semantical decision, that only human hand primes had an effect on the motor resonance mechanism of humans. Differently from the mentioned studies involving robot agents, in our study we focused attention on paired objects because our purpose was to test if the participants can consider an agent at a higher level, as characterized by the capacity to "think" an action goal.

The difference with the other studies mentioned above is that in these other studies, the robotic agents were presented in a relatively simple context, in which they were related to low level perceptions.

In our study, however, we used pairs of objects where coupling in functionally matching or incongruent pairs led to different perceptions of the final outcome of the action, and therefore of the purpose of the robot agent. We can therefore think of our robot agent not just as a mere performer, but as a performer with a intent. The presence of a paired-object affordance effect can support the thesis that humans can perceive a humanoid entity as capable of performing a complex action with two objects.

Chapter 5: General Discussion

The results of the experiments presented in this thesis provide evidence on the existence of various mechanisms interacting with object affordances.

In Chapter two, we descried three experiments aimed to clarify whether the affordance effects can be attributed to the activation of objects affordance or they are due to a generic spatial encoding effect. We found that the visual asymmetry of the stimulus and affordance effects due to presence of an object's graspable part interacted with the object state (i.e. switched on vs switched off torches). At a first glance, the findings from Experiment 1 seem to support the affordance view since they showed a facilitation effect in discriminating the size of an object when the graspable part of the object matched the position of the requested response only when the object was presented in an active state. However, we should remember that in this experiment the stimulus was centred in relation to the entire image frame. In this case, in the switched-on condition, the torches were perceived as asymmetrically unbalanced in the handle tip direction. To address this issue, in Experiment 2, the stimulus was centred in relation to the body of the torch; in this case, the asymmetry on the horizontal axis was more salient in the direction of the light bulb of the torch, and indeed we found a spatial compatibility effect in the direction of the light bulb in the active state condition. This finding is in accordance with the location coding account that claims that affordance effects reflect stimulus-response compatibility effects. In Experiment 3, we tested whether the effect found in Experiments 1 and 2 emerged when a discrimination on the vertical axis was required, that is participants had to discriminate the height instead of the length of the torch. Results showed that also when a discrimination on the vertical axis is required, horizontal asymmetry plays a fundamental role in affecting performance under the different experimental conditions.

The experiments described in Chapter 3 were aimed at assessing whether affordance effect in response to pictures of graspable objects emerged even when these objects appeared as already grasped. Also, we wanted to clarify if the observed effects could be explained by spatial compatibility between the most salient part in the object and the responding hand or if they were due to an action potentiation effect due to the presence of a hand near the object. The results in the object-only condition replicated those of the previous studies (e.g., Iani et al., 2011; Tucker & Ellis, 1998), with faster responses when the object handle was located on the same side of the responding hand. This result is usually interpreted as suggesting that the object motor-related information automatically triggers congruent motor responses (e.g., Adamo & Ferber, 2009; Tucker & Ellis, 1998). We observed that when the object was grasped, the effect was stronger. We interpreted this result as due to a process of motor simulation. Despite the fact that the object was occupied and not available to perform a proper action, simulation mechanisms were activated by the presence of the biological stimulus. Furthermore, the activation of this action potentiation was present even when a hand was shown as approaching the object. Results from our studies could be explained by considering the perspective taken by the participants. It is possible that participants perceived the hand as belonging to the self, this increasing the simulation process.

As discussed in Chapter 3, there is increasing evidence supporting a location coding account of the affordance effects observed with handled objects (e.g., Cho & Proctor, 2011, 2012, 2013). Such a view could explain the results of our Experiments 1 and 2. For this reason, in Experiment 3, we presented the object along with a distractor (hand or a geometrical shape) positioned on the opposite side of the object, to determine if the observed effect could be due to a saliency based on spatial code. The results indicated that the location coding produced a Simon like effect, but the analyses showed that this effect was smaller than the effect found in the grasped-object condition in Experiments 1 and 2 when an approaching hand was displayed grasping or near the object. Besides, a hand displayed in the opposite side of the handle acted in the same way as a non-biological stimulus such as a square. Our findings are in line with the increasing evidence indicating that both motor affordances and spatial compatibility mechanisms contribute the effects observed in tasks as those described in this thesis. However, our results showed that contextual information may modulate which mechanism prevails over the other affecting responses: a hand displayed near the object that seems to reach an object to grasp it potentiate the same action in the observer. Differently, a hand close to an object but in a position that is not compatible with grasping it (i.e. the hand located on the non-graspable part of an object) is more likely to capture attention, thus creating the preconditions for the emergence of a spatial compatibility effect.

In Chapter 4, we presented an experiment aimed at determining if a robotic and a human hand exert the same effect in the activation of affordances when pairs of objects are presented. The paired- object affordance effect emerges when individuals are presented with objects that can be used together or not and they have to categorize them: responses are faster when the two objects are action-related compared to when they are unrelated. Studies have shown that this effect is sensitive to the presence of action primes (i.e. a human hand approaching the objects) (Borghi et al., 2012, Laverick et al., 2015). In our study we used as primes two human hands, two robotic hands or, as a control condition, two squares and presented pairs of objects the participants had to categorize as belonging to the kitchen context or the garage context. We manipulated whether the objects in the pair could be used together and whether the active object was located on the right or left. Participants showed different response patterns as a function of the prime type. When two squares were as primes, participants were faster in responding when the active object was located on the right and the response has to be emitted with the right hand. Participants were not affected by whether the object could be used together. We interpreted this result by suggesting that participants tended to pay attention to the salient object in the scene and, in line with previous findings (Laverick et al., 2015; Yoon et al.,2010), the more salient object is usually the active one, which is in fact the one providing more affordance information. When the robotic hands were shown as primes, participants were influenced by both the location of the active object and the possibility to use the objects together with faster responses in trials in which two functionally related objects were presented and the active object was positioned on the same side of the response. This type of prime acted as a motor prime. We hypothesized that participants perceived the robotic hands as capable to operate on the objects and perform actions with them. Surprisingly, no effect was found with human hand primes. This could be due to the fact that human hands were shown in the same position as the participants' hands. This could have activated a simulation mechanism unrelated to the task that masked the other effects.

The results of this experiment are important because they suggest that a human agent can internally simulate the actions performed by a robotic agent. The simulation of others' actions is crucial to know other people's intention and to predict the final result of an observed action. In the next future there will be an increase need of human-robot interactions and a crucial theme is whether and how humans can adapt to complex interactions with robots. Our study suggests that it is possible for humans to embody robotic hands that present similar features to those presented by human hands in terms of joints and degree of movement freedom, but which are dramatically different in shape, colour and composition. The presence of a modulation in the paired-object affordance effect following the presentation of robotic hands confirms that simulation mechanisms similar to those described in Chapter 3 observed when a human hand is seen while approaching an object or a while grasping can be activated also when the observed hands belong to artificial agents.

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