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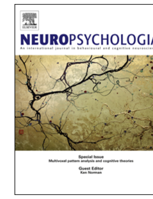

I give you a cup, I get a cup: A kinematic study on social intention

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ABSTRACT

While affordances have been intensively studied, the mechanisms according to how their activation is modulated by context are poorly understood. We investigated how the Agent's reach-to-grasp movement towards a target-object (e.g. a can) is influenced by the other's interaction with a second object (manipulative/functional) and by his/her eye-gaze communication. To manipulate physical context we showed participants two objects that could be linked by a spatial relation (can-knife, typically found in the same context), or by different functional relations. The functional relations could imply an action to perform with another person (functional–cooperative: can-glass), or on our own (functional–individual: can-straw). When objects were not related (can-toothbrush) participants had to refrain from responding. In order to respond, in the giving condition participants had to move the target object towards the other person, in the getting condition towards their own body.

When participants (Agents) performed a reach-to-grasp movement *to give* the target object, in presence of eye-gaze communication they reached the wrist's acceleration peak faster if the Other previously interacted with the second object in accordance with its conventional use. Consistently participants reached faster the MFA when the objects were related by a functional–individual than a functional–cooperative relation. The Agent's *getting* response strongly affected the grasping component of the movement: in case of eye-gaze sharing, MFA was greater when the other previously performed a manipulative than a functional grip. Results reveal that humans have developed a sophisticated capability in detecting information from hand posture and eye-gaze, which are informative as to the Agent's intention.

1. Introduction

Offering a cup of tea or pouring some juice to somebody who is holding a glass are apparently very simple actions. However, in order to perform actions as simple as the above mentioned ones, we need to possess a lot of sophisticated perceptual, motor and social abilities, which are at the core of our human endowments. These abilities include the capability to be sensitive to the messages objects send to us, i.e. to perceive their affordances. The ability to predict others' actions and to plan our own actions is a consequence of what we see, and of the ability to tune ourselves with others, taking into account the actions they are executing. For example, when we see a mug in front of us and another person holding a teapot we might be able to infer – from the combination of the two objects and from the observation of the other's action – whether he/she intends to pour some tea in our cup. If this is the case we could decide to facilitate his/her action, for example holding tight our cup, getting closer to him/her, etc. The present study investigates how physical context (i.e. different configurations and relations between pairs of objects) and social context (i.e. the intentions we infer observing actions of others) modulate the kinematics of our movement when we perform goal-directed actions with objects. To investigate the interplay between the information we extract from observation of objects and of others' actions we briefly overview two research lines which are relevant for our work, research on affordances and research on joint action, with a special focus on signalling.

In the last years the study of affordances has gained increasing interest in the field of cognitive neuroscience. Starting from the general idea elaborated by Gibson (1979), according to which there are forms of direct perception of action possibilities, scholars moved to investigate specific components of actions evoked by objects, as for example the reaching and the grasping action components evoked by objects differing in size and orientation (Ellis & Tucker, 2000; Tucker & Ellis, 1998, 2001). Empirical studies on affordances mainly focused on 2D images of single objects (Tucker & Ellis, 1998); in some studies participants were shown real objects (e.g. Tucker & Ellis, 2001) but were not allowed to directly interact with them;

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in any case, objects were not embedded within a context. Recently authors have focused also on the activation of motor information determined by 3D images of objects located in physical-interactive contexts (Costantini, Ambrosini, Tieri, Sinigaglia, & Committeri, 2010; for kinematics studies on real objects see Mon-Williams, & Bingham, 2011; Sartori, Becchio, & Castiello, 2011a), showing that this motor activation is differently enhanced by different action verbs (Costantini, Ambrosini, Scorolli, & Borghi, 2011). At the same time scholars investigated motor information activated by 2D images of objects embedded in a physical and social context. The physical context could be given by a complex scene (e.g. Kalenine, Shapiro, Flumini, Borghi, & Buxbaum, in press; Mizelle & Wheaton, 2010; Mizelle & Wheaton, 2011; Mizelle, Kelly, & Wheaton, 2013) or by the presence of a further object – typically used together with the first one or typically found in the same situation (Yoon, Humphreys, & Riddoch, 2010; Borghi, Flumini, Natraj, & Wheaton, 2012; Natraj et al., 2013). In some of these studies objects were embedded also in a sort of social context, given by the image of a hand with different postures in potential interaction with one of the two objects (Yoon et al., 2010; Borghi et al., 2012; Natraj et al., 2013). An fMRI study by Iacoboni et al. (2005) is relevant to the present one: the authors presented three kinds of stimuli: grasping hand actions without a context, context only (scenes containing objects), and grasping hand actions on a cup performed in two different contexts. In the latter condition the hand posture (either manipulative or functional) and the context suggested the final aim of the grasping action (drinking or cleaning). Actions presented within a context activated the premotor mirror neuron areas, revealing that these areas are activated during comprehension of the intention of others.

This evidence demonstrates that activation of affordances is modulated not just by the physical context (by the scene in which objects are embedded and by the different relations between object pairs) but also by the social one: context, hand-posture and kinematics information are used by the observer to recognise the motor intention of another agent; all these cues can be exploited to anticipate others' behaviour during social interaction (for a recent review on neuro-scientific literature on intentional actions see Bonini, Ferrari, & Fogassi, 2013). Further studies reveal that eye-gaze is an important indicator of others' intention (Castiello, 2003; Becchio, Bertone, & Castiello, 2008; Innocenti, De Stefani, Bernardi, Campione, & Gentilucci, 2012), as both hand posture and eye gaze are modulated by our current goal (e.g. Tomasello, Carpenter, Call, Behne, & Moll, 2005; for neuroimaging evidence see also Pierno et al., 2006).

Even if these studies have the merit to understand object affordances within a context, the physical context is clearly oversimplified, due either to the 2D presentation and to the static character of the presented images, or to the absence of a scene where objects are embedded. This simplification characterizes even more the social context, where the social dimension is simply suggested through the presentation of the image of a hand with different postures (often limited to the precision and the power grip) in potential interaction with objects (e.g. Vogt, Taylor, & Hopkins, 2003; Borghi et al., 2012; Yoon et al., 2010; Vainio, Symes, Ellis, Tucker, & Ottoboni, 2008; Setti, Borghi, & Tessari, 2009; Iacoboni et al., 2005).

In specific social contexts, the automatic resonance mechanism triggered by the observation of others' actions (e.g. Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995) can be disadvantageous. Seeing another person grasping a can to pour orange juice in my glass actually calls for a nonidentical complementary action (see Ocampo, Kritikos, & Cunnington, 2011; Sartori, Cavallo, Bucchioni, & Castiello, 2011b; Sartori, Bucchioni, & Castiello, 2012a; Sartori, Cavallo, Bucchioni, & Castiello, 2012b). Recent evidence has revealed that the mirror neuron system is activated not only during motor resonance, when we covertly imitate others, but also when we perform complementary actions with others (Newman-Norlund, Noordzij, Meulenbroek, & Bekkering, 2007). Consistently, a basic representational system that codes for imitative and complementary actions underlies joint actions (Knoblich & Sebanz, 2008). During joint activity the partner's perspective is implicitly calculated and represented in concert with one's own, outside of conscious awareness (for reviews, see Sebanz, Bekkering, & Knoblich, 2006; Knoblich, Butterfill, & Sebanz, 2011; for a recent study on early developments in joint action see also Brownell, 2011; for modeling work see Pezzulo & Dindo, 2011). Such work demonstrates that people tend to coordinate themselves in a variety of ways, for example following the same matematical principles in limbs movement (e.g. Schmidt, Carello, & Turvey, 1990) or swaying their body in similar ways during conversation (Shockley, Santana, & Fowler, 2003). Coordination can be emergent or planned. Research in cognitive psychology, for example on the Simon task, has provided compelling demonstration of how people are able to predict the actions of others while performing coordinated tasks. Evidence has shown that people tend to form a shared representation representing both their own task and the task of their coactor (e.g. Sebanz et al., 2006).

In this framework, particularly relevant to our work is literature on signaling. When we have to perform a joint action with somebody, we need to signal our action intention and to tune ourselves with the needs of the other. Paradigmatic examples are studies on infant-directed speech and actions. Evidence on motherese (Kuhl et al., 1997) and on motionese (e.g. Brand, Baldwin, & Ashburn, 2002) show that mothers tune themselves to children's needs during learning, for example stressing the vowels during speaking to allow children to better understand them or performing very simple-repetitive movements in their close proximity to capture kids' attention. Some recent studies investigate how agents in a dyadic interaction tune themselves to perform a joint action with an object, such as trying to grasp a bottle as synchronously as possible (Sacheli, Candidi, Pavone, Tidoni, & Aglioti, 2012; Sacheli, Tidoni, Pavone, Aglioti, & Candidi, 2013). In a kinematic study, Sacheli et al. (2013) manipulated the role participants could play (leader vs. follower): when they assumed the “leader role” they were instructed to manipulate the bottle without further specifications, while when they played the “follower role” they were told to coordinate with the other performing either imitative or complementary actions. Results showed that leaders tended to render their movements more communicative: they emphasized their movements reducing their variability, to allow the other to easily predict their actions.

Studies on signalling have merit to investigate online adjustments during a joint action. However, they mostly focus on communication and signalling between partners who interact with a single object, manipulating for example their interpersonal relations (Sacheli et al., 2012). As recognized by scholars studying coordination (Knoblich et al., 2011), the role of affordances in emergent coordination with multiple objects has not been investigated.

In the present experiment we combine insights from these two research areas, the study of affordances and the study of joint action and signalling. With respect to previous evidence on affordances the present study presents two novelties. First, we tested participants in an ecological and dynamical setting, using a paradigm that addressed the role of both the physical and the social contexts where participants interacted with a real object while observing the experimenter interacting with another object. Second, we manipulated the agent's goals by varying the kind of response. With respect to previous work on signaling and joint action, the present study presents other two novelties. First, we verified how objects suggested individual vs. cooperative actions by manipulating the kind of relations linking pairs of objects. Further, we focused on two kinds of signals, eye gaze and hand posture. While the influence of eye gaze (e.g. Innocenti et al., 2012) and of cooperative or competitive contexts (Georgiou, Becchio,

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Glover, & Castiello, 2007) on the kinematics of the reach-to-grasp movement has been extensively studied (for the specific effects determined by face/arm observation on participants judgments on social vs. individual actions see also Sartori, Straulino and Castiello (2011c), highlighting their role for social interaction, to our knowledge nobody so far has investigated the role hand posture can play to signal whether the agent intends to perform an individual or a cooperative action with an object. In addition, we verified how information derived from eye-gaze and posture interacts with information desumed from objects' reciprocal relations. Specifically, in a kinematic study we investigated how an agent's reach-to-grasp movement towards a target-object (e.g. mug) is influenced by the interaction with another known person (the experimenter). The experimenter moved or used an object (manipulative/functional grip), looking at the participant or at her own hand (i.e. the eye-gaze communication could be present or absent). We selected a manipulative and a functional grip on the basis of previous work (see for example Borghi et al., 2012; Iacoboni et al., 2005): the functional grip is aimed at grasping the object to use it, the manipulative grip is similar in terms of fingers configuration (both grips are power grips) but the object is held from its upper part, as when we move it. The participant had to catch a second object (target object), to give it to the experimenter or to move it towards her own body (Giving/Getting response). The two objects could be linked by a spatial (e.g. mug-kitchen paper), a functional–individual (e.g. mug-teabag) or a functional–cooperative relation (e.g. mug-teapot). In case of no relation (e.g. mug-hairbrush) the participant had to refrain from responding.

The goals of this research are threefold. One is to determine whether the eye gaze and the hand posture of another person interacting with an object are informative cues indicating whether she will perform a cooperative action or an action on her own. The second is to verify whether different kinds of relation between objects evoke different kinds of actions, individual vs. cooperative. The final goal of this work is to determine how the different goals of participants (getting vs. giving an object), together with social cues and relations between objects, modulate the motor responses.

2. Method

2.1. Participants

Twelve students took part in the experiment (mean age 23.81, SD=3.70; 6 women). All were right-handed according to a reduced revised version of the Edinburgh Handedness Inventory (Oldfield, 1971; Williams, 1991) ("which hand you use for writing/throwing/toothbrush/knife (without fork)/computer mouse?"), native Italian speakers with normal or corrected-to-normal vision and were naive as to the purpose of the experiment. The study was carried out along the principles of the Helsinki Declaration and was approved by the local ethics committee.

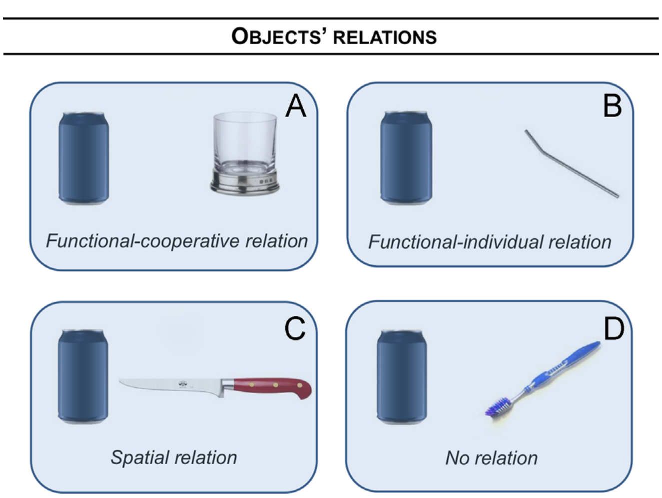

Fig. 1. The two objects could be linked by a spatial relation or by a functional one. When the two objects were not related participants had to refrain from responding.

2.2. Apparatus and stimuli

The participant and the experimenter sat in front of each other (at a distance of about 110 cm), at the opposite side of a 80 × 200 cm table. Two objects were placed on the table, one in the peripersonal space of the participant and the other in the peripersonal space of the experimenter: both objects were located at a distance of 10 cm from the table's edge. The participant performed an action on an object, the 'target object' (e.g. a can); the 'shown object' (e.g. a glass) was only seen (and not acted upon) by the participant. The target object could be linked to the shown object by four levels of relation: (1) a spatial relation (e.g. a can and a knife), if both objects are typically found in the same context (e.g. set table); (2) by a functional cooperative relation, if they are typically used together to perform an action with another person (e.g. pouring orange juice from the can in a glass Fig. 1); (3) by an individual functional relation, if they are typically used together to perform an action on our own (e.g. drinking with a straw in a can); (4) objects could be not linked at all (e.g. a can and a toothbrush).

As target objects we used an orange juice can, a tonic water can, a violet (non-handled) mug and a brown (non-handled) mug: all the objects had the same diameter (6 cm) so that participants' grips could be compared across conditions. The cans were presented with a knife (spatial relation), a glass (functional–cooperative relation), a straw (functional–individual relation), or a toothbrush (no relation) (see Fig. 1). The mugs were presented with a kitchen paper (i.e. paper towel, spatial relation), a teapot (functional–cooperative relation), a teabag (functional–individual relation), or a hairbrush (no relation).

2.3. Procedure

The experimenter [M.M.] performed a manipulative or a functional grip on the object located in front of him (see Fig. 2). The functional grip is aimed at grasping the object to use it; with the manipulative grip the object is held from its upper part, as when we move it. Then he lifted the object and relocated it in the starting position; then the participant had to perform a reach-to-grasp movement to give or to get the target object. The order of presentation of the giving and the getting blocks was counterbalanced between participants. While in the giving condition the experimenter performed the grip on the 'shown object' (i.e. the object located in the peripersonal space of the experimenter) and the participant acted on the 'target object', in the getting condition both the agents, in turn, acted on the 'target object'. Experimenter's social intention was conveyed not only by hand posture but also by the eye-gaze communication: in one condition he looked at his own hand; in another condition he looked at the participant.

In the giving condition participant's task consisted of reaching and grasping the target object (e.g. the can), located in front of her, and moving it towards the experimenter [M.M.]: the final position was fixed on the table, at a distance of 10 cm from table's edge (see Fig. 3, upper panel). In the getting condition participant's task consisted in reaching and grasping the target object, located in front of the experimenter, and moving it towards her own body: the final position was at a distance of 10 cm from table's edge (see Fig. 3, lower panel). When the two objects on the table were not related (e.g. can and toothbrush) participants had to refrain from responding.

The kind of response (giving/getting) defined two blocks of 32 trials, whose order was randomly assigned; each block was presented twice.

2.4. Data recording and analysis

Movements of the participant's right hand were recorded using the 3D-optoelectronic SMART system (BTS Bioengineering, Milano, Italy) by means of four video cameras detecting infrared reflecting markers at a sampling rate of 120 Hz and spatial resolution of 0.3 mm. Recorded data were filtered using a linear smoothing rectangular filter. Participants were informed that their movement was recorded and they were asked to perform the movement as naturally as possible. Three reflecting markers were used to record the participants' right hand. Two markers, applied on the tip of the index and thumb fingers, were used to evaluate the grasp component of movement through the time course of the distance between index and thumb. The last marker was applied on the wrist, to analyze the reach component of movement. The markers we used were fixed on a pedestal; the distance between the finger and the sphere (specifically the *center* of the sphere, used by the kinematic system to calculate the position of the spherical marker) was about 5 cm. The value of the maximal fingers' aperture actually refers to the distances between the two markers (located on the index finger and on the thumb).

The distance between the thumb and the index finger was used to determine the onset (o_g) and the termination (t_g) of the grasping component of the movement

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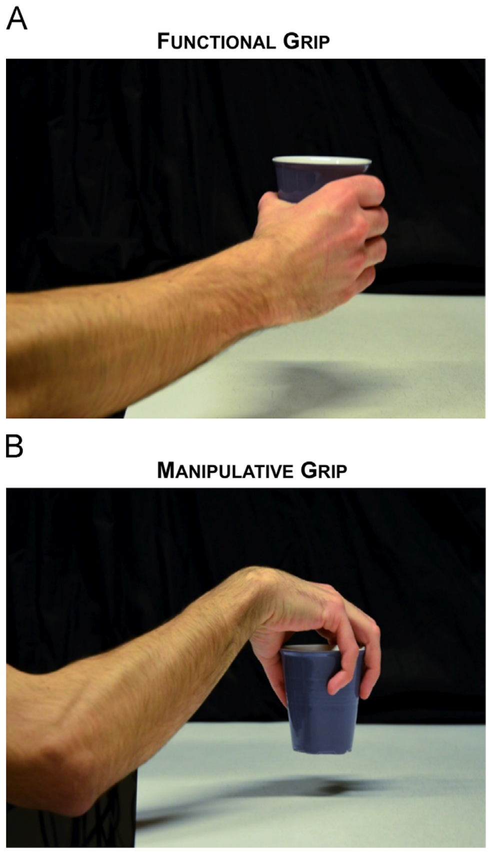

Fig. 2. The experimenter performed a functional (A) or a manipulative (B) grip on the object located in front of him. The functional grip is aimed at grasping the object to use it, the manipulative grip is similar in terms of configuration of the fingers but the object is held from its upper part, as when we move it.

(defined by the distance crossing a threshold of 5%); wrist velocity was used to determine onset (o_r) and termination (t_r) of the reaching component (defined by the tangential velocity crossing a threshold of 5% of peak velocity). As some participants started to move the fingers before the wrist, the onset of the overall movement execution was defined as the first kinematics event (o_g or o_r); symmetrically, the end of the overall movement corresponded to the last kinematics event (t_g or t_r). We used the movement execution time to define the respective distribution of the grasp and reach components, measuring the normalized Reaching Time (percentage) with respect to the overall movement time.

We investigated both the reach and grasp components of the movements, focusing on kinematics parameters already known to be affected by social cues (see Becchio, Sartori, Bulgheroni, & Castiello, 2008a; Becchio, Sartori, Bulgheroni, & Castiello, 2008b; Georgiou et al., 2007; Ferri, Campione, Dalla Volta, Gianelli, & Gentilucci, 2011; Ferri et al., 2010). Specifically, the grasping was characterized by the key parameter of latency of maximal fingers aperture (time between the grasp beginning and maximal finger aperture, MFA) and its scalar absolute value (magnitude). Similarly, the latency of wrist's acceleration peak (corresponding to the time to reach the acceleration peak during the accelerative phase) and the percentage of reaching time were considered as informative indexes for the reaching component. All these kinematic parameters have been shown to be modulated by social cues (see above). Specifically, these indexes should be affected by the type of social interaction occurring between two participants as well as by the kind of involvement of the two persons in the social interaction (e.g. Gianelli, Scorolli, & Borghi, 2013). Consistently our dependent variables were: (1) latency of wrist's Acceleration Peak (lAP); (2) Reaching Time respective to the overall movement; (3) latency of Maximal Fingers Aperture (lMFA); (4) scalar absolute value of Maximal Fingers Aperture, i.e. magnitude (mMFA).

We performed separate analyses for the giving and getting conditions, as the kinds of requested movements differed. All variables were submitted to a 2 (Eye-gaze Communication: absent vs. present) × 2 (experimenter's kind of Grip: manipulative vs. functional) × 3 (relation between the two objects: spatial vs. functional–cooperative vs. functional–individual) ANOVA; the variable eye-gaze communication was manipulated *between* participants. The significance level was set at.05. Fisher's Least Significant Difference (LSD) test was used for post-hoc comparisons when justified.

3. Results

3.1. Latency of wrist's acceleration peak (lAP)

3.1.1. Giving condition

Analyses did not show significant main effects (Eye-gaze Communication: $p=.39$; Relation between the Objects: $p=.95$), even if Experimenter's Grip showed an almost significant effect, $p=.06$: latencies were slightly shorter after a functional grip ($M=386.05$ ms) than after a manipulative grip ($M=413.43$ ms).

The interaction between Eye-gaze Communication and Experimenter's Grip was significant, F (1,10)=7.25, $MSe=3123.17$, $p<.05$. When the eye-gaze communication was absent latencies did not differ after a functional or a manipulative grip ($M=368.29$ ms and $M=360.19$ respectively, post-hoc LSD-test: $p=.67$). Conversely when the eye-gaze communication was present latencies were shorter after the experimenter's functional grip ($M=403.82$ ms) than after her manipulative grip ($M=466.67$ ms, post-hoc LSD-test: $p<.01$, see Fig. 2).

3.1.2. Getting condition

We did not find any significant effect: Eye-gaze Communication: $p=.56$; Experimenter's Grip: $p=.10$; Relation between the Objects: $p=.29$.

3.2. Reaching time respective to the overall movement (%reaching time)

3.2.1. Giving condition

We found no significant effects: Eye-gaze Communication: $p=.94$; Experimenter's Grip: $p=.94$; Relation between the Objects: $p=.10$.

3.2.2. Getting condition

Analyses on Reaching Time respective to the overall movement showed no significant effects for Eye-gaze Communication ($p=.29$) and Experimenter's Grip ($p=.29$), but a main effect of Relation between the Objects: $F(1,10)=3.67$, $MSe=2.88$, $p<.05$. Post-hoc LSD-test showed that the reaching time did not differ in case of functional–individual relation ($M=96.81$ ms) and functional–cooperative relation between the objects ($M=97.20$ ms, post-hoc LSD-test: $p=.44$). For functional–individual relation and spatial relation ($M=95.91$ ms) the reaching time slightly differed (post-hoc LSD-test: $p=.08$), but the significant effect was mainly due to the difference between functional–cooperative relation and spatial relation between objects (post-hoc LSD-test: $p<.05$).

3.3. Latency of maximal Fingers' aperture (lMFA)

3.3.1. Giving condition

Analyses showed no significant effects of Eye-gaze Communication ($p=.24$) but significant effects of both the Experimenter's Grip, F (1,10)=15.41, $MSe=1740.16$, $p<.01$, and the Relation between the Objects, $F(1,10)=4.10$, $MSe=3118.48$, $p<.05$. As to the Experimenter's Grip, the latencies to MFA was shorter in case of functional grip ($M=764.93$ ms) than manipulative grip ($M=803.53$). As to Relation between Objects, post-hoc LSD-test showed that the latencies differed for functional–cooperative ($M=808.85$) and functional–individual relation between the objects ($M=762.15$, $p<.01$). The latencies did not differ for spatial and functional relations (both cooperative and individual, post-hoc LSD-test: $ps<=.11$, see Fig. 3).

3.3.2. Getting condition

We found no significant effects: Eye-gaze Communication: $p=.50$; Experimenter's Grip: $p=.22$; Relation between the Objects: $p=.52$.

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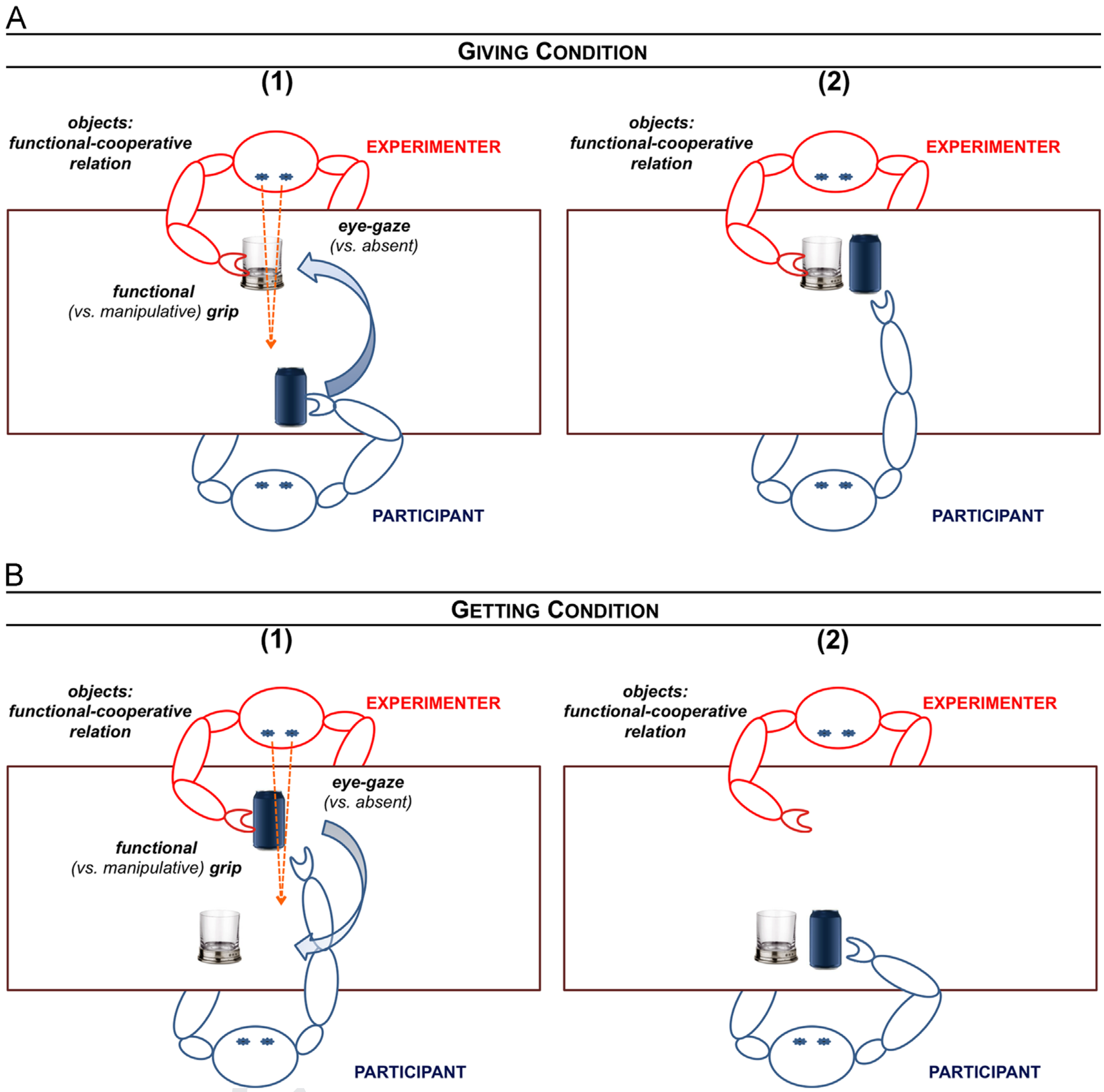

Fig. 3. For both the giving and the getting conditions (A) and (B) the experimenter interacted with an object (the glass, (A) (1); the can, (B) (1)); immediately after the participant had to perform a reach-to-grasp movement towards the target-object (the can: (A) (2), (B) (2)). In the giving condition participants had to move the target object towards the other person (A); in the getting condition towards his/her own body (B).

3.4. *Scalar absolute value of maximal fingers aperture (mMFA)*

3.4.1. *Giving condition*

We found no significant main effects: Eye-gaze Communication: $p=.94$; Experimenter's Grip: $p=.63$; Relation between the Objects: $p=.71$.

Analyses showed an almost significant interaction between the Eye-gaze Communication and the Relation between the Objects ($p=.06$), due to the smaller MFA in case of functional–individual relation between the objects and presence ($M=24.53$ cm) vs. absence of eye-gaze contact ($M=24.80$ cm, post-hoc LSD-test: $p=.05$). In case of eye-gaze present, also functional–individual relation and spatial relation ($M=24.73$ cm) slightly differed ($p=.07$).

3.4.2. *Getting condition*

We found no significant main effects of Eye-gaze Communication: $p=.94$ and Experimenter's Grip: $p=.31$, but an almost significant effect of Relation between the Objects, $p=.06$, due to the difference between spatially related objects ($M=24.40$ cm) and functionally related ones (functional–cooperative relation $M=24.56$ cm; functional–individual relation $M=24.57$ cm, $p<.04$).

Interestingly we found a significant interaction between Eye-gaze Communication and Experimenter's Grip, $F(1,10)=5.12$, $MSe=5.67$, $p<.05$, mainly due to the fact that for the eye-gaze sharing condition the MFA was smaller after the Experimenter's functional grip ($M=24.40$ cm) than after the Experimenter's manipulative grip ($M=24.59$ cm, post-hoc LSD-test $p<.05$). The interaction to some extent was also due to the difference between the MFA after Experimenter's functional grip for eye-gaze absent or present ($M=24.57$ cm and $M=24.40$ cm respectively, $p=.06$, see Fig. 4).

4. Discussion

Results from the present study reveal that we are sensitive to the physical context (i.e. the relations between objects) but also to the social one. During the giving response, that is when participants had to grasp the close object (target object: a can or a cup) to move it in the peripersonal space of the experimenter, interaction with the object in accordance with its conventional use (functional grip) anticipated the MFA. In presence of a social request conveyed by the eye-gaze communication, the effect became significant also

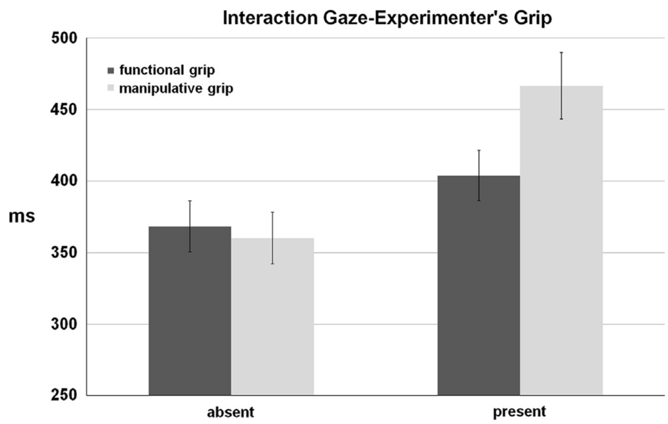

Fig. 4. Latencies of acceleration wrist for the giving condition: interaction between Eye-gaze and Experimenter's grip. Error bars represent the standard error.

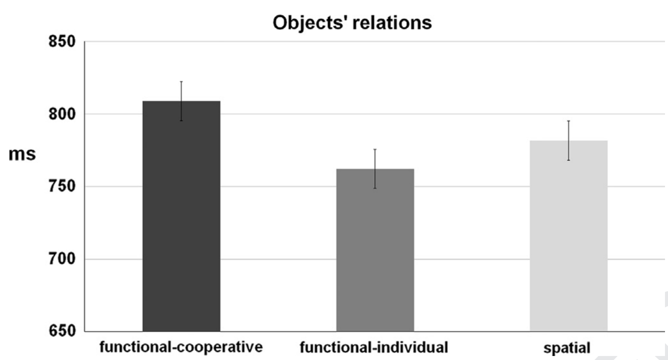

Fig. 5. Latencies of maximal fingers aperture for the giving condition: main effect of the kind of Relation between the Objects. Error bars represent the standard error.

for the reaching component of the movement (latency of maximal wrist' acceleration). Moreover we found that objects' relations affected the grasping component since – when participants had to grasp the target object to give it to the experimenter – the MFA was reached faster whether the 'target object' and the 'shown object' (i.e. the object located in the peripersonal space of the experimenter) were objects typically used to perform an action on our own (e.g. a can and a straw: functional–individual relation) rather than a cooperative action (e.g. a can and a glass: functional–cooperative relation). This result suggests that also the reciprocal relation between objects conveyed a sort of request: when they were linked by a functional–individual relation, the first (firstly used) object asked for the second one. Crucially this request, conveyed by physical context, could be enhanced by the presence of eye-gaze: for functionally–individually related objects, when the experimenter looked at the participant the MFA was smaller (consistently with a fine-grained action) compared to the absence of gaze-request condition Fig. 5.

During the getting response both the experimenter and the participant performed the action on the same object (target object: a can or a cup); the second object was located in the peripersonal space of the participant. In this condition the aim of the agent (participant) consisted in grasping the target object, located in the peripersonal space of the experimenter, to move it towards her own peripersonal space. For the getting response, both the reaching and the grasping component of the movement highlighted a modulation determined by the kind of relation between the two objects: the percentage of reaching time respect to the overall movement was longer and the MFA was greater for the functionally linked objects than for the spatially linked ones. Moreover, when the experimenter was not looking at the participant, the MFA after a manipulative or functional grip did not differ. Crucially, in presence of eye-gaze contact, the MFA was smaller (fine-grained action) when the experimenter had previously performed a functional rather than a manipulative grip, as if participants coordinate-mediate between experimenter's intention to use the object and their own intention to get-use it. But: if the experimenter had previously performed a manipulative grip (i.e. suggesting the intention to pass the object), participants' MFA significantly increased, as they 'felt entitled' to get the object, similarly to when the objects are functionally, and not just spatially, linked (i.e. when the first objects "ask for" the second one) Fig. 6.

Our interpretation of a *small* MFA as expressing an accurate action is also consistent with results we found in case of giving condition (even if the parameter of MFA does have a different meaning in case of giving or getting response). The almost significant interaction between the eye-gaze communication and the relation between objects is (partially) due to a smaller MFA with eye-gaze contact when the objects were linked by a functional–individual relation than by a spatial relation: that is, when the experimenter, with 'her' teabag, is looking at me and I have to pass her the mug, I need to carefully coordinate my action with her. Consistently, in the giving condition we found that with functionally–individually linked objects participants' MFA was smaller when the experimenter was looking at the agent than when he was looking somewhere else. This last result mirrors findings for the getting condition: after the experimenter's functional grip (conveying the intention to use the objects), participants' MFA was smaller for presence than for absence of eye-gaze.

Finally, it is worth noting that in the getting condition the target object was close to the experimenter, and the experimenter performed an action on it. Recent studies conducted in our lab have demonstrated that the physical proximity as well as the object-interaction are powerful indexes in determining the ownership of a neutral object (Tummolini, Corolli, & Borghi, 2013; Scorolli, Borghi, & Tummolini, in preparation). Our understanding of the magnitude of MFA for the getting condition is consistent with this evidence: grasping an object previously used by another person to move it from the other's peripersonal space to our own close space, could be interpreted as 'taking possession' of that object. Therefore the MFA index should be strongly modulated by both the other person's eye-gaze and his/her kind of grip, that is by his/her intention to collaborate.

Further evidence supporting this interpretation is that in the getting condition the relation between objects affected the reaching time: when objects were only spatially linked, participants

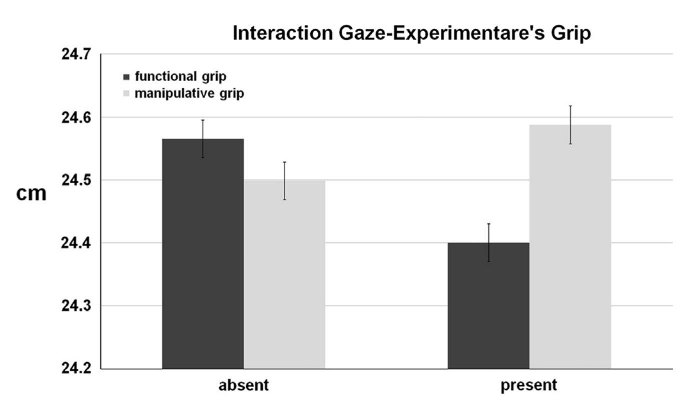

Fig. 6. Scalar absolute value of maximal fingers aperture for the getting condition: interaction between Eye-gaze and Experimenter's grip. Error bars represent the standard error.

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reached and got them faster than when they were related by a functional–cooperative relation. That is: when objects (e.g. a teapot and a mug) are typically used in collaboration with another person, and in absence of a previous knowledge of/relation with this person (that would possibly allow to predict his/her intention, see Gianelli et al., 2013), we do not feel entitled to get ('to subtract') the target object from her/him (e.g. to pour tea from her/his own teapot on our mug). Conversely, in case of spatially related objects (e.g. a knife and a mug), participants 'safely' got (took away) the mug from the experimenter's peripersonal space, to put it close to the knife.

To summarize, the giving response can be interpreted as a less competitive context, as agents did not compete for the same object. In this condition both the experimenter's functional grip and the functional–individual relation between objects anticipated the reach-to-grasp movement and made it fine-grained. The eye-gaze contact, if present, amplified these effects. This is consistent with functional imaging and developmental studies showing evidence for (a) modulation of activity in structures of the social brain network during eye contact as well as (b) preferential orienting towards face with direct gaze (for a recent review see Senju & Johnson, 2009; for a direct comparison of "direct gaze", "averted gaze", and "gaze to the acting hand" see Wang & de Hamilton, 2013). Conversely, the getting response defined the context as competitive (for kinematic and neural investigations of cooperative and competitive behavior see respectively Georgiou et al., 2007; Decety, Chaminade, Grèzes, & Meltzoff, 2002). The kinematic index particularly sensitive to this manipulation seemed to be the magnitude of the MFA: analyses on MFA showed that the experimenter's manipulative grip and the functional (individual or cooperative) relation between the objects caused a great MFA, as if participants felt entitled to take possession of the object. The presence of the experimenter's eye-gaze communication after a functional grip inhibited participants' getting response.

Moving from the analysis of affordances, we have demonstrated that, when objects are presented in a social context (i.e. in presence of a dyadic interaction between two agents), mechanisms of complementary actions are activated (Ocampo et al., 2011; Q3 Sartori et al., 2011a, 2011b, 2011c; Sartori et al., 2012a, 2012b; Knoblich & Sebanz, 2008). The other person's hand posture, the position of her body with respect to the objects and her gaze direction provide important cues in discriminating whether the agents are acting for a shared goal or individual purposes (e.g. Ferri et al., 2010). We will discuss below what in our view are the most novel results of our study.

4.1. Hand posture as a signal of individual vs. cooperative action

Our study indicates that the hand posture with respect to an object can provide a very informative cue on the individual or cooperative character of the action that will follow (see also Sartori et al., 2011a). In additon, as highlighted in the first part of the discussion, together with the object location with respect to the bodily space, it can provide information on object ownership.

A number of studies have shown that observing another person hand posture can help to predict the kind of action he/she will perform, and to prepare for acting as a consequence of this (e.g. Borghi et al., 2012; Natraj et al., 2013; De Stefani, Innocenti, De Marco, & Gentilucci, 2013). But to our knowledge all studies so far have focused on individual actions. The novelty of the present work is that it suggests that hand posture can be a powerful predictor of the social or individual character of the action that will follow. Our results consistently show that the differences between grip affected both the reaching and the grasping components of the action kinematics. More specifically, during reaching for the object to give it to the other, participants were faster in reaching the acceleration peak after the other's functional compared to the other's manipulative grip, in case of eye gaze sharing. The advantage of the functional over the manipulative grip was maintained also in the latency of MFA (independently from the presence or not of eye gaze). This sensitivity to the difference between the functional vs. the manipulative grip of others is crucial to understand the signal conveyed by the other, indicating whether he/she intends to interact with the object on his/her own or in a collaborative fashion (manipulative grip). The fact that observing a functional grip fastens the reaching of wrist's acceleration peak (see the *giving* condition) can seem in contrast with results of the literature on power and precision grip (i.e. faster movement for power grips, see Castiello, Bennett, & Paulignan, 1992). We clarify below why we do not believe this is the case.

There is evidence showing that processing of power grip, more associated with manipulation, is faster than precision grip, which is more complex and more typically associated with functional actions (Gentilucci et al., 1991; Begliomini, Wall, Smith, & Castiello, 2007; Castiello, 2005; see also Borghi et al., 2007; Vainio et al., 2008; Kalenine et al., in press). The higher complexity of the precision grip is further testified by neurophysiological studies (Henrik, Fagergren, & Forssberg, 2001). One of the reasons why the power grip is processed faster than the precision one is its lower level of determination: the hand shape characterizing the power grip can correspond to the initial phase of a precision grip. In our study the functional grip is not a precision grip, but a differently oriented power grip (for the use of a similar posture see Iacoboni et al., 2005). The difference found in the motor responses to the two kinds of grips cannot therefore depend on the processing of grips having different degree of determination. At the same time, it is hardly the case that the advantage of the functional grip in our study depends on its association with function (it should eventually slows down the response. The advantage of the functional grip can instead be understood if the information on hand grip is considered in light of our interactive experimental setting. In our paradigm the manipulative grip is not less determined than the functional grip in terms of configuration of the fingers, but it is less determined in terms of the final outcome of the action it implies. It is indeed more open to the possibility of interacting with another person, for example of offering the object to her, or of letting her interact with it.

In sum, the present study is the first to highlight that hand posture can work as a cue indicating whether the agent intends to perform an action with the object on his/her own or whether he/she intends to engage in a cooperative action. While the importance of eye-gaze for social interaction has been widely emphasized also due to its role in development (Tomasello, Hare, Lehamann, & Call, 2007; for a recent study on in infants of blind parents see also Senju et al., 2013a; for a recent review on processing of others' gaze direction by individuals with autism spectrum disorders see Senju, 2013b), the role that hand posture can play to inform on the intention to perform an individual vs. a cooperative action strikes us as completely new. Notice that in our study the hand posture of the experimenter was established a priori, but our results clearly show that participants are sensitive to its signalling character and adjust their actions as a consequence of it. Thus we found a complex interplay of planned and emergent coordination. Further research is needed to investigate the role hand posture might play in more free situations of emergent coordination.

4.2. Relations between objects as affording individual vs. cooperative actions

Literature on affordances has provided compelling evidence that objects evoke motor responses. Studies on objects in physical context have revealed that depending on the scene/on other displayed objects, objects can afford a different kind of action,

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for example a manipulative or a functional one (Kalenine et al., in press). The difference between the responses activated during observation of spatial and functional relations between objects has been investigated in a number of studies, both in research on categorization (see studies on thematic relations, e.g. Castiello, Scarpa, & Bennett, 1995; Bennett, Thomas, Jervis, & Castiello, 1998; Estes, Golonka, & Jones, 2011) and on affordances (Yoon et al., 2010; Borghi et al., 2012). All these studies have focused on individual actions (for an exception, see Ellis et al., 2013). Other recent studies investigated cooperative/competitive complementary actions, focusing on two agents (e.g. Ocampo et al., 2011; Sartori et al., 2011a, 2011b, 2011c; for a recent review on complementary abilities see Creem-Regehr, Gagnon, Geuss, & Stefanucci, 2013). The present study greatly extends this evidence as our new experimental design allows to simultaneously evaluate the reciprocal weight of social cues (i.e. the other's hand shaping; the eye-gaze contact; the intention of the agent) as well as of physical cues (e.g. the relations between objects). Our results demonstrate that observing objects evokes a motor response (affordance), and that that this response differs depending not just on common goals or social requests, but also on the kind of relation existing between objects (simply linked by spatial relations vs. complementary in use): the specific kind of relation can suggest other possible ways to interact with others (emergence of social affordance). The possibility that participants are sensitive to the fact that the relationships between objects can lead to an individual vs. a social action is in our view completely new.

Finally, as highlighted in the initial part of the discussion, the different action goal modulate movements in a complex interplay with social cues and objects relationships, both signalling an action intention.

In sum, our study goes beyond current literature on affordances since it reveals that different relations between objects suggest individual vs. cooperative actions, and it extends literature on signalling since it highlights the role played by hand posture, as indicating the start of an individual vs. cooperative actions. Findings clearly show how hand posture, eye gaze and the bodily position in space, together with the different agent's goal, can suggest an interactive vs. and individual action. Overall, the social dimension can contaminate in depth our relationship with the environment: the way in which objects are positioned not only suggests how we might interact with them, but also how we can use them together with other people, for cooperative or competitive actions (for a similar view, see Ellis et al., 2013); the way in which we perceive the hand posture, the position of the body in space and the eye gaze of others opens possibilities of interaction. This strongly suggests that the environment has to be intended not only as physical but as social from the very start.

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