

# Grasping affordances with the other's hand: A TMS study

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**The power of an object to afford a suitable act has been shown to depend on its reachability. Nevertheless, most of our perception and action occur in a social context. Little research has directly explored whether the possibility for other people to act upon an object may affect our processing of its affording features. To tackle this issue, we magnetically stimulated the left primary motor cortex and recorded motor-evoked potentials (MEPs) while participants were presented with a handled object (i.e. a mug) close either to them or to a virtual individual such as an avatar. We found highest MEPs both when the mug was near enough to be actually reachable for the participants and also when it was out of reach for them, provided that it was ready to the avatar's hand. We propose that this effect is likely to be due to an interpersonal bodily space representation, which plays critical role in basic social interaction.**

**Keywords:** affordance; social cognition; peripersonal space; interpersonal body; representation

## INTRODUCTION

Neurophysiological (Rizzolatti *et al.*, 1988; Jeannerod *et al.*, 1995; Murata *et al.*, 1997; Raos *et al.*, 2006; Umiltà *et al.*, 2007), brain imaging (Chao and Martin, 2000; Creem-Regehr and Lee, 2005) and behavioural studies (Tucker and Ellis, 1998, 2001, 2004; Borghi *et al.*, 2007) demonstrated that visual features afford actions even in the absence of any intention to act. As is well known, J.J. Gibson (1979) coined the term affordance to denote the power of the surrounding things to furnish the viewer with possible actions. More recently, Ellis and Tucker (2000) introduced the notion of micro-affordance, to characterize the objectual features typically suggesting or even demanding object-related motor acts (e.g. hand- or mouth-grasping, manipulating, tearing, etc.).

Previous experiments have shown that the power of an object (e.g. a handled mug) to afford a suitable motor act (hand grasping with a precision grip) is modulated by its actual reachability. At the behavioural level, Costantini *et al.* (2010) took advantage of the spatial alignment effect paradigm (Bub and Masson, 2010). Participants were instructed to replicate a reach-to-grasp movement with the right or the left hand as soon as a task irrelevant to signal (e.g. a left–right-oriented handled mug) appeared. The results showed that the spatial alignment effect occurred only when the task irrelevant to object was presented within the reaching space of the participants. Subsequently, in a TMS study, Cardellicchio *et al.* (2011) recorded motor-evoked potentials (MEPs) from the right first dorsal interosseus (FDI) and opponens pollicis (OP), while participants observed 3D stimuli depicting a room with a table and a mug placed on it. Crucially, the mug could be located either within or outside the reachable space of the participants. The results showed higher MEPs only when the mug was near enough to be actually reachable.

These findings clearly indicate that the spatial location of an object may impact on its actual power to evoke action. However, we usually do not perceive and act upon objects by ourselves. Therefore, the question arises as to whether affordance processing might be affected

by the presence of other people. It has been shown that the affective evaluation of objects can be influenced by the fact that the objects are jointly attended (Bayliss *et al.*, 2006) or that they are looked at by someone else with a happy or a disgusted expression (Bayliss *et al.*, 2007).

Nevertheless, little research has directly explored whether the mere presence of another individual may shape our perception of affording features. Does the possibility for another individual to reach for an object and to act upon it affect the way that object is given to us, starting from its affording features?

In a previous behavioural experiment (Costantini, Committeri and Sinigaglia, 2011), we showed that an object does afford a suitable action not only when the affording object falls within the reaching space of an individual, but also when it is presented outside her own reaching space but within the reaching space of a virtual actor such as an avatar.

The present TMS study aims to provide the aforementioned findings with a neuronal counterpart, by assessing whether and to what extent the presence of another individual might impact on the observer's processing of affording features as measured by the excitability of the motor cortex. To this purpose, we magnetically stimulated the left primary motor cortex and recorded MEPs from the right FDI and OP, while participants observed 3D stimuli depicting a room where a virtual individual such as an avatar was seated on a table with a handled mug ready to hand. The mug could be located either within or outside the reaching space of the participants. In a control condition, the virtual avatar was replaced by a non-corporeal object such as a cylinder.

The results showed that the mere sight of an affording object located outside the reaching space of the participants, but within the reaching space of a virtual individual, such as an avatar, might evoke a suitable motor response similar to that afforded by an object falling within the participants' reaching space. Indeed, we found highest MEPs both when the mug was near enough to be actually reachable for the participants and also when it was out of reach for them provided that it was ready to the avatar's hand. No significant MEPs modulation was found when the mug was close to the cylinder. In a second experiment, we ruled out that MEP modulation could be merely due to unspecific attention cues provided by the avatar gazing at the affording object.

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## MATERIALS AND METHODS

### Experiment 1

#### Participants

Twenty healthy naïve volunteers took part in the experiment (19 females, mean 24 years, range 20–29). All participants were right-handed, as assessed with the Edinburgh Handedness Inventory, and screened to exclude a family history of psychiatric, neurological or medical disease. All of them gave informed consent before the experiment, which had been approved by the Ethics Committee of the G. d'Annunzio University, Chieti, and conducted in accordance with the ethical standards of the 1964 Declaration of Helsinki.

#### Stimuli

The visual stimuli consisted of 3D rooms, with a table and a mug on it, created by means of 3D Studiomax v.13. The handle of the mug was oriented towards the right (Figure 1, panel A). In half of the trials, the mug was placed within the reachable space of the participants (30 cm), whereas in the other half, it was in the non-reachable space (150 cm). Moreover, within each spatial sector, in half of the trials, an avatar was seated on a chair on the right side of the table, facing the object, while in the other half of the trials a non-corporeal object, namely a cylinder, was placed on the same chair. It is important to note here that both the avatar and the cylinder occupied the same area. As a control condition, participants were presented with the 3D room furnished with the table and either the avatar or the cylinder. In these trials, the mug was not present. Moreover, at the beginning and at the end of the experimental session, a 3D room with only a table was used. This stimulus served as baseline and was presented in a separate block. Each participant provided us with 20 trials per experimental condition and 40 trials which served as baseline.

#### TMS and electromyography recording

MEPs were recorded simultaneously from the right OP and FDI hand muscles by means of a CED Micro 1401 (Cambridge Electronic Design, Cambridge, UK). EMG signals were amplified (1000×), digitized (sampling rate: 8 kHz) and filtered with an analogical online band-pass (20–250 Hz) and a notch (at 50 Hz) filter. EMG signals were stored on a computer for offline analysis. Pairs of Ag–AgCl surface electrodes were placed in a belly tendon montage on each muscle, with further ground electrodes on the wrist. A figure-of-eight coil connected to a Magstim Rapid2 stimulator (Magstim, Whitland, UK) was placed over the left primary motor cortex with the handle pointing backwards at 45° from the midline. The optimum scalp position (OSP) was chosen so as to produce maximum amplitude MEPs in the FDI muscle. Pulse intensity was set at 120% of the resting motor threshold (rMT), defined as the lowest level of stimulation able to induce MEPs of at least 50 mV in both muscles with 50% probability. Thus, in each subject, the rMT was based on the higher threshold muscle. This way a stable signal could be recorded from both muscles. The absence of voluntary contraction before the TMS pulse was continuously verified visually by monitoring of the EMG signal.

#### Procedure

Participants sat on a comfortable chair in front of a computer screen with a resolution of 1024 horizontal pixels by 768 vertical pixels, at a distance of ~57 cm. The right hand was placed in a totally relaxed prone position on a seat cushion. Each trial started with the presentation of a fixation cross. After 500 ms, the fixation cross was replaced by the stimulus for 500 ms. Based on the previous evidence (Coello *et al.*, 2008; Makin *et al.*, 2009; Ortigue *et al.* 2010), a TMS pulse was delivered 75 ms after stimulus presentation. Stimulus presentation was

followed by a blank screen of 6000 ms duration. Participants were verbally requested to simply observe the stimuli. The order of the stimuli was pseudorandomized. The presentation of the stimuli and the timing of the TMS pulses were controlled by custom software (developed by Gaspare Galati; Galati *et al.*, 2008), implemented in MATLAB (The MathWorks Inc., Natick, MA, USA). Before the experimental session, participants were familiarized with the visual stimuli.

#### Data analysis and results

Neurophysiological data were processed offline. Trials with EMG activity prior to TMS were discarded from the analysis (<5% in each subject). Mean MEPs amplitude values (row values are reported in Supplementary Table S1) in each condition were measured peak-to-peak (in mV). MEPs amplitude values recorded during the experimental and control conditions were divided by MEPs amplitude values recorded during the baseline block collected at the beginning and at the end of the experimental session (MEP ratios). Then, the MEPs amplitude values evoked during the condition in which the mug was not present were used to compute an index of MEPs modulation, obtained by the ratio between the averaged MEPs recorded in each condition in which the mug was present and the averaged MEPs recorded in the condition in which the mug was not present. Tests for normal distribution utilized the Lilliefors modification of the Kolmogorov–Smirnov test. MEP indexes were entered into a three-way ANOVA with recorded muscle (FDI vs OP), object location (reachable vs non-reachable) and agent presence (avatar vs cylinder) as within-subjects factors. The ANOVA revealed only a significant second-order interaction object location by agent presence [ $F(1,19) = 8.4, P < 0.01$ ; see Figure 2]. Post hoc analysis (Newman–Keuls test) showed that when the cylinder was present MEPs were higher for objects located within the reachable space (mean = 107%; s.e.m. = 2.64) as compared to the observation of the same object in the non-reachable space (mean = 98%; s.e.m. = 2.66;  $P = 0.015$ ). On the other hand, when the avatar was present, such difference was not there (reachable: 104%, non-reachable 106%;  $P = 0.47$ ). Finally, post hoc analysis revealed that when the object was located within the non-reachable space of the participants, MEPs were higher when the avatar was present (mean = 106%; s.e.m. = 2.84) as compared to when the cylinder was present (mean = 98%; s.e.m. = 2.66  $P = 0.037$ ).

#### Experiment 2

In the previous experiment, we found that the presence of the avatar modulated the cortical activity, while a graspable object was presented. However, one may argue that such an effect could be accounted for just in terms of a mere gaze–object relation. Indeed, it has been shown that simply observing an actor looking at an object does selectively recruit the sensori-motor system of the onlooker (Pierno *et al.*, 2006; Becchio *et al.*, 2008). Thus, the fact that in our experiment the avatar always faced the object could be construed as both a necessary and a sufficient condition for the recruitment of the participant's motor representation relative to the affording feature of the presented object. To disentangle this question, we ran a second experiment in which we interposed a near transparent panel between the avatar and the affording object. This panel did not prevent the avatar from seeing the object, but did prevent the possibility to interact with it (for a similar manipulation see Farnè *et al.*, 2003; Kitagawa and Spence, 2005; Caggiano *et al.*, 2009). This manipulation allowed us to assess whether the effect we found in the first experiment was due to unspecific attentional cues or to the actual reachability by someone else of the affording object.

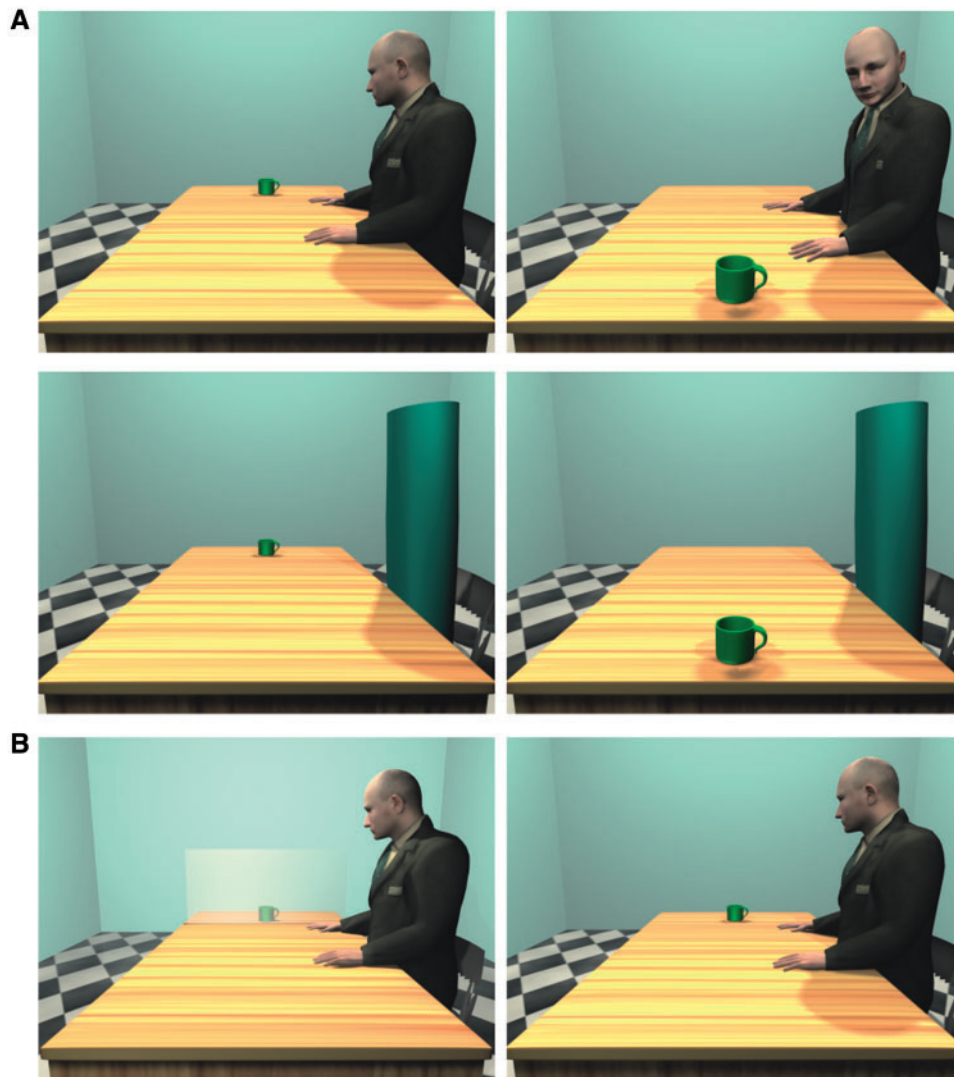


Fig. 1 Example of stimuli used in experiment 1 (Panel A) and experiment 2 (Panel B).

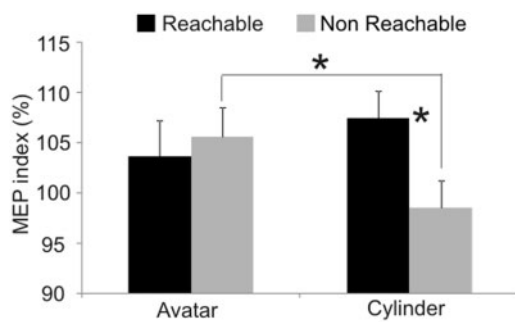


Fig. 2 MEPs index in the experimental conditions. Error bars indicate standard errors. \* $P < 0.05$ .

**Participants**

Twenty healthy naïve volunteers took part in the second study (16 females, 4 men, mean 25 years, range 22–28). All participants were right-handed as assessed with the Edinburgh Handedness Inventory and were screened to exclude a family history of psychiatric, neurological or medical disease. All of them gave informed consent before the experiment, which had been approved by the Ethics Committee of

the ‘G. d’Annunzio’ University, Chieti, and conducted in accordance with the ethical standards of the 1964 Declaration of Helsinki.

**Stimuli and procedure**

The visual stimuli consisted of 3D rooms, with a table and a mug on it, created by means of 3D Studiomax v.13. The mug was always located beyond the reachable space of the participants, and its handle was oriented towards the right (Figure 1, Panel B). An avatar was always seated on a chair on the right side of the table. In half of the trials, the mug was placed in the reachable space of the avatar, whereas in the other half, it was beyond a semi-transparent panel, thus resulting metrically at the same distance as the previous condition, but outside its reaching range. As a control condition, participants were presented with the 3D room furnished with the table and the avatar. In these trials, the mug was not present. Moreover, at the beginning and at the end of the experimental session, a 3D room with only a table was used. This stimulus served as baseline and was presented in a separate block. Each participant provided us with 20 trials per experimental condition and 40 trials which served as baseline. The procedure, TMS and electromyography (EMG) recording were the same as in the previous experiment.

### Data analysis and results

As in experiment 1, neurophysiological data were processed offline. Trials with EMG activity prior to TMS were discarded from the analysis (<4% in each subject). Mean MEPs amplitude values (row values are reported in Supplementary Table S2) in each condition were measured peak-to-peak (in mV). MEPs amplitude values recorded during the experimental and control conditions were divided by MEPs amplitude values recorded during the baseline blocks collected at the beginning and at the end of the experimental session (MEP ratios). Then, the MEPs amplitude values evoked during the condition in which the mug was not present were used to compute an index of MEPs modulation, obtained by the ratio between the averaged MEPs recorded in each condition in which the mug was present and the averaged MEPs recorded in the condition in which the mug was not present. MEP indexes were entered into a two-way ANOVA with recorded muscle (FDI vs OP), object location (reachable vs non-reachable) as within-subjects factors. The ANOVA revealed only a significant main effect of object location [ $F(1,19) = 10.8, P < 0.01$ ], being MEPs while observing the object within the reachable space of the avatar (mean = 100%; s.e.m. = 2.60) higher than the same object located in the non-reachable space of the avatar (mean = 93%; s.e.m. = 2.12).

### DISCUSSION

In this study, we aimed to investigate whether and to what extent the presence of another individual, even a virtual one such as an avatar, might impact on the brain processing of the affording features of a given object. Our results provided neurophysiological evidence that the mere sight of an affording object significantly recruits the cortical motor system provided that the seen object is ready either to one's own or to others' hands. Indeed, we found that MEPs recorded from the right FDI and OP muscles were higher in amplitude when the affording object (i.e. a mug) fell within either the participants' or the avatar's reaching space than when the very same object was presented outside the participants' reaching space and close to a non-corporeal object such as a cylinder.

These findings extend previous TMS results on micro-affordances (Ellis and Tucker, 2000) demonstrating that the observer's motor system is selectively recruited by graspable near objects only, being FDI and OP facilitation absent for both graspable far and ungraspable near and far objects (Cardellicchio *et al.*, 2011). They indicate that the space dependence of micro-affordances does not make them a private business of a single individual, thus preventing her from being sensitive to others' affordances. According to our findings, the affording features of an object may evoke a suitable motor response in the observer's brain even when it is out of her reach, provided that it falls within the reaching space of another (potential) actor.

One might argue that seeing someone else gazing at an object could be enough to recruit the observers' motor system. The presence of an object through gaze has been shown to elicit in an observer a similar neural response to that elicited by the observation of a grasping action performed on the same object (Pierno *et al.*, 2006; Becchio *et al.*, 2008). However, the gaze-object relation seems to be a necessary but not sufficient condition to account for the motor responses in the observers' brain when the mug was presented close to the avatar. Indeed, our second experiment showed that MEPs significantly decreased when the avatar was still facing the mug but was prevented from reaching it by a near transparent barrier. This also rules out the confound that the increased MEPs recorded in the two avatar conditions of the first experiment simply reflected the presence of the avatar, thus being not selectively related to the reachability of the mug.

Taken together, our experiments indicate that people are sensitive not only to the affording features of an object ready to their own

hands, but also to someone else's being afforded by an object ready to her hands. Our neurophysiological data are in line with previous evidence demonstrating, at the behavioural level, not only that we are able to make accurate perceptual estimates of what the environment affords others, but also that such ability is shaped by our own action capability (Stoffregen *et al.*, 1999; Ramenzoni *et al.*, 2008). What our data seem to add to such behavioural evidence is that the recruitment of the motor resources in the observer's brain may also be modulated by the actual possibility for the agent to make use of her alleged action capabilities (Ambrosini *et al.*, in press).

How to account for one's sensitivity to someone else's being afforded by the surrounding world? Our proposal is that such sensitivity can be explained by means of an interpersonal bodily space representation allowing one to map the body of other people in terms of their actual motor possibilities. There is evidence for the existence of an interpersonal bodily space mapping in the visuo-tactile domain (Sirigu *et al.*, 1991; Reed and Farah, 1995; Maravita *et al.*, 2002; Thomas *et al.*, 2006; Ishida *et al.*, 2009). In particular, this spatial mapping has been shown to play a crucial role in processing sensory events on others' body at the behavioural level (Thomas *et al.*, 2006). Tactile stimuli were delivered on the participants' body either at a congruent or incongruent anatomical location with respect to the location of a visual stimulus (brief flash of light) delivered on the body of another individual. The results showed that participants were faster at detecting tactile stimuli on their own body, when the visual stimulus was delivered at the same location on the body of the other individual. Crucially, this effect was body specific, not occurring when visual stimuli were delivered at a non-bodily object (e.g. a house).

Similar results have been found at the neuronal level. Visuo-tactile neurons have been recorded from the ventral intraparietal (VIP) area of the macaque brain (Ishida *et al.*, 2009). Most of these neurons exhibited visual receptive fields in register with the tactile ones and anchored on a single bodily part (face, forearm, hand, trunk, leg, etc.), selectively responding to the visual stimuli delivered within the interpersonal space of the monkey. Interestingly, a significant portion of them exhibited both visuo-tactile RFs on the monkey's body and visual RFs close to the experimenter's body, selectively discharging when a visual stimulus was delivered at 120 cm from the monkey's bodily parts but close to the corresponding experimenter's bodily parts. When visual stimuli were presented at the same distance from the monkey but in the absence of the experimenter, the responses were almost absent.

Our data expand the range of the interpersonal bodily space representation to the motor domain, highlighting that such representation enables one not only to map the sensory stimuli around the body of others, but also to grasp their body as a situated body which might be afforded by the surrounding things, provided that the latter are ready to hand. A natural question arises as to what this motor interpersonal bodily space representation is for.

Our findings seem to suggest that this bodily space mapping might bridge the gap between the sensorimotor processing of objects and others' actions. There is plenty of evidence that observing other people acting recruits in the observer's brain the same motor resources as if she were performing the observed action, and it has been argued that this motor recruitment allows the observer to immediately understand what other people are doing (Rizzolatti and Sinigaglia, 2010) as well as to anticipate what they are about to do (Kilner *et al.*, 2004; Urgesi *et al.*, 2010). Interestingly, the observer's motor recruitment has also been shown to be selectively modulated by the fact that the observed actions occurred within or beyond her reach (Caggiano *et al.*, 2009).

We propose that the interpersonal bodily space representation enables one to map other people's being afforded by the surrounding

things, thus providing her with an immediate understanding of what they may wish to do. Indeed, representing the affording features of a given object in terms of their effective readiness-to-hand allows one to catch what other people are in the position to do and therefore to guess what they most likely may intend to do. Our proposal does not rule out that other factors might be involved in ascribing to other people an intention to act, of course. Rather, it indicates that this ascription can be prompted by one's mapping of others' reaching space, thus suggesting that the interpersonal bodily space representation plays a crucial role in figuring out the most likely actions other people might carried out below and before they perform any overt motor behaviour.

One may wonder whether flesh and blood people could really map the reaching space of a virtual individual as an avatar. There is no doubt that our experimental set-up differs from real life. However, stimuli similar to those employed in this study have been successfully used to investigate mapping phenomena such as, for instance, explicit perspective taking (e.g. Amorim, 2003; Vogeley *et al.*, 2004; Lambrey *et al.*, 2008). In particular, in the works by Amorim (2003) and Lambrey *et al.* (2008), the visual scenes were created with the same software as our own and presented with the same technology, and the mere presence of a static avatar was able to prime the future viewpoint on the scene.

In conclusion, although our proposal needs to be further investigated, we pose that such bodily space mapping may shed new light on the first steps in making sense of others as well as in sharing a common world with them.

## SUPPLEMENTARY DATA

Supplementary data are available at SCAN online.

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