Dispatch

Metacognition: Pre-verbal Infants Adapt their Behaviour to their Knowledge States

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Metacognitive abilities, such as knowing we know something or that we made the wrong decision, can be powerful tools for adapting behaviour and accelerating learning. Apes, dolphins, and even rats demonstrate some such abilities; a new study provides evidence that human infants can too.

It is only at around the age of three that children start to use correctly verbs such as "know", "guess" and "remember" [1], and for this reason developmental psychologists thought for a long time that metacognition — the ability to reflect on one's knowledge or memory — is not available to younger children. When a child starts using a word, however, is not a good indicator of when they acquire the underlying concept, which can happen many months earlier [2]. More importantly, many non-human species, including rats [3], have been shown to adapt their behaviour when faced with uncertainty, in ways that suggest they are able to access their knowledge states. It is therefore more reassuring than surprising that human infants are capable of no less: in this issue of *Current Biology*, Goupil and Kouider [4] report how they adapted paradigms previously used in animal studies to show that 12-month old and 18-month-old human infants persist in their choices only when they are likely to have been correct (suggesting that they know that they know) and change their mind when they are likely to have been be wrong (an index of error detection).

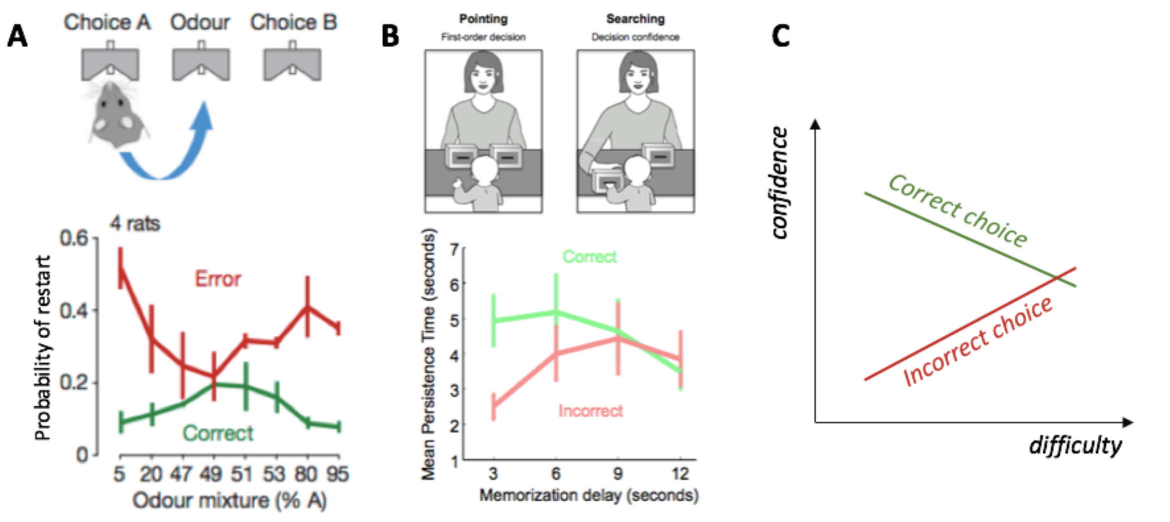

Figure 1. Acting on knowledge and uncertainty.

(A) Rats are more likely to restart a trial if they made an incorrect choice following an easy decision [3]. (B) Infants do not persist in their search when they made an incorrect choice following a short memory delay [4]. (C) Metacognitive abilities are inferred from a significant interaction between decision difficulty and confidence measures (for example, persistence time).

Measuring metacognition without language

When verbal reports on states of confidence or ignorance are unavailable, as with nonhuman animals and preverbal infants, researchers have had to creatively design non-verbal equivalents. One such proxy for confidence ratings is the persistence on a particular choice. To modulate confidence levels, the decision difficulty of a task is varied (Figure 1). In one of these paradigms, rats had to discriminate between two odours which indicated the position of a reward [3]. In some trials, the discrimination was made difficult by mixing the two odours. Rat behaviour in these trials was suggestive an appreciation of uncertainty. They persisted for longest in their choice when this choice was correct, in trials when the discrimination was easy; this was interpreted as reflecting confidence in their decision. They persisted the least when making incorrect choices on the same easy trials, as if aware that they had made an error. Wait times in the difficult trials were intermediate in duration, suggestive of low certainty, or “I don’t know” judgments. Neurons in the rat’s orbitofrontal cortex fired when the rat had made an incorrect choice, in easy trials, even before the correct outcome was revealed — a potential signature of error detection.

For their first study, Goupil and Kouider [4] adapted this paradigm for use with 18-month old infants (Figure 1). Response uncertainty was induced by asking children to indicate the location where they had seen a toy hidden after a variable delay. After they made a choice, the authors measured for how long children searched at the chosen location. Just as in the rodent study, children searched for shorter times when making a correct choice after a long than a short delay, but searched for even shorter times when making an incorrect choice after short delays. In a subsequent study, children were given the option to switch to another box after making their first choice, and again they switched most often when they had made an incorrect choice after a short delay. Finally, a more direct measure of acknowledging a wrong decision was captured using electroencephalography (EEG): a particular EEG component, the error related negativity (ERN), is observed in adults when they make an incorrect decision. Goupil and Kouider [4] measured an ERN-like response when infants oriented towards the incorrect side of the screen after the other side had been primed by the appearance of a face, when that face had been on the screen for long enough to be visible.

The challenge of proving metacognitive abilities

In a 2012 book dedicated to The Foundations of Metacognition, Sodian *et al*. [5] decried the paucity of developmental studies assessing the ontogeny of these abilities. Goupil and Kouider [4] have thus provided much needed new data on this difficult topic. Developmental psychologists' avoidance of this topic is not at all surprising given the on-going debate about what constitutes satisfying non-verbal evidence for metacognition. As the term implies, metacognition occurs when a second computation has been carried out on a first cognitive process, such as a memory or a decision. Some researchers have argued that performance in all available paradigms claiming metacognitive processes can be explained based on the primary process — that is, the behaviour being a result of not remembering something, rather than of knowing that one does not remember [6,7].

The same concerns can be levied against the new findings of Goupil and Kouider [4]. The interpretation of their results rests on our acceptance that, when infants changed their minds about whether or where to search, it was because they were aware that they had chosen wrongly. It is not sufficient to argue that they just had a weaker memory trace of the object in the wrong-choice location (because they had no record of seeing the object there) because, during the longer delay times, when infant's memory trace was presumably even weaker, they searched more persistently. But a possible alternative explanation is that, on the trials where infants were incorrect, they simply began searching earlier than their memory permitted (impulsively) but switched as soon as they remembered the real location of the object. This would not imply any meta-representation of their knowledge. Future studies could investigate whether memory retrieval follows rather than precedes choice in these incorrect trials. The same line of reasoning can be applied to the authors' second experiment, where infants made a choice to continue with their initial search, or shift to a second box. A specific error related neural response measured in the third study might suggest that infants are, after all, able to acknowledge errors of decision. This interpretation is questionable as well, given that it is still a matter of debate whether the ERN really reflects error awareness in adults [8].

Metacognition about the self and about the others

But let's say that Goupil and Kouider's [4] demonstration really does provide convincing evidence for early metarepresentational abilities. After all, perhaps this is the most plausible interpretation given that infants of the same age are seemingly able to metarepresent the knowledge states of others [9]. If they have this metarepresentational ability, perhaps we should expect them to be able to turn such an ability inwards, especially if, as some believe, we have privileged access to our own mental states [10].

But if infants are indeed metarepresenting their own knowledge, how do we reconcile this ability with evidence that infants between 12 and 18 months of age appear not to have a concept of the cognitive self that should logically be necessary for metarepresenting one's own knowledge of absence thereof? The absence of a 'cognitive self' [11], typically inferred from failing to recognize themselves in the mirror, is thought to underlie the absence of things like autobiographical memory in young children. So if we accept that 12-month-olds have metacognitive awareness, are we also tacitly accepting that they have a concept of the self?

What would infants gain from metacognition ?

The search for infant metacognition will be helped by asking in which situations infants would most benefit from knowing they don't know, as compared to simply not knowing. It has been suggested that knowing that one does not know might be necessary for promoting information-seeking behaviors, either through asking others for information, or searching oneself. Indeed, 20-months-olds asked for help when faced with the uncertainty of where an object was hidden [12]. In another study [13], 2.5 year olds, who had no prior knowledge about the container in which a reward had been hidden, first looked into the containers and then chose one of them. However, others have argued that the use of specific information-seeking behaviors that reduce uncertainty could be learned by association to the particular emotional or cognitive states accompanying uncertainty itself. Uncertainty has been shown to lead to increased arousal, resetting of neural states and stochastic behaviour [14], but there is arguably a difference between a feeling of uncertainty and knowing what that uncertainty is.

Perhaps we should consider situations in which there is the need that infants communicate or make known their knowledge states to others. It is in these contexts that as adults we use metacognitive judgements, as when letting others know we don't know where the theatre is so that they don't follow us. A stronger test of metacognitive ability would then be to present infants with situations in which they need to consider whether *someone else* thinks the infants know something or not. We are not sure exactly what such a test might look like, but it might extricate us from the difficult task of isolating second-order, rather than first-order, representations as driving infants' behaviour. Goupil and Kouider's [4] paper is a real *tour de force* of experimentation on very challenging populations, but the quest for infant (and non-human) metacognition has only been reignited with this study. The experimental and theoretical challenges remain big but whatever the findings, this is an exciting field that lies ahead.

References

1. Johnson, C.N., and Wellman, H.M. (1980). Children's developing understanding of mental verbs: Remember, know, and guess. Child. Dev., 1095-1102.
2. Hespos, S.J., and Spelke, E S. (2004). Conceptual precursors to language. Nature 430, 453-456.
3. Kepecs, A., Uchida, N., Zariwala, H.A., and Mainen, Z.F. (2008). Neural correlates, computation and behavioural impact of decision confidence. Nature *455*, 227-231.

4. Goupil, L. and Kouider, S. (2016). Behavioral and neural indices of metacognitive sensitivity in preverbal infants. Curr. Biol. thi issue.

5. Sodian, B., Thoermer, C., Kristen, S., and Perst, H. (2012). Metacognition in infants and young children. In Foundations of metacognition, M.J. Berran ed. (Oxford University Press), pp. 119-133.

6. Carruthers, P. (2008). Meta-cognition in animals: A skeptical look. Mind Lang. *23*, 58-89.

7. Kornell, N. (2014). Where is the “meta” in animal metacognition? J. Comp. Psychol. *128*, 143.

8. Wessel, J.R. (2012). Error awareness and the error-related negativity: evaluating the first decade of evidence. Front. Human Neurosci. *6*, 88.

9. Baillargeon, R., Scott, R.M., and He, Z. (2010). False-belief understanding in infants. Trends Cog. Sci. *14*, 110-118.

10. Goldman, A. (2006). Simulating Minds: The Philosophy, Psychology, and Neuroscience of Mind-reading. (Oxford University Press)

11. Howe, M.L., and Courage, M.L. (1997). The emergence and early development of autobiographical memory. Psychol. Rev. *104*, 499.

12. Goupil L, Romand-Monnier M, Kouider S. (2016) Infants ask for help when they know they don’t know. Proc. Natl. Acad. Sci. USA *113*, 3492–6.

13. Call, J., and Carpenter, M. (2001). Do apes and children know what they have seen?. Anim. Cogn. *3*, 207-220.

14. Tervo, D.G., Proskurin, M., Manakov, M., Kabra, M., Vollmer, A., Branson, K., and Karpova, A.Y. (2014). Behavioral variability through stochastic choice and its gating by anterior cingulate cortex. Cell *159*, 21-32.

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