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(Article begins on next page)

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Observer's body posture affects processing of other humans' actions

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Abstract

Action observation triggers by default a mental simulation of action unfolding in time. We assumed that this simulation is “embodied”: the body is the medium through which observer’s sensorimotor modalities simulate the observed action. The participants in two experiments observed videos, each depicting the central part of an action performed by an actress on an object (e.g., answering the phone) and soon after each video they observed a photo portraying a state of the action not observed in the video, either depicting the initial part or the final part of the whole action. Their task was to evaluate whether the photo portrayed something before (backward photo) or after the action in the video (forward photo). Results showed that evaluation of forward photos was faster than evaluation of backward photos (Experiment 1). Crucially, participants’ body posture modulated this effect: keeping the hands crossed behind the back interfered with forward simulations (Experiment 2). These results speak about the role of the observer’s body posture in processing other people’s actions.

Key words: body posture, mental simulation, action observation, anticipation.

1. Introduction

One of the most important features of our cognitive system is the ability to escape from the present and mentally go forth in time to anticipate events: by looking forward we interact quickly and effectively with the environment. For instance, the ability to anticipate moving objects' trajectory allow us to reconstruct invisible parts of the trajectory (Pozzo, Papaxanthis, Petit, Schweighofer, & Stucchi, 2006) and the ability to anticipate linguistic inputs facilitates fluent reading and writing acquisition (see, e.g., Guasti, Pagliarini, & Stucchi, 2017; Järvillehto, Nurkkala, & Koskela, 2009). Also, humans are able to predict and anticipate features of others' action kinematics: this process relies on a forward mental simulation and allows us to understand other people's intentions (e.g., Kilner, Friston, & Frith, 2007). Forward mental simulations triggered by body movements observation seem to be obligatory (i.e., compulsorily activated by external stimuli), out of conscious control and very rapid (Wilson, 2001). However, the exact nature of these mental representations of actions is still unexplored and highly debated in the literature. The present study aims at shedding light on the nature of the forward simulations triggered by action observation, by testing whether it depends upon features of the observer's body. Since embodied approaches suggest that the body has, at least in part, a causal and constitutive role in several cognitive domains (for a discussion of embodiment effects involving in action observation see, Ianì, 2021), we tested whether the manipulation of the observers' body posture changes the cognitive processing of others' actions.

In a pioneering experiment, Freyd (1983) demonstrated that observers of a photo portraying a man jumping down from a wall, after a short interval in which the original photo was removed, struggled to notice that a forward distractor (i.e., a photo showing the man as having jumped a little beyond the position of the first stimulus) was different from the original one. Participants tended to consider a photo portraying the natural continuation of the action as if it was the same stimulus previously observed. Freyd concluded that the "mental representation" of the stimulus was shifted

along the actual pattern of movement implied in the photo. Similarly, studies have revealed that observers automatically anticipate the future posture of the actor in a video so that this mental simulation facilitates later identification of the forward posture, compared to the backward one (Verfaillie & Daems, 2002). These studies demonstrated that the observation of an agent who is performing a given action induces an unintentional and dynamic mental representation, which in turn affects memory for the original scene. These and similar findings lead to the now widely shared assumption that looking forward during action observation relies on an “automatic, implicit, and non-reflexive simulation mechanism” (Gallese, 2005, p.117). The present investigation concerns this kind of mental simulation and aims at exploring its “embodied nature”.

Several studies seem to suggest how anticipation mechanisms strongly rely on observers’ motor system activation (see, e.g., Buccino et al., 2001); this motor recruitment would allow them to mentally simulate what other people are going to do (Rizzolatti & Sinigaglia, 2010; Rizzolatti, Fogassi, & Gallese, 2001). Evidence that motor activation is maximal when participants observe ongoing and incomplete actions, rather than during the observation of final postures that suggest completed movements (Urgesi et al., 2010), enforces the assumption that motor representations provide an internal model of the ongoing action (Wilson & Knoblich, 2005). Further, the observers’ motor system becomes active in a somatotopic manner (Buccino et al., 2001; Sakreida, Schubotz, Wolfensteller, & von Cramon, 2005; Wheaton, Thompson, Syngieniotis, Abbott, & Puce, 2004): observing an action performed with a given effector activates in observers only the pre-motor area involved in movements of the same effector (for a causal involvement of the motor system in action processing see Michael et al., 2014).

All this evidence seems to suggest that observers exploit their sensorimotor systems to simulate other people’s actions; the mirror neuron system’s activity recruits a motor representation similar to the representation that would occur if observers were planning and executing the observed action themselves. In other words, other humans’ actions “can be mapped isomorphically

onto our own body” (Wilson & Knoblich, 2005, p. 460), thereby allowing mutual influence between perception and action planning (Wilson, 2001). Thus, the mental representation of posture and movement of others’ bodies is deeply connected with the processing of posture and movement of one’s own body (Prinz, 1990). It has been suggested that a single body schema may underlie the representation of one’s own body and the perception of bodies of others (e.g., Reed & Farah, 1995). Such isomorphic mechanism facilitates “the flow of information processing between perception and action” (Wilson, 2001; 543), with the consequence that perceptual events may trigger in the observer the activation of motor representations in a rapid and near-automatic fashion.

Given the mutual influence between perception and action (Hamilton, Wolpert, & Frith 2004), an implied consequence is that the observers’ body postures or movements should facilitate or interfere with the brain processes underlying mental simulation (see, for a review, Iani, 2019). Such body manipulations have already been used successfully to study sensorimotor simulations in domains different from action observation. For instance, they have been used to interfere with sensorimotor simulation involved in memory for objects. The task of the participants in a study was to observe manipulable and non-manipulable objects and then to recall as many objects as they could. When they were asked to keep hands and arms behind the back (i.e., a condition interfering with actions triggered by manipulable objects) they showed a decrease in recall of manipulable objects, but not of non-manipulable ones (Dutriaux & Gyselinck, 2016; see also, Dutriaux, Dahiez, & Gyselinck, 2019). Relevant to the present investigation, these results suggest that a body posture that is incompatible with a specific action interferes with its motor simulation (for similar effects but in imagery rotation tasks see, e.g., Sirigu & Duhamel, 2001). Furthermore, as a TMS study revealed, when the participants mentally simulated actions while keeping body postures incompatible with them, the excitability of their motor cortex decreased (Vargas et al., 2004).

The present study aims at shedding light onto the nature of forward simulations triggered by action observation. Its novelty relies in using manipulations used in former studies to investigate the

embodied nature of anticipatory mechanisms involved in action observation. Participants in our experiments observed short videos of a single action performed by an actress on an object. An object's known functions favour processing of action goal (Hudson, Nicholson, Ellis, & Bach, 2016; McDonough, Costantini, Hudson, & Bach, 2020), even when the object falls outside the peripersonal space of the observer (see, e.g., Cardellicchio, Sinigaglia, & Costantini, 2013). In our study, each video represented the central part of an action. For example, the video in which the actress is eating a hamburger does not represent the whole action (i.e., from the moment in which she grasps the hamburger on the table to the moment of actual eating), but just the middle phase (see Figure 1). Immediately after each video the participants were shown a photo. It was either the central frame of the first part of the whole video (backward condition) or the central frame of the third part of the whole video (forward condition). Their task was to respond “before” or “after” according to their evaluation of the photo as depicting what happened before or after the observed action, respectively.

In a first experiment we used this new experimental procedure to replicate the anticipation effects detected in the literature (Gerrie, Belcher & Garry, 2006; Verfaillie & Daems, 2002) with new and ecological materials. We hypothesize that forward simulations from action observation should favour processing of what is still to come, which might occur at the expenses of backward simulations of what already happened. We tested the prediction that evaluation of forward photos should be faster than evaluation of backward photos (Experiment 1).

The aim of a second experiment was to verify whether an interfering body posture may affect anticipation mechanisms: if the cognitive mechanism underlying action anticipation is embodied, then manipulations of the observer's body should result in modulation of the simulation processes. Hence, we tested the prediction that manipulations of the observers' body posture should modulate the anticipation effect (Experiment 2). The participants in the experiment were invited to perform a secondary motor task involving interfering postures and movements. Specifically, one

group of participants kept their hands and arms crossed behind their back, a position incongruent with the observed action (similar to Dutriaux & Gyselinck, 2016). Since performance of movements incongruent with the observed actions can also interfere with simulation processes (e.g., Ping, Goldin-Meadow & Beilock, 2014), another group of participants performed a pattern of movements different from those involved in the observed action, but involving the same effectors: starting with their hands on their knees, they alternately touched with the index fingers the table in front of the computer. These two secondary tasks were used to potentially interfere with the ongoing action simulation. Participants in two more groups were invited to keep their arms and hands still on the table and to move their legs and feet, different effectors from those moved by the actress in the video. These two secondary tasks were the control conditions of the interfering ones. We predicted a significant interaction between the temporality of the photo to be evaluated and the secondary task performed by participants: whereas in the control conditions evaluation of forward photos should be faster than evaluation of backward photos, this should be not the case in the interfering conditions.

Since the tasks in both Experiments 1 and 2 were relatively easy, we tested our predictions in terms of reaction times rather than accuracy. Also, several studies in the literature that used secondary body-related task detected effects of body manipulations just in terms of reaction times, as body manipulations seem to affect cognitive *processes* rather than mental *representations* (Iani, 2019).

The Bioethical Committee of Turin University approved the investigation.

2. Experiment 1: Evaluation of forward photos is faster than evaluation of backward photos

The participants in the experiment observed a series of videos and after each video they saw a backward or forward photo. Their task was to answer “before” or “after” depending on whether they thought the action in the photo portrayed something before or after the action seen previously, respectively. The prediction was that evaluation of forward photos should be faster than evaluation

of backward photos.

2.1. Methods

2.1.1. Participants

Thirty-four students from Turin University (6 males and 28 females, mean age = 23.26; $SD = 6.09$) voluntarily took part in the experiment in exchange of a course credit. They previously signed the informed consent. Using an a-priori power analysis, we estimated that at least 32 participants were required to obtain a suitable statistical power level of .80 to detect a significant paired comparison, assuming an effect size (d_z) of .46 (with $\alpha = .05$). This effect size was based on a previous pilot research in which 23 participants were tested with the same procedure. The d_z value was computed using the formula $t/\sqrt{n}$ (see, Lakens, 2013).

2.1.2. Material

The material consisted in a series of 16 videos each depicting a single action performed with the upper limbs, with either one or two arms (e.g. answering the phone; see the full set in Appendix). Each video was cut into three same-length parts. The middle part of each video was presented to the participants in the experiment. The first frame of these videos remained on the computer screen for 1000 ms before the actual video presentation (for a mean length of 2060 ms); this procedure runs against our prediction, since the first frame of each video is closer to the backward photo than to the forward photo relative to the video. Also, the experimental material comprised a couple of photos for each video: the middle frame of the first part of the whole video (backward photo), and the middle frame of the third part of the whole video (forward photo). In Figure 1 are examples of stimuli obtained by the video *Eating a hamburger*. The two photos (backward and forward) were presented only at recognition.

2.1.3 Design and procedure

Stimuli were organized in two protocols. In Protocol 1 videos numbered from 1 to 8 in

Appendix were paired with backward photos and videos numbered from 9 to 16 were paired with forward photos. In Protocol 2, videos numbered from 1 to 8 in Appendix were paired with forward photos, and videos numbered from 9 to 16 were paired with backward photos. Half of the participants were assigned to Protocol 1 and half to Protocol 2. The presentation order of the videos (and relative photos) was randomized for each participant in each protocol using E-Prime 3.0 Software.

Figure 1. The experimental stimuli extracted from the video *Eating a hamburger*.

The experiment took place with the presence of experimenter and an assistant. Participants sat in front of the computer screen approximately at 15 inches and received the following general instructions:

Thank you for participating in this experiment on how we understand the performance of an action over time. You'll see a series of short videos. In each video there is an actress who performs an action. Immediately after each video, a fixation cross will appear in the middle of the screen, followed by a photo. Your task is to decide if the photo represents what happened before or after what you saw in the video. Answer aloud by saying BEFORE if you think it happened before, or by saying AFTER if you think it happened after.

After each video, and a black screen of 250 ms, each photo remained on the screen for 7 seconds and then a white slide with the instruction "Next video" appeared, before the following video. This inter-stimulus interval (ISI) granted that participants had to rely on simulation mechanisms; indeed, it is a well-established finding that ISIs shorter than 150 ms generate apparent visual motion that relies on perceptual mechanisms (Verfaillie & Daems, 2002). We used vocal responses to avoid classic manual responses (e.g., key presses), which would have loaded up the same hand-related motor resources required to process the observed action. We measured participants' response times with MatLab 2018 software, from photo presentation to participants' oral answer. Specifically, RTs were measured by calculating milliseconds from photo presentation onset to oral answer onset (the matlab script used to calculate RTs is available online at <https://DOI.ORG//10.17605/OSF.IO/TGQ4R>). We chose this solution, compared to measuring milliseconds from photo presentation to oral answer ending, to avoid potential differences in the lexical processing required to say "before"/"after" ("prima"/"dopo" in Italian).

2.2. Results

We analysed response times for accurate evaluations (erroneous evaluations were 15% in backward condition and 3% in forward condition). We excluded from the analyses two participants whose number of correct evaluations was 2 standard deviations below the mean. We present the results for the remaining thirty-two participants. Figure 2 shows RTs for correct evaluations in backward and forward conditions.

We run a paired sample *t* test between the two conditions (backward and forward photos) for RTs. As predicted, RTs for evaluations of forward photos were shorter than for backward photos (T test: $t(31) = 2.60$, one-tailed $p = .007$, Cohen's $d_z = 0.46$). We provide also Bayes factors in order to determine the relative likelihood of observing the present data under the null hypothesis compared to the alternative hypothesis (see Rouder, Speckman, Sun, Morey & Iverson, 2009). Bayes factor tests were run using JASP software (JASP Team: JASP (Version 0.8.2), 2017) with a default JASP prior, that is a Cauchy prior with a location parameter of 0 and scale parameter of 0.707. Evidence in favour of the null hypothesis is denoted as BF_{01} and in favour of the alternative hypothesis as BF_{10} . For this crucial comparison we detected a BF_{10} of 3.29, thereby providing moderate evidence in favour of our experimental hypothesis.

As a general result, participants were more accurate to identify forward photos (mean = 0.97; $SD = .06$) compared to backward photos (mean = 0.85; $SD = .18$: T test: $t(31) = 4.19$, two-tailed $p < .001$, Cohen's $d_z = 0.74$; $BF_{10} = 129.19$).

The overall results of Experiment 1 confirm the prediction that forward simulation of observed actions is faster than backward simulation.

Figure 2. Responses times (in ms) and standard deviations for correct evaluations in Experiment 1.

3. Experiment 2: Observers' body posture modulates forward simulation's effects

The task of the participants was the same as in Experiment 1, with the exception that we manipulated their body posture and movements. Hands behind the back can interfere with forward simulation from observation of actions on objects, while hands in front of the body is a posture that may not interfere. Also, hands and arms movements might interfere, while feet and legs movements may not. The participants in the experiment were randomly assigned to one of these experimental groups.

3.1. Methods

3.1.1. Participants

One hundred and twenty-eight students from Turin University (31 males and 97 females, mean age = 23.40; $SD = 2.66$) voluntarily took part in the experiment in exchange of a course credit. A power analysis revealed that at least 21 participants in each group were required to obtain a suitable statistical power level of .80 in order to detect a significant within-between interaction, assuming a small effect size ($\eta_p^2 = .01$), a high correlation among repeated measures ($r = .86$, obtained by our pilot study and Experiment 1 collapsed), and $\alpha = .05$.

3.1.2. Material

The material was the same as in Experiment 1.

3.1.3. Design and procedure

Design and procedure were the same as in Experiment 1, with the exception that each participant was invited to perform the task in one of four different groups.

In the *interfering posture* group, participants were invited to keep their hands behind their back and to hold a plastic tube. The instructions were as follows: “During the entire experiment, we ask you to keep your hands crossed behind your back and hold a tube”.

In the *interfering movement* group, participants were invited to perform a continuous and alternate tapping with index fingers on a pad, which was positioned on the PC desk, between them and the PC. The instructions were as follows: “Start with your hands placed on your knees, and alternately touch with your index fingers a casual point on the table in front of the computer. It is important that your movements be continuous and alternate. Start with an arm’s movement (left or right), only after the other hand has come back on the knee”.

Two other conditions were the controls of these interfering conditions.

In the *control posture* group, participants were invited to keep their hands in front of them and they were instructed as follows: “During the entire experiment, put your hands on the desk in front of you, at rest.”

In the *control movement* group, participants were invited to perform a continuous and alternate tapping with feet on a yoga mat, which was positioned under the PC desk. The instructions were as follows: “With alternate movements, first stretch your legs in front of you and then touch the floor with just your heels”.

The experimenter’s assistant checked that participants adopted the requested posture or performed the requested movements for the entire duration of the experiment.

3.2. Results

We analysed response times for accurate evaluations. We excluded from the analyses the data of four participants whose number of correct evaluations was two standard deviations below the mean and the data of three participants who did not properly accomplish the secondary task. In particular, two participants in the interfering movements group (one used the hands rather than the fingers and did not alternate the tapping and one whose tapping was not continuous) and one participant in the control posture group (the participants moved the fingers all the times). We present the results for the remaining one hundred and twenty-one participants. Figure 3 shows RTs for correct evaluations in backward and forward conditions within each group.

Figure 3. Response times (in ms) and standard deviations for correct evaluations in Experiment 2.

RTs were analysed with a mixed 2 (Temporality: backward; forward) x 4 (Group: interfering posture; interfering movement; control posture; control movement) ANOVA that revealed a main effect of temporality factor ($F(1,117) = 19.30; p < .001; \eta_p^2 = .14$), with shorter RTs for forward photos than for backward photos, but not a main effect of group ($F(3,117) = .89; p = .97, \eta_p^2 = .00$). Crucially, the interaction was significant ($F(3,117) = 2.89; p = .039; \eta_p^2 = .07$). We explored this significant interaction. With two one-way ANOVAs we compared groups for backward and for forward photos, separately: there were no significant differences between groups (backward: $F(3,117) = .74, p = .53$; forward: $F(3,117) = .47, p = .70$). Within group comparisons revealed, as predicted, a significant difference between backward and forward factor in the control groups: hence, forward evaluations were faster than backward evaluations in control movement group ($t(30) = 2.52$; one-tailed $p = .01$, Cohen's $d_z = 0.45$; $BF_{10} = 2.84$) and in control posture

group ($t(29) = 3.58$; one-tailed $p < .001$, Cohen's $d_z = 0.65$; $BF_{10} = 27.99$). Contrary to our expectation, we detected an advantage of forward evaluations also in the interfering movement group: the comparison yielded a marginally significant difference ($t(28) = 2.05$; two-tailed $p = .047$, Cohen's $d_z = 0.38$; $BF_{10} = 1.22$). However, the Bayesian analysis ($BF_{10} = 1.22$) does not provide evidence for H_0 or H_1 , thereby suggesting how results in this condition should be interpreted with caution. Crucially, no difference was found in the interfering posture group ($t(30) = .095$; two-tailed $p = .93$, Cohen's $d_z = 0.017$; $BF_{01} = 5.20$). Bayesian analyses strengthen what we can legitimately infer when interpreting comparisons that reveal the absence of statistically significant differences. By comparing RTs for backward and forward conditions, testing the H_0 (no differences between the two conditions) and the H_1 (differences between the two conditions), the result of the Bayesian t-test provides substantial support for the null hypothesis, being 5.20 times more likely to occur under the null hypothesis, compared to the alternative hypothesis (see, Jarosz & Wiley, 2014).

For explorative purpose we analysed the results in terms of accuracy. Table 1 presents the means of correct evaluations in each experimental group. A mixed 2 (Temporality: backward; forward) $\times$ 4 (Group: interfering posture; interfering movement; control posture; control movement) ANOVA revealed a main effect of the temporality factor ($F(1,117) = 50.87$; $p < .001$; $\eta_p^2 = .30$), with more correct evaluations of forward photos than backward photos. The main effect of Group was also significant ($F(3,117) = 6.70$; $p < .001$; $\eta_p^2 = .15$). Post hoc tests (Bonferroni adjusted) revealed that, on the overall accuracy (backward and forward conditions considered together), participants in the interfering posture group were less accurate both than participants in the interfering movement group (a mean of 0.85, $SD = .35$ and 0.92, $SD = .27$ respectively; $p = .04$) and in the control movement group (a mean of 0.94, $SD = .23$; $p < .001$). Further, participants in the control posture group were less accurate than those in the control movement group (a mean of 0.88, $SD = 0.32$ and 0.94, $SD = .23$ respectively; two-tailed $p = .02$). The other comparisons between groups were not significant.

(p value ranging from 1 to .70). The interaction between temporality and group was also not significant ($F(3,117) = 1.43$; $p = .24$).

Table 1. Means proportions of correct evaluations (and standard deviations) in Experiment 2.

	Accuracy	
	Backward	Forward
Interfering posture	0.78 ($SD = 0.42$)	0.93 ($SD = 0.25$)
Interfering movement	0.87 ($SD = 0.33$)	0.96 ($SD = 0.18$)
Control Posture	0.85 ($SD = 0.36$)	0.92 ($SD = 0.27$)
Control movement	0.91 ($SD = 0.29$)	0.98 ($SD = 0.13$)

4. General discussion

In line with well-established findings in the literature, the present investigation provides evidence for anticipatory mechanisms during action observation within a novel experimental paradigm. In Experiment 1, participants evaluated forward photos faster than backward photos; forward simulation primed forward photos evaluation at the expenses of backward photos evaluation. Experiment 2 investigated the nature of these effects and revealed the role of the observers' body posture: when participants kept their arms still, behind their back, they struggled in simulating the ongoing action, and thus they did not show the advantage in evaluating forward photos. Overall, the results of the two experiments indicate that when humans run automatic

forward simulations from action observation, they rely at least in part on their potentiality of action: bodily conditions incompatible with the observed action (i.e., hands and arms still behind the back) modulate the effect, hindering the tendency to recognize forward photos faster than backward ones.

Skeptics might argue that holding a tube in the hand (interfering posture condition) is an object-oriented action that activates mental simulations of actions associated with the tube. This, rather than posture “*per se*”, would be the reason why we detected interferences with the actions observed. While this might be a factor that could be considered, one needs to bare in mind that participants were asked to stay still (they were not actively involved in any potential action with the object) and the still posture adopted may at the most represent the final state of a tube grasping movement. This is a condition in which the motor system is definitely not activated in the same way as in upcoming (see, e.g., Urgesi et al., 2010) and planned actions (Tanji, & Evarts, 1976).

The results of the current experiments concerning interfering movements are apparently in contrast with those of studies that have successfully used performance of movements incongruent with mental simulation to interfere with simulation processes. For instance, in the study by Ping et al. (2014) the task of the participants was to observe a series of videos in which an actor utters a series of sentences - e.g., “The woman hammered the nail into the wood” - while performing a specific gesture - e.g., a gesture suggesting either a vertical or a horizontal nail’s position. Then, they saw an object’s picture that could be in a position congruent or incongruent with the gesture observed in the video (for instance, a nail in a vertical or horizontal position). Their task was to respond “yes” or “no” according to whether the name of the object in the picture was mentioned in the sentence. Results revealed that when the object in the picture was in a congruent position, thus when the information conveyed by gesture matched the picture information, the participants were faster at responding compared to when the object in the picture was in an incongruent position. When they had to execute a secondary motor task during action observation (i.e., move the same effectors moved by the actor in a different and non-repetitive fashion), the effect of gestures on

sentence processing disappeared, thereby suggesting that loading the observer's motor system interferes with gestures understanding. Apart that, as we already pointed out, the results for the interfering movement condition in our studies have to be interpreted with cautions, there could be two non-mutually exclusive explanations for their inconsistency with those in the cited literature. First, we used everyday actions of heterogeneous nature as experimental stimuli. For this reason, the movement required by the secondary task might have had a facilitating effect on the processing of observed actions. As one example, actresses' movements made when "answering a phone" or "drinking a glass of water" are partially comparable to the movements required by interfering movement condition (i.e., moving arms backwards and forwards). Consistent with this explanation, the results on accuracy suggest that movements favored the correct evaluation of the photos (see Table 1). Furthermore, as the results of a recent free recall memory study revealed (Halvorson, Bushinski, & Hilverman, 2019), a secondary motor task does not interfere with participants' performance as long as they are engaged in the motor task at both encoding and retrieval. Since participants in our experiment were invited to perform the interfering movements both during action observation and during photo evaluation, this may have not interfered with the sensorimotor simulations underlying the two phases. As an additional important remark, one should consider that we investigated the impact of sensorimotor interferences on anticipation mechanisms, whereas these previous studies investigated the impact of sensorimotor interference on sentences comprehension (Ping et al., 2014) or memory (Halvorson et al., 2019; see also Ianì & Bucciarelli, 2018; Ianì et al., 2018).

The results of the present investigation, along with those in the literature, suggest that during action observation we unintentionally predict what is going to happen. Barsalou (2008) highlighted how our cognitive system evolved primarily to rapidly process moving stimuli around us, an ability that supports our direct perception of other persons' intentions (Gallagher, 2008). Former studies have revealed that memory for the final position of a moving object is systematically distorted

forward along its path of motion (see, e.g., Freyd & Finke, 1984). Studies have revealed that similar processes are involved in human movement observation (Iani, Mazzoni, & Bucciarelli, 2018; Iani, Limata, Bucciarelli, & Mazzoni, 2020) and, in line with this finding, other studies have shown that the eyes of observers look ahead of the agents' hand to the goal of each reaching movement (Flanagan & Johansson, 2003). These forward mental simulations, as the results of the present investigation suggest, involve an embodied mental representation. A growing series of evidence reveals that bodily postural features involved in planning and executing actions are involved also in imagining to act (see, e.g., Jeannerod, 2001); in a similar way, they modulate perception of other people's actions. Because of its bodily format, a forward mental simulation can be easily shaped and constrained by body postures. Several studies suggest that, for imitable stimuli like other humans' actions, observed and internal motor programs are isomorphic to one another (Wilson, 2001). As the results of an eye movements study have revealed, when participants observed graspable or ungraspable objects their functional knowledge of the stimuli affected gaze behavior towards the objects (Ambrosini & Costantini, 2017). In particular, the way they visually explored objects was biased towards action-relevant information. Crucially, this effect was modulated by participants' posture: when their hands were tied behind their back the bias was reduced. These results enforce the assumption that our possibilities to move affect how we perceive the environment. As the results of less recent studies have revealed, visual perception of human body motions is constrained by proprioceptive information concerning the observer's own body (Reed & Farah, 1995) and humans can simulate and anticipate only actions which are anatomically possible (not those impossible to be performed by a human body), i.e. actions that also the observer potentially might perform (Daems & Verfaillie, 1999).

The results of the present investigation, along with those in the literature, suggest that humans, during perception of other people's movements, rely on implicit motor knowledge of biomechanical constraints to anticipate the forthcoming states of observed actions. This implicit

motor knowledge is acquired through an embodied process that exploits the observer's body, and thus manipulations of the observer's body results in a change in the anticipation mechanisms. In particular, keeping a body posture that does not favour motor simulation triggered by action observation may affect perception of other humans' behaviour.

A limit of the present investigation is that it cannot say much about the nature of the cognitive processes underlying backward photos evaluations. Backward simulations have received less attention also in general in the action observation literature, and they might involve different processes. One possibility is that they run as purely inferential mechanisms that take into account the current state and infer the action steps that are required to lead to the current state. It happens that observing pictures portraying an effect but not a cause can result in false memories in which participants mistake new pictures depicting a cause as old (Hannigan & Reinitz, 2001). In other words, participants during the encoding phase draw backward inferences and, later on, they mistake these inferences as the original scenes (Foster & Garry, 2012). In these studies, however, the nature of the backward inference was not clear. Inferring the cause from an effect seems to be based on logical/verbal backward inferences that are higher cognitive processes compared to those postulated in action observation.

In light of the literature, future studies need to disambiguate two major types of mental simulation from action observation: a forward simulation automatically triggered by observed action and representing their unfolding in time (sensory-motor simulation), and a "backward simulation" deliberately activated by individuals to reconstruct the possible antecedents of observed actions (high-level simulation). A related issue that future studies might investigate is simulation from observation of action videos presented in a backward direction. We might expect that our ability to escape from the present, and mentally go forth in time to anticipate events, be an obstacle to performing backward simulations of this nature.

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The Supplementary Materials, Matlab script and the data reported in this paper are archived at the following database: <https://osf.io/7j586>

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Appendix

The 16 actions performed by the actress in the experimental material.

1. Sniff a flower

Video onset → Video offset

Backward photo

Forward photo

2. Open a book

Video onset → Video offset

Backward photo

Forward photo

3. Close a portable computer

Video onset → Video offset

Backward photo

Forward photo

4. Drink a glass of water

Video onset → Video offset

Backward photo

Forward photo

5. Cut a pizza

Video onset → Video offset

Backward photo

Forward photo

6. Use eye drops

Video onset → Video offset

Backward photo

Forward photo

7. Tear a sheet of paper

Video onset → Video offset

Backward photo

Forward photo

8. Wear the eyeglasses

Video onset → Video offset

Backward photo

Forward photo

9. Eat a hamburger

Video onset → Video offset

Backward photo

Forward photo

10. Smoke a cigarette

Video onset → Video offset

Backward photo

Forward photo

11. Answer the phone

Video onset → Video offset

Backward photo

Forward photo

12. Peel a banana

Video onset → Video offset

Backward photo

Forward photo

13. Pour the soup

Video onset → Video offset

Backward photo

Forward photo

14. Infuse the tea

Video onset → Video offset

Backward photo

Forward photo

15. Blow the nose

Video onset → Video offset

Backward photo

Forward photo

16. Put on a hat

Video onset → Video offset

Backward photo

Forward photo