interactive uses of language in dialogue are rendered possible by underlying (predictive) mechanisms common to language production and comprehension. To test accounts such as this, we propose the use of joint language tasks in a way that is analogous to testing whether co-actors form representations of each other's actions (i.e., of their own performed actions and of another's observed actions; Sebanz et al. 2006). Such tasks should of course involve two speakers "talking together"; however, we argue they need not necessarily involve fully-fledged interaction (i.e., "talking to each other").

One way of "talking together," for example, is talking at the same time. Albeit rare in natural conversations, it is theoretically interesting to investigate what happens when production and comprehension occur simultaneously. If the two share mechanisms, one would sometimes expect interference when they are engaged concurrently (Gambi & Pickering 2011). Another way of "talking together" is completing each other's utterances. Paradigms in which speakers are asked to jointly produce a sentence allow tests of the hypothesis that, given shared mechanisms between production and comprehension, coordinating with others is similar to coordinating with oneself. For example, timing in speech is affected by properties of upcoming linguistic elements (e.g., Griffin 2003). One could therefore ask whether it is also affected by the properties of an expected continuation by somebody other than the current speaker.

Although such tasks are unlike natural dialogue in many ways, they allow us to test the role of predictions about what another speaker is about to say. Thus, they can investigate questions like: How do beliefs about one's interlocutor influence anticipatory adaptation to their upcoming utterances? What is the minimum degree of interaction necessary for such beliefs to be taken into account in the first place? To what extent are beliefs modified as a result of the interaction? In addition, such tasks allow tight experimental control and therefore permit a meaningful comparison between "isolated talking" and "talking together," since in natural conversations it is much harder to disentangle the relative contribution of beliefs about one's partner from the direct influence of what they say or do during the interaction itself.

The latter point also relates to the interesting observation that there are various ways of entering a joint activity, with explicit commitments to shared goals and seamlessly automatic entrainment playing different roles at different times (Tollefsen & Dale 2012). Interestingly, the gaze coordination task proposed by Schilbach et al. could be used both in the investigation of how low-level entrainment influences the perception of being in a joint activity and in the study of how higher-level beliefs influence interactional dynamics (sect. 3.2.1). Similarly, with the joint sentence production task mentioned above, it would be possible to investigate how the degree of achieved coordination influences beliefs and feelings towards one's interlocutor, as well as the extent to which previous knowledge about one's interlocutor and their utterances affects the amount of coordination attained.

Finally, communication is best seen as existing on a continuum from monologue at one end to truly interactive dialogue at the other. In a casual conversation between intimates, the "flow" from one speaker to the other is likely to be seamless and the conversation is internally managed (i.e., the participants control the nature of the interaction). In a more formal situation such as an interview, a large-group discussion, or an audience attending to a story, the opportunities to interact are limited and are constrained by social rules.

Linguistic communication, therefore, represents an ideal case for the study of what it means to interact, because it allows researchers to compare behavior or neural activity in settings involving different degrees of interactivity. The study of communication is therefore likely to be very fruitful in the development of a second-person perspective in the cognitive sciences and neurosciences.

Brain games: Toward a neuroecology of social behavior

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Abstract: In the target article, Schilbach et al. defend a "second-person neuroscience" perspective that focuses on the neural basis of social cognition during live, ongoing interactions between individuals. We argue that a second-person neuroscience would benefit from formal approaches borrowed from economics and behavioral ecology and that it should be extended to social interactions in nonhuman animals.

The "second-person neuroscience" proposed by Schilbach et al. in the target article proffers the intriguing idea that social cognition during real-time interactions with another individual may be fundamentally different from passive observations of another's actions. Understanding the contribution of neural processes to ongoing interactions with complex beings is a fascinating research direction, with potential implications for the treatment of disorders attended by social deficits, as well as for ethics and public policy.

Several decades of neuroscientific research have sketched out the neural circuits that may translate perceptual information about other individuals into purposeful action. Specifically, regions of the human and nonhuman primate brain including the superior temporal sulcus and fusiform face area contribute to social identification (Tsao et al. 2008). The ventromedial prefrontal cortex, orbitofrontal cortex, and striatum appear to play a role in translating knowledge of others into motivational signals (Azzi et al. 2012; Burke et al. 2010; Cooper et al. 2010). The anterior cingulate cortex and fronto-insular cortex contribute to empathy and other-regarding cognition (Chang et al. 2013; Decety 2010; Gu et al. 2010). The so-called mentalizing and mirroring networks appear to participate in action and intention understanding (Becchio et al. 2012; Rizzolatti & Sinigaglia 2010). Circuits connecting these areas could translate social perceptual information into appropriate actions via decision-making mechanisms (Baumgartner et al. 2009, 2011; Knoch et al. 2009).

To better understand the neural mechanisms underlying social cognition, we propose that social neuroscience needs to ground its predictions and hypotheses in a formal framework such as that provided by behavioral game theory (Dorris & Glimcher 2004; Gintis 2009; Kosfeld et al. 2005; Lee 2008; Platt & Glimcher 1999; Tomlin et al. 2006). Schilbach et al. criticize game theoretical approaches for not recreating the dynamics of everyday real-life social encounters, but this common opposition has been rebutted before (Gintis 2009). Game theoretical frameworks are general and open, allowing formal delineation of specific hypotheses while not imposing restrictions on the behaviors that are being described. Formal approaches borrowed from economics, game theory, and behavioral ecology have been extremely useful in describing decisions in dynamic foraging or social environments (Chang et al. 2011; Hayden et al. 2011; Lee 2008; Sugrue et al. 2004).

These approaches can be extended to describe the dynamics of interacting individuals, with several advantages. First, they allow us to generate empirically testable and mathematically formalizable predictions about the neural mechanisms that could underlie decisions in complex social environments. Second, they allow for comparative analyses of decision processes in humans and other animals with respect to the demands placed on them in specific physical and social environments (Heilbronner et al. 2008; Kacelnik & Bateson 1996; Stephens et al. 2002).

Schilbach et al. also raise the concern that classical game theory paradigms involve mainly one-shot interactions or turn-taking. Although this structure is often used for simplicity, we contend that continuous interactions in interactive games can also be effectively described using a similar theoretical framework (Braun et al. 2009; Debreu 1952). Such mathematical tools would help translate some of the intuitive aspects of Schilbach et al.'s approach into concrete experimental predictions.

Second-person neuroscience would also benefit from broadening its inquiry to the interactions of nonhuman animals (Chang et al. 2011; Fujii et al. 2007; Washburn et al. 1990). Social complexity appears to have favored the evolution of higher social cognition in animals that have brains similar to ours, like macaques (Azzi et al. 2012; Barsalou, 2005; Chang et al. 2012; Rudebeck et al. 2006; Tsao et al. 2008) and in animals that have very different brains as well, like scrub jays and rooks (Bird & Emery 2010; Emery & Clayton 2001). We know from research in macaques, sheep, and mice that social cognition in mammals appears to rely on neural circuits that are similar, and perhaps homologous, to those in humans (Azzi et al. 2012; Barsalou, 2005; Jeon et al. 2010; Rudebeck et al. 2006; Sanchez-Andrade & Kendrick 2009; Tsao et al. 2008). One possible explanation is that we inherited those circuits from a common ancestor that possessed some level of social complexity. Alternatively, similar constraints applying to neural circuits could also have caused them to evolve in similar ways to support similar functions. How such functions are accomplished by neural circuits in animals with brains that are very different from our own – such as birds – remains an open question.

We agree with Schilbach et al. that studying the neural processes mediating live interaction between real agents is crucial for the maturation of social neuroscience as a discipline. What we propose is to supplement this approach with formal game theory and value-based analysis of preferences in humans and nonhuman animals. In our lab, for example, we study pairs of monkeys interacting both in economical and interactive games (Chang et al. 2011; Chang et al. 2013). Estimating preferences allows us to quantify how much monkeys value certain options (e.g., giving juice to another monkey). Game theory will allow us to generate predictions of the equilibriums that could develop over time between two interacting individuals (see Braun et al. 2009). Understanding the neural processes that underlie social cognition in such animals could powerfully inform our understanding of the evolutionary origins of our own social abilities.

Second person neuroscience needs theories as well as methods

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Abstract: Advancing second-person neuroscience will need strong theories, as well as the new methods detailed by Schilbach et al. I assess

computational theories, enactive theories, and cognitive/information processing theories, and argue that information processing approaches have an important role to play in second-person neuroscience. They provide the closest link to brain imaging and can give important insights into social behaviour.

Schillbach et al. make a strong case that studying human social behaviour requires more than our traditional "isolation paradigms." They detail a number of methods which will allow the neuroscientists of the future to study social interaction in a more meaningful way. They also suggest that new theoretical approaches are needed, going beyond traditional cognitive theories. However, they dedicate much less space to specifying what these new theories should be. In this commentary, I would like to reiterate the need for strong theories to drive forward the field of second-person neuroscience. Such theories must be clearly specified so that other researchers can test them, and must be falsifiable because theories that accept all data do not make strong predictions.

Here I consider three possible categories of theories drawn from different research traditions: computational models, dynamical systems, and cognitive models. I suggest that cognitive/information-processing models remain the most promising, but that all three approaches may be able to converge.

First, advances in the non-social domains of reinforcement learning and motor control have led to computational models of social interaction. Such models often use tasks or games derived from game-theory in which people interact within a set of rules. Impressive localisation of specific computational parameters in the brain has been possible with these models (Behrens et al. 2009; Hampton et al. 2008; Tomlin et al. 2006). Other related approaches include adapting motor control models to control not just physical objects (e.g., a tennis racket), but also social objects (e.g., another person) (Wolpert et al. 2003). These computational approaches are very powerful in the cases where the model can be specified. However, a current limitation is that these models are only applied to abstract, rule-bound contexts (e.g., iterated trust games). Such tasks are somewhat artificial and lack many of the behavioural cues (eye gaze, emotion, etc.) of real social interactions.

Second, research derived from ecological psychology and dynamical systems has led to an enactive approach to social neuroscience (Thompson 2007). This approach rejects traditional cognitive models, together with ideas of symbolic information processing and representation. Instead, it relies on dynamical systems (Port & van Gelder 1995; Thelen & Smith 1996). A key idea is that social cognition exists in the interactions between agents rather than in the information processing within the head of a single agent (De Jaegher et al. 2010). The target article endorses these approaches, and they seem particularly useful in thinking about infant development. However, there seems to be some tension between the claims of the strong enactivist models, and the neuroimaging method, which remains routed in studying activation within one brain at a time. This is clear in Figure 1 of the target article, which assumes localised information processing systems within each brain as the originators of the dynamic social interaction.

These diagrams of brain systems seem more compatible with a third approach, that of embodied information processing models. This type of model emphasises the overlap of motor, proprioceptive, linguistic and affective information processing streams (Prinz 2005). It thus rejects the strict modularisation of Fodor but retains the cognitive idea that the brain is an information processing device and that we can localise specific types of processing to specific areas of cortex. Such information processing models have in the past been used to describe performance on "spectatorial" tasks and in contexts without dynamics. However, this does not mean that they should always be used in this way.

An example of a more socially engaged information processing model is the STORM (social top-down response modulation) model (Wang & Hamilton 2012). This is based on the idea the