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Tool-use observation makes far objects ready-to-hand

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ABSTRACT

Previous evidence has shown that active tool-use remaps agents' reaching space with far objects being perceived as reachable and graspable. To date, however, there is no evidence that tool-use observation might also be effective in reaching space remapping. The present six experiments show that not only performing but also observing tool actions may extend the representation of reaching space, useful for grasping objects. In addition, like active tool-use, tool-use observation also impacts on visual distance judgment. Interestingly, these effects only occurred when observers shared the same action potentialities with the agent, i.e., while passively holding a tool compatible with the goal and the spatial range of the observed action. The present findings demonstrate that observing someone else acting with a tool may actually shape the way we map the objects and the space around us, suggesting that such a mapping could provide us with a keystone for coordinating and integrating our actions with those of others.

1. Introduction

Tool use may extend our action space by making out-of-reach objects reachable. Often, we use tools alone, but it is not uncommon for us to need to coordinate our tool actions with those of another individual in order to reach for and grasp a common target. In this case it is necessary to tune our own tool use with that of the other, by matching executed with observed actions in terms of both their motor goals and their spatial range.

There is converging evidence from neurophysiological, neuropsychological and behavioral studies that active tool-use deeply impact on agents' space representation, extending their own reaching space according to the range of tool action. In their seminal studies, Iriki, Tanaka, and Iwamura (1996) (Ishibashi, Hihara, & Iriki, 2000) showed that the visual receptive fields of monkey's parietal neurons can be modified by actions involving tool use. They trained monkeys to retrieve pieces of food with a small rake, and found that, when the instrument was used repeatedly, the visual receptive fields (vRFs) anchored to the hand expanded to encompass the space around both the hand and the rake. If the animal continued to hold the rake, but stopped using it, the vRFs shrank back to their normal extension.

The dynamic mapping of peripersonal space has been also demonstrated at the behavioral level in both healthy (Maravita, Spence, Kennett, & Driver, 2002; Serino, Bassolino, Farne, & Ladavas, 2007) and brain damaged humans. Line-bisection studies on patients with selective neglect for the hemi-space close to (or far from) their body showed that tool use might reduce or increase the neglect according to the status of the line to be bisected (reachable or out-of-reach) in relation to tool use (Ackroyd, Riddoch, Humphreys, Nightingale, & Townsend, 2002; Berti & Frassinetti, 2000; Neppi-Modona et al., 2007; Pegna et al., 2001). Similar results have been found in patients with visuo-tactile extinction selectively confined to the space close to one hand. Several studies have shown that the severity of extinction can be modified by tool use, which extends the reach of hand actions (Farnè & Ladavas, 2000; Farne, Iriki, & Ladavas, 2005; Maravita, Husain, Clarke, & Driver, 2001).

To date, however, there is no evidence on the impact of tool-use observation on the observers' action, particularly on the space representation they should recruit when actively performing reach-to-grasp movements. The above-reviewed studies demonstrate that passive tool holding does not have any effect on the reaching space of an individual. But what happens if the passive tool holder were observing someone else using that same tool?

Previous studies (Cardellicchio, Sinigaglia, & Costantini, 2011; Costantini, Ambrosini, Tieri, Sinigaglia, & Committeri, 2010) have shown that the perception of object-related or micro-affordances (such as a mug with handle, Ellis & Tucker, 2000) is spatially

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constrained, that is, dependent on the actual extent of one's own reaching space. Here, we took advantage of this spatial constraint in order to investigate whether, and to what extent, not only active tool-use but also tool-use observation might remap the representation of one's own reaching space. Participants were instructed to replicate a reach-to-grasp movement as soon as a task irrelevant go-signal (e.g., a mug located either within or outside the reachable space of participants with the handle orientation either congruent or incongruent with the grasping hand) was presented. The experimental task was performed *before* and *after* a training session in which participants were requested to actively use, or passively hold, a grasping tool such as a garbage clamp (experiments 1–2), as well as to observe someone else using the garbage clamp while holding or not holding the same tool (experiments 4 and 3, respectively) or holding a tool similar in terms of goal (e.g., a pair of pliers, experiment 5) or length (e.g., a rod, experiment 6).

2. Method

2.1. Participants

150 healthy participants took part in the study (95 females, mean ± SD age 26.2 ± 1.8 years, range 22–30). Participants were randomly assigned to one of the six experiments, thus 25 participants took part in each experiment. All participants were right-handed as defined by the Italian version of the Edinburgh Inventory (Oldfield, 1971), had normal or corrected-to-normal visual acuity, were naïve as to the purposes of the experiments, and gave their informed consent. The study was approved by the Ethics committee of the "G. d'Annunzio" University, Chieti, and was conducted in accordance with the ethical standards of the 1964 Declaration of Helsinki.

2.2. Materials

In the experimental task, two sets of stimuli were used. The first one included colored pictures depicting either a right or a left hand pantomiming a precision grip movement (instruction stimuli), while the second one included 3D scenes (go stimuli) (Fig. 1B). These scenes were 3D rooms in which there was a table with a mug on it. The scenes were created using 3D StudioMax v.13 (Fig. 1A). The handle of the mug was oriented either to the right or to the left. In half of the trials, the mug was placed within the participants' peripersonal space (50 cm) while in the other half it was placed in the extrapersonal space (150 cm).

The tool used during the training phase of all the experiments was a 100 cm-long garbage clamp (see supplementary Fig. 1 panel A) composed of an ergonomic handle with a lever (12 cm), a 85 cm-long rigid aluminum shaft and an articulated 'hand', composed of two curved plastic 'fingers' (14 cm each), with a total weight of 360 g. Squeezing the lever vertically made the fingers of the tool close (horizontally). The tool had never been used previously by participants and no practice, except for the training sessions, was allowed. In experiment 5 the employed tool held by observers was a 20 cm-long pair of common pliers, whereas in experiment 6 a 100 cm-long plastic rod was used (see supplementary Fig. 1, panels B and C, respectively).

2.3. Procedure

Experimental sessions – Stimuli were presented by means of a LCD monitor (1024 × 768 pixels). All stimuli were displayed on a black background, from a viewing distance of 57 cm. Each trial began with the presentation of a white fixation cross at the centre of the screen followed by presentation of the instruction stimulus for 150 ms. After a variable delay (150–450 ms), the go stimulus was presented for 500 ms. Participants were requested to replicate the grip presented in the instruction stimulus by performing a reach-to-grasp motor act as soon as the go stimulus appeared. Thus, congruent trials refer to the condition in which participants had to pantomime a reach-to-grasp motor act with either the right or the left hand when the handle of the mug (presented in the go stimulus) was located ipsilaterally, on the contrary, incongruent trials refer to the condition in which the responding hand and the handle were in opposite hemispaces (see Costantini et al., 2010; Costantini, Ambrosini, Scorolli, & Borghi, 2011a; Costantini, Committeri, & Sinigaglia, 2011b). It should be noted here that such reach-to-grasp motor acts were not related to an effective target object the request being to simply pantomime as soon as the go stimulus appeared on the computer screen. At the beginning of each trial, participants rested their right and left index fingers on two response buttons arranged horizontally on a button box. Responses were given by lifting the index finger of the responding hand and then making the grasping movement as instructed. This allowed us to measure liftoff time. Each participant performed 16 trials per condition, for a total of 108 trials. The presentation of the stimuli and the recording of participants' responses were controlled by a custom software (developed by Gaspare Galati at the Department of Psychology, Sapienza Università di Roma, Italy; Galati et al., 2008), implemented in MATLAB (The MathWorks Inc., Natick, MA, USA) using Cogent 2000 (developed at FIL and ICN, UCL, London, UK) and Cogent Graphics (developed by John Romaya at the LON, Wellcome Department of Imaging Neuroscience, UCL, London, UK).

Visual distance judgment – At the end of each experimental session participants were requested to perform a visual distance judgment in order to estimate the distance of the mug shown in the experimental task with respect to their bodies. Subjects sat along the short side of a table of the same size as that depicted in the go stimuli. The experimenter placed a mug (identical to that represented in the go stimuli) on the table at a distance of 100 cm from the participant and then shifted it towards the participant (or in the opposite direction, with the order counterbalanced across experimental sessions and participants). Thus, subjects passively adjusted the distance of the 'real' mug with respect to their bodies to match the perceived distance of the near and far 'virtual' mug depicted in the go stimuli. We used this measure of perceived distance because of its reduced variability and higher sensitivity compared to verbal estimation.

Training phase – Participants performed two experimental sessions: one before (pre) and one after (post) the training phase (see Fig. 2), which was the only phase that differed across the six experiments. In all experiments, a garbage clamp was used either by the participant (experiments 1–2) or by the experimenter (experiments 3:6). In experiments 1–3–4–5–6 the tool was used to move five small common-use objects placed on the table (these objects were all graspable with a precision grip). Participants (and experimenter, in experiments 3:6) sat along the short side of the table holding the tool with their right arm. In experiment 1, participants were requested to use the tool in order to grab and move one object at a time

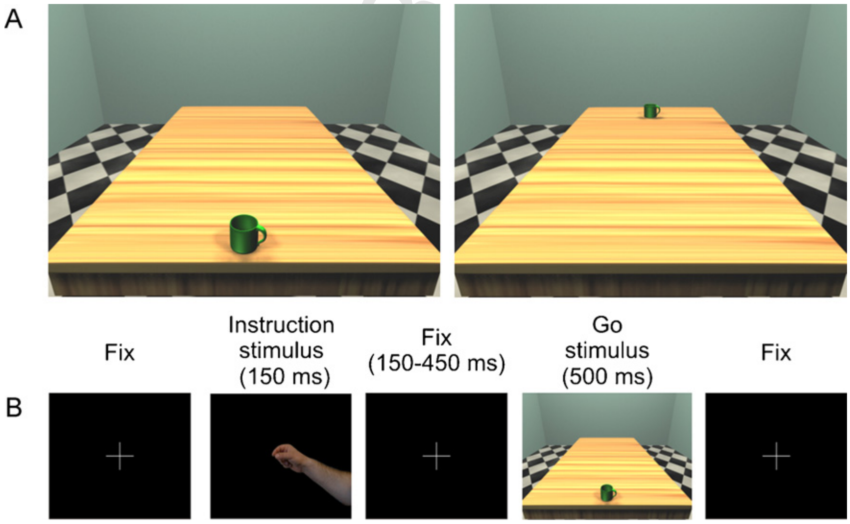

Fig. 1. (A) Exemplar go stimuli used in the experimental task; (B) exemplar trial.

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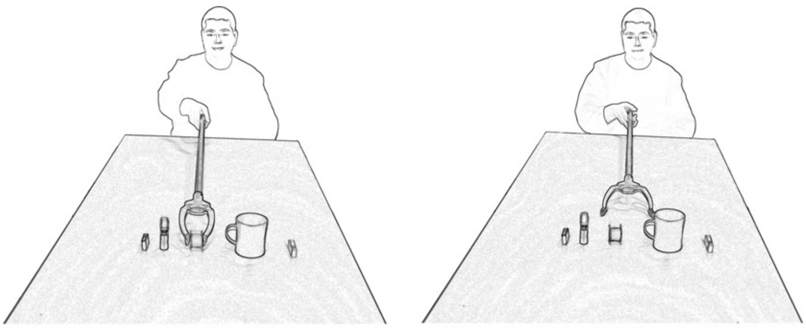
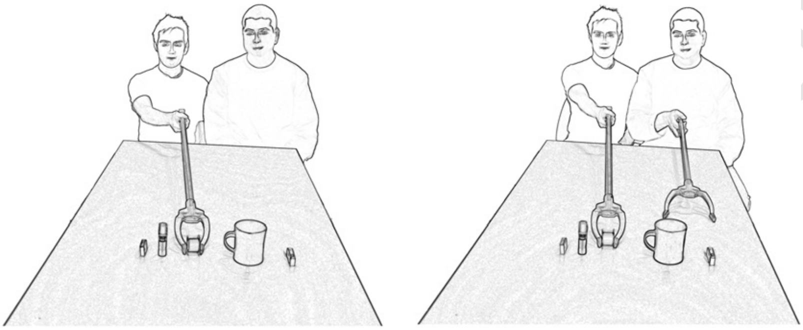


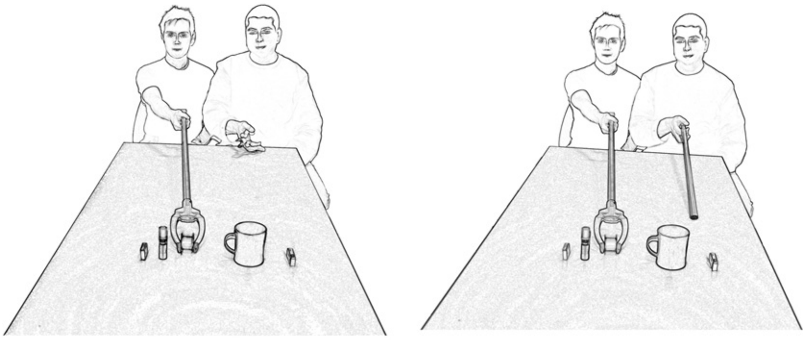
Exp 1: Active Tool-use

Exp 2: Passive Tool-hold



Exp 3: Observation Hand free

Exp 4: Observation Same Tool-hold



Exp 5: Observation - non compatible Tool-hold (in terms of length)

Exp 6: Observation - non compatible Tool-hold (in terms of goal)

Fig. 2. Schematic representation of the training phase in the six experiments.

across the table (maintaining it at the same distance from their bodies), whereas in experiment 2 they had to passively hold the tool without using it. In the remaining experiments, the experimenter used the garbage clamp to grab and move the five objects while the participants (seated on the left of the researcher) were requested to simply observe the movements performed by the experimenter. While observing the experimenter using the garbage clamp, participants were empty handed (experiment 3) or held in their right hand an identical garbage clamp (experiment 4), a pair of common pliers (experiment 5) or a 100 cm-long plastic rod (experiment 6). The training phase lasted 5 min, during which about 50 movements were performed. Experimental sessions started immediately after the training phase.

2.4. Results

2.4.1. RT analysis

For all the experiments, trials in which participants failed to respond correctly (always $\leq 1.1\%$) were discarded from the analysis. The mean RT for correct responses was calculated for each condition; responses longer than 2 standard deviations from the individual mean were treated as outliers and were not considered (always < 5% of the data set). For each experiment, data were entered in a $2 \times 2 \times 2 \times 2$ repeated measure ANOVA with responding hand (left vs. right), experimental session (pre- vs. post-training phase), Location of the object (peripersonal vs. extrapersonal space) and Congruency (between the responding hand and the handle of the mug, Congruent vs. Incongruent) as within-subjects factors. Paired-sample *t*-tests were performed where necessary.

2.4.2. Experiment 1: tool-use

RT analysis revealed a significant main effect of Congruency ($F_{1,24} = 6.11$, $p < 0.05$, $\eta_p^2 = 0.20$), showing that RTs in congruent trials (400 ms) were faster than RTs in incongruent trials (410 ms), and a significant Location by Congruency interaction ($F_{1,24} = 9.1$, $p < 0.01$, $\eta_p^2 = 0.27$). The interaction was explained by the fact that while RTs in congruent and incongruent trials were comparable in the extrapersonal space (404 and 406 ms, respectively), they were significantly longer in incongruent (413 ms) than in congruent trials (396 ms, $t_{(24)} = 2.9$, $p < 0.01$) in the peripersonal space, see Fig. 3. This indicates that the spatial alignment effect only occurred in the peripersonal space. The ANOVA also revealed a significant hand by session by Congruency interaction ($F_{1,24} = 4.52$, $p < 0.05$, $\eta_p^2 = 0.16$). Moreover, the highest order four-way interaction, of prime theoretical interest, was significant ($F_{1,24} = 6$, $p < 0.05$, $\eta_p^2 = 0.20$, see Fig. 3). Simple effect analysis revealed faster RTs in the post-training session for congruent condition (391 ms) compared to incongruent condition (417 ms, $t_{(24)} = 3.6$, $p < 0.01$) for trials in the extrapersonal space executed with the right hand,. In other words, after the training phase the spatial alignment effect also occurred in the extrapersonal space, but only in trials performed with the hand that actively used the tool during the training session.

2.4.3. Experiment 2: passive tool-hold

RT analysis revealed a significant main effect of Congruency ($F_{1,24} = 12.41$, $p < 0.01$, $\eta_p^2 = 0.34$), with faster responses in the congruent (418 ms) than in the incongruent condition (429 ms). The Location by Congruency interaction was significant ($F_{1,24} = 18.81$, $p < 0.001$, $\eta_p^2 = 0.44$, see Fig. 3). Simple effects analysis showed

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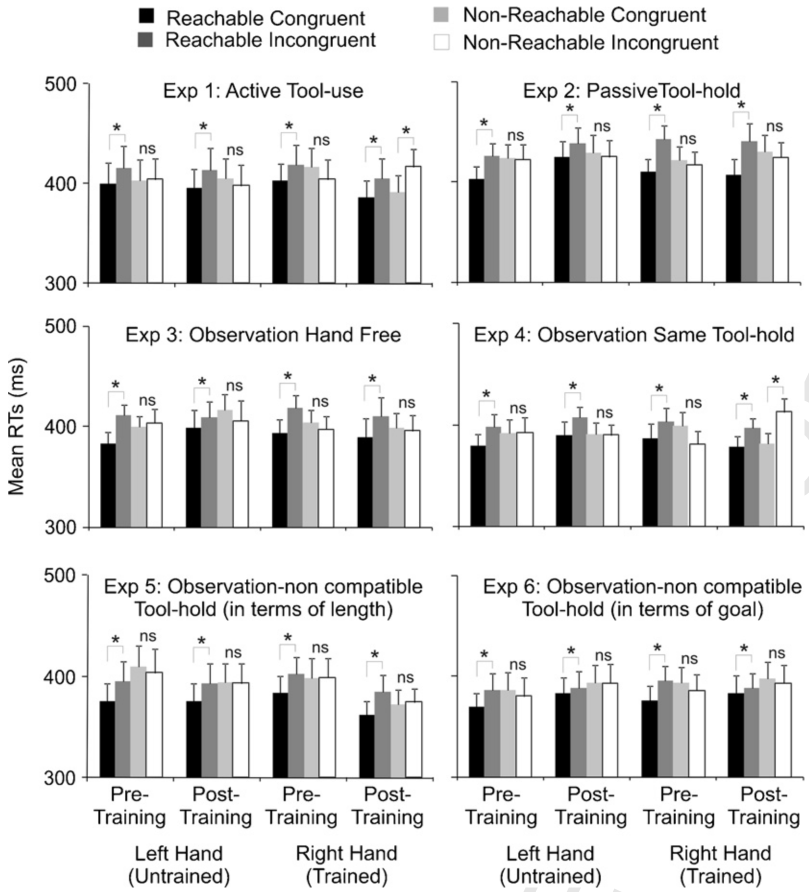

Fig. 3. Mean RTs in the six experiments.

that RTs were significantly faster in congruent (411 ms) than in incongruent trials (437 ms, $t_{(24)} = 4.6$, $p < 0.001$) for peripersonal space only (see Fig. 3).

2.4.4. *Experiment 3: observation – hand free*

RT analysis revealed a significant effect of the Location by Congruency interaction ($F_{1,24} = 11.48$, $p < 0.01$, $\eta_p^2 = 0.32$, see Fig. 3). The interaction was explained by the fact that while RTs in congruent and incongruent trials were comparable in the extrapersonal space (405 and 401 ms, respectively), in the peripersonal space they were significantly faster in congruent (391 ms) than in incongruent trials (412 ms, $t_{(24)} = 3.2$, $p < 0.01$), see Fig. 3.

2.4.5. *Experiment 4: observation – same tool-hold*

RT analysis revealed a significant main effect of Congruency ($F_{1,24} = 9.35$, $p < 0.01$, $\eta_p^2 = 0.28$), with faster responses in congruent (387 ms) compared to incongruent trials (398 ms). Once again, the Location by Congruency interaction was significant ($F_{1,24} = 10.01$, $p < 0.01$, $\eta_p^2 = 0.29$). Simple effects analysis showed that only in the peripersonal space were RTs faster for congruent (383 ms) than for incongruent trials (401 ms, $t_{(24)} = 3.6$, $p < 0.001$). A further two-way interaction was the session by Congruency effect ($F_{1,24} = 7.68$, $p < 0.05$, $\eta_p^2 = 0.24$), indicating that the difference between congruent and incongruent trials reached significance only in the post-training session (congruent: 385 ms; incongruent: 402 ms, $t_{(24)} = 3.7$, $p < 0.001$).

In addition, the ANOVA revealed two higher order significant interactions: hand by session by Congruency ($F_{1,24} = 9.02$, $p < 0.01$, $\eta_p^2 = 0.27$) and session by Location by Congruency ($F_{1,24} = 5.23$, $p < 0.05$, $\eta_p^2 = 0.18$). Moreover, the four-way interaction reached statistical significance ($F_{1,24} = 6.4$, $p < 0.05$, $\eta_p^2 = 0.21$, see Fig. 3). Simple effects analysis revealed that, for trials performed with the right hand in the extrapersonal space, responses were faster in the post-training session for the congruent condition (381 ms) compared to the incongruent condition (413 ms, $t_{(24)} = 4.3$, $p < 0.001$). In other words, this finding replicates the effect found in experiment 1.

2.4.6. *Experiment 5: observation – non compatible tool-hold (in terms of length)*

The ANOVA revealed a main effect of both Location ($F_{1,24} = 6.13$, $p < 0.05$, $\eta_p^2 = 0.20$), with faster RTs in peripersonal (384 ms) than in extrapersonal condition (393 ms), and Congruency ($F_{1,24} = 14.67$, $p = 0.001$, $\eta_p^2 = 0.38$), indicating that responses in congruent trials were faster (384 ms) compared to incongruent trials (393 ms). The ANOVA also yielded a significant Location by Congruency interaction ($F_{1,24} = 24.23$, $p < 0.001$, $\eta_p^2 = 0.50$, see Fig. 3). Simple effects analysis showed that only in the peripersonal space were RTs faster in congruent (374 ms) than in incongruent trials (394 ms, $t_{(24)} = 5.9$, $p < 0.001$), see Fig. 3.

2.4.7. *Experiment 6: observation – non compatible tool-hold (in terms of goal)*

RT analysis revealed a significant main effect of both the Location ($F_{1,24} = 6.12$, $p < 0.05$, $\eta_p^2 = 0.20$), with faster responses in the near (384 ms) than the far condition (391 ms). Moreover, there was a significant Location by Congruency interaction ($F_{1,24} = 6.90$, $p < 0.05$, $\eta_p^2 = 0.22$, see Fig. 3). Once again, this finding reflects the presence of the spatial alignment effect in the peripersonal space only (378 vs. 390 ms, respectively in congruent and incongruent trials, $t_{(24)} = 2.8$, $p < 0.01$), see Fig. 3.

2.4.8. *Comparison across experiments*

To test for the strength of our effect we ran a mixed-model ANOVA. In this analysis we included the experiment (experiments 1–6) as a between subject factor and RTs to congruent and incongruent trials (Congruency factor) in the far space after tool training for the right hand as a within subject factor. The ANOVA revealed the significant interaction experiment by Congruency ($F_{5,144} = 5.5$, $p < 0.001$). Simple effects analysis confirmed that the spatial alignment effect was present only in experiments 1 and 4 (experiment 1: $t_{(24)} = 3.6$, $p < 0.01$; experiment 4: $t_{(24)} = 4.3$, $p < 0.001$; experiments 2–3–5–6: $t_{(24)} \leq 0.71$, $p \geq 0.48$ in all cases).

2.4.9. *Visual distance judgment*

The judgments about the distance of the stimuli in the pre- and post-training session (see Table 1) were compared using paired-sample *t*-tests. After the post-training session, in experiment 1 and experiment 4 only the far stimuli were judged as being closer compared to pre-training session (experiment 1: pre-training = 140 ± 24 cm (Mean ± SD), post-training = 135 ± 24 cm, $t_{(24)} = 2.6$, $p < 0.05$; experiment 4: pre-training = 137 ± 14 cm, post-training = 131 ± 13 cm, $t_{(24)} = 2.56$, $p < 0.05$).

3. Discussion

Previous behavioral and neurophysiological evidence from our group (Cardellicchio et al., 2011; Costantini & Sinigaglia, 2011; Costantini et al., 2010, 2011a,b) showed that the actual processing of the affording features of an object depends on the spatial

Table 1
Visual distance judgments.

	Peripersonal				Extrapersonal			
	Pre-training		Post-training		Pre-training		Post-training	
Exp 1: tool use	60	(14)	61	(14)	**140**	**(24)**	**135***	**(24)**
Exp 2: passive tool hold	54	(9)	54	(7)	142	(20)	140	(14)
Exp 3: observation – hand free	54	(8)	53	(10)	138	(13)	136	(12)
Exp 4: observation – same tool hold	53	(8)	52	(9)	**137**	**(14)**	**131***	**(13)**
Exp 5: observation – non compatible tool hold (in terms of length)	56	(8)	56	(10)	135	(14)	138	(12)
Exp 6: observation – non compatible tool hold (in terms of goal)	57	(12)	56	(13)	144	(17)	145	(16)

relationship between the object and the perceiver, being effective only when the former falls within the reaching space of the latter.

In the present series of experiments we took advantage of the spatial constraint of the object-related- or micro-affordances (Ellis & Tucker, 2000) in order to investigate whether, and to what extent, both using a tool and observing its use by someone else might remap the representation of one's own reaching space. The results show that both performing and observing tool actions extend the representation of the reaching space of an individual.

Experiment 1 provides further evidence that active tool-use extends the reaching space of the agent. Indeed, after being trained in the use of a garbage clamp, participants became sensitive to the affording feature of an object (the oriented handle of a mug) even when it was presented far from them. This sensitivity strongly suggests that training in active tool-use deeply impacted on the agents' representation of their own reaching space (Cardinali et al., 2009), thus making outside-reach objects ready-to-hand. Experiment 2 shows that this phenomenon is action dependent, because it did not occur when the agent passively held the tool without using it.

These results are fully consistent with previous studies on the effects of tool-use on space representation in both monkeys (Iriki et al., 1996; Ishibashi et al., 2000) and humans (Maravita et al., 2002; Serino et al., 2007). To date, however, the relationship between tool-use and space representation has never been investigated after tool-use observation. In the last four experiments we addressed this issue, by devoting training sessions to mere tool-use observation.

Experiment 3 shows that tool action observation *per se* does not remap observers' space representation. Interestingly, however, experiment 4 demonstrates that when tool-use observation is accompanied by holding the very same tool, observers' representation of their own reaching space is indeed remapped, making far objects near enough to be perceived as reachable and graspable. Finally, in experiments 5 and 6 we found that space remapping during tool-use observation is constrained by the actual possibilities for the observers to perform the observed tool action. Holding a pair of normal pliers (much shorter than the garbage clamp, thus suitable for grasping only within peripersonal space) or a rod (long as the garbage clamp, but not suitable for grasping) did not produce any effect on participants' representation of their own reaching space, these tools not being compatible with the observed tool action.

A possible candidate for explaining the impact of tool-use observation on the observers' reaching space is likely to be found in the action execution/action observation matching properties of the mirror mechanism (Rizzolatti, Fogassi, & Gallese, 2001). Strong evidence in monkeys and humans indicates that the observation of an action performed by someone else elicits in the observer's brain the representation of the motor goal driving that action (Rizzolatti & Sinigaglia, 2008, 2010). Critically, for the purpose of our study, single cell recordings from the ventral premotor cortex (area F5) of the monkey brain recently showed that mirror neurons discharge when the animal observes both hand- and tool grasping actions (e.g., grasping with pliers or spearing with a stick (Rochat et al., 2010)). Note that the pattern of mirror responses differed according to the motor expertise of the monkey. Hand grasping observation determined the earliest discharge, while pliers grasping and spearing observation triggered responses at longer latencies.

Were the mirror mechanism really at stake here one would expect a significant effect after tool training in all the observation conditions, starting from the hand-free observation condition in experiment 3. However, tool-use observation was really effective in remapping the observers' reaching space only when observers held a tool compatible with the goal (i.e., grasping) and with the range of the observed action. These findings seem to be in contrast with how the mirror mechanism allegedly operates. However, on closer inspection, they are not only fully in line with the mechanism's functional properties, but they also suggest what the mirror-based reaching space remapping might be relevant for.

Indeed, compelling neurophysiological evidence shows that the action observation/action execution matching mechanism runs at different levels of generality, ranging from the goal of an action to the way it has to be executed (for reviews see (Rizzolatti et al., 2001; Rizzolatti & Sinigaglia, 2010)). Several behavioral studies have measured whether, and to what extent, these different levels of mirror matching may impact on the observers' planning and execution of their own actions (Brass, Bekkering, & Prinz, 2001; Kilner, Paulignan, & Blakemore, 2003). In particular, it has been demonstrated that observing someone else performing a given action may affect the execution of that action according to the degree of congruence between the observed and the executed actions (Castiello, Lusher, Mari, Edwards, & Humphreys, 2002; Edwards, Humphreys, & Castiello, 2003; Kilner et al., 2003).

Taken together, these data may account for the occurrence of the reaching space remapping in experiment 4 only, where the observed and the held tools are congruent with respect to both the general goal (grasping) and to the range (extrapersonal) of the action they enable. It is likely that all observation conditions led to activation of the mirror processing of tool actions. However, mirroring impacted on the reaching space representation only when observers were actually able to perform the very same tool-action they witnessed.

This point may also help in highlighting the putative function of such mirror-based reaching space remapping. If tool-use observation always led to reaching-space remapping, regardless of the observer's actual possibilities to act, it would be definitely misleading, because it would represent out-of-reach objects as ready to hand. In contrast, reaching space remapping is constrained by the observer's actual possibility to perform an action compatible, both in terms of goal and range, with the observed one. We hypothesize that this effect might be critically involved in coordinating and joining our own actions with those of others, at least at the basic level. Indeed, by matching others' with our own reaching space, we would not only be able to understand others' actions but also, and above all, able to coordinate our motor behavior with them, thus enabling cooperation or competition when reaching for a remote target.

Such construal seems to be further supported by the effect of training in tool-use observation on visual distance judgments. In

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experiment 1 participants were asked to judge near and far stimuli before and after the training session in active tool-use. We found that they judged far stimuli as being closer compared to the pre-training session, while their judgment about the near stimuli did not vary. This effect was not present in experiment 2, in which participants were requested to passively hold the tool without using it.

These results are fully in agreement with the elegant series of studies by Proffitt and colleagues showing that the extent of reachability serves as a metric in visual perception (Linkenauger, Witt, Stefanucci, Bakdash, & Proffitt, 2009; Witt & Proffitt, 2008). Our experiment 4 demonstrates that, not only active tool-use but also tool-use observation, affects visual distance judgment. Indeed, after the training session participants judged far stimuli as being closer compared to the pre-training session, while their judgment about the near stimuli did not vary. Crucially, this was not the case in experiments 3, 5, and 6, where participants were asked to observe tool action either without holding any tool or while holding a tool that was not compatible with the range or with the goal of the observed action.

In conclusion, our findings clearly show that both active tool-use and tool-use observation might actually shape the way individuals map objects around them. In addition they suggest that such mapping could be crucial in building up basic social interactions, providing people with a keystone for coordinating and integrating actions.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.neuropsychologia.2011.05.013.

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