Psychological Review
2016, Vol. 123, No. 2, 228–233

0033-295X/16/$12.00 http://dx.doi.org/10.1037/rev0000022

COMMENTARY

Is Goal Ascription Possible in Minimal Mindreading?

Stephen A. Butterfill
University of Warwick

Ian A. Apperly
University of Birmingham

In this response to the commentary by Michael and Christensen (2016), we first explain how minimal mindreading is compatible with the development of increasingly sophisticated mindreading behaviors that involve both executive functions and general knowledge and then sketch 1 approach to a minimal account of goal ascription.

Keywords: theory of mind, goal attribution, 2 systems theory, cognitive development, minimalism

We very much welcome the commentary from Michael and Christensen (2016; M&C henceforth). We agree, of course, that in offering a minimal account of belief ascription we said little about goals, that an account of mindreading is incomplete without an account of goal ascription and that an account of minimal mindreading is incomplete, and indeed, would be threatened if goal ascription could never be achieved in a cognitively efficient manner. However, at the end of their commentary, M&C offer two potential ways in which we might respond to their critique: Either we must abandon the idea that minimal mindreading is strongly encapsulated and accept that it might consist of multiple systems, which require integration through the use of executive functions, or else we must appeal to "ad hoc representations" in offering an account of cognitively efficient goal ascription. In the first part of our response we explain why do not accept the terms of this dilemma; in particular, we will clarify the degree of encapsulation that we see as necessary for minimal mindreading and explain where we think that increasing knowledge and executive processes may contribute to minimal mindreading. We then briefly sketch one approach to minimal goal ascription with the aim of showing how existing research already gives grounds for thinking that efficient goal ascription is possible; this does not require appeal to ad hoc representations; and such a suggestion makes distinctive, testable predictions.

It is informative to make an analogy with the well-studied case of number cognition to see how a relatively encapsulated cognitive process might interact with other processes. One part of infants' early numerical abilities is the ability to enumerate sets of up to three objects (e.g., Feigenson, Dehaene, & Spelke, 2004). This ability is initially only apparent in the relatively simple behaviors observable in young infants, such as habituation and preferential looking. But as infants develop more sophisticated motor and cognitive abilities, the same capacity influences the number of times that they will search for objects hidden in a box (Feigenson & Carey, 2003) and their strategic decisions to crawl toward the more potentially rewarding of two boxes containing hidden food items (Feigenson, Carey, & Hauser, 2002). It is interesting that in the latter case infants' decisions are based on their estimate of the total quantity of available food made up by items of varying size and not on the number of items, per se. However, infants are only able to make this calculation if the total number of items in each box does not exceed three. This result implies that infants' ability to enumerate small sets acts in concert with an ability to quantify the amount of material in the objects comprising the set (food in this case) and also with an ability to make and act on a strategic decision to select the larger total amount of food. For our current purposes, this case is helpful as an illustration of how a relatively encapsulated process comes to enable a growing range of responses and an increasingly rich set of judgments over development. At least some of these developments are likely to depend on infants' increasing knowledge and increasing executive function, of course. However, note that this does not affect the ability to enumerate sets of up to 3 objects, whose signature limit of three to four items remains unaffected by these other developments. This example shows that it is possible for relatively encapsulated processes to be among the causes of behaviors requiring knowledge and placing demands on executive function.

A similar situation may exist for minimal mindreading abilities. These abilities are cognitively efficient in the sense that compared with full-blown mindreading they trade some flexibility for reduced demands on scarce cognitive resources such as working memory and inhibitory control. We have proposed that minimal mindreading achieves cognitive efficiency by use of a stripped-down model of the mental involving registrations rather than beliefs as standardly conceived and by being informationally encapsulated to some degree. Minimal mindreading may underpin relatively automatic belief tracking in adults (Kovács, Téglás, & Endress, 2010; van der Wel, Sebanz & Knoblich, 2014; Schneider, Nott, & Dux, 2014) as well as infants' various expectations about the behaviors of agents with false beliefs (Onishi & Baillargeon, 2005; Southgate, Senju, & Csibra, 2007).

Stephen A. Butterfill, Department of Philosophy, University of Warwick; Ian A. Apperly, School of Psychology, University of Birmingham.

Correspondence concerning this article should be addressed to Ian A. Apperly, School of Psychology, University of Birmingham, Edgbaston, Birmingham B15 2TT, United Kingdom. E-mail: i.a.apperly@bham.ac.uk

Ascriptions of registrations may also explain older infants' ability to help someone with a false belief (as in Buttelmann, Carpenter, & Tomasello, 2009) and to selectively intervene by pointing (Knudsen & Liszkowski, 2012). The latter presumably depend on abilities to ascribe registrations operating in concert with infants' increasingly sophisticated abilities to plan, decide, and act in social situations; and success presumably depends, among other things, on infants' increasing social knowledge and increasing memory and executive function. There is no contradiction between such developing sophistication and the idea that registrations are computed by a relatively encapsulated and cognitively efficient process, provided this process itself does not become increasingly dependent on knowledge, memory, or executive function. But how could one tell whether this is indeed the case? As for the case of number cognition, positive evidence would come from finding that the signature limits remained constant even while the outputs come to have increasingly sophisticated consequences. The evidence base on this question remains small, but it is noteworthy that both the anticipatory eye movements of 3-year-olds on an action prediction task (Low et al., 2014) and of adults on a reference resolution task (Mozuraitis, Chambers, & Daneman, 2015) appear sensitive to whether a protagonist has a false belief about the existence of an object but not to whether a protagonist has a false belief about the identity of an object. This is a key signature limit of minimal theory of mind.

Just as an encapsulated process may act in concert with a variety of other abilities, so it is also coherent to suppose that the influences on encapsulated processes may be relatively sophisticated in adults and become increasingly sophisticated through development. There is already evidence that automatic visual perspective taking (Samson et al., 2010) and some other automatic social processes can be influenced by knowledge about whether the protagonist, who is the target of these processes, can see or not (e.g., Furlanetto et al., 2015; Teufel, Fletcher, & Davis, 2010). These effects do not entail that representations from flexible mindreading form direct inputs to more efficient mindreading processes, but we see no decisive reason in theory why even this should be ruled out under appropriately limited circumstances. Although our account emphasized the need for minimal mindreading to exhibit a significant degree of encapsulation (which perhaps led to some misunderstanding of our position; Christensen & Michael, 2015; De Bruin & Newen, 2012), our project is not (and was not) to stipulate that minimal mindreading processes operate entirely independently from more flexible mindreading processes, either in their online operation or during development (e.g., Apperly, 2010, p. 137, allows that minimal mindreading processes may provide important inputs into the development of full-blown mindreading). Rather our project was to suggest that minimal mindreading processes are independent from other cognitive processes to a degree sufficient to enable their efficient operation. In our view, such independence does require the possibility of there being a single scenario in which different mindreading processes in a single individual can result in incompatible expectations and predictions (e.g., Clements & Perner, 1994; and Wang, Hadi, & Low, 2015). In addition, it does entail that minimal mindreading processes will be subject to distinctive signature limits. However, this does not preclude the possibility that the overall effects of minimal mindreading sometimes depend on knowledge.

There is also a more specific side to M&C's critique that perhaps has most force against our account of minimal mindreading, M&C noted that our account presupposes the ability to ascribe goals to actions and that goal ascription itself can depend on tracking beliefs (perhaps by representing registrations). M&C expressed doubts that such goal ascription could be achieved within a minimal framework, whereby the processes are relatively encapsulated. Our primary response to this challenge will be to sketch one account of minimal goal ascription, but first we must make a clarification.

The claim that an individual can only track beliefs by representing registrations does not entail that she must be similarly restricted to minimal mindreading in tracking the goals of actions. On a two-systems account of mindreading, adult humans have both relatively efficient and relatively flexible systems for mindreading, and they can track beliefs using the relatively flexible system. Why not suppose that infants also have one or more relatively flexible systems for mindreading which enable them to represent beliefs? Perhaps some of the most convincing evidence is that typically developing children who pass tasks requiring relatively flexible and accurate reasoning about desire, perception, or pretense nevertheless fail very similar tasks involving belief (Custer, 1996; Gopnik & Slaughter, 1991; Gopnik, Slaughter, & Meltzoff, 1994; Rakoczy, Warneken, & Tomasello, 2007). Together with findings that responses based on relatively flexible belief ascription can dissociate from responses based on the efficient system within the same individual (Clements & Perner, 1994; Low & Watts, 2013), this indicates that belief does not typically feature in flexible mindreading until sometime after abilities to reason flexibly about other mental states have been acquired. By contrast, there is presently no comparable body of evidence concerning goal ascription. We are, therefore, provisionally open to the possibility that one- or 2-year-olds' goal ascription may sometimes rely on a flexible system. Evidence for this would not be more surprising than the evidence just mentioned that flexible desire ascription appears earlier in development than flexible belief ascription. The development of mindreading probably involves multiple transitions if it involves any. So contrary to what we take M&C to be suggesting, the existence of some flexible goal ascription in infancy would not, by itself, be inconsistent with our account. That said, we do agree with M&C's central claim that an account of minimal mindreading is incomplete without an explanation of how goal ascription could sometimes be achieved in a cognitively efficient manner. How might minimal mindreading involve goal ascription?

A Proposal: Stage 1

A *goal* is an outcome to which an action is, or will be, directed (not to be confused with a *goal state*, which is a state, such as an intention, in virtue of which an action has a goal). *Goal ascription* is the process of identifying an outcome to which an observed or anticipated sequence of bodily configurations and joint displacements are directed. How could goal ascription, sufficient to explain success on a range of false belief tasks, be cognitively efficient?

As success on different false belief tasks appears to involve goal ascription in several ways, let us start with the simplest. Consider a case in which identifying, at least approximately and

partially, the goals of a means–end action must be done before tracking beliefs (e.g., Träuble, Marinović, & Pauen, 2010).[1] One strand of existing research on this topic hinges on the idea that motor processes and representations are involved in some cases of goal ascription. Control of action involves motor representations of outcomes that are relatively distal from bodily configurations and joint displacements; outcomes such as the grasping of a handle or the movement of an object from one place to another (Cattaneo et al., 2009; Hamilton & Grafton, 2008). It is important that motor representations of an outcome can occur not only when agents are performing an action directed to that outcome but also when they are passively observing such an action (Rizzolatti & Sinigaglia, 2010). How does it come about that, often enough, an outcome represented motorically in the observer of an action is actually a goal of the observed action? One possibility is that this is because of the occurrence of motor processes in action observation. It is well-established that motor processes are planning-like in two respects. First, they involve computing means from representations of ends (Bekkering, Wohlschlager, & Gattis, 2000; Grafton & Hamilton, 2007). Second, they are planning-like in that they involve computing a best way to do something now in the light of things that will be done later, such as grasping a cup with a slightly awkward posture to avoid a more uncomfortable posture after turning it around (Jeannerod, 2006; Rosenbaum et al., 2012; Zhang & Rosenbaum, 2008). Further, such planning-like processes also occur in action observation, as has been demonstrated in studies of interference effects (e.g., Brass et al., 2000; Costantini, Ambrosini, & Sinigaglia, 2012) and also by measuring predictive gaze (e.g., Ambrosini, Costantini, & Sinigaglia, 2011; Costantini et al., 2014; Flanagan & Johansson, 2003). Planning-like processes generate expectations about how observed actions will unfold and about their sensory consequences. Errors in these expectations would be evidence that the outcome represented motorically in the observer is not a goal of the observed action. Suppose such errors weakened the representation of an outcome in the observer: Then it could be that planning-like motor processes in action observation are what ensure that, often enough, outcomes represented motorically in the observer of an action are actually goals of the observed action. In this way, a limited but useful kind of goal ascription could be achieved in which the only representations are motor representations (see further Sinigaglia & Butterfill, in press).

The conjecture that motor representations and processes underpin a kind of goal ascription is relevant to us because such processes enable rapid, online action predictions, indicating that they may be cognitively efficient in the sense required for minimal mindreading. Because there are clear limits on the kinds of outcomes that can be represented motorically (which are linked to abilities to act),[2] the conjecture also generates many testable predictions (Ambrosini, Sinigaglia, & Costantini, 2012; Beets, Rösler, & Fiehler, 2010; Urgesi et al., 2007; see also Michael et al., 2014). Whether or not the conjecture about motor representations and processes enabling minimal goal ascription is correct, its existence does show that theorizing about cognitively efficient goal ascription need not require ad hoc postulations: Instead, there is a testable conjecture that coheres with a large and rapidly growing body of evidence.

Stage 2: Belief Tracking Informs Goal Ascription

So far we have considered only how goal ascription might inform belief tracking in situations where one can first identify the goal of an action and then ascribe a belief or belief-like state. A further challenge arises from the fact that in some false belief tasks, success apparently requires belief tracking to inform goal ascription. To illustrate, suppose Ayesha performs an action the goal of which is to retrieve some chocolate. She falsely believes that the chocolate is behind the red occluder, whereas actually it is behind the green occluder. What happens if someone attempting to identify the goals of Ayesha's action in the way described above ignores her false belief? In this case, fixing on retrieving the chocolate as a goal of her action would generate incorrect expectations about how her action will unfold. Therefore ignoring Ayesha's false belief would prevent correct goal ascription. But how could belief tracking inform cognitively efficient goal ascription?

Suppose the above conjecture about motor representations and processes underpinning a cognitively efficient kind of goal ascription is right. Where this kind of goal ascription occurs in false belief tasks, it must be possible for a representation of a registration to modulate expectations concerning how an observed action will unfold in much the way that a perceptual input would. But could such modulation occur? We know that when planning-like motor processes generate expectations concerning how actions will unfold, they take into account various facts about about the agent's environment. The fact that such processes occur in motor imagery (see Jeannerod, 2006) suggests that planning-like motor processes are not tied to the actual environment but can also generate expectations based on nonactual environments. Accordingly, it is at least coherent to conjecture that, when observing an agent, planning-like motor processes in the observer generate expectations by taking into account not only facts about the actual environment but also facts about the environment as specified by the agent's registrations. This is one way in which planning-like motor processes might be modulated by belief tracking processes.[3] We mention this conjecture not because our view commits us to accepting it but only as an illustration of how belief tracking may inform goal ascription where both belief tracking and goal ascription are underpinned by cognitively efficient systems.

[1] M&C suggested that goal ascription depends on ascribing agents beliefs about means–ends relations in this case; we suggest this is unnecessary as facts about means–ends relations may be taken for granted.

[2] As M&C anticipated, we think minimal goal ascription is to some degree "limited in the extent to which it can incorporate functional type information"; however, the possible link between minimal mindreading and motor processes shows that minimal goal ascription can sometimes reflect both the context in which actions occur and also functional properties of objects (Bonini et al., 2011; Cattaneo et al., 2007; Costantini et al., 2011; Fogassi et al., 2005; Hamilton and Grafton, 2008; Iacoboni et al., 2005). Minimal goal ascription is not, contra M&C, "unable to incorporate situational goal attribution."

[3] van der Wel, Sebanz, and Knoblich (2014) provided evidence that information about another's belief can systematically perturb processes underpinning action performance. This may lend some initial plausibility to our conjecture that information about another's belief can modulate motor processes underpinning goal ascription.

Stage 3: Preferences and Expecting Actions

In offering an account of minimal goal ascription, we have yet to address one aspect of M&C's challenge. As they noted, belief tracking can involve not merely ascribing goals to actions but also forming expectations about the goals to which an agent's actions are likely to be directed. Having observed someone repeatedly reaching for the ball when she could have been reaching for the teddy (as in Woodward, 1998), you may form an expectation about the goals any future actions will have. Forming such expectations about future actions goes beyond ascribing goals, although of course such ascriptions are typically formed in part as a consequence of goal ascription and cannot be met or violated without further goal ascription. Part of M&C's discussion asks how cognitively efficient mindreading might support forming expectations about the goals to which an agent's actions are likely to be directed.

This question could be answered by invoking a notion of preference. Consider this fragment of a minimal theory of preferences in which *prefers* is a relation between an agent, a pair of outcomes (o_1, o_2), and a probability. Intuitively, the idea will be that *prefers* tracks the probability that the agent will perform an action directed to o_1 rather than to o_2. More carefully,

1. When an agent could perform an action with a goal that is one outcome, o_1, or an action with another goal, o_2, and in fact performs an action of the former kind, the probability associated by *prefers* with a and the pair $<o_1, o_2>$ increases.

2. When the agent, a, could perform an action directed to either of two outcomes, o_1 or o_2, and the probability associated by *prefers* with a and $<o_1,o_2>$ meets a certain criterion, she will not perform an action directed to o_2.

Consider a minimal mindreader whose ability to track preferences depends on a system implementing a model this fragment partially characterizes. She has been observing an agent repeatedly reaching for the ball when the agent could have been reaching for the teddy. The above two principles entail that she will now expect the agent not to reach for the teddy; thus, observing her reach for the teddy would violate an expectation in the minimal mindreader, consistent with the observed behavior in Woodward (1998).

Applying the above principles involves being able to track which actions an agent could perform. How might a minimal mindreader do this? One possibility is that past experience plays a role (the actions an agent could perform are the actions others have performed in this sort of situation in the past); another complementary possibility is that motor representations and processes play a role here too (e.g., Costantini, Committeri, & Sinigaglia, 2011).

Although this fragment is far from fully characterizing the potential of minimal mindreading in relation to preferences, it does serve to show how it is possible to extend the construction of minimal theory of mind to incorporate a simple but useful preference relation.[4]

Stage 4: Belief Tracking and Preferences

Up to this point we have kept things simple by treating belief tracking and preference tracking as independent. But this is likely to be too simple where the aim is to characterize efficient belief tracking in humans. The final challenge M&C offer concerns cases in which preference tracking and belief tracking jointly inform expectations about an agent's future actions. Is such a case beyond the scope of minimal mindreading?

Our answer is "no." Consider observing a caterpillar whose past behavior enables a minimal mindreader to track its preference for approaching cheese over approaching an apple (as in Surian, Caldi, & Sperber, 2007). Now suppose that a situation is contrived in which the caterpillar has false beliefs about the locations of the cheese and the apple and that the minimal mindreader is able to track these false beliefs. The above ideas about preference tracking enable the minimal mindreader to expect that when the caterpillar can act either with the goal of approaching the cheese or with the goal of approaching the apple, it will act with the former goal. Further, the part of minimal theory of mind that deals with registration enables the mindreader to expect that when the caterpillar acts on a goal involving the cheese, its actions will accord with what it registers concerning the cheese rather than only with the facts about the cheese. Therefore, although we expect that adding further principles linking preferences, registrations, and the goals of actions will be necessary in constructing a minimal theory of mind, the theory as we have elaborated it so far already enables representations of preferences and registrations to have a common effect on a mindreader's expectations about another's future actions.

Conclusion

We find ourselves in strong agreement with M&C that an account of minimal mindreading must concern not only belief-like states but also goals and preferences; emotion is surely also critical. But our approach differs from theirs in some ways. We are not yet convinced that the forms of goal ascription M&C discuss are beyond the theoretical limits of minimal mindreading. More fundamentally, whereas M&C are primarily concerned with evidence from mindreading in infants, our objective in developing an account of minimal mindreading is to make sense of evidence indicating cognitively efficient mindreading in adults as well as precocious mindreading abilities in infants. An important upshot of this is that the account generates predictions about signature limits which allow minimal mindreading to be identified across different paradigms and different participant groups, including adult and infant humans as well as nonhumans. In the present response we hope to have illustrated the usefulness of this approach by drawing from research on motor cognition in adults to sketch the first steps in the construction of minimal goal ascription.

[4] The fragment of a minimal theory of preferences also illustrates one way in which minimal theory of mind might unproblematically involve what M&C called "agentic linking" or "the association of a goal with an agent."

References

Ambrosini, E., Costantini, M., & Sinigaglia, C. (2011). Grasping with the eyes. *Journal of Neurophysiology, 106,* 1437–1442. http://dx.doi.org/10.1152/jn.00118.2011

Ambrosini, E., Sinigaglia, C., & Costantini, M. (2012). Tie my hands, tie my eyes. *Journal of Experimental Psychology: Human Perception and Performance, 38,* 263–266. http://dx.doi.org/10.1037/a0026570

Apperly, I. A. (2010). *Mindreaders: The cognitive basis of "theory of mind."* Hove, England: Psychology Press/Taylor & Francis Group.

Beets, I. A., Rösler, F., & Fiehler, K. (2010). Nonvisual motor learning improves visual motion perception: Evidence from violating the two-thirds power law. *Journal of Neurophysiology, 104,* 1612–1624. http://dx.doi.org/10.1152/jn.00974.2009

Bekkering, H., Wohlschläger, A., & Gattis, M. (2000). Imitation of gestures in children is goal-directed. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology, 53,* 153–164. http://dx.doi.org/10.1080/713755872

Bonini, L., Serventi, F. U., Simone, L., Rozzi, S., Ferrari, P. F., & Fogassi, L. (2011). Grasping neurons of monkey parietal and premotor cortices encode action goals at distinct levels of abstraction during complex action sequences. *The Journal of Neuroscience, 31,* 5876–5886. http://dx.doi.org/10.1523/JNEUROSCI.5186-10.2011

Brass, M., Bekkering, H., Wohlschläger, A., & Prinz, W. (2000). Compatibility between observed and executed finger movements: Comparing symbolic, spatial, and imitative cues. *Brain and Cognition, 44,* 124–143. http://dx.doi.org/10.1006/brcg.2000.1225

Buttelmann, D., Carpenter, M., & Tomasello, M. (2009). Eighteen-month-old infants show false belief understanding in an active helping paradigm. *Cognition, 112,* 337–342. http://dx.doi.org/10.1016/j.cognition.2009.05.006

Cattaneo, L., Caruana, F., Jezzini, A., & Rizzolatti, G. (2009). Representation of goal and movements without overt motor behavior in the human motor cortex: A transcranial magnetic stimulation study. *The Journal of Neuroscience, 29,* 11134–11138. http://dx.doi.org/10.1523/JNEUROSCI.2605-09.2009

Cattaneo, L., Fabbri-Destro, M., Boria, S., Pieraccini, C., Monti, A., Cossu, G., & Rizzolatti, G. (2007). Impairment of actions chains in autism and its possible role in intention understanding. *Proceedings of the National Academy of Sciences of the United States of America, 104,* 17825–17830. http://dx.doi.org/10.1073/pnas.0706273104

Christensen, W., & Michael, J. (2015). From two systems to a multi-systems architecture for mindreading. *New Ideas in Psychology*. Advance online publication.

Clements, W., & Perner, J. (1994). Implicit understanding of belief. *Cognitive Development, 9,* 377–395. http://dx.doi.org/10.1016/0885-2014(94)90012-4

Costantini, M., Ambrosini, E., Cardellicchio, P., & Sinigaglia, C. (2014). How your hand drives my eyes. *Social Cognitive and Affective Neuroscience, 9,* 705–711. http://dx.doi.org/10.1093/scan/nst037

Costantini, M., Ambrosini, E., & Sinigaglia, C. (2012). Does how I look at what you're doing depend on what I'm doing? *Acta Psychologica, 141,* 199–204. http://dx.doi.org/10.1016/j.actpsy.2012.07.012

Costantini, M., Ambrosini, E., Sinigaglia, C., & Gallese, V. (2011). Tool-use observation makes far objects ready-to-hand. *Neuropsychologia, 49,* 2658–2663. http://dx.doi.org/10.1016/j.neuropsychologia.2011.05.013

Costantini, M., Committeri, G., & Sinigaglia, C. (2011). Ready both to your and to my hands: Mapping the action space of others. *PLoS ONE, 6*(4), e17923. http://dx.doi.org/10.1371/journal.pone.0017923

Custer, W. L. (1996). A comparison of young children's understanding of contradictory representations in pretense, memory, and belief. *Child Development, 67,* 678–688. http://dx.doi.org/10.2307/1131840

De Bruin, L. C., & A. Newen. 2012. An association account of false belief understanding. *Cognition, 123,* 240–259. http://dx.doi.org/10.1016/j.cognition.2011.12.016

Feigenson, L., & Carey, S. (2003). Tracking individuals via object-files: Evidence from infants' manual search. *Developmental Science, 6,* 568–584. http://dx.doi.org/10.1111/1467-7687.00313

Feigenson, L., Carey, S., & Hauser, M. (2002). The representations underlying infants' choice of more: Object files versus analog magnitudes. *Psychological Science, 13,* 150–156. http://dx.doi.org/10.1111/1467-9280.00427

Feigenson, L., Dehaene, S., & Spelke, E. (2004). Core systems of number. *Trends in Cognitive Sciences, 8,* 307–314. http://dx.doi.org/10.1016/j.tics.2004.05.002

Flanagan, J. R., & Johansson, R. S. (2003). Action plans used in action observation. *Nature, 424,* 769–771. http://dx.doi.org/10.1038/nature01861

Fogassi, L., Ferrari, P. F., Gesierich, B., Rozzi, S., Chersi, F., & Rizzolatti, G. (2005, April 29). Parietal lobe: From action organization to intention understanding. *Science, 308,* 662–667. http://dx.doi.org/10.1126/science.1106138

Furlanetto, T., Becchio, C., Samson, D., & Apperly, I. A. (2015). Altercentric interference in Level 1 visual perspective taking reflects the ascription of mental states, not sub-mentalising. *Journal of Experimental Psychology: Human Perception and Performance*. Advance online publication.

Gopnik, A., & Slaughter, V. (1991). Young children's understanding of changes in their mental states. *Child Development, 62,* 98–110. http://dx.doi.org/10.2307/1130707

Gopnik, A., Slaughter, V., & Meltzoff, A. (1994). Changing your views: How understanding visual perception can lead to a new theory of mind. In C. Lewis & P. Mitchell (Eds.), *Children's early understanding of mind: Origins and development* (pp. 157–178). Hove, England: Erlbaum.

Grafton, S. T., & Hamilton, A. F. de C. (2007). Evidence for a distributed hierarchy of action representation in the brain. *Human Movement Science, 26,* 590–616. http://dx.doi.org/10.1016/j.humov.2007.05.009

Hamilton, A. F. de C., & Grafton, S. T. (2008). Action outcomes are represented in human inferior frontoparietal cortex. *Cerebral Cortex, 18,* 1160–1168.

Iacoboni, M., Molnar-Szakacs, I., Gallese, V., Buccino, G., Mazziotta, J. C., & Rizzolatti, G. (2005). Grasping the intentions of others with one's own mirror neuron system. *PLoS Biology, 3*(3), e79 EP–e79 EP.

Jeannerod, M. (2006). *Motor cognition: What actions tell the self*. New York, NY: Oxford University Press. http://dx.doi.org/10.1093/acprof:oso/9780198569657.001.0001

Knudsen, B., & Liszkowski, U. (2012). 18-month-olds predict specific action mistakes through attribution of false belief, not ignorance, and intervene accordingly. *Infancy, 17,* 672–691. http://dx.doi.org/10.1111/j.1532-7078.2011.00105.x

Kovács, Á. M., Téglás, E., & Endress, A. D. (2010, December 24). The social sense: Susceptibility to others' beliefs in human infants and adults. *Science, 330,* 1830–1834. http://dx.doi.org/10.1126/science.1190792

Low, J., Drummond, W., Walmsley, A., & Wang, B. (2014). Representing how rabbits quack and competitors act: Limits on preschoolers' efficient ability to track perspective. *Child Development, 85,* 1519–1534. http://dx.doi.org/10.1111/cdev.12224

Low, J., & Watts, J. (2013). Attributing false beliefs about object identity reveals a signature blind spot in humans' efficient mindreading system. *Psychological Science, 24,* 305–311. http://dx.doi.org/10.1177/0956797612451469

Michael, J., & Christensen, W. (2016). Flexible goal attribution in early mindreading. *Psychological Review, 123,* 219–227. http://dx.doi.org/10.1037/rev0000016

Michael, J., Sandberg, K., Skewes, J., Wolf, T., Blicher, J., Overgaard, M., & Frith, C. D. (2014). Continuous theta-burst stimulation demonstrates a causal role of premotor homunculus in action understanding. *Psychological Science, 25,* 963–972. http://dx.doi.org/10.1177/0956797613520608

Mozuraitis, M., Chambers, C. G., & Daneman, M. (2015). Privileged versus shared knowledge about object identity in real-time referential

processing. *Cognition, 142,* 148–165. http://dx.doi.org/10.1016/j.cognition.2015.05.001

Onishi, K. H., & Baillargeon, R. (2005, April 8). Do 15-month-old infants understand false beliefs? *Science, 308,* 255–258. http://dx.doi.org/10.1126/science.1107621

Rakoczy, H., Warneken, F., & Tomasello, M. (2007). "This Way!", "No! That Way!"—3-year olds know that two people can have mutually incompatible desires. *Cognitive Development, 22,* 47–68. http://dx.doi.org/10.1016/j.cogdev.2006.08.002

Rizzolatti, G., & Sinigaglia, C. (2010). The functional role of the parieto-frontal mirror circuit: Interpretations and misinterpretations. *Nature Reviews Neuroscience, 11,* 264–274. http://dx.doi.org/10.1038/nrn2805

Rosenbaum, D. A., Chapman, K. M., Weigelt, M., Weiss, D. J., & van der Wel, R. (2012). Cognition, action, and object manipulation. *Psychological Bulletin, 138,* 924–946. http://dx.doi.org/10.1037/a0027839

Samson, D., Apperly, I. A., Braithwaite, J. J., Andrews, B. J., & Bodley Scott, S. E. (2010). Seeing it their way: Evidence for rapid and involuntary computation of what other people see. *Journal of Experimental Psychology: Human Perception and Performance, 36,* 1255–1266. http://dx.doi.org/10.1037/a0018729

Schneider, D., Nott, Z. E., & Dux, P. E. (2014). Task instructions and implicit theory of mind. *Cognition, 133,* 43–47. http://dx.doi.org/10.1016/j.cognition.2014.05.016

Sinigaglia, C., & Butterfill, S. A. (in press). Motor Representation in Goal Ascription. In Y. Coello & M. H. Fischer (Eds.), *Foundations of embodied cognition 2: Conceptual and interactive embodiment. Hove,* England: Psychology Press.

Southgate, V., Senju, A., & Csibra, G. (2007). Action anticipation through attribution of false belief by 2-year-olds. *Psychological Science, 18,* 587–592. http://dx.doi.org/10.1111/j.1467-9280.2007.01944.x

Surian, L., Caldi, S., & Sperber, D. (2007). Attribution of beliefs by 13-month-old infants. *Psychological Science, 18,* 580–586. http://dx.doi.org/10.1111/j.1467-9280.2007.01943.x

Teufel, C., Fletcher, P. C., & Davis, G. (2010). Seeing other minds: Attributed mental states influence perception. *Trends in Cognitive Sciences, 14,* 376–382. http://dx.doi.org/10.1016/j.tics.2010.05.005

Träuble, B., Marinović, V., & Pauen, S. (2010). Early theory of mind competencies: Do infants understand others' beliefs? *Infancy, 15,* 434–444. http://dx.doi.org/10.1111/j.1532-7078.2009.00025.x

Urgesi, C., Candidi, M., Ionta, S., & Aglioti, S. M. (2007). Representation of body identity and body actions in extrastriate body area and ventral premotor cortex. *Nature Neuroscience, 10,* 30–31. http://dx.doi.org/10.1038/nn1815

van der Wel, R. P. R. D., Sebanz, N., & Knoblich, G. (2014). Do people automatically track others' beliefs? Evidence from a continuous measure. *Cognition, 130,* 128–133. http://dx.doi.org/10.1016/j.cognition.2013.10.004

Wang, B., Hadi, N. S. A., & Low, J. (2015). Limits on efficient human mindreading: Convergence across Chinese adults and Semai children. *British Journal of Psychology, 106,* 724–740. http://dx.doi.org/10.1111/bjop.12121

Woodward, A. L. (1998). Infants selectively encode the goal object of an actor's reach. *Cognition, 69,* 1–34. http://dx.doi.org/10.1016/S0010-0277(98)00058-4

Zhang, W., & Rosenbaum, D. A. (2008). Planning for manual positioning: The end-state comfort effect for manual abduction-adduction. *Experimental Brain Research, 184,* 383–389. http://dx.doi.org/10.1007/s00221-007-1106-x

Received September 23, 2015
Revision received November 24, 2015
Accepted November 24, 2015 ■