Opinion

Can social interaction constitute social cognition?

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An important shift is taking place in social cognition research, away from a focus on the individual mind and toward embodied and participatory aspects of social understanding. Empirical results already imply that social cognition is not reducible to the workings of individual cognitive mechanisms. To galvanize this interactive turn, we provide an operational definition of social interaction and distinguish the different explanatory roles – contextual, enabling and constitutive – it can play in social cognition. We show that interactive processes are more than a context for social cognition: they can complement and even replace individual mechanisms. This new explanatory power of social interaction can push the field forward by expanding the possibilities of scientific explanation beyond the individual.

The interactive turn in social cognition research

Research in social cognition increasingly focuses on how people act together and understand each other in interactive situations [1–3]. The role of interaction has also been a central theme in developmental studies [4–7], and in recent discussions in philosophy of mind [6,8–11]. In spite of this trend, most investigations of social cognition still concentrate on individual mechanisms and the observational perspective (in which one subject observes others and tries to explain or predict their behaviour). They consider mainly third-person aspects of social-cognitive processes [12], although many have argued for the importance of second-person, participatory capabilities [2,4,5,7,10,11,13–15]. Inasmuch as social interaction figures in current accounts, it is typically viewed as the end goal that individual cognitive functions should achieve (e.g. through online or implicit mentalizing [16,17]), not as part of the cognitive processes themselves.

In this article, we argue that investigating interaction is central to understanding social cognition. This focus is not meant to be normative, as if interactive explanations were always preferable. Our proposal is rather that the role of interactive and individual elements in social cognition must be systematically re-evaluated. To this end, we provide a definition of social interaction and identify the possible roles that it can play in social cognitive performance. These conceptual tools will facilitate the assessment of the factors that shape social cognition and motivate novel experimental designs.

Does social cognition research not already take social interaction seriously?

We use social cognition as a general term to describe cognition involving others, for example understanding others' emotions, intentions and actions and acting

Glossary

Autonomous system: A network of co-dependent, precarious processes able to sustain itself and define an identity as a self-determined system. The same systemic relation can be found on many different levels. Examples include living cells, immune networks, sensorimotor flows of neural and bodily activity, habits, social institutions and so on.

Coordination: A non-accidental correlation in the activity of two or more systems that are coupled at present or were coupled in the past, or are or were coupled to another system in common, over and above what is expected from their normal behaviour in the absence of such couplings. A typical example of coordination between two people is synchronization of speech and bodily movements during a conversation. A situation where two people not directly influencing each other turn their attention to the same object at the same time because a strange sound is coming from it, is an example of coordination because of an external event.

Coupling: The influence between a system's variables and another system's parameters. It can be mutual, for instance a person walking a dog held by a leash.

Engagement: The qualitative aspect of a social interaction as it starts to 'take over' and acquires a momentum of its own. This can happen for example in conversations or contagious laughter. There can be coupling between agents without engagement, for instance heat exchange between people waiting at a crowded bus stop.

Individualist (or internalist) explanation: One that relies solely on individual factors, for example neural mechanisms, and for which social interaction plays no role, or at most a contextual role. Example: an interaction is judged to be 'live' by an infant, and not a playback of a previous interaction, by means of an internal 'social contingency detection' module implemented in her brain.

Interactive explanation: One that relies on social interaction playing an enabling or constitutive role. Example: an infant behaves differently in a 'live' interaction because the coupling is more dynamically stable and disposes the infant to keep interacting as opposed to a playback of a previous interaction, which is dynamically less stable and easier to disengage from.

Regulated coupling: Motivated changes that an agent makes to the constraints and parametrical conditions that influence the coupling between the agent and another system. The other system can be an agent that could itself be regulating the coupling, in which case we speak of a 'co-regulated' coupling. A simple example: moving closer to someone speaking in a low voice to hear him better.

Social cognition: General term used to describe different forms of cognition about, or actions in regard to, agents or groups of agents, their intentions, emotions, actions and so on, particularly in terms of their relation to other agents and the self.

Social interaction: Two or more autonomous agents co-regulating their coupling with the effect that their autonomy is not destroyed and their relational dynamics acquire an autonomy of their own. Examples: conversations, collaborative work, arguments, collective action, dancing and so on.

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towards and with them in social settings. Social cognition is more than figuring out the other. It involves understanding others but also understanding with others [11,15]. 'Understanding' in this context does not require a capability for verbalising reasons for actions, but rather a pragmatic ability to act appropriately in a particular situation. Following embodied approaches [18,19], we take social cognition to involve the know-how that allows us to sustain interactions, form relations, understand each other, and act together.

The current understanding of the role of social interaction in social cognition is limited. Most empirical research in psychology and neuroscience focuses on individual mechanisms in the absence of interaction (e.g. functional imaging research typically examines passive differential understanding of social stimuli [20] – but see Box 1 for exceptions). The importance of interactive processes, however, has been highlighted in the study of different forms of coordination in dynamical systems approaches [3,21] and developmental studies [4,5,22] indicating that complex coordination patterns result from the mutual regulation of a social encounter.

However, it remains unclear how to incorporate such findings. The prevailing view is that interactive patterns figure in explanations of social cognition merely as inputs to be processed by individual mechanisms (e.g. contingency detection modules tuned to pick up social contingency [23]). Thus, the study of processes of interaction remains on the margins of the supposed central question that asks how individual cognitive mechanisms work.

Another reason for not sufficiently examining the role of social interaction is the lack of a definition. It is often uncontroversially assumed to signify no more than the copresence of more than one individual. A more adequate definition is needed.

Box 1. Methods for studying social interaction

Social interactions show some form of autonomy, or 'take on a life of their own'. This makes them difficult to study under controlled conditions, but not impossible. It is crucial that experimental designs do not prevent engagement from developing [28]. Although several methods cannot guarantee this, there are some ways in which a situation of engagement can be approached.

Imaging studies tend to be restricted to noninteractive situations because of their low time resolution [20]. However, they can approach interaction through games in which participation is simulated [17,42,43] or by studying self-involvement through differential response to communicative vs. noncommunicative stimuli [44–46]. The use of virtual characters is a promising route for exploring contingent stimulation, although it does not yet amount to social interaction [47,48]. Dual EEG studies are more suitable for studying fine temporal aspects of interactive coordination and their corresponding neural support [49,50].

Naturalistic studies can adapt techniques from conversation and gesture analysis [51–54] and measure degrees of coordination between interactors to test hypotheses regarding cognitive and affective aspects of engagement. For instance, Motion Energy Analysis [55] has been applied to psychotherapy sessions to measure bodily coordination between patient and therapist, finding it to be a good predictor of subjective assessments of session quality [56]. Similar links between coordination and affect have been studied in developmental psychology [57].

Dynamical systems tools can be useful for analysing the structure of interaction patterns [2,3,21]. Degrees of coordination can be measured in different ways, and associated with the dimensionality of systems involving several interactors, which can be estimated, for instance, by Principal Component Analysis [3]. Measures of influence between bi-variate time series [58–60] could be used to study intra- and inter-individual coordination between neural, bodily and environmental variables.

Synthetic modelling techniques [61] can distil the essence of complex experimental situations into simpler models that are better suited to dynamical analysis, making it possible to generate novel hypotheses. Di Paolo *et al.*'s [30] model of Auvray *et al.*'s study has yielded predictions that were later verified [32].

The study of engagement can demand the development of second person methodologies, in which the experimenter intervenes directly as a participant in the interaction [7,14]. Such methodologies are challenging but potentially powerful, as long as they are kept rigorous by complementary third person measures.

This variety of methods indicates that it is already feasible to approach the study of social interaction. What remains to be seen is which of these methods can be used to systematically assess the roles of individual and interactive factors.

Defining social interaction; capturing engagement

Social interactions are complex phenomena involving different dimensions of verbal and nonverbal behaviour, varying contexts, numbers of participants and – frequently – technological mediation. They impose strict timing demands, involve reciprocal and joint activity, exhibit a mixture of discrete and continuous events at different timescales, and are often robust against external disruptions. Essential to interaction is that it involves engagement between agents.

The notion of engagement [7,14] is meant to capture the qualitative aspect of social interaction once it starts to 'take over' and acquires a momentum of its own. It also reflects the way this experience is described in everyday language. A definition of social interaction should capture these intuitions concerning the engagement of at least two agents in a complex co-regulated pattern. Engagement can correspond to fluctuating feelings of connectedness with the other – whose meaning sometimes seems transparent and sometimes opaque – and of increasing and decreasing possibilities for participation [11]. This experience sometimes turns into that of being taken up in the flow of the interaction (e.g. getting caught up in an argument or a flirtation). Indeed, interaction with complex, but not fully autonomous systems (such as virtual characters or some social robots) can provoke an experience of engagement. It is also true that engagement can occur without a clear experience of there being another person (see Auvray *et al.*'s experiment below). The reasons for these phenomena deserve examination, but the phenomena would remain obscured if we integrated the subjective element directly into the definition. Thus, although these subjective aspects are important, our definition needs to focus on objective aspects, because only then can the link between interactive patterns and the experience of interacting be scientifically examined instead of assumed.

Our definition must capture the notion of an encounter 'taking on a life of its own' – for this we draw on the systemic concept of autonomy. Accordingly, we define social interaction as a co-regulated coupling between at least two autonomous agents, where: (i) the co-regulation and the coupling mutually affect each other, constituting an autonomous self-sustaining organization in the domain of relational dynamics and (ii) the autonomy of the agents involved is not destroyed (although its scope can be augmented or reduced) (see [11], p. 493).

The notion of autonomy here means a self-sustaining network of processes under precarious conditions [11,19,24,25]: a self-sustaining identity. It applies here both to the agents and the relational dynamics of their coupling. Autonomy can happen on different levels (metabolic, neural, cognitive and social) and different timescales, and autonomous agents can interact at various levels.

Interactions are social as long as the autonomy of the agents is not dissolved. If one agent becomes the sole regulator of the coupling, as in the use of a tool, this is no longer social interaction. The definition excludes such cases, for example situations of strong coercion. Moreover, mere co-presence or even some forms of coupling between agents do not automatically guarantee a co-regulated, self-sustaining pattern of joint activity. The definition also excludes cases in which there is no mutuality, such as remotely observing a social scene, the mere presence of another, or the belief that another is present. Such situations are social in an obvious sense and have measurable cognitive effects [17,26], but do not involve interactions. We do not restrict social interaction to the human species. As long as the terms of the definition can be verified, they can apply to cross-species interactions or interactions with robots that are autonomous in the sense intended.

The cognitive processes involved in social interaction can be sophisticated. Even though social interaction seems to come naturally most of the time, interactive processes are not automatic and higher cognitive processes such as reflection, imagination and self-monitoring can influence them.

Factors, conditions and constitutive elements

Towards a clarification of the possible explanatory roles of social interaction, consider the collection of past and present events, processes and relations that are observed with a phenomenon X. We call this the set of circumstances, or situation, in which X occurs. X could occur in different situations, for instance different historical paths might lead to an instance of X. Given a specific situation, some elements in this set will play no role in the explanation of X, whereas others will; we call the latter contextual factors. Moreover, other elements will be necessary for the phenomenon to occur; we call them enabling conditions. And yet others will be part of the phenomenon itself; we call them constitutive elements. Accordingly, given X, and a particular situation in which X occurs:

- F is a *contextual factor* if variations in F produce variations in X,
- C is an *enabling condition* if the absence of C prevents X from occurring and
- P is a *constitutive element* if P is part of the processes that produce X.

A contextual factor is simply something that has an effect on X, and can be determined by observing how X is changed when the factor is changed. An enabling condition not only influences the phenomenon (therefore also being contextual), but is also necessary (either contemporaneously or historically) for X to occur. A constitutive element is part of the phenomenon (it must be present in the same time frame as the phenomenon). The set of all the constitutive elements is the phenomenon itself. The *presence* of these elements is necessary, and therefore also enabling.

What exact role (if any) an element plays in X depends on how one chooses to describe and observe X. This imposes a requirement of added precision on the case-by-case description of the phenomenon.

The three roles follow a scale of increased specificity. For instance, a change in air pressure can affect the process of boiling water in an electric kettle, thus making it a contextual factor. An enabling condition, in turn, is required for the phenomenon to exist, but it might not be constitutive. Boiling water in an electric kettle requires the invention of such an appliance and a supply of electricity, although these are not themselves part of the phenomenon – they are enabling conditions. In normal conditions, boiling is constituted by an appropriate heat exchange between a metal plate and the water provoking a phase transition from liquid to steam.

Using these concepts we can now examine the explanatory role assigned to social interaction in some examples.

Social interaction as contextual factor

Consider Murray and Trevarthen's double TV monitor experiment [27] in which 2-month-old infants interact with their mothers via a live television link. When presented with a recorded replay of their mother's previous actions, infants disengage and become distracted and upset. Replications of these results have eliminated explanations such as infants' fatigue [28,29].

On one explanation, the phenomenon (the difference in the infant's behaviour) results from the infant's use of a contingency detection module [23]. This module takes as input the relevant aspects of the interaction (e.g. information about the timing of one's own and the other's actions) and outputs the integrated information as knowledge about the presence or absence of social contingency. On this explanation, the cognitive mechanism is not constituted by social interaction. If contingency detection modules are considered innate, past social interactions do not play an enabling role either. As input to this module, interaction is only a contextual factor: variations in the interaction pattern change the output of the module.

It is important to clarify that even though this is an individualist explanation (because all the enabling and constitutive elements are internal; see Glossary), it is possible to imagine noninternalist explanations in which social interaction nevertheless plays only a contextual role. This would be the case if some external factor other than social interaction plays an enabling or constitutive role. For instance, a person who has recently lost his hearing and speech is able to communicate with others using a notepad and pen. This person can in this way ask someone for directions in an unknown city. The reply he obtains has an influence on his success in finding the way, but it can be construed as only providing information: the interaction here is no more than contextual. However, the notepad and pen are necessary for the successful performance of the task and therefore play at least an enabling role. In this case, the explanation is noninternalist and noninteractive. By contrast, and by definition, if interaction were to play an enabling or constitutive role (see examples below) the explanation could not be internalist.

Social interaction as enabler of social cognition

An alternative explanation of the double video results based on an evolutionary robotics model reveals an enabling role for social interaction [30]. Artificial simulated agents controlled by small dynamical neural networks moving along a one-dimensional space interact with each other by repeatedly crossing their positions. When the real-time movement of one of the agents is replaced by a recording of its previous movement, the other agent quickly retreats from the interaction (behaving analogously to the infants when shown a recording of their mothers).

During normal interaction, both agents keep each other in dynamic transient activity, which prevents them from losing contact. They oscillate back and forth and repeatedly stimulate each other's sensors. This self-sustaining coordination is robust and resistant to significant amounts of noise. However, when trying to interact with a recording, this robustness is lost and a single agent is unable to sustain the coordination pattern. Eventually it moves to one side and disengages.

There is no internal module for detecting contingencies in the agents' neural controllers. Rather, it is a property of the interaction dynamics (the difference in the stability of the coordination pattern in 2-way and 1-way coupling) that allows the agents to either sustain interaction or disengage. Without interaction the necessary processes would not function and the phenomenon would not occur, making interaction an enabling condition.

The model suggests a new hypothesis for the double video experiment: the infant's involvement is partly sustained by the stability of the live interaction and is lost without it. If it were empirically supported (for instance, by testing the infant's susceptibility to external distraction when engaged vs. disengaged from the interaction), this would indicate that social interaction plays an enabling role in the infant's behaviour. Implicit support for this hypothesis is found in a study that failed to replicate the original results because it did not allow mothers and infants to develop sufficient engagement before the introduction of the replay [28,31]. This illustrates how our definition of social interaction (that insists on the autonomy of the mutually regulated coupling) can be used to examine existing explanations and generate novel hypotheses, making the presence of engagement (and not only contingency) the appropriate independent variable.

Social performance constituted by social interaction

An experiment by Auvray, Lenay and Stewart [32] shows a constitutive role for interaction. Two blindfolded participants sitting in different rooms interact by moving a sensor along a shared virtual line using a computer mouse. Every time the sensor encounters an object on this line, the participant receives a tap on the finger (all objects are the same size and produce the same stimulation). Each participant can in this way sense three different objects

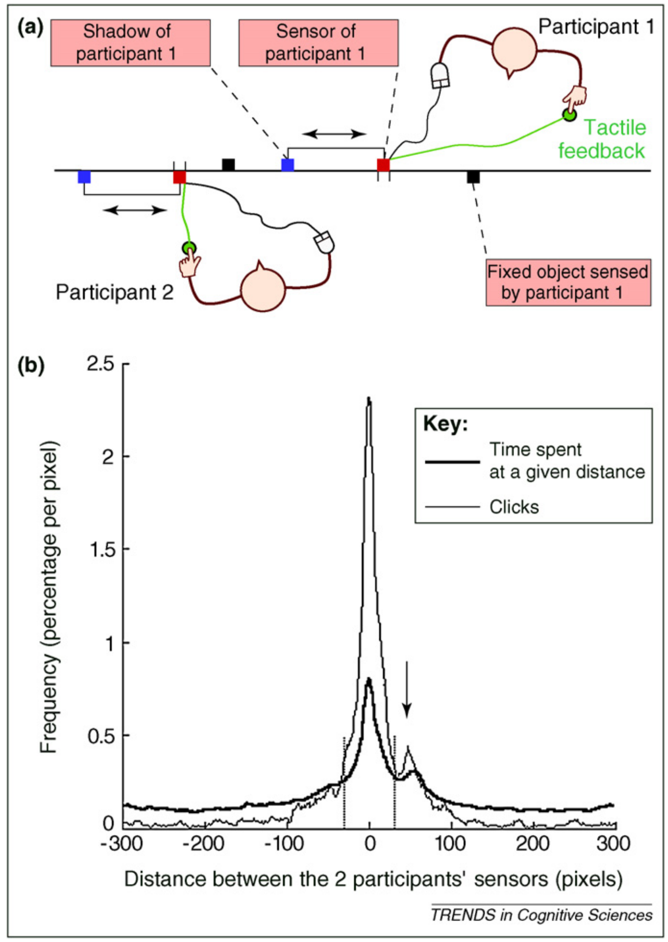

Figure 1. **(a)** Set-up for perceptual crossing experiment [32]. Both participants are isolated, each controlling the position of a sensor along a shared virtual 1-D line using a computer mouse (the ends of the line meet making it a circle). The squares on each side of the line represent the objects that can be sensed by each participant respectively. Objects are identical in size. When the sensor touches an object the participant gets a tactile feedback on the finger (green circle). Each participant can sense only three objects, a static one (black square), the sensor of the other participant (red square) and a 'shadow' object that copies exactly the movement of the other's sensor at a fixed distance (blue square). (Copyright 2010 H. De Jaegher, E. Di Paolo and S. Gallagher. Licenced under Creative Commons Attribution 3.0 Unported [http://creativecommons.org/licences/by/3.0]). **(b)** Participants are asked to signal with mouse clicks when they judge they are in contact with an object controlled by the other person. The distribution of clicks as a function of the distance between the two sensors (thin line) shows a significant peak at zero (sensor-sensor contact) as does the distribution of distances during the interaction (regardless of clicking events) between the two sensors (thick line). A small peak (arrow) at a distance of 50 pixels indicates response to the position of the shadow object. Reproduced, with permission, from Ref. [32].

(Figure 1a): a static object, the sensor of the other participant, and a 'shadow' object that copies the movements of the other's sensor at a fixed distance. Participants are unaware of this connection between sensor and shadow. They are told that there is a moving object controlled by the other participant. Their task is to click on the mouse whenever they judge that they are in contact with the other participant.

Even in such an impoverished sensory situation, participants find each other and concentrate their mouse clicks on each other's sensors (65.9% of clicks) and not on the identically moving, but non-contingent shadow objects (23%) (Figure 1b). We could postulate an individual capability for recognizing stimuli as social based on their contingency. However, this explanation is ruled out. An analysis of the clicks that follow each type of stimulation indicates that participants individually cannot tell the difference between touching the other's sensor and the other's shadow. Both events are followed by clicks with comparable probabilities. The larger number of clicks on each other's sensors is explained by the higher frequency of sensor-sensor encounters (52.2% versus 15.2% for sensor-shadow). The higher frequency of sensor-sensor encounters, in turn, is explained by the collective dynamics. Participants scan objects in a back and forth pattern. This strategy helps differentiate static from moving objects but by itself it cannot differentiate between sensors and shadows: it cannot detect contingency in the stimulus. Only when both participants scan each other's sensors – crossing their positions repeatedly – does the situation stabilize. By contrast, a situation in which one participant scans the other's shadow is an unstable disengaged 1-way coupling. The other participant will move away because she is still searching and there is no interaction.

Thus, participants consistently find each other's sensors in spite of their individual inability to tell the difference between sensors and shadows (they sometimes even report doubts about the presence of the other). Of course, individual factors enable this social performance (e.g. implementing a scanning search strategy), but they function the same whether scanning sensors or shadows. The variation in the number of clicks is attributable only to the differences in the stability of the coupling and not to individual strategies. This experiment shows that the interaction process is not only enabling but plays a constitutive role. The phenomenon is a manifestation of the properties of the interaction pattern.

Reconsidering individual mechanisms

If social interaction can play more than a contextual role, then this implies, minimally, a reassessment of individualist explanations (Figure 2). At the very least, they need to be complemented with an interactional component. Mirror neurons, for example, could function differently in interactive contexts. Evidence already indicates differential activation according to whether an interactive situation presents conflict or not [33]. Combined with evidence for their plasticity [34], this indicates that mirror neurons could develop as a result of the agent's skilful involvement in social interaction rather than being the wellspring of capacities for social understanding. Most findings on mirror neurons do not arise out of interactive situations. Their proposed functionality, such as for recognizing goal intentions in others [35], needs to be re-evaluated in interaction contexts. Their activity might even turn out to be epiphenomenal.

In another case, an interactive perspective on the development of self–other awareness can resolve apparent mysteries that are hard to elucidate from an individualist viewpoint. In infants, the gap between self-experience and awareness of others as intentional beings can be bridged by interactive elements. Reddy argues that at 2 months, before evidence of shared attention, infants already respond to being the object of another's attention in emotion-rich interactions [6]. Thus, social interaction furnishes infants with know-how about others as bearers of

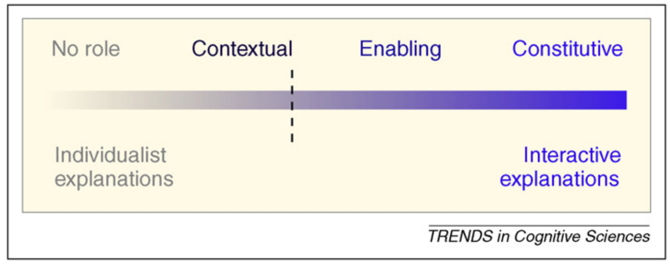

Figure 2. Possible roles played by social interaction in social cognition. The dotted line represents the point from which individual mechanisms need to be re-thought in terms of the explanatory role of the interaction process. (Copyright 2010 H. De Jaegher, E. Di Paolo and S. Gallagher. Licenced under Creative Commons Attribution 3.0 Unported [http://creativecommons.org/licences/by/3.0]).

intentions, a step towards understanding others' perspectives.

Maximally, if we take seriously the idea that interaction can enable and constitute social cognition, we can conceive of interaction dynamics as, in some cases, delivering the necessary cognitive performance. There is no need to duplicate their effects by an individual mechanism. For instance, stability of the interactive dynamics could explain infants' attention in the double video test, with no need for contingency detection modules. More strongly, in Auvray *et al.*'s [32] experiment, sensitivity to social contingency as an individual accomplishment is ruled out. Only the interaction process fully explains the result.

Conclusion: social interaction as explanatory tool

Resistance to interactive explanations may be partly due to a false impression that interaction patterns are abstract. They seem hard to pin down because they are not easily associated with material structures such as brain regions; but this is doubly misleading. Interaction dynamics do have a measurable material basis and recruit not only interacting bodies (including brains) but also elements of social technologies and cultural norms (e.g. tools and toys [36]). It is also misleading to conceptualize neural function as less abstract given that it is increasingly understood as a matter of complex relational dynamics ([37–40]). There is no reason to privilege skull-bound theories over what are essentially explanations at the same level of concreteness.

We have illustrated the explanatory roles of social interaction considered in general, without focusing on features relevant to particular cases. Sometimes fluid engagement enables a specific social cognitive task; sometimes, instead, a history of coordination breakdowns and recoveries is the essential feature. Interaction could be present, but a crucial feature such as fluency or asymmetry might be absent, thus disabling or reducing social cognitive performance.

Social cognition has noninteractive aspects (e.g. remote observations of social scenes, reflection on others' actions). But even here, social interaction is likely to play an enabling role in the processes involved, at least in a developmental sense [7].

It is imperative to investigate the ways in which interaction dynamics influence, enable, or constitute social cognition, using and expanding current methods (Box 1). Candidate phenomena can be found in studies linking

Box 2. Questions for future research

- What are the characteristics of asymmetric interactions (e.g. mother–infant, teacher–student, doctor–patient) and how does significant asymmetry influence each participant's possibilities for understanding and acting?
- What are the diagnostic and therapeutic implications of adopting an interactive perspective on pathologies such as autism, schizophrenia and Moebius syndrome?
- How do more observational forms of social understanding (e.g. understanding a film, passing false belief tests) develop? What is the role of interaction in these capacities?
- How do the autonomy of the interaction partners and of the interaction process itself relate? How do social institutions and cultural norms affect this relationship?

interpersonal coordination with social cognition [2,3,7,32,41].

Previously, if thought to have an impact at all, the role of social interaction in social cognition remained unclear. With its definition and the clarification of its different roles, unanswered problems in social cognition research (Box 2) can benefit from a new explanatory tool, putting social cognition back where it belongs: between individuals and not only in their heads.

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