Mirror neurons are central for a second-person neuroscience: Insights from developmental studies

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Abstract: Based on mirror neurons' properties, viewers are emotionally engaged when observing others – even when not actively interacting; therefore, characterizing non-participatory action-viewing as isolated may be misleading. Instead, we propose a continuum of socio-emotional engagement. We also highlight recent developmental work that uses a second-person perspective, investigating behavioral, physiological, and neural activity during caregiver–infant interactions.

We comment on two points: one conceptual, relating to the implications of the discovery of mirror neurons, and the second methodological, relating to the application of a second-person perspective in developmental psychology. Schilbach et al. wish to distinguish two types of social interactions – active participation among individuals (e.g., face-to-face), and passive social viewing (e.g., watching a movie of someone) – claiming there may be key differences in the neurophysiology underlying these different types of interactions. However, we think this is in part a false dichotomy; rather, there is a continuum of social-emotional engagement, influenced by a variety of factors. The level of (current or future) active interaction is one such factor, but others include the relationship between individuals, the perceiver's goals, and the types of actions viewed (e.g., Breithaupt 2012). We are in agreement with Rizzolatti and colleagues that mirror neurons allow viewers to go beyond cold, detached, third-person, mere spectator perspectives, even if viewers make no active interaction attempts (Rizzolatti & Sinigaglia 2010; Sinigaglia 2010). Therefore, the characterization of non-participatory action viewing as isolated (an "isolation paradigm") may be misleading.

Instead, viewers can be emotionally engaged by simply viewing others. Anyone who has felt the emotional pain of a favorite actor or actress while watching a movie can testify to this. The importance of phenomenology in theorizing – that viewers are not pure spectators, but that social perception involves emotional engagement – has been arguably the greatest implication of the discovery of mirror neurons. Several scholars, including Husserl, who is considered the father of phenomenology, and Merleau-Ponty, previously reasoned and theorized that our perception of the world activates sensorimotor programs and thus allows our bodies to have first-person knowledge about the object of our perception. Work on the mirror neurons system for facial expressions (Ferrari et al. 2003) and emotions – by Iacoboni, Aglioti, Wickler, Singer, and others from our group in Parma – demonstrate that when we see emotions, there is a brain mirroring in the traditional mirror areas (premotor-parietal), as well as in deep areas of the brain involved in first-person perception of emotion, such as the cingulate cortex and the anterior insula. In other words, it is *as if* viewers experience the same emotion as that displayed by the other. The simulation account (Gallese & Goldman 1998) is tightly linked to the empirical work on mirror neurons, and the simulation account is indeed an empirical bridge between the mirror neuron work and the phenomenological grounding previously mentioned. Moreover, nearly all work on single cell recordings of mirror neurons involves second-person interactions; thus, the simulation paradigm and the mirror neuron discovery are of utmost importance for theorizing about a neuroscience of social interaction.

We agree with the authors that there is a need to look more at interactions involving brain networks for coordinating actions and second-person engagements. The dynamics occurring during a social interaction have different requirements when the observer is passively viewing a scene, compared to actively engaging with another individual. For example, in an active engagement there is concurrent activation of executive function networks, which plan and coordinate online movements with the interacting agent, during potential intersubjective exchanges.

Developmental psychological studies have utilized this second-person perspective, and in doing so have been useful in describing the complexity of social interaction from early in the postnatal period. In particular, emotional responses between caregivers and infants are of utmost importance in tracking the developmental emergence of social understanding. Early interactions between caregivers and infants are formative in a number of ways, giving infants opportunities for learning and also strengthening bonds between infants and caregivers. Studying caregiver–infant interactions is particularly important, as those early interactions can have lasting impacts on later social and emotional development. Interactions with real social partners – not simply avatars – can provide more ecologically valid measures of social engagement and perception. Moreover, caregiver–infant interactions can be used as a guide for the creation of ecologically valid adult studies (e.g., Dumas 2011).

A number of developmental studies (not mentioned by Schilbach et al.) have successfully utilized a second-person perspective, investigating behavioral, physiological, and neural synchrony during caregiver–infant interactions, which may serve as models for second-person developmental research. For example, in work with humans, Feldman and colleagues found heart rate synchrony between mothers and infants during face-to-face interactions (Feldman et al. 2011), Messinger and colleagues discovered stable individual differences in infants' attention to mothers' faces, controlling for maternal behaviors, such as smiling (Messinger et al. 2012), and Musser and colleagues found neural correlates of maternal sensitivity during face-to-face interactions (Musser et al. 2012). Recent work in our lab examined newborn infant monkeys' live face-to-face interactions with human caregivers. Electroencephalogram (EEG) recordings revealed a 5–6 Hz activity suppression when the infants produced facial gestures and when infants observed facial gestures, but not when they observed non-biological stimuli (Ferrari et al. 2012). This EEG suppression, named mu-rhythm, is considered a signature of the mirror neuron system. This finding suggests that the basic elements of the mirror neuron system are operational in the first week of life and might be central for early face-to-face interactions.

Toward a neuroscience of interactive parent–infant dyad empathy

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Abstract: In accord with social neuroscience's progression to include interactive experimental paradigms, parents' brains have been activated by emotionally charged infant stimuli – especially of their own infant – including baby cry and picture. More recent research includes the use of brief video clips and opportunities for maternal response. Among brain systems important to parenting are those involved in empathy.

This research may inform recent studies of decreased societal empathy, offer mechanisms and solutions.

Within the field of social neuroscience, investigators are now studying the brain basis of human parenting, using paradigms in accord with the ideas of Schilbach et al. in the target article. Recent neuroimaging studies, in which mothers respond to infant stimuli, have demonstrated the functional significance of many parental care-giving-related brain regions – building on rodent neuroscience. In summary, a broad array of brain regions activate to baby-cries (Swain, Mayes, & Leckman 2004) and pictures (Swain & Ho 2010) and according to measures of parent–infant interaction, thoughts, and behaviors – highlighted by parts of the amygdala (alarm), striatum/nucleus accumbens (NA; motivation and reward). In humans, cortical response circuits are added, including the anterior cingulate for decision-making, inferior frontal gyrus for theory of mind, as well as orbitofrontal cortex, insula, periaqueductal grey, and dorsomedial prefrontal cortex that regulate complex social-cognitive functions currently under study. (For reviews, see Barrett & Fleming 2011; Mayes et al. 2005, Swain 2011a; 2011b; Swain et al. 2011.)

One of the key conceptualizations in the neuroscience of parenting has been that of empathy, which has been a central topic in social neuroscience highlighting the insula (Decety & Jackson 2004, Lamm et al. 2007). Among parents, the insula was activated while reacting to own baby cry (Kim et al. 2010) and more among breast-feeding versus formula-feeding mothers (Kim et al. 2011). Furthermore, observing and actually imitating faces of their own child activated in the insula and other cortical motor imitation and mirror neuron systems (Lenzi et al. 2009), which correlated positively with levels of maternal empathy assessed with independent validated interviews. Support for the insula being part of a general system of empathy includes responses of non-parents to baby-pictures (Schechter et al. 2012) – which also involves premotor cortex activation in preparation for appropriate behavioral responses (Caria et al. 2012).

Direct studies of reciprocal baby brain function in response to their parents are yet to be done; however, a recent neuroimaging study of mothers showed how perceived maternal care (a proxy for animal models' licking and grooming behaviors) affects both brain structures and functional response to own-baby cries in adult mothers (Kim et al. 2010). In this study, mothers who reported higher maternal care in their own childhood showed higher gray matter density, proportional to the number of neurons, in a range of higher cortical areas and executive function areas, including the insula, superior and middle frontal gyri, orbital gyrus, superior temporal gyrus, and fusiform gyrus. There were also increased functional responses in a number of frontal brain regions and the insula in response to own-baby cries. This may reflect long-term effects in humans of early-life mother–child interactions affecting adult maternal mother–infant interactions.

Three recent studies of maternal interactions with brief video clips come closest to second-person neuroscience. (Atzil, Hendler, & Feldman 2011, Atzil, Hendler, Zagoory-Sharon, Winetraub, & Feldman 2012, Schechter et al. 2012). In Atzil et al. (2011; 2012), mothers were scanned while observing several own and standard infant-related vignettes. Beyond basic motivation/reward nucleus accumbens (NA) responses, functional NA and amygdala were functionally correlated with emotion modulation, theory-of-mind, and empathy networks including the insula. In studies by Schechter et al. (2012) mothers with post-traumatic stress disorder (PTSD) and controls, epochs of play and separation from their own and unfamiliar children were processed by regions including the insula. Extensions of this work might be to ask mothers to respond to the visual stimuli as if they were actually there with a push-button device to attempt parenting responses. Other experimental approaches on the horizon include direct electroencephalography (EEG) or functional near-infrared spectroscopy (fNIRS) studies of simultaneous interacting mother–infant dyads.

The neuroscience of maternal–infant dyadic interaction and empathy leads to a concern regarding apparent societal declines in other-orientation in the United States. For example, Americans are less likely than ever to participate in many types of social experiences, from sharing dinner to attending religious services (Putnam 1995; 2000). Moreover, dispositional empathy has declined among American college students from the 1980s onward (Konrath et al. 2011), suggesting that young people today find it difficult to experience others' emotional worlds (O'Brien et al. 2013). Finally, there has been a recent change in attachment style. Today's college students increasingly report having a predominantly avoidant attachment style (Chopik et al. 2011; Konrath et al., under review), which is characterized by having positive views of the self but negative views of others (Bartholomew & Horowitz 1991). It has been suggested that these trends may be related to modern electronic "social" interactions, many of which are at the level of mere observation (e.g., email, social networking sites) instead of dynamic interaction (discussed in the target article), and many of them are also lower in emotional engagement. Even tools that are more socially interactive (like Skype) do not currently allow eye contact. In fact, the "virtual" characters described in the target article have more properties of actual social interaction (i.e., eye contact, real-time responsiveness) than many social interactions commonly experienced today.

These considerations beg many broad social policy questions regarding the effects of different media environments on mother–child interactions. Parents may be continually distracted by their social media from caring for their infant – effectively simulating a still-face paradigm to their own infant (Tronick et al. 1978), which encourages infants to first try harder to engage their parent, and then to withdraw and become distressed (Mesman et al. 2009). Could some of the social changes described above be partially explained by an increase in still-face-like parent–infant interactions? Moreover, it is not just parents who are increasing their screen time in recent years. Children are now watching more television than ever and it is now common for toddlers to be proficient iPhone users (Konrath 2013). Does this affect the development of fundamental social cognitive capacities?

We recommend that future research take into account parental and child media use when examining neural signatures of attachment and bonding. Excessive media use may be a relatively unexplored risk factor, or a marker, for poor parent–infant attachment, with concerning implications for social-cognitive development. Second-person neuroscience used to optimize dyadic interventions may offer a solution (Swain et al. 2012).

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It takes two to talk: A second-person neuroscience approach to language learning

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Abstract: Language is a social act. We have previously argued that language remains embedded in sociality because the motivation to communicate exists only within a social context. Schilbach et al.

underscore the importance of studying linguistic behavior from within the motivated, socially interactive frame in which it is learnt and used, as well as provide testable hypotheses for a participatory, second-person neuroscience approach to language learning.

Language is a strikingly social behavior. While it is possible to have social behavior that is not linguistic, the converse is not true. Language is learned, perceived, and produced within the fabric of social interaction. Using developmental and comparative literature, we have previously contended that the presence of structural and functional linkages between subcortical motivation systems, and conventional language and social circuits in the brain, are critical determinants of the evolution and development of language in a given species (Syal & Finlay 2011). A research program that aims to study language-learning needs to attend to language as embedded in its ecological context, acquired in the early development of an obligatorily social, gregarious, and often-altruistic species, where the motivation to learn to communicate with conspecifics drives both its ontogeny and phylogeny. To that end, researchers have thus far focused on the role of socially derived motivation in language learning through studying infant-caregiver interactions in the development of vocal communication (Goldstein & Schwade 2008; Kuhl 2007b). However, this corpus of knowledge has been constrained by the inability to study brain-behavior linkages through the acquisition of functional neuroimaging data that model ecologically valid social interactions. The novel methodologies discussed by Schilbach et al. in the target article use eye-tracking in conjunction with functional magnetic resonance imaging (fMRI) to create interactive paradigms that allow human participants to experience the effects of their gaze on that of a social counterpart, simulating a naturalistic social interaction, while allowing researchers to gather MRI data that elucidates underlying neural networks. This approach provides an immensely pliable platform on which social motivation in vocal learning can now be placed and probed, in both adult and infant language learners. For instance, the role of joint attention in guiding the learning of artificial object-labels in (a) adults, using both eye-tracking and fMRI, or (b) infants, using interactive eye-tracking setups, are immediate examples of experimental questions that can be addressed using these paradigms.

From early life, human children attend to social cues, share information, join games, and generally cooperate, serving a form of social learning limited largely to humans (Moll & Tomasello 2007). These prosocial tendencies also sustain vocal learning behavior during development, wherein numerous structural aids to language learning are presented to the infant in a characteristically social environment replete with positive feedback. For example, mothers reliably use predictable prosodic contours to modulate infant affect and attention (Fernald 1992; Fernald & Simon 1984). They engage in contingent turn-taking vocal interactions with their infants that facilitate vocal development (Goldstein & Schwade 2008). They use variation sets – sentences with partially overlapping syntactical structure – to aid word learning (Onnis et al. 2008). Recent work has shown how learning of the structural regularities of language can emerge from the richness of social interactivity embedded in the human ecological niche. Specific forms of contingently delivered vocal reinforcement from a social counterpart cause infants to change correspondingly specific features of their own vocalizations towards developmental advancement (Goldstein & Schwade 2008). Contingency of social interaction remains a core requirement in these learning processes – infants do not display vocal learning when the same amount of stimulation is provided in a non-contingent social interaction (Goldstein & Schwade 2008; Goldstein et al. 2003; Goldstein et al. 2010a), or through audio-visual media (Kuhl et al. 2003). Indeed, the extent of learning is in fact determined by the amount of social engagement – greater shared visual attention between infants and interactive social agents facilitates greater language learning (Conboy et al. 2008).

An idea essential to this approach is that social contingency in dyadic or triadic interactions is inherently rewarding, and promotes learning through the recruitment of motivational neurocircuitry, and the facilitation of shared attention. In support of this, initial data using the experimental paradigm outlined in the target article suggest a role for reward-related circuitry in initiating joint attention on both neural and behavioral levels (Schilbach et al. 2010b). Numerous studies have highlighted the role of contingency in specific forms of reward-based learning. In adults, the caudate nucleus within the dorsal striatum is sensitive to reinforcement of action and shows a robust response when subjects perceive a contingency between their actions and task-outcomes (Tricomi et al. 2004). The caudate is also involved in encoding stimulus salience (Zink et al. 2006) and, in language learning, reward-related caudate activation in response to contingent feedback facilitates the learning of non-native phonetic contrasts in adults (Tricomi et al. 2006). This social hypothesis of language learning suggests that reward-based instrumental learning and positive affect systems may be critical to language development, not only in terms of acquisition, but also in the flexible integration of newly learned information within the existing lexicon. Positive affect embedded in social interaction could facilitate language-learning through salience-tagging information and/or shifting focus towards a broader information encoding context. Data from adults indicates that positive affect can lead to fundamental shifts in information processing through the facilitation of flexible modes of cognition (Isen 2002), which increase the breadth of attentional allocation in both perceptual and conceptual domains (Rowe et al. 2007; Schmitz et al. 2009). Additionally, as a social act, language learning and use involves not only the ability to make narrow associations between words and their referents, but also the broader capacity of reading another's mental states, possibly invoking a network of shared activation between minds. The affiliative role of positive emotions is likely critical to this interpersonal network resonance.

Past work on language learning has accorded limited significance to emergent properties of social interactions. The second-person approach to neuroscience posits social interaction and emotional engagement with social counterparts as fundamental features of social living that enable us to understand and learn from the minds of others, highlighting the importance of studying real-time interaction dynamics between individuals in an ecologically valid manner. Within the ecological framework of vocal learning, the parent-infant dyad constitutes a socially distributed system of learning, best viewed as a consolidated network that incorporates the learner, the social interactor, the interaction between the two, and the effect of each actor on its own and the other's nervous system.

Second-person social neuroscience: Connections to past and future theories, methods, and findings

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Abstract: We argue that Schilbach et al. have neglected an important part of the social neuroscience literature involving participants in social interactions. We also clarify some part of the models the authors discussed superficially. We finally propose that social neuroscience