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Short Communication

I see what you say: Prior knowledge of other's goals automatically biases the perception of their actions

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ABSTRACT

We investigated whether top-down expectations about an actor's intentions affect action perception in a representational momentum (RM) paradigm. Participants heard an actor declare an intention to either take or leave an object and then saw him either reach for or withdraw from it, such that action and intention were either congruent or incongruent. Observers generally misperceived the hand's disappearance point further along the trajectory than it actually was, in line with the idea that action perception incorporates predictions of the action's future course. Importantly, this RM effect was larger for actions congruent with the actor's goals than for incongruent actions. These results demonstrate that action prediction integrates both current motion and top-down knowledge about the actor's intention. They support recent theories that emphasise the role of prior expectancies and prediction errors in social (and non-social) cognitive processing.

1. Introduction

One's predictions of an action's future course are guided not only by incoming sensory information but also by prior knowledge of the actor's goals. If I said "I'm thirsty!" while reaching for a mug, you might predict that I would soon drink from it. However, if I said "The mug isn't safe here" you would make a completely different prediction, perhaps to move the mug to a different place. Such predictions are central to fluent social interactions, allowing people to direct attention towards anticipated action goals (Eshuis, Coventry, & Vulchanova, 2009; Gredeback & Melinder, 2010), to coordinate joint actions (Sebanz & Knoblich, 2009), and to fill in information missing from perceptual input (eg. Sparenberg, Springer, & Prinz, 2012). Yet, despite their ubiquity, little is known of how social predictions come about, and via which mechanisms they exert such far-reaching effects on behaviour.

Recent hierarchical feedback models of cognition suggest that predictions themselves are perceptual, and therefore affect all subsequent processes – both motor and cognitive – that depend on perceptual input (Clark, 2013; Den Ouden, Kok, & De Lange, 2012). In social interactions, people continuously second-guess others' intentions, using cues such as nearby objects (Bach, Knoblich, Gunter, Friederici, & Prinz, 2005; Bach, Nicholson, & Hudson, 2014), gaze (Becchio, Bertone, & Castiello, 2008; Hudson, Liu, & Jellema, 2009), emotional expression (Hudson & Jellema, 2011), and inferred mental states (Teufel, Fletcher, & Davis, 2010). In hierarchical feedback models of social perception (Kilner, Friston, & Frith, 2007a, 2007b), such inferences do not remain abstract: instead they are immediately translated into concrete behaviour predictions – a thirsty person will drink from a glass, a cautious person may merely move it – and compared with sensory input. If there is a match, one's goal assumptions are confirmed. "Prediction errors", however, render the mismatching event more salient and cause re-evaluations of the prior assumptions or the perceptual input. Because these processes happen in sensory processing areas themselves (Coventry, Christophel, Fehr, Valdés-Conroy, & Herrmann, 2013; Summerfield et al., 2006), predictions have direct perceptual consequences. Perception, especially when ambiguous, is biased towards one's predictions. The perception of mismatches, however, is enhanced.

Such models are a marked departure from prior work where observed actions are matched, in a bottom-up manner, to own motor or goal representations (Rizzolatti & Sinigaglia, 2010). Instead, any high-level information about others' intentions will directly affect, in a top-down manner, the perception of their actions, biasing them in the direction of their (predicted) future course. Here, we test whether others' action goals have such a top-down influence. We used the well-established representational momentum (RM) paradigm (Freyd & Finke, 1984;

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Hubbard, 2005). Participants see a moving object, which suddenly disappears. They then compare the objects' last position with a probe stimulus, which is either displaced slightly forward in time (in an anticipated future position) or backward in time (a previous position). As predicted by hierarchical feedback models, perceptual judgements are typically biased towards the immediate future: Backwards displacements elicit large prediction errors and are readily detected, whereas equivalent forward displacements, which are in line with one's predictions, are perceived as identical with the object's last position. The amount of forward bias – the size of the RM effect – is thus directly related to the strength of action prediction. Subsequent research has shown that the effect reflects one's internal model of future motion, and integrates information about the object, its environment, the effect of one's own actions, and the physical forces acting on it (Hubbard & Bharucha, 1988; Jordan & Hunsinger, 2008; Jordan & Knoblich, 2004; Kerzel, Jordan, & Muesseler, 2001; reviewed in Hubbard, 2005). Moreover, because participants are asked to accurately judge the hand's disappearance point, the effect reflects automatic, involuntary effects of motion predictions on perceptual judgments.

Here, we apply this paradigm to social perception and test, whether top-down knowledge of others' intention is directly transformed into perceptual action predictions. Any information about an actor's intention should then be automatically integrated with the observed kinematics, and bias perceptual judgments towards this goal, even when asked to accurately report disappearance points. Participants watched an actor's hand either reaching for or withdrawing from an object, and then judged the hand's disappearance point relative to probes that were either identical to the hand's last seen position, or displaced either forward or backward to the direction of motion. To manipulate perceived goals, prior to action onset, the actor declared an intention to either reach for the object ("I'll Take It!") or withdraw from it ("I'll Leave It!"). If others' goals are immediately integrated into predictions of their action's course, then the match between goal and action should directly affect motion prediction. RM for reaches toward an object should increase when the actor has stated that he wished to "take it" than "leave it", and vice versa for withdrawals.

Such effects would support hierarchical feedback models of social perception and show that perception itself is influenced by what we predict others to do, explaining why goal attributions have such pervasive effects on subsequent attention and behaviour (Eshuis et al., 2009; Gredeback & Melinder, 2010; Sebanz & Knoblich, 2009). In the first experiment the intentions were linked with object type. The actor said "I'll Take It" for safe objects and "I'll Leave It" for dangerous objects. The second experiment orthogonally manipulated object and intention to test whether object types or intention statements gave rise to the effects (i.e. actors could now say "I'll take it" for both painful and safe objects). Moreover, while in Experiment 1 the utterances of the actors were task relevant, they were completely irrelevant in Experiment 2 (see also Supplementary Experiment). While prior work has assessed how gaze cues (Hudson et al., 2009) and overt instructions to others (Hudson, Nicholson, Simpson, Ellis, & Bach, in press) affect action prediction, this study tests for the first time whether others' stated intentions are automatically integrated into the perception of their action.

2. Method

2.1. Participants

Participants (Experiment 1: 35 participants, 23 females, mean age of 27.7 years, *SD* = 10.3; Experiment 2: 32 participants, 20 females, mean age of 26.8 years, *SD* = 9.2), were right handed, native English speakers, and were recruited from the Plymouth community. They gave written informed consent and were recompensed with £6. The experiments adhered to the ethical guidelines of Plymouth University and the ESRC, in accord with the declaration of Helsinki.

2.2. Apparatus

Visual stimuli were filmed using a Canon Legria HFS200 and edited using MovieDek and Corel Paintshop Pro X6. Audio stimuli were recorded using a M-Audio Microtrack 2 Digital Voice

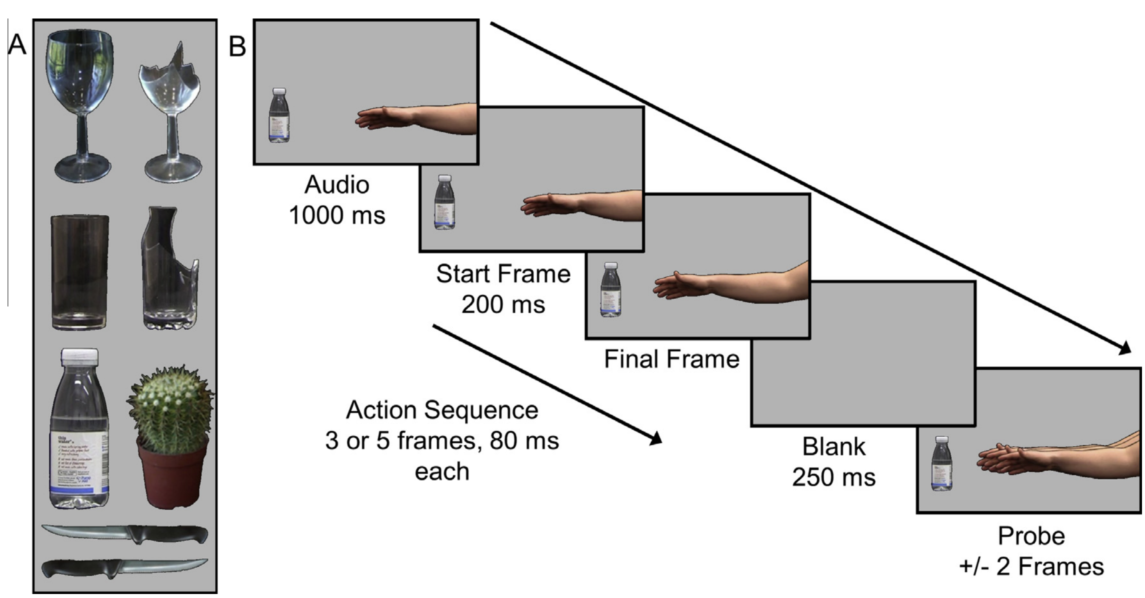


Fig. 1. Experimental stimuli and trial sequence. The range of objects is depicted in panel A, with safe objects in the left column and the equivalent painful objects in the right column. The knife oriented with either the handle (safe) or blade (painful) oriented to the hand is depicted at the bottom. An example of the trial sequence is depicted in panel B. In this example, the hand reached toward the object, which was safe to grasp. The probe stimulus could be in one of three positions (each superimposed over the other for illustrative purposes). It was either the same as the final position of the action sequence (centre), displaced forward in time (nearest the object) or displaced backward in time (farthest from the object). The probe could be displaced by 1 frame or 2 frames (illustrated here). For actions withdrawing from the object, probes displaced forward in time were farther from the object and probes displaced backward in time were nearer the object. The black background has been changed to grey for illustrative purposes.

Recorder. The experiment was administered using Presentation (NeuroBS) on a Viglen DQ67SW computer with a Philips Brilliance 221P3LPY display (resolution: 1920 × 1080, refresh rate: 60 Hz). Audio stimuli were delivered using a Logitech PC120 combined microphone/headphone set.

2.3. Stimuli

2.3.1. Visual stimuli

The stimulus (Fig. 1) was derived from videos of a hand starting in a rest position then reaching for one of four objects on the left (glass, wine glass, plastic bottle, knife with handle oriented to the hand). For each reach, a second sequence was created by digitally replacing the safe objects with painful objects that were matched for size and grip type (broken glass, broken wine glass, cactus, knife with blade oriented towards hand). All background details were replaced with a uniform black background. The action sequences (.07 × .12 degrees visual angle) used in the experiment consisted of 26 frames of these movies and showed the complete transport phase, while the final grasp was omitted. Each sequence was either 3 or 5 frames long and started in the middle of the reach (starting frame randomly chosen between frames 13 and 17). Reaches and withdrawals were created by stepping either forwards or backwards through the sequence (e.g. frame 15–17–19 for reaches, frame 15–13–11 for withdrawals). Each frame was presented for 80 ms.

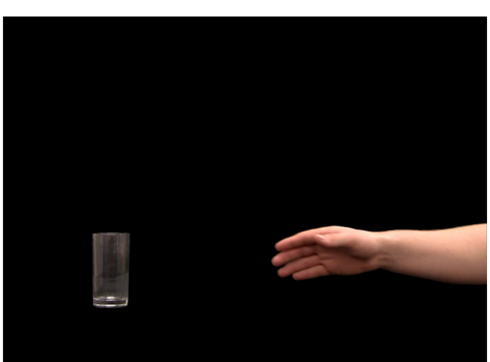
2.3.2. Audio stimuli

Two audio stimuli of an actor saying "I'll Take It" and "I'll Leave It", each of 1000 ms duration, were played through the headphones, biased 50% to the right to match the actor's position on the right of the screen.

2.4. Procedure

Participants sat approximately 60 cm from the computer screen. Each trial began with a fixation cross followed by a blank screen (combined duration 1000 ms), followed by the first static frame of the action sequence, showing a hand near the object. After a random delay between 1000 ms and 3000 ms, the intention statement – "I'll Take It" or "I'll Leave It" – was presented. The action sequence (grasp or withdrawal) always started 200 ms after statement offset, creating a causal link between intention statement and action.

After a blank screen (250 ms), the probe stimulus consisting of a single frame taken from the same action sequence was presented (4000 ms or until response). It showed the hand in either the same position as the final frame of the action, displaced forward along the trajectory ("+", nearer the object for reaches, farther for withdrawals), or displaced backward ("−"). This displacement of the forward and backward probes was either 1 frame or 2 frames forward or backward, producing 5 possible probe positions (−2, −1, 0, +1, +2). Participants pressed the spacebar if they thought the probe position was different from the hand's final position, and did not respond if they thought it was the same. Please see the multimedia file below (see online) for an example of the trials (see Supplementary table for trial descriptions).



Video 1. Trial Examples.

2.4.1. Experiment 1

Each level of Intention ("I'll Take It", "I'll Leave It"), Action Direction (reach, withdrawal), and Probe Direction (−2, −1, 0, +1, +2) was varied factorially and repeated 8 times (160 trials). The object was randomly selected on each trial. To ensure that participants would process the intention statements, in a further 16 trials the actor stated the wrong intention ("I'll Take It" for painful objects, "I'll Leave It" for safe objects"). Participants were required to say "Stop!" as soon as they detected this mismatch and the trial ended. Additionally, 16 catch trials were included in which the probe was displaced by 4 frames from the final position of the action sequence. These catch trials were used to identify participants who did not comply with task instructions and were not analysed further.

2.4.2. Experiment 2

The factors Object Type (safe, painful), Intention ("I'll Take It", "I'll Leave It"), Action Direction (reach, withdrawal), and Probe (−2, −1, 0, +1, +2) were varied factorially and repeated 6 times, producing 240 trials, in addition to the 16 catch trials in which the probe was displaced by 4 frames. There were no catch trials in which the actor uttered an incorrect intention.

2.5. Analysis

RM was measured as the difference between the frequencies with which backward displaced probes were detected relative to forward probes. Positive values therefore reflect increased likelihoods of accepting forward displaced hands as "same" compared to backwards displacements. While RM has been quantified in various ways (see Hubbard, 2010, for overview), this measure corresponds to the original approach (Freyd & Finke, 1984), and provides a straightforward measure of perceived forward displacements, without requiring further assumptions (although identical results are obtained with alternative measures, e.g. weighted means, Hayes & Freyd, 2002).

3. Results

Participants were excluded if their ability to detect the catch trials was 1SD less than the mean group accuracy, or when their accuracy was less than 10% higher than in the experimental trials (±2, ±1), suggesting an insensitivity to even the largest probe differences. This was the case for eleven participants in Experiment 1 and seven in Experiment 2. However, the results are remarkably robust to the exclusion criterion, and the results remain significant even if no participants are excluded (see Supplementary Material).

3.1. Experiment 1

The percentage of trials in which the probe stimulus was reported as different from the final position of the action sequence were entered into an ANOVA with Intention ("I'll Take It" vs. "I'll Leave It"), Action Direction (reach vs. withdrawal), Probe Distance (2 frames vs. 1 frame), and Probe Direction (forward vs. backward) as repeated measures factors. It revealed a main effect of Probe Direction ($F(1,23) = 68.6$, $p < .001$, $\eta_p^2 = .749$, 95% CI [20,32]) and Probe Distance ($F(1,23) = 137.4$, $p < .001$, $\eta_p^2 = .857$, 95% CI

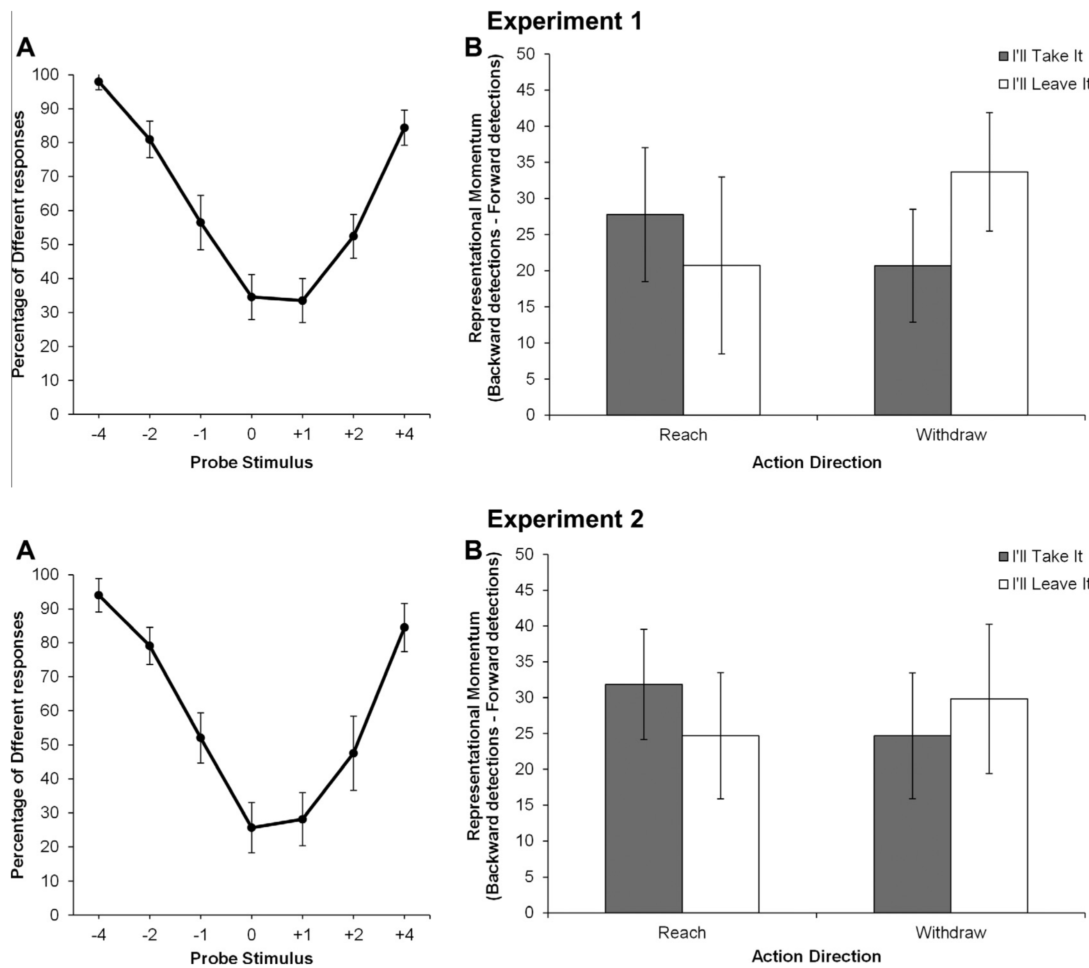


Fig. 2. Results for experiments 1 (top) and 2 (bottom). In panel A the proportion of trials in which the participants judged the probe position to be different from the final position of the action sequence is plotted for each level of the probe stimulus. The proportion of different responses decreases as the displacement of the probe position decreases. However, the extent of this decrease for probes displaced forward in time (+) and backward in time (−) was not symmetrical. This representational momentum effect (backward probe detection – forward probe detection) was significant both when the probe was displaced by 1 frame and 2 frames. The same probes (not analysed) and displacements by 4 frames (catch trials) are included for illustrative purposes. In panel B the representational momentum effect (proportion of detected backwards minus forward displacements) is depicted for reaches toward or withdrawals from the object, after the actor had said either "I'll Take It" or "I'll Leave It". The size of the representational momentum effect was larger when the action direction was congruent with the actors intentions (outer bars) than when incongruent (inner bars). Error bars represent 95% confidence intervals.

[18,25]). Larger displacements (±2) were detected more readily than smaller displacements (±1), and backward displacements detected more readily than forward displacements (Fig. 2. Top/Panel A), reflecting the classic RM effect. Importantly, there was a three-way interaction between Intention, Action Direction and Probe Direction ($F(1,23) = 14.9$, $p = .001$, $\eta_p^2 = .395$, 95% CI [10,30]), showing that RM (detected backwards displacements minus detected forward displacements) depended on the congruency of action and intention. This three-way interaction is depicted in Fig. 2, Top/Panel B, with the Probe Direction factor already resolved to show the size of the RM effect. It illustrates that the RM effect was greater when the action was congruent with the intention than when it was incongruent. There were no further main effects or interactions (*F*s < 2.22).

In a further experiment (see Supplementary Material) we replicated these results when the stated intentions were task irrelevant. Identical effects were observed, demonstrating that intentions affect RM automatically.

3.2. Experiment 2

Data were analysed with the same ANOVA model as Experiment 1, with Object Type (painful vs. safe) as an additional repeated measures factor. There again was a significant RM effect (Probe Direction: $F(1,24) = 53.3$, $p < .001$, $\eta_p^2 = .690$, 95% CI [20,35]), and probes displaced by 2 frames were more readily detected than 1 frame displacements (Probe Distance: $F(1,24) = 89.0$, $p < .001$, $\eta_p^2 = .788$, 95% CI [18,28]). The RM effect was marginally larger for probes displaced by 2 frames than 1 frame (Probe Direction × Probe Distance: $F(1,24) = 4.21$, $p = .051$, $\eta_p^2 = .149$, 95% CI [0,15]). Importantly, as in Experiment 1, there was a three-way interaction of Intention, Action Direction and Probe Direction ($F(1,24) = 7.62$, $p = .011$, $\eta_p^2 = .241$, 95% CI [4,21]). Actions congruent with the intention elicited larger RM than incongruent actions (Fig. 2, Bottom/Panel B). There were no further main effects or interactions. In particular, no effects were qualified by Object Type (all *F*s < 2.1).

4. Discussion

As predicted, observers consistently overestimated the amount of perceived motion in others' actions, such that probes further along the trajectory were seen as indistinguishable from the hand's last position. This RM effect confirms that perception of actions – like that of moving objects – is biased towards the future and anticipates their further course. Importantly, we show that this bias is driven, at least in part, by prior knowledge of the actor's intention. Stated intentions to reach for an object ("I'll Take It") increased RM for movements towards it. In contrast, intentions to withdraw ("I'll Leave It") increased RM for movements away. This was evident even when the statements were completely task irrelevant, and independent of object type, revealing for the first time an involuntary integration of low-level motion and inferences about the actor's goals.

Such direct effects of inferred intentions are problematic for models assuming primarily bottom-up action recognition mechanisms (e.g., based on one's motor experience, Rizzolatti & Sinigaglia, 2010). Instead, they suggest that such pathways are, at the very least, accompanied by parallel top-down mechanisms (cf. Gredeback & Melinder, 2010). They specifically support the proposal that top-down knowledge about the actor's goals is constantly integrated, in a Bayesian manner, with sensory motion information (cf. Kilner et al., 2007a, 2007b). When goal and motion are in line, displacements against these predictions (backward probes) elicit large prediction errors while displacements towards one's predictions (forward probes) remain undetected. For incongruent actions and goals, however, forward and backward probes are more equivocal, and RM is reduced.

Prior work on predictive coding has focussed on the motion of abstract stimuli, stimulus likelihoods (e.g. Hubbard & Bharucha, 1988; Summerfield et al., 2006), and the anticipated effects of one's own actions (Jordan & Hunsinger, 2008; Jordan & Knoblich, 2004; for a review see, Hubbard, 2005). Our finding that high-level knowledge of others' intentions directly biases action perception, even affecting the perception of low-level action kinematics, reveals that very similar mechanisms govern social perception. Such top-down views of social perception (Brown & Brune, 2012; Csibra, 2007; Kilner et al., 2007a, 2007b; Koster-Hale & Saxe, 2013; Teufel et al., 2010) have the potential to unify several findings and theoretical approaches. First, while such models assume that inferred intentions are directly translated into action predictions, there is disagreement about the underlying processes, with some assuming a perceptual or abstract/cognitive mediation (Gredeback & Melinder, 2010; Jellema, Baker, Wicker, & Perrett, 2000; Saxe, Xiao, Kovacs, Perrett, & Kanwisher, 2004), and others implicating motor/action planning processes (Jordan, 2009; Jordan & Hunsinger, 2008; Keysers & Gazzola, 2014; Kilner et al., 2007a, 2007b). Our paradigm is ideally suited to disentangle these possibilities, by testing, for example, whether similar perceptual biases are induced by either low-level motion stimuli (suggesting a perceptual mediation) or overt motor actions of the participants (suggesting a motoric mediation). Second, humans infer others' goal from various cues, such as gaze and emotional expression (Hudson & Jellema, 2011; Hudson et al., 2009), prior behaviour (Joyce, Schenke, Bayliss, & Bach, 2015; Tipper & Bach, 2011), objects and context (e.g. Bach, Bayliss, & Tipper, 2011; Bach et al., 2014; Iacoboni et al., 2005), or action kinematics (Manera, Becchio, Cavallo, Sartori, & Castiello, 2011). Our results specify a common top-down pathway via which such goal inferences affect subsequent processing. By influencing perception, predictions act as an entry mechanism by which one's own behaviour (e.g., actions, Sebanz & Knoblich, 2009; gaze/attention, Eshuis et al., 2009; Gredeback & Melinder, 2010) can be guided by one's inferences about others.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version, at http://dx.doi.org/10.1016/j.cognition.2015.09.021.

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