Rapid communication

When far becomes near: Shared environments activate action simulation

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It has been proposed that one means of understanding a person's current behaviour and predicting future actions is by simulating their actions. That is, when another person's actions are observed, similar motor processes are activated in the observer. For example, after observing a reach over an obstacle, a person's subsequent reach trajectory is more curved, reflecting motor priming. Importantly, such motor states are *only* activated if the observed action is in near (peripersonal) space. However, we demonstrate that when individuals share action environments, simulation of another person's obstacle avoiding reach path takes place even when the action is in far (extrapersonal) space. We propose that action simulation is influenced by factors such as ownership. When an "owned" object is a potential future obstacle, even when it is viewed beyond current action space, simulations are evoked, and these leave a more stable memory capable of influencing future behaviour.

Keywords: Action observation; Action simulation; Peripersonal space; Object ownership; Mirror neurons.

A core function of the brain is to extract information from the environment that enables animals to make appropriate responses. From encoding the rough terrain while running to processing the shape and location of an object to be grasped, the conversion of vision into action is crucial for survival (Gibson, 1979). A qualitative distinction in such visuomotor representations is between near (peripersonal) space where objects can be acted on immediately and far (extrapersonal) space where objects are beyond immediate action. There is clear evidence that these two forms of representation do coexist in the brain (e.g., Previc, 1998). For example, Vuilleumier, Valenza, Mayer, Reverdin, and Landis (1998) describe a patient who suffered from lateral neglect in far (extrapersonal) but not near (peripersonal) space; while Halligan and Marshall (1991) report the opposite pattern of neglect in near but not far space. Healthy participants also show a smaller version of neglect called

pseudoneglect (Bowers & Heilman, 1980; for a review see Jewell & McCourt, 2000) when bisecting a line. In near space this bias is towards the left, shifting rightward when bisecting lines in far space.

This contrast between near and far representations of space has now been extended to action observation. When a motor act is observed, the same motor processes are activated in the observer (e.g., Binkofski et al., 1999; DiPellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti 1992), and such action simulation might be a means by which we can understand and predict the actions of other people. A typical everyday action could consist of a reach over an obstacle to grasp a target object, as when during dinner a wine glass is in the reach path to the desired salt. Our recent work has demonstrated that when a person is observed reaching over an obstacle to grasp a target, a participant's subsequent reach is more curved even when there is no obstacle present. Thus viewing the curved obstacle avoiding reach activates similar motor processes in the observer, and these influence subsequent actions. However, of central importance, this obstacle avoidance priming effect is *only* detected if the observed reach and obstacle is within the near (peripersonal) action space of the observer. In sharp contrast, if the observed action is only slightly outside the near action space of the observer, the action simulation processes are not activated (e.g., Griffiths & Tipper, 2009).[1]

Therefore the simulation of how another person reaches through space is only activated when that action is relevant to the observer, because the avoided object is a potential obstacle for the observer. However, a key question remains concerning this "hand centred" action priming effect. Is the effect invariant in the sense that reach path priming can only ever be obtained when the observed reach is within near (peripersonal) action space? Or is it the case that the action simulation processes can be activated when an object is a potential obstacle for a participant, even when a viewed action is in far space beyond the range of action?

To test these alternative accounts, we devised two experimental situations. In both conditions, observed obstacle avoidance was 120 cm from the viewer's hand and hence was well outside near action space. In the "separate-workspace" condition (Experiment 1), participants reached for their own objects in their own work environment and observed the actions of another person within a separate work environment (see Figure 1, Panel A). In this situation, we predicted no priming of reach trajectory when observing actions in far space. The "shared-workspace" condition (Experiment 2) was identical except that, after reaching for an object, the experimenter moved the work environment and objects to the other participant. This procedure is represented in Figure 1, Panel B. Of note, the produced and observed reaching actions were identical in the separate- and shared-workspace conditions; only the events intervening between trials differed.
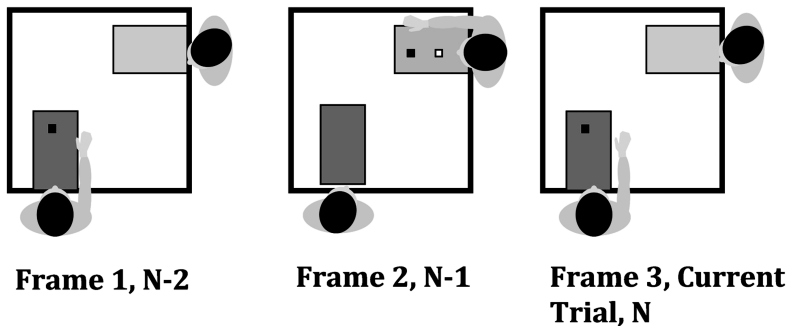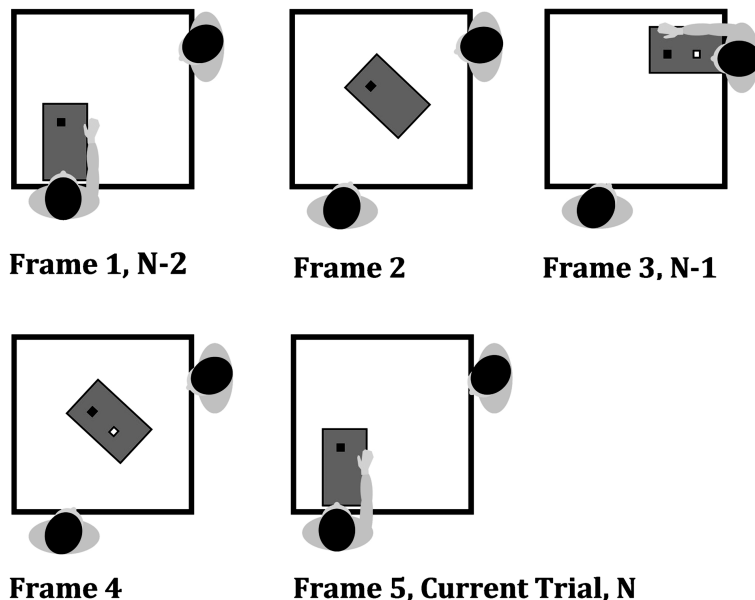
EXPERIMENT 1: SEPARATE-WORKSPACE CONDITION

Method

Participants

A total of 16 right-handed students (13 female), with a mean age of 20.7 years, participated in this

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[1] It is important to note that the important role of observing actions within peripersonal space has been specifically observed in reach trajectory priming effects—that is, the path the hand takes to reach a target object (Griffiths & Tipper, 2009). However, the majority of studies of mirror systems and priming via action observation have examined action goal priming. This represents the goal to be achieved rather than the specific motor properties of the action. For example, some parietal cells discriminate between identical reach and grasp actions based on the subsequent goal of either eating or placing the grasped object (Fogassi et al., 2005). Such goals can be primed in an observer even when only heard (Kohler et al., 2002), or produced behind an occluder (Umiltà et al., 2001), or when the goal is achieved by different effectors (hand or foot: e.g., Constantini, Committeri, & Galati, 2008). In these action goal priming procedures, the issue of whether actions are observed within near peripersonal or far extrapersonal space has rarely been engaged. As many action goal priming effects can be detected even when the observed action is presented on a computer screen where objects cannot be acted upon (e.g., Tipper & Bach, 2008), we feel such goal-based effects are not so influenced by the ability to act on objects and the distance from the observer's body.

PANEL A: Experiment 1

Frame 1, N-2   Frame 2, N-1   Frame 3, Current Trial, N

PANEL B: Experiment 2

Frame 1, N-2   Frame 2   Frame 3, N-1

Frame 4   Frame 5, Current Trial, N

Figure 1. *Panel A: the separate–workspace condition. Frame 1 shows Participant 1 reaching while Participant 2 observes. The black square is the target, the white square the obstacle. Between Frames 1 and 2, both participants have their eyes closed. The experimenter removes Participant 1's blue set of objects and places Participant 2's yellow objects. Frame 2 shows Participant 2's reach after their eyes have been opened. Panel B: the shared–workspace condition. The trial is the same, except for Frames 2 and 4, which show that both participants observe the workspace being moved between them. They both have their eyes open as the workspace and blocks are moved. After the workspace has been moved, participants close their eyes while the experimenter positions the blocks for the next reach (just before Frames 3 and 5). To view a colour version of this figure, please see the online issue of the Journal.*

study in return for course credits. All participants had normal or corrected-to-normal vision.

Procedure and design
Both participants used their right hands. They were seated at 90° to each other on two sides of a table.

Each participant had their own obstacle (4.5 × 4.5 cm, by 18 cm high) and target block (3 × 2 cm, by 9 cm high); one participant had a yellow obstacle and a yellow target, the other a blue set. Each participant also had a thin (12-mm) A3-sized (420 mm × 297 mm) wooden tablet work

surface on which the objects were placed, one grey, the other dark green. Each participant's obstacle was 20 cm from their hand's resting position, and the target was 40 cm away.

A retro reflective marker was placed on each participant's wrist, and their movements were tracked using a Qualisys ProReflex motion capture system (Qualisys AB, Gothenburg, Sweden).

Participants alternated between reaching and watching the other participant reach. Participants started with their eyes closed. The experimenter arranged the blocks for the acting participant. They were then instructed to open their eyes. One participant reached out and lifted the block, while the other, as instructed, observed the action. After the action was completed, the experimenter gave the instruction to close their eyes, the blocks of the first participant were then removed, and the other participant's blocks were put in place. Participants were then instructed to open their eyes again.

Obstacles were present on half of the trials. Counterbalancing the current trial (N), $N - 1$ trial (the other participant's reach), and $N - 2$ trial (the participant's previous reach) gave eight possible trial orders. Each trial order occurred (randomized) 10 times for each participant. Figure 2 shows the key trial conditions. Panel A shows a trial sequence where the previous two reaches to the current trial did not involve obstacle avoidance—that is, a baseline of no obstacles (No) in any trial in the sequence (No–No–No). Panel B shows a sequence where Participant 1's (currently acting participant) previous reach was over an obstacle (Ob) whereas Participant 2's was not (No), resulting in the Ob–No–No condition. The analysis of this reach sequence would reveal within-person priming effects—that is, the effect of the participant's own previous actions on their current action (as described in Griffiths & Tipper, 2009; Jax & Rosenbaum, 2007). Panel C shows a sequence where Participant 2's previous reach, but not Participant 1's own reach, was over an obstacle (i.e., No–Ob–No condition). The analysis of these reaches would reveal the effect of observing another person's reach action.

Results

A number of trials were removed due to collisions or recording failure, and where participants had failed to open their eyes on the previous observation trial (1.18%).

Only those trials where the current reach was without an obstacle were analysed. The trials where an obstacle was present were not analysed because there was little variation in height, as participants cleared the obstacle with as much room as possible, to avoid toppling the block (see also Griffiths & Tipper, 2009).

The results are shown in Table 1. As predicted, there was no effect of observing the other participant reach over an obstacle outside peripersonal space: $N - 1$, $F_{(1, 15)} = 0.00$, $p = .993$. The participants were affected by their own previous reaches over obstacles: $N - 2$, $F_{(1, 15)} = 4.80$, $p = .045$. There was no interaction, $F_{(1, 15)} = 0.25$, $p = .627$. Further planned contrast t tests (two-tailed) between the baseline No–No–No and an obstacle at $N - 2$ (Ob–No–No) revealed a significant difference, $t_{(15)} = 3.02$, $p = .004$. No significant difference was found between No–No–No and those trials where an obstacle appeared at $N - 1$ (No–Ob–No), $t_{(15)} = 0.33$, $p = .371$.

For complete data, Table 1 also shows reach height for trials where obstacles were present in both $N - 1$ and $N - 2$ (Ob–Ob–No), where higher reaches were also observed. However, because this condition reveals effects of own and other person's prior reaches, it does not help our specific investigation of action observation and hence is not discussed further.

EXPERIMENT 2: SHARED-WORKSPACE CONDITION

Method

Participants
A total of 16 right-handed students (14 female), with a mean age of 21.3 years, participated in this study in return for course credits. All participants had normal or corrected-to-normal vision.

PANEL A: No-No-No

N-2 N-1 N

PANEL B: Ob-No-No

N-2 N-1 N

PANEL C: No-Ob-No

N-2 N-1 N
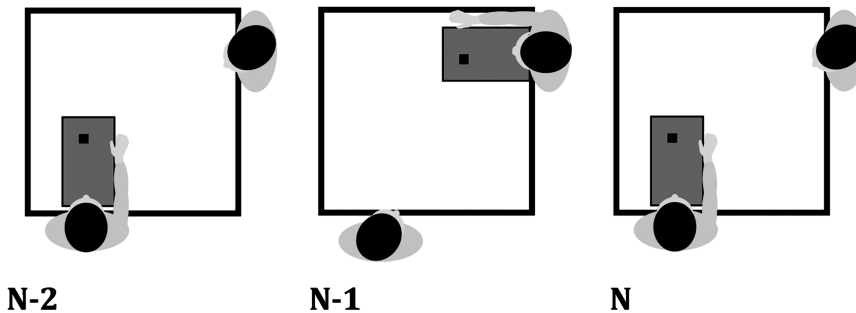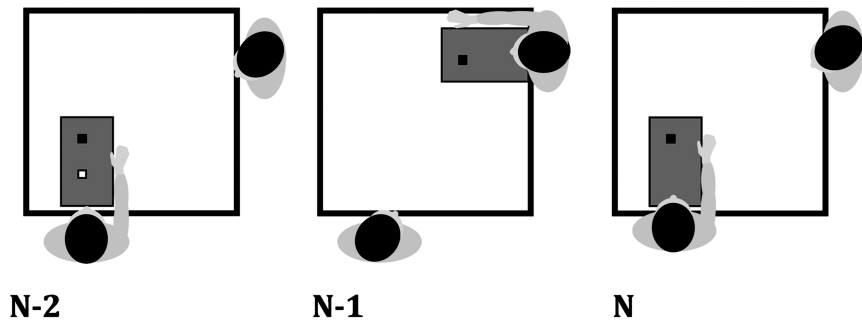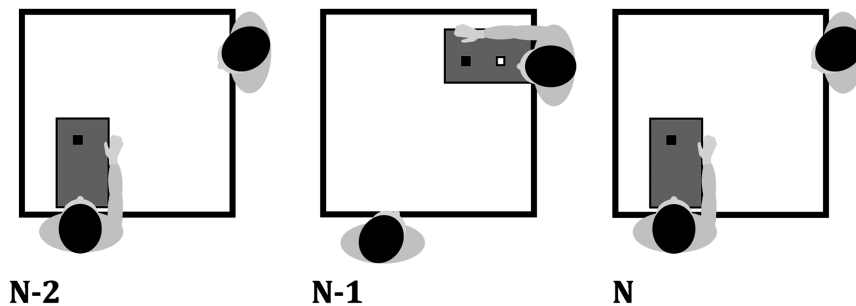
Figure 2. *The key conditions that test our hypothesis. The effects of previous trials (N − 2, N − 1) are observed on trial N. Panel A represents the baseline where no obstacle is present in trials N − 2, N − 1, and N (No–No–No condition). Panel B presents the within-participant priming condition, where trial N − 2 contains an obstacle (Ob–No–No). Panel C represents the critical between-person priming condition where N − 1 contains an obstacle (No–Ob–No). To view a colour version of this figure, please see the online issue of the Journal.*

Procedure and design

The seating arrangement and distance of target and obstacle from the participants was identical to the separate-workspace condition of Experiment 1. However, in Experiment 2, participants were explicitly told that there was only one set of blocks and one workspace/tablet and that they would be sharing them. Again the participants

Table 1. *Mean reach heights for Experiments 1 and 2*

Experiment	Workspace	No–No–No	Ob–No–No	No–Ob–No	Ob–Ob–No
1	Separate	200.40	206.58	201.21	205.73
2	Shared	204.73	217.37	215.64	222.67

Note: Heights in mm. Ob = obstacle. No = no obstacle.

started with their eyes closed, opening them upon instruction. After the first participant had finished their reach, the participants observed the experimenter slide the tablet with the blocks on it across to the second participant. They were then instructed to close their eyes while the experimenter arranged the objects for the next trial. The participants were then given the instruction to open their eyes, and the second person executed their reach.

Results

A number of trials were removed due to collisions or recording failure and where participants had failed to open their eyes on the previous observation trial (1.36%).

Results are shown in Table 1. As with the separate-workspace experiment, there was a significant effect of a participant's own previous reach on their current reach: $N-2$, $F(1, 15) = 22.49$, $p < .001$. However, in stark contrast to the previous experiment, there was a significant effect of observing the other participant's reach over an obstacle: $N-1$, $F(1, 15) = 5.83$, $p = .029$. There was no interaction between $N-1$ and $N-2$, $F(1, 15) = 2.64$, $p = .125$. Further planned (two-tailed) contrast t tests, comparing the baseline (No–No–No) to conditions with obstacles at $N-2$ and $N-1$, revealed significant effects in both cases: Ob–No–No, $t(15) = 4.86$, $p < .001$; No–Ob–No, $t(15) = 3.65$, $p = .001$.

In addition to the analysis above, the results from the shared-workspace Experiment 2 were compared to those from the separate-workspace Experiment 1 in a mixed two-way analysis of variance (ANOVA). This revealed a significant interaction between $N-1$ (obstacle priming by observation) and experiment, $F(1, 15) = 4.50$, $p = .042$—that is, the $N-1$ effects significantly differed between experiments. There was no

significant interaction between $N-2$ and experiment, $F(1, 15) = 1.96$, $p = .172$—that is, no significant difference in the priming of participants by their own previous reaches between experiments. There were no other significant interactions.

Because the key issue is the effect of observing another person's reaching action on the subsequent response of a participant, more detailed analysis of the $N-1$ between-person priming effects was undertaken where points along the reach trajectory were analysed. Figure 3, Panel A shows the reach trajectories from the separate-workspace trials of Experiment 1 where there were no obstacles on previous trials (No–No–No) and an obstacle on the previous $N-1$ trial (No–Ob–No). Panel B shows this data for the shared-workspace conditions (Experiment 2). These figures show the qualitative distinction between the experiments. The vertical lines show the points of comparison along the trajectories where the analysis was carried out in a 2 (obstacle condition) × 7 (location: 7 loci at 5-cm steps) ANOVA.

For the separate-workspace Experiment 1, there was no $N-1$ effect when observing another person's reach over an obstacle, $F(1, 14) = 0.17$, $p = .684$. Furthermore, there was no interaction with distance, indicating that there was no priming across the whole of the reach. In sharp contrast, the shared-workspace Experiment 2 showed a significant effect of $N-1$, $F(1, 14) = 6.90$, $p = .020$. Again this did not interact with distance, demonstrating that there was a consistent $N-1$ priming effect throughout the analysed regions of the reach.

Discussion

The results are clear. In terms of the participant's own priming effect ($N-2$), there is clear evidence that reaching over an obstacle results in a more

A

Separate-Workspace

B
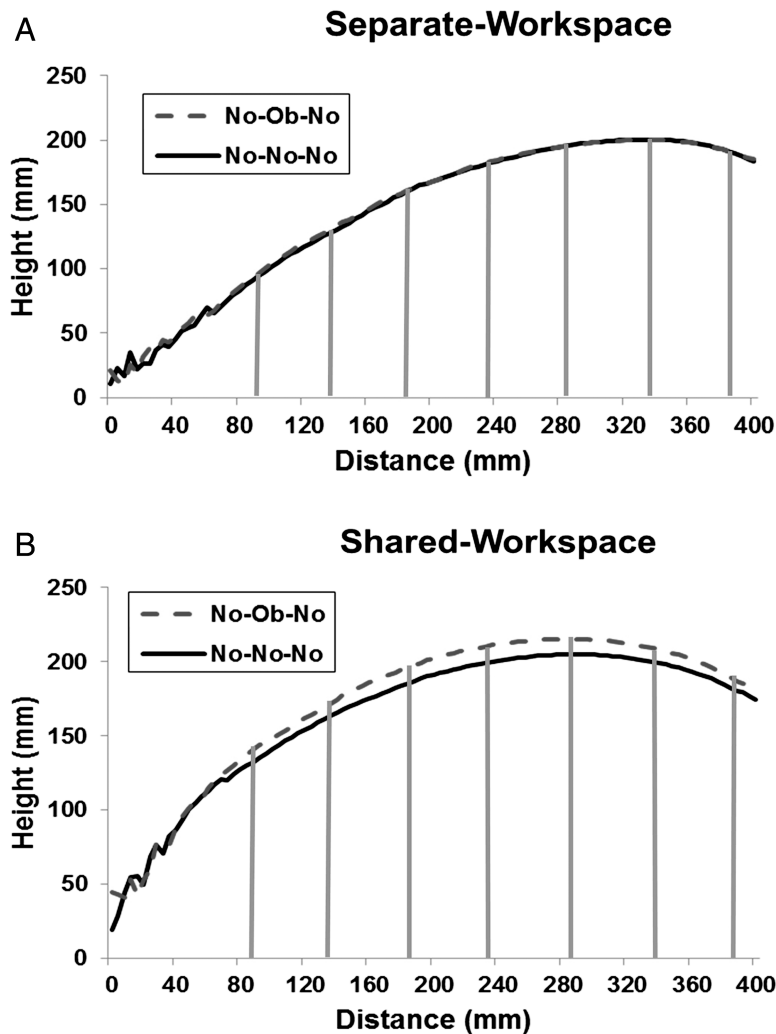
Shared-Workspace

Figure 3. *Panel A: Experiment 1: Separate workspace, N − 1, No–No–No versus No–Ob–No trials (Ob = obstacle; No = no obstacle). Panel B: Experiment 2: Shared workspace, N − 1, No–No–No versus No–Ob–No trials. The trajectories shown are the aggregate of each participant's average reach in that condition. The vertical lines mark the points of the curve used in the analysis of variance (ANOVA) analysis described in the Results section. To view a colour version of this figure, please see the online issue of the Journal.*

curved reach some time afterwards. Critically this priming effect is detected both when separate and when shared workspaces are experienced in the intervening trial. This is in sharp contrast to the priming effects produced when another person's actions are observed ($N − 1$), where separate or shared workspace plays a critical role. Only in the latter shared-workspace condition is another

person's reach trajectory simulated such that it influences the observer's subsequent reaching action. Therefore, sharing a workspace and objects with another person appears to activate action simulation processes and facilitates memory of such motor states such that a participant's subsequent reach is influenced by the previous observation.

At first glance, this result may be considered to be similar to the effects when individuals learn to use tools. That is, after experience of interacting with objects with a tool, near (peripersonal) space is extended to include the tool (e.g., Iriki, Tanaka, & Iwamura, 1996). However, critically this tool effect requires direct interactions between the hand, the tool, and the manipulated object, where visuomotor and tactile feedback adjust the representation of space, so that more distant objects are encoded as within action space. The requirement for direct interactions between hand, tool, and object is reflected in the nature of learning, where it is specific to the hand trained to use the tool (e.g., Bassolino, Serino, Ubaldi, & Làdavas, 2010) and does not take place if the tool is merely held (e.g., Làdavas & Farnè, 2006). In sharp contrast, in our study there is *no* visuomotor/tactile feedback. Participants do not learn to manipulate far space, as they passively view another person's actions, and objects always remain out of reach. Furthermore, the observation and production of action are identical in the separate- and shared-workspace conditions, but only the latter situation produces action simulation.

Another interpretation of our results might be in terms of joint actions—that is, when individuals interact together to achieve a joint goal, such as lifting a heavy weight or dancing, by coordinating their actions (e.g., Sebanz, Bekkering, & Knoblich, 2006). However, a joint action account would seem to be unlikely in our experiment. Participants were instructed to perform their own reaching task and were asked to merely passively observe the other person's actions. Both individuals' actions are therefore undertaken at different times, not coordinated in any way, and the observed action is not relevant to a participant's own subsequent action.

Finally, the current effects might be mediated by memory processes influenced by ownership. That is, in the separate-workspace condition, observed actions are outside action space, and they are not encoded into memory, hence no priming effects are observed a few seconds later. However, in the shared-workspace condition, participants have greater ownership of the objects and workspace, and ownership has previously been shown to improve memory (e.g., van den Bos, Cunnigham, Conway, & Turk, 2010). That is, objects that are "owned" by a participant are better encoded into episodic memory and subsequently recalled than those "owned" by another person. Hence, in our study, we propose that the motor states activated when a participant observes another person reach over an obstacle that the participant also interacts with are maintained in memory and influence a participant's own reach trajectory a few seconds later.

The simulation of another person's actions as a means of understanding them is an important process. The current work shows that these action simulation processes are not automatic and inflexible, but can be influenced by ownership of objects and environments. These findings are novel because they cannot be accounted for by typical explanations based on tool use or joint actions. Rather we propose that simulation of observed actions can be selectively activated and maintained in memory when of particular relevance, which can be determined by ownership.

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