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## **Predictive Eye Movements are Driven by Goals, Not By the Mirror Neuron System**

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The importance of a Mirror Neuron System (MNS) as a mechanism for understanding the actions of others has been established (e.g., Rizzolatti et al., 1996). Neurons in the primate premotor cortex fire both when a monkey performs an action (e.g., grasping), and when the monkey observes someone else performing the same action. The stronger claim that the MNS is the starting point for understanding the intentions and goal-directed behavior of others has also been proposed (Gallese & Goldman, 1998; Fogassi et al., 2005). Consistent with this, Falck-Ytter, Gredebäck and von Hofsten (2004) argue that the MNS is implicated in proactive goal-directed (predictive) eye movements. In a series of eye tracking studies participants observed a toy object moving along a trajectory towards a container. Adults and one-year olds looked ahead of the toy towards the goal container only when a hand was observed moving the toy (the “human agent” condition). In two further conditions where the toy (with rudimentary facial features) was observed moving along the trajectory by itself (the “self-propelled” condition), or where a ball with no distinctive features moved along the trajectory (the “mechanical motion” condition), proactive goal-directed eye movements were not found. Falck-Ytter et al. interpret these data as evidence that the MNS is necessary for proactive goal-directed eye movements to occur. Moreover, the absence of proactive goal-directed eye movements in 6 month olds (too young to perform the actions themselves) is taken as further support for the MNS account.

These claims are premature. The conditions run by Falck-Ytter et al. do not discriminate between predicted human motion tied to intention, versus predicted agent goals tied to intention. Movement of the hand, consistent with the mirror neuron hypothesis, may necessarily involve the simulation of motion via the MNS, and proactive goal-directed eye movements may only therefore occur when a hand is shown to move the object. Alternatively a hand moving an object involves the intention of an agent to place the object in the goal container, and the expectation that the agent intends the object to end up in a goal location

may cause the proactive eye movements (consistent with teleological stance theory; Gergely, & Csibra, 2003). In order to arbitrate between these accounts it is necessary to run a human agent condition without human movement.

We therefore set out to test Falck-Ytter, et al.'s claims, but with the addition of a new critical condition missing in the original study. We ran three movement conditions as follows; a [+human agent, +human motion] condition (the “human agent” condition), a [-human agent, -human motion] condition (the “self-propelled” condition), and a new [+human agent, -human motion] condition. For this latter manipulation a human agent was shown with hand behind the starting point of the toy (a toy frog), flicking it so as to propel it along a trajectory (as in the game “Tiddlywinks”) (Figure 1(a)). In this condition the human agent intention is matched to that of the “human agent” condition, but human motion is not shown along the trajectory. This allows a clean test of the mirror neuron versus goal intention explanations for the proactive eye movement data.

We also ran each condition in two ways. In the original “human agent” condition run by Falck-Ytter et al., when the toy object reached the bucket a sound was played and a smiley face on the bucket was animated. This could serve to heighten the desirability of the goal state, encouraging proactive eye movements consistent with teleological stance theory. Hence we ran each of the three conditions with and without “end effects”. For the [+end effects] conditions, when the toy entered the bucket water ripples were shown and the sound of a frog croaking was played. In the [-end effects] conditions no animations were seen or sounds were heard when the frog entered the bucket.

The procedures and analyses mirrored those of the original study as closely as possible. 72 adult participants were randomly allocated to one of six conditions; [+human agent, +human motion, +end effects], [+human agent, +human motion, -end effects], [+human agent, -human motion, +end effects], [+human agent, -human motion, -end effects],

[-human agent, -human motion, +end effects], and [-human agent, -human motion, -end effects]. Participants sat in front of the monitor of a Tobii 1750 eye tracker, and after calibration were instructed simply to watch the video that followed, comprising 27 trials (the same number used by Falck-Ytter et al.).

A 3(movement) x 2(end effects) ANOVA examining the average gaze arrival time relative to the arrival time of the frog (Figure 1(b)) produced only a significant main effect of end effects on gaze arrival time ( $F(1, 66)=7.153$ ,  $p_{\text{rep}}=0.97$ ,  $\eta_p^2=0.098$ ). Gaze arrival time at goal was earlier for [+end effects] conditions (mean = 0.1217s) compared to [-end effects] conditions (mean = 0.0326s).

For each condition we also compared gaze arrival times to the arrival times of the frog. Significant proactive goal-directed eye movements occurred for the [+human agent, +human motion, +end effects] ( $t(11)=4.34$ ,  $p_{\text{rep}}=0.99$ ,  $d=1.25$ ) and the [+human agent, -human motion, +end effects] ( $t(11)=2.38$ ,  $p_{\text{rep}}=0.93$ ,  $d=0.69$ ) conditions, but not for any of the other four conditions (all  $t(11)\leq 1.99$ , all  $p_{\text{rep}}\leq 0.90$ , all  $d\leq 0.57$ ) (Figure 1(b)). Most notably, predictive eye movements do not occur for the [+human agent, +human movement, -end effects] condition ( $t(11)=0.35$ ,  $p_{\text{rep}}=0.59$ ,  $d=0.10$ ).

These results allow us to tease apart the relative merits of the MNS explanation of proactive goal-directed eye movements versus an alternative account based on understanding of goals. Proactive eye movements occur as a function of the combination of the intention of an agent to achieve a goal and the desirability of a goal state, and not as a consequence of whether a human agent is seen moving an object. As such, the results support teleological stance theory, as well as recent accounts claiming that the MNS is a reflection of action understanding rather than the origins of it (Csibra, 2007).

## References

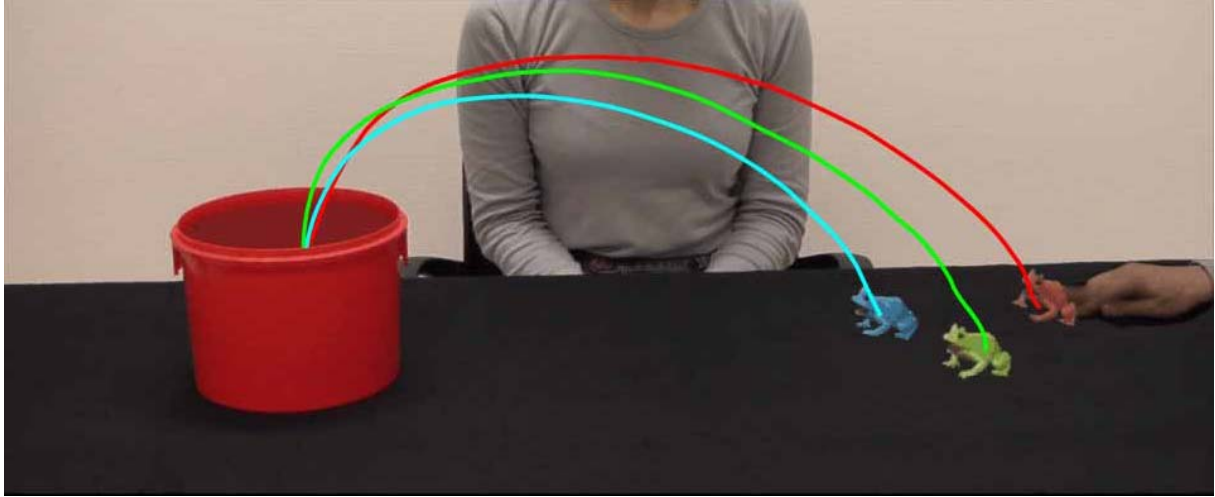
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## **Author Contributions**

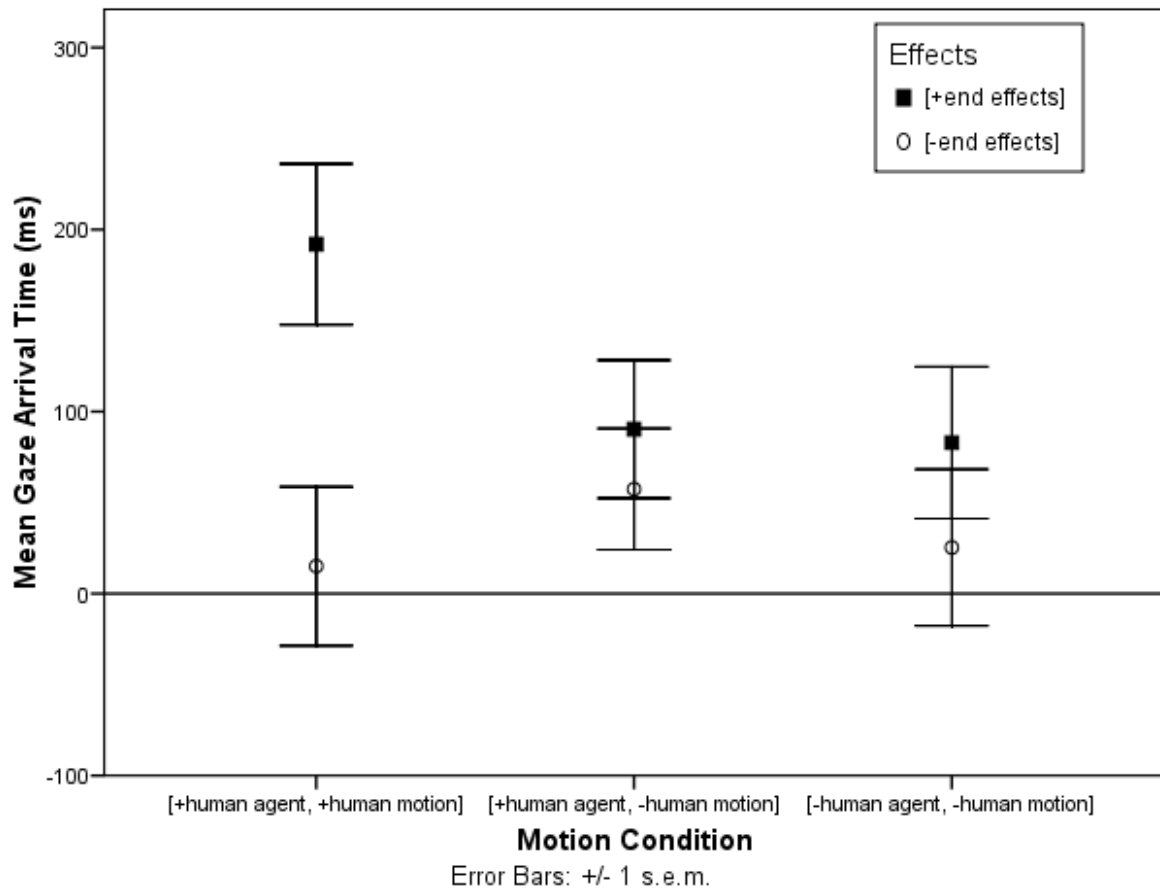
The order of authorship is arbitrary; all authors contributed equally to the work reported.

## **Figure Captions**

Figure 1 (a) Illustration of the new Tiddlywinks condition video. Drawn in are the trajectories traversed by the frogs (not visible during the experiment). (b) Mean gaze arrival time relative to frog arrival time (the frog arrives at time 0; positive values indicate that gaze arrives before the frog).



**Figure 1(a)** Illustration of the new Tiddlywinks condition video. Drawn in are the trajectories traversed by the frogs (not visible during the experiment).



**Figure 1(b)** Mean gaze arrival time relative to frog arrival time (the frog arrives at time 0; positive values indicate that gaze arrives before the frog).