**Action Restriction of Others Modulate Automatic Belief Tracking in the Observer**

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Tracking what is likely to happen in dynamic social situations is inherently challenging, and – because observing others activates our own motor systems – one view is that motor representations facilitate action and social understanding. Converging evidence revealed through brain imaging, transcranial magnetic stimulation (TMS), and reaction times suggests that observation of an agent’s action leads to activation of a corresponding motor representation in the observer (as reviewed by Rizzolatti & Sinigaglia, 2016). Neuroimaging studies support that the observation of actions done by others triggers activity in the motor execution-related brain areas that includes the ventral premotor and inferior parietal cortices (Cattaneo & Rizzolatti, 2009; Rizzolatti, Fogassi & Gallese, 2009). Consistent with imaging data, studies applying magnetic stimulation to the motor cortex during observation of reach-to-grasp actions reveals increased excitability in those parts of the motor cortex that correspond to the observed movement. For example, when adults watch another individual grasp an object, motor evoked potentials triggered by the stimulation are elevated in the very same muscles that would be active if the observers were actually making that grasping action (Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995; Urgesi, Moro, Candidi, & Aglioti, 2006). Most importantly for the present study, b

Notably, there can be different motor coding levels during action observation (Grafton & Hamilton, 2007; Rizzolatti & Sinigaglia, 2010; Sartori, Betti, Chinellato, & Castiello, 2015). Whilst some motor representations can map the low-level parameters that compose action (patterns of bodily configurations, joint displacements or muscle activations), others can selectively carry information relating to the goal of an agent’s action (i.e., the anticipated or observed outcomes to which another’s purposive behaviour is directed). There are TMS data indicating that motor representations code the goal of an agent’s tool-mediated behaviour and not necessarily the muscular pattern required to perform the movement, and that virtual lesions to the ventral premotor cortex impair judgments about the outcomes that bodily actions are directed to, but preserves judgements about which body parts are being observed (Cattaneo, Caruana, Jezzini, & Rizzolatti, 2009; Urgesi, Candidi, Ionta, & Aglioti, 2006). Likewise, when we witness an agent perform an action goal using a non-typical effector (kicking a ball with her finger or grasping a pencil with her foot, for instance), there is motor facilitation in the effector muscles that we typically use to achieve that action goal (i.e., the leg or the hand, respectively) (Betti, Castiello, & Sartori, 2015; Senna, Bolognini, & Maravita, 2014). Collectively, these findings suggest that goals of observed actions can be represented motorically in the observer~~. A number of researchers interpret the evidence as fitting with the conjecture that putative mirror neuron activity in our motor cortical network automatically transforms sensory aspects of an agent’s action into a matching motor representation of that action as if we were planning and executing that act, and therefore, because we can model ‘from the inside’ the outcome of that particular action, we can implicitly and efficiently track the agent’s goal~~ (Rizzolatti & Sinigaglia, 2016; Rizzolatti, Fogassi & Gallese, 2001).

Tracking others’ behaviour involves being sensitive not just to an action itself but also to the context of an action. There is evidence suggesting that our motor system can identify the context in which specific actions are embedded. Iacoboni, Molnar-Szakacs, Gallese, Buccino, and Massiota (2005) monitored adults’ brain activity as participants watched three types of movies: clips of different background contexts (cup, teapot and plate of food arranged as if someone was about to have breakfast, or had finished); clips of a hand physically executing different grips (precision or whole-hand) to grasp a cup without context; and clips of a hand physically executing different grips to grasp a cup in the different contexts. The imaging data showed that the condition where participants witnessed grasping actions in embedded contexts, compared to the other conditions, elicited higher cortical motor activations. The results suggest motor representations can code more complex goal outcomes (grasp for drinking, grasp for putting away) of which the immediate action is a part.

[Paragaph on motor representations of affordances even when there is no observed action, triggered by objects graspable by you (Costantini et al, 2010; and by objects graspable by an observed agent Costantini et al, 2011).]

If tracking the outcome-directedness of potential actions is an extension of motor processing, constraining an agent’s opportunity to act should significantly disrupt motor representations concerning another’s actions. Liepelt, Ullsperger, Obst, Spengler, von Cramon and Brass (2009) instructed participants to lift their index or middle finger in response to a number stimulus presented between the index and middle finger of a photograph of an agent’s static hand. There was a marked slowing of participants’ reaction time in the condition where the observed agent’s corresponding index and middle fingers were tied to the table with metal clamps as compared to the conditions where the agent’s fingers were unrestrained or where the agent’s non-corresponding fingers (thumb and ring finger) were restrained. The findings suggest that motor activations can be deployed even without watching movements being overtly performed, such that anticipating another person’s potential action can excite planning and control of actions in the observer to influence task performance. The results highlight that the physical body of an agent is constitutively relevant to certain kinds of cognition. The fact that another person’s restraint leads to a finger-specific slowing of reaction time in the observer, even when the restraint was response irrelevant, suggests that our motor system automatically takes on the task-relevant circumstances governing someone else’s potentially upcoming goal-directed action. Dovetailing with Liepelt et al.’s findings, other work indicates that temporarily restricting motor movements can also stall how fast our eyes latch onto the intended target object of someone else’s reach-to-grasp action (Ambrosini, Constantini, & Sinigaglia, 2011).

The available evidence that motor representations enable us to track the goals of others’ actions, although broad, does not entail that motor representations can play a role in the tracking of beliefs which specify someone’s reasons for action (Rizzolatti & Sinigaglia, 2010 p. 271). To make this bridge, our research experiment aims to test whether and to what extent contextual movement constraints of others modulate our ability to automatically track others’ belief. Our experiment is important for several reasons.

First, in many social situations, successfully tracking an agent’s motor goal that specifies a particular object also involves tracking the correctness of the agent’s belief about that object. Consider, for example, that Maxine is going to perform an action the goal of which is to grasp her ball. She falsely believes that her ball is in the right-side box, whereas actually it is inside the left-side box. If we ignore the agent's false belief, then fixing only upon grasping the ball as the goal of Maxine’s action would generate the wrong expectation of how her action would unfold—incorrectly predicting that she would reach to the left-side box to grasp her ball (Butterfill & Apperly, 2016). We need to track Maxine's belief to correctly identify the potential motor outcome of her action, which is that she would reach to the empty right-side box to grasp her ball. This creates a challenge for action observation: if we are to track how someone's action will potentially unfold, we cannot always rely on how things actually are but must also take into account the agent’s belief or belief-like state. No study, until now, has demonstrated that motor representations also matter to the successfulness of adults’ tracking of an agent’s belief.

Second, given that the witnessing of someone else’s action leads to a direct activation of corresponding motor processes in the observer, researchers have pondered about how observers could ever distinguish between motor representations that are self-triggered and other-triggered. The agency challenge of shared motor representations can be acute. For example, patients with frontal lobe injury overly imitate someone else’s interfering finger movements that are not response relevant, and patients with Parkinson’s disease find it difficult to control automatic imitation of others’ postural instability as induced by motor contagion (Brass, Derfuss, Matthes-von Cramon, & von Cramon, 2003; Pelosin, Bisio, Pozzo, Lagravinese, Crisafulli, Marchese, et al., 2018). Neurotypical individuals, however, can enforce their own internally planned movement against an externally perceived movement. Bardi and Brass (2016) suggest that a deeper understanding of control of concurrently activated goal-directed motor representations may be gained by considering its embedding in theory-of-mind (ToM) abilities. Consistent with this suggestion, studies show that there are overlapping brain activations when adults perform mentalising and motor-priming tasks (Spengler, von Cramon, & Brass, 2009), and that training on a motor task that makes salient differences between the one’s own motor action and someone else’s motor action can transfer to improvements in spontaneously tracking another’s visual perspective on a ToM task (Santiesteban, White, Cook, Gilbert, Heyes, & Bird, 2012). There appears to be functional overlap between sensorimotor tasks situations where externally-triggered and internally-generated motor plans are co-represented and can thus affect our performance, and ToM task situations where tracking of another’s belief is referenced to the environment just as the tracking of our own belief and can thus also affect behaviour. Bardi and Brass suggest that interfacing between control of motor representation and ToM may be empirically evident in implicit forms of mentalising where task performance (per Kocacs et al.’s object-detection paradigm, 2010) depends on concurrent activations of different representations of the environment.

Paragraph on Kovacs Task ….

Paragraph on our Task and Predictions ….

Positive findings from our experiment documenting whether and to what extent action restriction modulates mental state tracking will offer broader insight into the processes underpinning how we distinguish between our own motor representations and externally activated representations.