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The Developmental Origin of Metacognition

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We explain metacognition as a management of cognitive resources that does not necessitate algorithmic strategies or metarepresentation. When pragmatic, world-directed actions cannot reduce the distance to the goal, agents engage in epistemic action directed at cognition. Such actions often are physical and involve other people, and so are open to observation. Taking a dynamic systems approach to development, we suggest that implicit and perceptual metacognition emerges from dyadic reciprocal interaction. Early intersubjectivity allows infants to internalize and construct rudimentary strategies for monitoring and control of their own and others' cognitions by emotion and attention. The functions of initiating, maintaining, and achieving turns make proto-conversation a productive platform for developing metacognition. It enables caregiver and infant to create shared routines for epistemic actions that permit training of metacognitive skills. The adult is of double epistemic use to the infant—as a teacher that comments on and corrects the infant's efforts, and as the infant's cognitive resource in its own right.

Key words: metacognitive skills; epistemic action; intersubjectivity; reciprocal interaction; attention; emotion

It has been argued from a variety of theoretical perspectives that intersubjectivity, or the sharing of experiences, constitutes the developmental basis for the awareness of mind and sustains socio-cognitive development generally (Hobson, 1993, 2002; Legerstee, 2005; Meltzoff, 2007; Rochat, 2001; Tomasello, Carpenter, Call, Behne and Moll, 2005). Available data corroborate its importance for the infant's growing understanding of other minds. In comparison, the role of intersubjectivity for the development of infants' understanding of their own minds has met with less interest. Nevertheless, it is clear that the concepts of self and other are interrelated and that intersubjectivity contributes to an understanding of both.

We maintain that intersubjectivity plays two distinct, yet complementary developmental roles. Intersubjectivity constitutes the foundation of, on the one hand,

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the awareness of mind and cognition, and on the other, the awareness of cognition about cognition, or metacognition. Metacognition consists in the monitoring and control of cognition and allows the subject to perform strategies and operations on the cognitions of the embodied mind. The term 'meta' signifies a change in emphasis to knowledge about cognition from the cognitions themselves (Brown, 1978).

Although the extant research on metacognition has emphasized the individual's knowledge about how to manipulate his or her own cognition, metacognition may also concern other people's cognitive states in the form of social metacognition (Flavell, 1999). As we will argue, what makes a given process or action metacognitive is its operative function—what it does when in use—whereas whether the process or action occurs in the internal context of the mind or in the external context of the shared environment is irrelevant to determining its metacognitive status. The vital point here is that *it serves to manage cognition*. In fact, a great deal of everyday metacognition takes place in the external environment and sometimes involves other subjects.

We suggest that metacognition has its developmental origin in certain features of early intersubjectivity that permit infants to internalize and construct rudimentary strategies for manipulating their own and others' cognitions. We will argue that metacognitive abilities and skills start to develop between 2 and 4 months of age in episodes of dyadic interaction. These abilities and skills are in a certain sense precursory to many of the metacognitive functions that have been explored in the research on human adult subjects. This does not mean that eventually they will disappear and be replaced by later developing metacognitive functions. On the contrary, implicit, perceptual, and metarepresentational metacognition co-exist in adult subjects, each type contributing in its particular way to the general metacognitive machinery.

Early intersubjectivity provides a context for learning metacognitive skills because of its intimate format that allows the subjects to directly experience and respond to each other's reactions to the ongoing interaction in real time—an interaction to which monitoring and control of pragmatic actions are inherent. As opposed to interaction with the physical environment that often involves perfect contingencies (e.g. the mobile always moves following leg kicking), social interaction is characterized by imperfect contingencies (e.g. parents often, but not always, respond with a smile to the infant's smile). This means that the social environment to a higher degree than the physical one is unpredictable, which causes the need for monitoring and control of cognition.

We think of the period of 2–4 months as a very first sensitive or critical period, a so-called window of opportunity 'during which certain types of experience have a foundational effect upon the development of skills or competencies' (Fox and Rutter, 2010, p. 23). By this age, infants begin to acquire the means for joint monitoring and control of the interaction with the caregiver by primarily visual attention and facial expression of emotion. As we will argue, such monitoring and control involves implicit and perceptual metacognitive skills, and subsequent metacognitive development is a function of the quality and quantity of the stimulation during this period. Because the plasticity of the prefrontal cortex does not decline until school age and metacognitive development continues well into adolescence, we expect there to be several more, later critical periods than the one discussed here. For example, it is very likely that another critical period, or window of opportunity, for learning metacognitive skills occurs when infants begin to engage in joint attention during triadic interaction. However, our present focus is on how early intersubjectivity promotes initial learning of metacognitive skills by 2–4 months.

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AN EXTENDED CONCEPT OF METACOGNITION

Traditionally, psychology has conceived of metacognition in terms that *prima facie* do not permit metacognition in preverbal infants. Under the influence of cognitive psychology, the received view models metacognition on logical, inferential reasoning, and suggests that metacognition is metarepresentational, that is, involves higher-level cognitive states that are about or represent cognitive states on a lower level (Carruthers, 2009; Nelson and Narens, 1990, 1994). According to Dienes and Perner (2002), metacognition in this sense is a case of fully explicit, propositional knowledge, which means that the subject is aware that he or she has a certain cognitive state about a fact at a certain time, and so consists in a third-order state that renders conscious the second-order state that it concerns.

The prevailing operationalizations of metacognition preclude metacognitive capacities in preverbal infants, much like how the operationalization of theory of mind in terms of the original false-belief test (Wimmer and Perner, 1983) rules out an understanding of other minds in children younger than 4 years of age. Yet there is direct and indirect evidence of metacognition at earlier ages. Having found directed, self-regulated learning in 3-year-olds, Balcomb and Gerken (2006, p. 1003) suggest that metacognition 'may be inherently intertwined with core processes, existing implicitly at very early ages and only emerging explicitly when children are much older'. They maintain that passive learning mechanisms such as associative learning are unlikely to explain the rapid growth in cognitive development in infancy. Balcomb and Gerken (2008) furthermore report that 3.5-year-olds demonstrate memory-monitoring skills in a non-verbal task in which they had to access their knowledge states. Balcomb and Gerken argue that theories about metacognition that presuppose metarepresentation and self-control cannot handle learned implicit processes of this kind—processes that, although not associated with or present in working memory (hence, not consciously aware), nevertheless permit monitoring and control of cognition.

New experimental paradigms have revealed cognitive functions in preverbal infants that presuppose at least such an implicit understanding of how cognition works and how to influence it. This makes the research relevant for metacognitive development. To exemplify, there is evidence that 2-year-old children monitor their own knowledge states (Call and Carpenter, 2001) and predict others' actions on the basis of an awareness of false belief (Southgate, Senju and Csibra, 2007), that 17-month-old infants track the status of a communicator's epistemic state in order to infer to what she intends to refer (Southgate, Chevallier and Csibra, 2010), that 15-month-olds predict an actor's behaviour on the basis of the actor's beliefs about a toy's hiding place as revealed by what the actor is seeing (Onishi and Baillargeon, 2005), and that 14-month-olds understand the experience of seeing (Sodian, Thoermer and Metz, 2007).

Furthermore, Agnetta and Rochat (2004) claim that testing behaviour suggests metacognitive awareness from 9 months of age. Testing behaviour occurs when the infant while oriented toward an imitating adult systematically modulates an object-directed action to check whether the adult is following what the infant does and will copy the action. Finally, Sheese, Rothbart, Posner, White and Fraundorf (2008) report that anticipatory looking by 6–7 months of age is positively related to cautious behavioural approach in response to non-threatening novel objects and is evidence of self-regulatory attention.

A constructivist approach may be used to explain the variety of data. Constructivism pictures development as gradual and reveals the different ways in which a given function is realized over time until it has reached its end state. Sodian and

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Thoermer (2008) suggest that in the second year of life, infants gradually develop an understanding of knowledge formation based on situational and behavioural cues rather than on a person's access to information in her own mind, whereas mental state attribution involving the representation of others' beliefs does not emerge until by 3 or 4 years. We maintain that construction starts even earlier. Already young infants are capable of grasping the intentions of others through the perception of goal-directed bodily movements, gestures, and facial expressions of emotion, and by 1 year of age, triadic interaction in pragmatic contexts further contributes to the infant's growing awareness of the mind (Brinck, 2004, 2008).

In sum, paradigms for testing for implicit cognitive capacities in human adults and preverbal infants have led to an extended concept of cognition: cognition used to be associated with capacities such as verbal competence, symbol processing, logical inferential reasoning and introspection, but nowadays is associated also with perceptual association, emotion, motivation and attention. We propose that the expanded conceptualization of cognition should be mirrored by a similar extension of the concept of metacognition.

We base our extended concept of metacognition in Flavell's original definition, which has provided the starting point for most of the research on metacognition in psychology. Flavell (1976, 1979) suggests that metacognition is the monitoring and control of cognitive processes such as memory, comprehension and learning in activities that require applying stepwise, or algorithmic, strategies to reach goals or complete tasks. Our definition is in line with Flavell's but does not necessitate metarepresentation or algorithmic strategies. We submit that metacognition determines (i) how much and what information is needed to reach the goal or complete the task, (ii) a strategy for obtaining the information required to reach the goal or complete the task, and (iii) when and how to use the available information to achieve the goal or complete the task.

We adapt Kirsh's (2005) framework for operationalizing metacognition that pictures metacognition as the management of cognitive resources internally in the agent's (embodied) mind and externally in the task environment. In a series of studies of problem solving in natural environments, Kirsh shows that metacognition is highly interactive and regulates the way learners are dynamically coupled with their environments (Kirsh, 1995, 1996, 2005). Coupling occurs when two systems co-ordinate their behaviour in real time in a progressive perception-action loop, where each system continually is influencing the processing of the other, mutually specifying each other in a co-implicative relation (Varela, Thompson and Rosch, 1991, p. 197). How perceptual cues are structured and the interaction is designed make a crucial difference for the ease and effectiveness of metacognition.

Following Kirsh, we distinguish between two kinds of action, the second kind being metacognitive in the sense we defined previously (cf. Kirsh and Maglio, 1994). *Pragmatic actions* are needed to perform a task or solve a problem and move the agent closer to the goal. They are physical actions that change the task environment. *Epistemic actions* are used to search for a solution to the problem or select a strategy or procedure to perform the task. They are physical actions that change the agent's cognition and how he or she is related to the task environment—by interacting with and thereby changing the physical environment. It should be noted that *epistemic thought* or reason has a similar function as physical epistemic actions but consists in purely mental acts (in the embodied mind).

DOI: 10.1002/icd

A DYNAMIC APPROACH TO METACOGNITION

Dynamic systems theory explains cognition in terms of how interactive forces make processes unfold over time. The interaction between organism and environment is a two-way, causal relationship between distinct systems that form an integrated, or coupled, whole. Cognitive processing is analyzed as continuous state change in such coupled systems. Subjects respond dynamically to changes in both the internal (the mind) and external environment via monitoring and control of their cognition in real time. This requires rapid execution at frequencies ranging from milliseconds to minutes (Kirsh, 2005; Reder and Schunn, 1996), and heuristic metacognitive processes, produced to be cost efficient and satisfactory (adequate, not necessarily optimal) given contextual constraints (Simon, 1956).

Proust (2006, 2007) describes the dynamics of metacognition in an organism as an adaptive control system consisting of regulated and regulating subsystems. The subsystems select strategies to control future states of the (entire) system relative to the environment based on evaluations of prior interaction and currently available resources. Proust's model can account for implicit directed learning and uncertainty judgments in infants that typically pose problems for traditional theories of metacognition. In line with this approach, we define *implicit metacognition* as the monitoring and control of hierarchical cognitive processes in activities that require purely causal strategies for reaching goals or completing tasks. Moreover, we define *perceptual metacognition* as such that requires emotional and attention-based strategies. Finally, we define *metarepresentational metacognition* as such that requires higher-order propositional or symbolic strategies (cf. Carruthers, 2009). The many phenomena investigated in the research on metacognition in cognitive, comparative, and developmental psychology and related areas (metamemory, self-control, uncertainty monitoring, affect heuristics, problem solving, strategy selection, implicit learning, feeling-of-knowing, etc.) are brought together under the same heading on the grounds that they share the same operative function.

Implicit metacognition guides behaviour but does not reach conscious awareness. Dienes and Perner (2002, p. 177) assert that we live in a 'pervasive sea of metacognitive monitoring' and control and that 'every moment of our waking life we are engaged in automatic and unconscious metacognitions providing us with all our conscious experiences' and with 'volitional control over our actions and mental processes'. Common examples of implicit metacognition include riding a bike or driving a car. These activities require constant multimodal monitoring of features in the passing environment, of proprioception, of input from the bike or car and from the interaction with surrounding road-users and traffic.

New experimental techniques produce increasing evidence of implicit metacognition. Functional magnetic resonance imaging (fMRI) scanning has revealed automatic processes in adults such as response activation and control engagement, resulting from conflicts of response to irrelevant input that predict attitude change in cognitive dissonance (van Veen and Carter, 2006; van Veen, Krug, Schooler and Carter, 2009). Event-related potentials of the brain are measured to investigate automatic, non-reflective responses to stimuli and reflect on-line processing (Rugg et al., 1998). The method can be used to reveal implicit metacognitive processes that underlie epistemic feelings. To illustrate, Paynter, Reder and Kieffaber (2009) show that in a problem-solving task, subjects can estimate whether the answer is known much faster than the answer can be retrieved, informing them whether they will need to calculate the solution or not. Paynter et al. conclude that initial feelings-of-knowing rely on a rapid assessment of the perceptual fluency with which the stimulus is processed.

DOI: 10.1002/icd

Perceptual metacognition constitutes the experiential dimension of metacognition and involves emotion and attention (Brinck, 2001). Koriat (2002) claims that subjective beliefs and feelings have a double function and contribute to both monitoring and control. They play a supervisory role in revealing the output of monitoring in the form of subjective, phenomenal experience, and a causal role in controlling the regulation of cognitive processes and behaviour. Koriat, Ma'ayan and Nussinson (2006) present evidence for, on the one hand, monitoring-based control when feedback concerns the outcome (e.g. feelings-of-knowing), and, on the other, control-based monitoring when feedback concerns the process itself (e.g. the effort required to perform a certain task; cf. Brinck, 1999). As conceived of here, implicit and perceptual metacognition interact and enable flexible, context-sensitive, complex, and controlled goal-directed behaviour. Instead of being devices for applying algorithms to reach well-defined goals in the format of representation, they exploit heuristics and environmental affordances as well as general, fixed principles, and goals may be fuzzy, interim and even intermittent.

Koriat (2000) maintains that certain metacognition consists in information- and theory-based judgments that involve high degrees of consciousness and control. Perner (1991) defines metarepresentation as a representation that represents the representational relation itself, and so it involves a representation being represented as a representation. We do not refuse metarepresentation in Perner's sense a role in metacognitive development, but this happens only once language acquisition has begun, through the semiotic resources that language affords.

We propose that implicit and perceptual metacognition can be coupled to a representational system that enables metarepresentation, like natural language (Clark, 2005). This means that once the child can use language, coupling allows for a higher-order re-description of implicit and perceptual metacognition in terms of algorithmic strategies operating on propositional representations. Language is the highest function of the sensory-motor capacities that enable human beings to organize their surroundings. It is a complement to internal states, not a mirror, and serves as a tool that extends cognition (Clark and Chalmers, 1998) in many directions, one of which pertains to the domain of metacognition: the management of cognitive resources. Natural language is a powerful means not just to off-load cognition from the brain to the external world but also to enhance cognitive processing (Vygotsky, 1962).

Like other tools and artefacts, language structures the experiences people have of their own cognitive episodes, which makes experiences socio-culturally rather than neurophysiologically grounded. Ultimately, the properties that usually are ascribed to mental experiences and metarepresentational thought belong to agent and environment taken together (e.g. the concepts used to describe and teach metacognitive strategies to enhance individual capacities, such as techniques for memorizing data). The use a person puts them to emerges from the socio-cultural context in which he or she is embedded. Consequently, social interaction and intersubjectivity grounds the way children come to make sense of metarepresentational metacognition by way of language. Sinha (2009) provides evidence for the dependence of children's metacognition on the environment in contexts of symbolic play, when reasoning involves dense, perceptually saturated, local couplings, and normative, material artefacts.

THE EARLY DEVELOPMENT OF METACOGNITION

In developmental psychology, *intersubjectivity* usually is defined as the sharing of manifest affective and perceptual experiences (cf. Brinck, 2008; Stern, 1985;

DOI: 10.1002/icd

Trevarthen and Hubley, 1978). Intersubjectivity first materializes in episodes of imitation between the newborn infant and the caretaker, and soon develops into mutual engagement, during which infant and adult characteristically take a second-person perspective toward each other. Mutual engagement occurs in the first 2 months in the form of a dynamic matching and exchange of facial and bodily expressions of positive emotion. This engagement develops into proto-conversation that involves turn-taking, usually defined as the reciprocal coordination and sequencing of behaviour in time (Trevarthen, 1979). Proto-conversations are regulated by vocalization, visual attention, emotion expression, bodily action and verbal communication. Infants take turns and can produce differentiated responses to adults' attention by 2 months.

The sharing of experiences requires the complementary abilities of recognizing the experiences of another individual (a second person) and making available one's own (first person) experiences to somebody else (Brinck, 2008). Although the two abilities correspond, they are distinct. The newborn infant needs to practise both and learns how to harmonize them by engaging in imitation soon after birth. Given that both similarity and difference between self and other are perceivable and that early intersubjectivity is grounded in concrete contexts of reciprocal interaction, the infant can directly experience the bi-directional relation between self and other in mutual engagement, and eventually develops an intuitive understanding of intersubjectivity and a sense of self.

Intersubjectivity presupposes that the infant is treated as a subject and that infant and adult show similar respect for each other's attempts at making contact and eagerness to maintain the other's attention to self. To account for how intersubjectivity can emerge, Trevarthen (1992) construes primary intersubjectivity as an innate drive that accounts for infants' readiness to partake in dialogue. Children are born with a receptivity to the subjective states of other persons and use their own and other persons' motives in the negotiation of purposes, emotions, experiences and meaning (Trevarthen, 1998, 2011).

However, a biological preparedness for engaging with other subjects will not as such bring about intersubjective behaviour. Intersubjectivity becomes operative when an adult triggers it by turning towards the newborn infant and initiating contact. The concept of preparedness refers to a genetic disposal to learn certain relations or associations that have a selective advantage (Seligman, 1971). Primary intersubjectivity relies on such genetically prepared behavioural propensities, but how they ultimately are realized in individual subjects varies relative to environmental stimuli.

Indeed, development is epigenetic in the sense that an individual's developmental trajectory is a function of the causal interaction between genetically coded information and stimuli in the external environment, including social interaction (Fagiolini, Jensen and Champagne, 2009; Meaney, 2010). The impact of the external environment is indirect on behaviour by the local environment of the cells in the body that regulate DNA expression. Environmental conditions can have a systematic influence on the expression of genes over time, because the interaction between genes, environmental forces, and the agent's experiences changes DNA structure and shapes the brain's architecture. As a result, although the developmental trajectory at large is biologically and genetically determined, what aspects will be accentuated or on the contrary neglected in the individual case is determined by factors in the infant's socio-cultural environment. Evidence for the importance of both the quantity and quality of early interaction comes from studies of brain development that show how early experience crucially modifies the structures and functions of the infant's brain (Fox, Levitt, & Nelson, 2010).

DOI: 10.1002/icd

Thus, we propose that cognitive development depends equally on the infant's innate motivations to engage psychologically with others and the adult's motivation to engage with the infant. It follows that the quantity and quality of the intersubjective relation as measured by the infant's and caregiver's respective degrees of engagement and responsiveness is an indication of its potential for promoting learning and transfer of (meta)cognitive skills. This prediction gains support from the research on attachment.

A great number of studies on attachment have shown that the emotional quality of dyadic interaction is a decisive component in the infant's socio-cognitive development generally. For example, Legerstee, Markova and Fisher (2007) report that affect attunement (a person's being tuned into the other's affect states) promotes gaze monitoring at 3 months and coordinated attention at 5, 7, and 10 months. They found that dyadic gaze monitoring by 3 months only predicts triadic coordinated attention by 10 months when maternal affect attunement is high. Apparently, the degree of experienced metacognitive control is tantamount to the degree of intimacy and trust in the social realm because trust involves the experience of a caregiver being able to both monitor the infant's needs and appropriately control them. In this process, self and other are 'complementary; that is, as one becomes confident in the caregiver's capacity to provide regulatory assistance, one also gains confidence in one's own capacities for regulation' (Sroufe, 2005, p. 357). In line with this argument, Main (1991) suggests that differences in attachment organization during childhood are strongly linked to later quality of metacognition. Pilot studies indicated relatively advanced metacognitive monitoring in secure children but difficulties with accessing early memories and understanding the privacy of thought, as well as lack of curiosity, in insecure children.

It should be noted that too 'perfect' an interaction pattern may not be conducive to growth in self-confidence and self-regulation. Self-confidence relates to practise of the ability to cope with situations that cause negative feelings and require that the subject change her behaviour. Successful coping then brings about feelings of satisfaction that promote self-confidence. To exemplify, Jaffe, Beebe, Feldstein, Crown and Jasnow (2001) show that midrange values on coordinated interpersonal timing at 4 months predict secure attachment whereas high and low extremes predict insecure attachment.

USING OTHERS AS TOOLS FOR METACOGNITIVE PURPOSES

We have argued that when pragmatic, world-directed actions cannot reduce the agent's distance to the goal, there is a need for epistemic actions, directed at cognition. A monitoring mechanism will alert the system that its overall cognitive state is inadequate for reaching the goal. Once the deficiency is identified, the control mechanism will implement a strategy for improving performance, for instance, to re-organize available information, search for new information, or activate memory. Thus, learning how to deal with threats such as breakdown and inefficiency of communication fosters learning of metacognitive strategies.

Crucially, intersubjectivity provides the infant with the necessary motivation for this kind of active learning. Human infants seem to have a special capacity for active, social and cultural learning, which makes such learning more efficient than habituation, especially in the case of complex and strategic flexible behaviour that involves the regulation of cognition. The proximal environment invites the infant to engage in a variety of individual and joint actions in two fundamental domains: the social and the physical. The social domain is primary and remains important

DOI: 10.1002/icd

for knowledge acquisition throughout life (Vygotsky, 1978). Before children can locomote and control the physical environment directly, they learn how to control the shared environment indirectly through other people. Their knowledge of the physical world initially is socially mediated, because adults act as their extension, performing pragmatic actions to satisfy basic needs and epistemic actions to satisfy their urge for information. Generally, the efficiency of parental scaffolding in dyadic interaction is determined by the child's ability to decode information and incorporate it in its action repertoire.

Reid and Striano's studies on gaze following in social contexts illustrate some of the ways in which infants' knowledge of the world is socially mediated. Examining eye-gaze cueing and object-processing in 4-month-olds, Reid and Striano (2005, 2007) show that infants who had been watching a video presentation of an adult gazing toward one of two objects, gazed toward the un-cued object significantly more when presented with the same objects a second time. They also exhibited enhanced neural processing of the un-cued object, suggesting that it was more novel. Reid and Striano (2005) maintain that in following the adult's gaze, the infants acquired information about the object that was the focus of the adult's attention. Related studies (Reid, Hoehl and Striano, 2006), investigating the neural correlates of joint attention in 9-month-old infants, show that they allocate significantly more attentional resources to objects that are targets of joint attention as compared with objects that are not. This explains how infants may exhibit complex social responses despite limited attentional and working memory capacities. Social referencing (Campos and Steinberg, 1981) constitutes another way in which infants intentionally acquire socially mediated knowledge of the world—when the infant looks at an object and then to the adult's face, seeking emotional and vocal information from the adult to evaluate the situation, and determine how to proceed to achieve the goal. We maintain that these behaviours involve metacognition, serving to manage the infants' cognition, and constitute epistemic actions, reducing the need for internal computation.

Reid and Striano (2007) argue that infants' increased attention to socially salient aspects of the shared environment allows infants to use adults as tools for controlling their own access to information (e.g. for reducing the amount of information that is available for the infants to process). The claim is substantial, because on our interpretation, applying a strategy for accessing information relative to a goal is an example of metacognition. It means that infants use others as tools for metacognitive purposes. In line with this, we maintain that dyadic and triadic interaction provide contexts for learning how to manage individual and shared cognitive resources and use others as metacognitive tools in epistemic agency.

Social interaction exerts significant influence on infants' metacognitive performance in enabling them to use adults as tools in metacognitive operations. Indirect effects occur through the adult's attempts to satisfy the infant's urge for knowledge and assist in the learning processes. Over time, caregiver and infant create shared routines for epistemic actions to maintain their interaction and stay tuned to the proximal environment in which it is situated. Such routines initially rely on the adults' metacognitive abilities and eventually permit training and learning of metacognitive skills in the infant. Closer examination of the elements of early dyadic interaction makes it possible to identify the mechanisms that drive the interaction and explain how it may support metacognitive development.

Three features make intersubjectivity apt for initiating early metacognitive development: First, shared monitoring and control of cognition are integral to it; second, it enables learning and training of actions that realize monitoring and

DOI: 10.1002/icd

control functions; and third, feedback is immediate. Proto-conversation proceeds by the sequencing of actions as guided by the agents' feelings of effort, ease, fluency, uncertainty, familiarity, stress, confidence and appeal. Although it is open-ended and requires the coordination and timing of multimodal action, its format, domain and content are restricted, which facilitates learning.

To ensure that the infant is in the position to pick up the intended information and respond as expected, the adult takes measures to initiate, maintain, calibrate, correct and on occasion repair the interaction, and modulates it too, making it as expressive and obvious as the situation permits. This involves paying attention to behaviour and cognition of both the self and the infant and producing a flow of pragmatic, epistemic and communicative actions. By actively participating in the interaction, the infant eventually learns to discriminate the various functions of the adult's actions and can practise how to respond.

We picture reciprocal interaction as a *monitoring-and-control game* in which infants are motivated to participate by the urge for engaging with another subject. The fundamental role of monitoring and control of cognition for the proper functioning of proto-conversation, is, we claim, initiating, maintaining, and achieving turns. These functions constitute the underlying mechanism that makes early intersubjectivity a productive platform for developing and learning socio-cultural norms and metacognitive skills. In taking turns, infants begin learning how to manage cognitive states by influencing affect, motivation, and attention, with a direct impact on the interaction. Eventually, the infant becomes more skilled in taking turns and comes to share the responsibility for the interaction with the adult. The adult then will be of double epistemic use to the infant: on the one hand, as a teacher that comments on and corrects the infant's efforts, and on the other, as the infant's socio-cognitive resource in its own right during the interaction. Infants who do not yet locomote, nevertheless process social information in a highly interactive manner and use adults to probe the environment for knowledge.

The way in which this kind of reciprocal interaction facilitates infants' metacognition is rooted in emotion and attention. Besides verbal expressions and vocalization, gesture, eye gaze and bodily and facial expression of emotion are strong communicative signals. They enable joint monitoring and control of the interaction between infant and adult and make it possible for them to communicate about what they are doing. Although there are no constraints on how vocalization may be used (although it often is used to modulate more coarse-grained behaviour), visual attention and facial expression of emotion have clear-cut roles in communication (Brinck, 2008). They are the principal means for sharing experiences around the interaction as well as for regulating it.

Eye gaze expresses interest and action-readiness. As Reddy (2003, 2005) observes, visual attention has a directing (control) function in dyadic interaction, even though this is more conspicuous in triadic interaction (joint attention) that is centred on a third element. This suggests that communication in dyads may acquire an intermittent referential function. According to Reddy, there is an element of joint attention also in dyadic intersubjectivity, in the sense that the subjects can direct each others' attention to their body parts or to objects that (in contrast to typical episodes of joint attention) are not spatially removed from the subjects but rather are in physical contact with them during the interaction. Mutual attention (episodes of prolonged eye contact) to one of the subjects involved in the interaction may also count as joint attention.

Eye gaze signals goal-directedness, and facial expression of emotion displays how eye gaze is directed. Emotion and attention act together, and perceiving them in another person generates an immediate reaction in the observer in the form of a

DOI: 10.1002/icd

directed response (Hobson, 2002). This process begins early in development. Attentive scanning of internal features of the face increases in the first 2 months in life. Evidence for discrimination among different facial expressions after 2 months of age implies a growing understanding of affective expressions (Witherington, Campos and Hertenstein, 2004). Grossmann et al. (2008) measured the brain activity of 4-month-olds watching facial communication signals in dynamic scenarios. The results showed that the cortical areas implicated in adults' perception of facial expressions are functionally active also in infancy, indicating an early specialization for reading facial expression of emotion. Already by 2 months, infants respond to the appropriateness of the attention they receive (cf. Reddy 2010).

Mutual attention has several regulative functions, such as signalling and monitoring the subjects' emotion, interest, motivation, attention and attitude, and coordinating turns. In the first year, it plays a pivotal role for socio-cognitive development at large. A preference for eye contact has been observed in 2- to 5-days-old newborns, who attend to direct, but not averted gaze (Farroni, Csibra, Simion and Johnson, 2002), whereas experiments on slightly older infants indicate that eye contact in newborns may facilitate later face processing and perception of gaze direction (Farroni, Johnson and Csibra, 2004). Later in the first year, eye contact has continued positive effect on performance, such as gaze following by 4 months (D'Entremont, Hains and Muir, 1997; Farroni, Mansfield, Lai and Johnson, 2003), processing of objects at 4 months (Hoehl, Reid, Mooney and Striano, 2008) and point following by 7 months (Striano and Bertin, 2005).

There also is evidence that mutual attention leads to self-awareness. Infants react emotionally to attention to the self by 2 months, with shy or coy smiles (Reddy, 2000), and actively make others direct their attention towards themselves and initiate turn-taking games by 3–4 months (Reddy, 2005). The ability to focus and maintain attention entails selection of information and is as important for memory encoding as for acquiring more information about an object or decreasing the amount of information to process in a given situation (Brinck, 2001, 2008). Active vision, when agents actively probe the environment looking for cues that are related to their goals, is in itself a manner of exercising monitoring and control of cognition. Active vision is a skill that depends on capacities for controlling the attention and knowing what to look for and how to look, behaviour that is socially learned. Proto-conversation also supports the development of inhibitory attention, such as when the caregiver manipulates the infant's attention to cause shifts. Disengagement of attention makes it possible to search for new information, and checking others' directed attention gives information about others' interest and vigilance as well as about salient events and objects in the environment (the focus of others' attention). Consequently, through the complex mechanisms involved in mutual attention, proto-conversation can boost the acquisition of fundamental regulatory skills such as inhibitory control (the ability to suppress automatic responses to stimuli) and attentional control (the ability to focus attention to task-related stimuli). This would make it highly interesting for understanding the developmental roots of metacognition to study how infants' emotion expression and gaze interact and change over time during episodes of monitoring and control in early intersubjectivity. We believe that eye-tracking technology would be helpful in this regard.

In sum, eye gaze and facial expression of emotion are available to the infant at an early age as means for communication and regulation of interaction. An understanding of the function and respective appropriateness of visual attention and emotion develops by 2 months. By 3 months, infants can take the initiative in

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episodes of proto-conversation and eventually learn to participate in the game as equal players to the adult. Hence, we suggest that the period between 2 and 4 months is critical for the very first phase of learning how to monitor and control cognitive states.

CONCLUDING REMARKS

We have argued previously that reciprocal social interactions have an essential role to play in metacognition. The Vygotskian tradition, too, emphasizes 'the role of others in guiding the child into areas of self-controlled activity and the part played by symbolic processes in higher-level mental functions' (Lewis and Carpendale, 2009, p. 8). Many functionalists since Kopp (1982) share this view, which receives support from the research on attachment. According to this view, metacognition is held to emerge in social interaction by 2 years when infants become aware of social control. It is not properly functional until fully internalized, when the caregiver stops being an external regulator. However, there are important differences between Vygotsky's view and the one put forward here.

First, we maintain that social control can be nonconceptually accessed, experienced, and attended to and that metacognitive skills start to develop long before the age of 2 years. It is not necessary to understand how representation functions to engage in epistemic action. Moreover, we argue that metacognition for its proper functioning always is fundamentally situated within the social and cultural environment experienced by the growing child. This is obviously the case when monitoring and control first start to develop in the context of young infants' reciprocal interactions with their caregivers. However, even when the child has acquired the representational means for recreating the physical environment symbolically, by 3 years of age, metacognition will involve intersubjectively shared, external means (Sinha, 2009). Thinking is an aspect of relating to the shared world and involves affect and motivation as the result of engaging with the world and other people in concrete situations (Hobson, 2008).

The key issue here concerns the interpretation of the term 'internalization'. According to the Vygotskian approach, internalization is a process by which socially learned functions gradually become automatized and detached from the environment. The child masters a given function when he or she can exercise it independently of the environment. According to the dynamic approach, that monitoring and control are internalized means that they function properly to maintain and possibly enhance the subject's cognition. To this end, metacognition may involve artefacts and people as props that are constitutive of the interaction and drive it forward towards the goal. Consequently, that a skill is internalized does not entail that it can be exercised independently of the physical and social context or severed from the task environment. This is central to the situated and distributed approach to (meta)cognition that we favour.

According to Reddy, 'it is only by exploring minds in engagement that we can understand infant capacities' (2010, p. 367). Kirsh (2005) uses the concept of cognitive workflow for the physical and mental activity involved in keeping agent and environment appropriately coordinated to achieve the agent's goals and consider cognition and metacognition as part of a continuum. Within this framework, it becomes important to study how agents actually interact and manage the activities in which they engage. There are many ways to do so while taking a developmental approach to metacognition such as ours. In the present context and at the present stage of inquiry, we prefer to leave open which methodology would be most

DOI: 10.1002/icd

efficient for investigating early metacognitive development. In the following text, we nevertheless give a few suggestions and indicate what directions we believe would be fruitful to pursue in future research.

Metacognitive flow in episodes of dyadic and triadic intersubjectivity may be studied, for example by observing the timing of the interlocking actions that serve to monitor and control ongoing interaction, by measuring the quantity and quality of breakdowns (some negative, others indicating a mere change of direction of the interaction as a response to decrease in fluency) including attempts to repair the interaction, or by measuring the quantity and quality of eye contact, gesture, and vocalization ostensibly used to influence the interaction (and not directly to engage with the other subject).

Attention and emotion constitute important behavioural indicators of metacognition in both infants and adults. Observations of gaze-related behaviour and facial, bodily, and vocal emotion expression reveal the manner in which the infant engages with the adult—pragmatic or epistemic. Does the infant use the adult as a cognitive resource, say, looking for information or guidance for coping with the interaction, or is the engagement direct, an instance of sharing and exchanging experiences? Furthermore, we believe it would be promising to compare infants' skills for using adults as cognitive resources at different times in the first year (arguably, at 4, 6 and 9 months), such as in episodes of social referencing, and study how, for example, the development of such skills in triadic interaction contexts depends on the quantity and quality of early dyadic intersubjectivity (cf. Reid and Striano, 2007).

Finally, we suspect that longitudinal studies in the tradition of attachment research would be fruitful, enabling an investigation of how the quality and quantity of early intersubjectivity affect later metacognitive abilities in childhood and adolescence. Such studies would reveal long-term effects of early intersubjectivity on later, metarepresentational abilities for monitoring and control of cognition. For instance, we would expect that how infants learn to deal with perturbations in dyadic and triadic intersubjectivity, and what means they select for coping, influence how they later in life succeed in managing their own learning, in exploiting epistemic resources and self-regulation generally, and crucially, in tasks that require cooperation.

To summarize, understanding metacognition as partly internal, partly external and controlling the dynamic interaction of subject and environment is fruitful for envisaging new ways of thinking about and testing for implicit and perceptual metacognition in non-verbal subjects. As argued by Lewis, Carpendale, Towse and Maridaki-Kassotaki (2010), it is equally important to consider the socio-cultural context itself and the fact that any environment is shared, as what this means for experimental paradigms and testing procedures. We suggest thinking about people and artefacts as cognitive resources in making predictions about how metacognition first arises, and how infants learn skills for managing cognition.

Our approach permits conceiving of metacognitive development as parallel to cognitive development from early on, and for re-interpreting some of the achievements of infants as genuinely metacognitive. It allows the formulation of new explanatory hypotheses about cognitive development in the first 2 years, and for new ways of treating recalcitrant data, such as why episodes of mutual attention facilitate subsequent face processing and gaze following and point following. Indeed, the present framework is intended to provide a starting point for determining how metacognition can be accessed by observation of epistemic (inter)action between infant and adult within shared contexts. Building on our argument that metacognition is manifest in and partly constituted by reciprocal

DOI: 10.1002/icd

interaction, such future work will be able to shed light on exactly what roles intersubjectivity plays in the metacognitive development of the growing child.

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