**4. Discussion**

We aimed to determine whether and to what extent visibly constraining an agent from potentially interacting with an object modulates observers’ abilities to automatically track that agent’s belief. The P−A+ < P−A− effect was elicited in the Free-Agent version of the ball-detection task where the agent was visibly unconstrained and free to potentially act on the ball. Importantly, confirming our primary prediction, the P−A+ < P−A− effect was not elicited in the Constrained-Agent version where the agent was visibly constrained from using his upper body and limbs to potentially act on the ball.

Our findings converged with studies of interference effects showing that physical constraints on others’ action possibilities are mapped onto observers’ own representations of the environment (e.g., Costantini et al., 2011; Liepelt et al., 2009). Costantini et al. documented that reaction-time advantages in adults’ predispositions to act towards a graspable mug – triggered whenever participants observed that the target object was presented within another person’s reaching space – disappeared when a transparent barrier was interposed between the agent and the observed object. Their argument was that the transparent barrier prevented any potential action on the part of the agent, and inhibition of motor simulation impacted upon participants’ own representation of appropriate goal-related acts towards the object. Our findings add that motor representations are not merely relevant to the prediction of another person’s goal-directed behaviour but they are also take into account information as though things were as they are believed as being (rather than they actually are), and intervening on how we represent another’s potential action motorically also affects our belief tracking. “Mummification” of the agent in the Constrained-version of the ball-detection task prevented participants from representing any kind of apparent ball-directed action motorically, and blocking motor tracking of potential goal-directed action meant that the belief-tracking process had nothing to facilitate.

However, participants may not have shown reaction time benefits in the Constrained-Agent version of the ball-detection task because the agent’s “mummified” appearance in the outcome phase was perceptually novel. Our Loose-Sheet version of the ball-detection task served as an important control that helped us to rule out a low-level interpretation based on perceptual novelty. In the Loose-Sheet version, the agent also returned with a novel appearance, but he remained visibly able to move his upper body and limbs and, potentially, to act upon the ball. In further support of our primary prediction, we found that the P−A+ < P−A− effect was elicited in the Free-Agent *and* Loose-Sheet versions but obstructed in the Agent-Constrained version.

Therefore, with respect to the P+A- < P-A- effect found in the Free-Agent and Loose-Sheet versions of the ball-detection task, a bold explanation is that the facilitation in response times is a consequence of motor tracking that is modulated by belief tracking. In the Free-Agent and Loose-Sheet versions of the ball-detection task, the agent can potentially reach for the ball which he believes is present, and it is that motor representation of potential outcome (modulated by belief tracking) which speeds up participants’ ball-detection responses. In the Constrained-Agent version of the task, the agent is in no position to interact motorically with the ball; since there is no affordance for action, motor representations of outcome are stalled and the information that is held about the agent’s belief-like state is lost. Our findings raise the new and exciting possibility that motor representations can be situated a relatively high level of abstraction. Motor representations can carry information about an agent’s belief-based potential action, and the automatic belief tracking signalled in the ball-detection task is a consequence of the motor processes that generate behavioural expectations of potential action. In other words, automatic belief-tracking can influence, and be influenced by, motor processes.

Classically speaking, motor activity can be reactive and responds to others’ ongoing movements towards some outcome. Where the stimuli depicted in the ball-detection task are concerned, however, participants never got to see the agent perform an action directed to an outcome at all (e.g., reaching to grasp a ball behind the wall). The agent never did anything with the ball aside from placing the ball onto the table; there was nothing obvious about what the outcome of the observed action might be. The broader literature indicates that whilst our motor system can discharge reactively to the visual features of others’ actions, a subset of motor activations can anticipate actions ahead of their unfolding and can represent inferred goals of withheld actions (e.g., Avenanti, Annella, Candidi, Urgesi, & Aglioti, 2013; Bonini, Maranesi, Fogassi, & Rizzolatti, 2014; Kühn, Gevers, & Brass, 2009; Maranesi, Livi, Fogassi, Rizzolatti, & Bonini, 2014). It is worthwhile pointing out that in Costantini et al.’s (2011) study, there was also no need for participants to witness any goal-directed action being performed by the agent for participants to map the agent’s action space onto their own frames of reference. Analogously, our research points to a tight connection between motor and belief-tracking processes producing behavioural expectations that facilitate response times even when participants did not witness a clear goal-directed action being performed by the agent. Adults’ abilities to generate belief-based motor representations of others’ potential action could be useful for monitoring what others are refraining from doing.

We are open to possibility that belief tracking is preserved and somehow still occurring in the Constrained-Agent version of the ball-detection task, and that the mindreading process is not feeding into motor processes to facilitate participants’ behavioural responses when motor representations are disrupted. More research will be needed to determine whether the belief tracking process could be detectable if we, aside from measuring the latencies of participants’ key-press responses, simultaneously measured skin conductance and pupil dilation effects. Researchers still do not have a good handle over whether and to what extent different responses may be dominated by certain processes and representations (Butterfill & Apperly, 2013; Edwards & Low, 2017). However, if the P+A- < P-A- effect is a consequence of the way that information about beliefs feeds into motor predictions of the agent and how those motor representations then facilitate (or not facilitate) response times – as our current findings documented – then we can begin to appreciate that automatic belief tracking can have functional consequences for generating expectations of potential action by how it interfaces with motor control.

Do we want to predict that anytime we have a fast belief-tracking process, impairing motor representations will impair the process? We probably do not. It is possible that some of the fast belief-tracking processes are based on motor representations but it could be that some of the fast belief-tracking processes are based on perceptual representations. We remain open to the idea that there may be some level of heterogeneity in the representations that support belief-tracking processes. What would distinguish when fast belief-tracking is motorically or perceptually based? One thought would be to run experiments that selectively interfere with either kinds of representations; physical binding of an agent should not change perceptual representations of the action context whereas manipulation of lighting effects (e.g., an object that is suddenly masked by darkness) should not affect motor representations of the scene.