Infant and Child Development
Inf. Child Dev. **22**: 111–117 (2013)
Published online in Wiley Online Library
(wileyonlinelibrary.com). DOI: 10.1002/icd.1788

Reply to Commentaries

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In our response, we address four themes arising from the commentaries. First, we discuss the distinction between cognition and metacognition and show how to draw it within our framework. Next, we explain how metacognition differs from social cognition. The underlying mechanisms of metacognitive development are then elucidated in terms of interaction patterns. Finally, we consider measures of metacognition and suitable methods for investigating it. Copyright © 2013 John Wiley & Sons, Ltd.

Key words: implicit metacognition; perceptual metacognition; coding schema for epistemic action; shared practice; intersubjectivity; measures of metacognition

THE CONCEPT OF METACOGNITION

Endorsing an approach to metacognition as recursive and metarepresentational, comprising higher-order (mental) representations about representational cognitive states, Perner and Dienes express concern with our concept of metacognition. They argue that approaches to metacognition that define it in terms of monitoring and control are unclear and that theories of implicit metacognition lead to inflationary use and 'pan-metacognition'. Markova and Legerstee express a similar concern that the concepts of implicit and perceptual (attention-based) metacognition are too inclusive. We agree that there is not much sense in making the distinction between cognition and metacognition unless there is a proper way of telling them apart, and furthermore, that if two phenomena tend to co-occur (i.e. be observed together), one may suspect that they are not distinct but of the same kind. In the succeeding text, we show that our framework allows for making a clear-cut distinction between cognition and metacognition.

We maintain that metacognition consists of the monitoring and control of cognitive processes in goal-directed activities. The distinction between pragmatic and epistemic actions underlies our distinction between cognition and metacognition, and prevents the theory from falling into the trap of 'pan-metacognition'. *Pragmatic actions* are needed to perform a task and move the agent closer to the goal by changing the task environment. They require on-line cognitive processing of information about the task,

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the environment and the agent's behaviour. *Epistemic actions* are needed to improve the conditions for pragmatic actions by changing the agent's cognition and the way she or he is related to the task environment. These actions require metacognitive processing of information about, primarily, the agent's cognitive states. Epistemic action is not necessary for pragmatic action, but it is required for working out how to repair a pragmatic action that has been disrupted or is malfunctioning because the information is insufficient or inadequate for performing the task.

Implicit metacognition concerns sensorimotor actions that occur on a rapid time scale from milliseconds to seconds. It is implicit in several senses: it involves causal processes, is cognitively impenetrable (Pylyshyn, 1999), is automatic and typically does not reach conscious awareness or experience (but see Brinck, 1999). Perner and Dienes correctly point out that modelling implicit metacognition in terms of the monitoring and control of dynamic systems obscures the difference between cognition and metacognition. According to such a model, a process that monitors the agent's on-going activity regulates the interaction between agent and environment in real time by comparing actual with predicted performance to correct errors. Because the process monitors and controls the agent's perceptions and actions, it appears to have a metacognitive function. If true, this would entail that almost any action is metacognitive, including motor actions and 'actions' on a neuronal level. There are different ways of reacting to pervasive metacognition. To simply bite the bullet and admit that metacognition is pervasive seems unsatisfactory in view of the large amount of empirical evidence that metacognition plays a distinct role for learning and managing cognitive resources.

One way of drawing the distinction between cognition and metacognition exploits the fact that real-time interaction can be more or less dynamic and so has two extremes (Phillips, von der Malsburg, & Singer, 2010). In cases where the interaction is familiar, it consists of stereotypical patterns of coordination that are highly stable. In contrast, a completely new situation is unpredictable, and actions cannot be prepared in advance but are computed and executed on-line. Usually, novel patterns of coordination are built from familiar components and interaction occurs somewhere in the middle. In the extreme case when actions are computed on the fly and the process requires continuous control and intervention, it may seem reasonable to say that the interaction involves metacognition. However, making metacognition a matter of degree does not really solve the problem. How can one justify having two terms for what fundamentally is one and the same function?

Proust (2010) suggests that it is possible to make a sharp distinction without introducing recursion into the model. She ascribes distinct control structures to mental and bodily actions, on the grounds that they involve different types of intentions to act and so are sensitive to different types of norms—epistemic and instrumental norms, respectively. Whereas meta-action processes evaluate the development of intentions of bodily actions and how the intended change is brought about, metacognitive processes evaluate the correctness of the outcome of mental acts such as memory retrieval. It is an important insight that meta-processes involve different kinds of norms. Nevertheless, we believe that the recursive condition needs to be satisfied, especially because it is not altogether clear to us how to draw the distinction between bodily and mental actions within an embodied approach to (meta)cognition such as ours.

We deny that on-line error correction constitutes control in a metacognitive sense. Being part of the perception-action loop that drives the on-going interaction, error correction is necessary for performing the pragmatic actions that advance the agent towards the goal. However, if error correction fails, this will trigger metacognitive control and a re-evaluation of the entire process. The purpose of epistemic

DOI: 10.1002/icd

action then is to re-engage pragmatic action by determining how much and what information is needed to repair the interaction, and how that information can be obtained and put to use to resume it.

To conclude, our framework allows for distinguishing cognition and metacognition in terms of their functions of use without invoking the concept of mental representation, and regardless of whether metacognition has a personal function. We are now in the position to reply to Perner and Dienes's question, regarding whether we consider a cat's gauging its ability to reach the other side of the abyss before it jumps a case of metacognition—no, we do not. The cat is preparing to jump (a pragmatic action) by assessing the distance to the other side. It is processing information about the task environment, not about cognition.

METACOGNITION AND SOCIAL COGNITION

Markova and Legerstee express doubts about the advantages of talking about metacognition as a social phenomenon. Moreover, they claim that many of the behaviours that we describe as metacognitive are examples of social cognition and suggest that we consider 'early metacognition' part of social cognition.

Markova and Legerstee have misunderstood two fundamental points in our account: the definition of metacognition and the role of intersubjectivity in metacognition. For instance, they argue that on our view, the attention following of newborns will be metacognitive because it optimizes learning and involves the monitoring and control of information (about the environment). They are wrong. On our definition, metacognition processes information about cognition (as opposed to the world), whereas attention following in newborns is exogenously controlled (Farroni, Massaccessi, Pividori, & Johnson, 2004) and so does not constitute metacognition.

Second, they assert that we conceive of metacognition as essentially intersubjective ('control of embodied cognition experienced between two people'). However, our hypothesis is developmental, not constitutive: we claim that children develop metacognition by learning in engagement with other subjects. This does not mean that metacognition as such must be social, although the significance of social metacognition for complex human behaviour, which involves joint planning, decision making in groups and collaborative cooperation, certainly is strong (Brinck & Gärdenfors, 2003; Efklides, 2008; Frith, 2012).

Contrary to what Markova and Legerstee appear to believe, our aim is to introduce a conceptual tool that permits more fine-grained analyses of infant behaviour and can categorize it as cognitive or metacognitive—not to re-describe social cognition in general as metacognition. When we assert that metacognition starts to develop by 2–4 months, we do not mean to imply that it is in place at that age. During this period, infants develop skills implicated in implicit and perceptual metacognition. Specifically, they engage in disengagement of attention and attentional control as in checking back and back-and-forth looking and learn to recognize various emotional states (Perra & Gattis, 2010), allowing for emotion regulation and, eventually, effortful control (Rothbart, Ellis, & Posner, 2004). The behaviour at this point has not yet acquired a metacognitive function for the infant.

Being a part of more complex behaviours, one and the same skill can be used for different tasks at different times and in a variety of contexts, and can acquire a cognitive or a metacognitive function. Consider attentional control. In the context of crossing a busy street, it affords repeated focusing of the attention, looking in the directions and at the parts of the scene that the agent believes are most useful to check in order to avoid being run over. In contexts of joint attention, it affords

DOI: 10.1002/icd

initiating interaction by making attention contact and ending it by looking away or avoiding eye contact. In metacognitive contexts, it affords strategic control, being used to, for example, re-organize the task environment or analyse the quality of an epistemic feeling of uncertainty. So how do we determine when attentional control acquires a metacognitive function to the infant? Explaining metacognitive development means to establish when a behaviour and skill that has a metacognitive function in adults first emerges in infancy, and when and how, in what contexts, and as part of what complex behaviours it acquires a metacognitive function for the child.

THE UNDERLYING MECHANISMS OF METACOGNITIVE DEVELOPMENT

Hobson acknowledges that our aim is to present a conceptual and theoretical framework that allows for investigating the roots of metacognition and clarifying its developmental trajectory by generating testable predictions. He asks for an account of the means that shape metacognition and of what changes from one phase to another and when. In the succeeding text, we describe how infants acquire perceptual and metarepresentational metacognitive skills by participating in script-like shared practices with their caregivers. The underlying mechanisms or patterns of interaction that drive metacognitive development and enable learning emerge naturally in infant–adult dyads in different formats during specific periods in time.

Perceptual metacognition, first, allows for epistemic action in a number of ways. First, visual attention is used for selection, analysis and update in both monitoring and control of cognition by, for example, shifting attention, focusing and maintaining attention, and alternating between figure and ground. Second, epistemic feelings (confidence, familiarity, uncertainty, fluency, flow, effort) are used for evaluation in monitoring and to initiate and choose strategies for control. Third, the regulation of impulse, emotion and motivation influences persistence and volition. Fourth, physical epistemic actions exploit properties in the environment to enable strategic control and extended monitoring and enhance performance in problem-solving tasks (Fioratou & Cowley, 2009; Kirsh, 2010). Artefacts are often used for epistemic purposes, sometimes in ways unrelated to their conventional function, such as to provide a structure that can serve as a shareable object of thought in a joint activity, create persistent referents during problem-solving, visualize a line of reasoning and process memory.

Perceptual metacognition operates on socio-culturally contextualized, motivated pragmatic actions (Gallagher & Marcel, 1999; Haugeland, 1995; Hutto, 2007). Being embedded in social situations and practices renders the actions directly meaningful, and the agents experience them as personally relevant (e.g. having afternoon tea at your aunt's, eating Sunday roast at the local pub, jogging with your training partner). Shared practices involve epistemic norms and procedures for metacognitive management of the interaction, via cognition, which agents jointly enact and can negotiate in real time.

We claim that children develop and can internalize metacognition by participating in shared practices, the structure of which initially is simplified but increases in complexity along different dimensions as they grow older. Primary intersubjectivity is the first context for learning metacognitive skills; partly because by this age, infants begin to develop behaviour that later acquires a metacognitive function for them, partly because the interaction involves monitoring and control on two levels, of actions and cognitions, and therefore affords learning metacognitive skills. The ritualized behaviours and play routines that infant–adult dyads continue to develop in the first year share the same format. The adult provides

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metacognitive scaffolding: structures goals, content and timing; controls emotion, volition and motivation; prompts and directs the child's behaviour, continuously increasing the level of difficulty as the infant's performance improves. Children do not begin to actively manage on-going interaction strategically until by 2 years (Brownell, 2011).

In a study of mother–infant interaction (8–17 months) in pretend play, Morrissey (2011) reports that metacognitive scaffolding includes identifying play goals and subgoals; selecting appropriate strategies and materials for use in pretence; predicting consequences of play actions; and performing evaluative functions. Morrissey concludes that metacognitive development depends on responsive tutoring strategies such as modelling, simplifying, maintaining interest and motivation and marking discrepancies.

Except for in spontaneous contexts of play, parental metacognitive scaffolding permeates everyday activities such as getting dressed in the morning, having dinner or going to bed, challenging the infant to develop new competencies. Some parents support their infants' performance by explicitly managing their cognition, giving hints, explaining how and what to do and telling them why, helping them to structure actions and evaluate performance and outcome. The more verbal the scaffolding, the more it encourages dialogue and reflection as in metarepresentational metacognition.

Children thus make gains in metarepresentational metacognition by being exposed to and eventually engaging in verbal interaction about the management of cognition with their caregivers. Intersubjectivity and participatory learning remain important. This view links the development of metarepresentational metacognition to language development. We think of perceptual and metarepresentational metacognition as in principle independent systems, co-existing in the adult.

Metacognitive skills originate in a bidirectional process of mutual responsiveness between parents and children. The outcome is a function of the subjects' combined efforts to manage the interaction. To exemplify, gifted children elicit high levels of stimulation—including verbal forms—from their parents already in the second year, some as early as by 1 year, as opposed to normally by 3 or 4 years, when many parents begin to help children acquire metacognitive skills (Moss, 1992). This boosts the development of metarepresentational metacognition.

Markova and Legerstee claim that we overemphasize what the adult brings into the learning context and ascribe a passive role to the child. This is not our intention. Adult and infant *both* actively shape their interaction and together drive it forward, and in this sense, the interaction is truly intersubjective. Nevertheless, infants are not capable of guiding it, using their metacognitive skills concertedly, before 2 years.

METHODS AND MEASURES

Perner and Dienes assert that so far nobody has presented a convincing way of showing that preverbal infants engage in recursive cognition about cognition. Consequently, they do not see how our hypothesis that the development of metacognition depends on intersubjectivity might be empirically testable, and challenge us to put forward 'a reliable measure of metacognition that does not depend on verbal report'.

First, it is not clear to us in what sense verbal report is a reliable measure of metacognition. Several studies have shown that verbal reports are highly unreliable and do not provide evidence about 'inner' or mental cognitive processes

DOI: 10.1002/icd

(Frith, 2012; Johansson, Hall, Sikstrom, & Olsson, 2005; Nisbett & Wilson, 1977). As a measure of metacognition in the form of verbal reasoning about one's own cognitive states in explanations and predictions of behaviour, verbal report may be reliable but can often seem trivial.

Our framework makes possible measuring implicit and perceptual metacognition by observation of bodily manifest, epistemic actions in physical task environments. Two examples are focusing and maintaining attention to select and organize information about the task environment and improve memory encoding, and placing and re-arranging physical objects in the task environment in order to decompose, structure and increase its transparency-both actions performed to improve the conditions for pragmatic action. Constructing a coding schema for epistemic action would be useful for studying the prevalence of metacognitive skills in preverbal infants and establishing what skills occur at what ages. We believe that eye-tracking technology would be an efficient means for examining how and when infants engage in early metacognitive skills, both self-directed and other-directed ones.

Two paradigms strike us as particularly promising for putting our theory to the test at this point. First, much can be derived from longitudinal studies of the interaction of infant–adult dyads, recorded monthly during the first or second year. They would provide data about, for example, how metacognitive development is influenced by the (i) intensity, (ii) frequency and (c) style of intersubjectivity of adult and infant, and whether a high degree of intersubjectivity in adults is correlated with high degrees of metacognitive scaffolding.

Second, the relative importance of different aspects of intersubjectivity can be illuminated by studies of the impact of attachment on metacognitive development, for example considering how infant–caregiver interactions at 2–4 months predict the development of metacognitive visual attention by 7–9 months, and how attachment in the second half of the first year predicts each of the three forms of metacognition by 2 and 3 years. Affect-mirroring, and factors associated with it such as mind-mindedness, would predict the degree of internalization of metacognition, that is, the degree to which the individual can manage his or her cognition independently of other people.

Markova and Legerstee suggest a third topic: infant attunement, 'the degree to which infants can attune to the on-going social interaction, how they take control of it and how they repair it when it is broken down'. We agree that this would be enlightening and would provide material for discriminating coping strategies that rely on metacognition.

None of these suggestions, on their own, can directly falsify our hypothesis, but not finding any systematic correlations between intersubjectivity and the development of metacognitive skills certainly would make it less probable. Thus, we think that there are good prospects for tackling the challenge presented by Perner and Dienes and testing the early development of metacognition as conceptualized in our theory.

CONCLUSION

Metacognition plays an important role in learning at all ages, particularly in individual and joint activities that require cognition about cognition, such as everyday decision making and cooperation. To clarify this role, we need to examine the development of metacognition as embodied and embedded in the physical and socio-cultural environment, and manifest in bodily interaction with other subjects

DOI: 10.1002/icd

and artefacts in the surroundings. We also need to investigate metacognitive processes on different time scales and their interaction in real time. Such an approach will open up the field in terms of new methods and new data. Finally, we think that elucidating the development of metacognition along the lines that we suggest will be helpful for understanding how metacognition once evolved and for examining it in other species. Developing strategies for the management of individual and social epistemic resources has been and continues to be a significant means for changing human conditions and forms of life. Tracing the developmental trajectory of metacognition from its very beginning into adolescence thus has the potential to shed light on the place of our species in nature.

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DOI: 10.1002/icd