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Comment

The role of social learning and socio-cognitive skills in sensorimotor communication
Comment on "The body talks: Sensorimotor communication and its brain and kinematic signatures" by Pezzulo et al.

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In their review, Pezzulo and colleagues [1] give a comprehensive account of different forms of sensorimotor communication (SMC). We appreciate the authors' approach of interpreting SMC in light of semiotics and communication theory, which allows classifying different forms of SMC where intentional signaling (i.e., the attempt to disambiguate one's action from alternatives) is presented as the most sophisticated.

In our comment, we will discuss the underlying cognitive substrate and the function of signaling in social interactions. We argue that signaling can be understood only within a second-person perspective [2], i.e., analyzing how the interacting unit develops communication strategies to achieve joint goals, both long and short term. Indeed, although we agree with the authors' claim that (a conventional) prior knowledge or arrangement is not strictly necessary for SMC, we suggest that signaling behaviors evolve and refine thanks to cumulative ***social motor learning*** (Point 1). To successfully interact with others, we need to learn what signals are more easily read by most of the interactive partners (e.g., when negotiating in which direction to walk through a corridor to avoid accidents), and also what signals are better for *that specific* interaction partner (e.g., when performing a choreography with my dance mate). Moreover, we believe that a theory of SMC would benefit from the integration of a neurocognitive perspective, offering an overview of what ***cognitive abilities*** scaffold the adaptation of signaling to different social scenarios (Point 2). Finally, we suggest considering that ***social motor representations*** characterize collaborative joint actions and might thus support the emergence of signaling and shape its implementation (Point 3).

1. Learning to signal to support short and long term (joint) goals

One fundamental aspect of signaling is that it is based on a cost-benefit utility computation, in which the costs for the sender (who needs to deviate from optimal action execution) and the benefits for the receiver or the dyad (in terms of joint goal achievement) can be computed and weighted against each other over the course of the interaction. Agents

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can use this utility computation to modulate their behavior at a given trial and to predict the behavior of the partner, who is expected to flexibly tune the *amount* of signaling to the needs of the dyad to optimally achieve the joint goal [3].

Interestingly, this computation may change dramatically as the agents shift from representing a short-term joint goal (i.e., the success of the next trial, or at the game), to representing a **long-term joint goal** (i.e., establishing a common ground for future interactions). The establishment of common ground between two interactive agents, on the one hand, may reduce the *amount* of signaling implemented [4]. On the other hand, it may determine a different *type* of interactive signals to be selected as efficient, e.g., deviations that require low-cost implementations, which convey both the relevant content and the commitment of the sender [5]. As we are immersed in social interactions since birth, it is plausible that adults implement behavioral strategies of signaling that, despite developed ad hoc for the given scenario, draw from a *life-long learned repertoire of social scripts*. By resorting to this repertoire, agents may select and produce types of signals that, because over-learned, are less costly for the sender, and possibly easier to recognize for the receiver.

Therefore, signaling might support coordination in more than one way: it may support the achievement of short-term joint goals, as a result of a strictly contingent utility calculation. But it may also support long-term joint goals, determining a change in costs-benefits computation, going beyond the given implementation within the experimental task. For instance, expert musicians, when playing with others, implement behavioral adaptations that are recognizable for their partners, but nor are necessary for the performance, nor decrease as their expertise increases [6,7]. Furthermore, different groups of musicians display different behavioral patterns of SMC among players [8], suggesting that suboptimal movements can become part of actual social scripts among interactive agents who share a common ground (a history of interaction).

We, therefore, suggest that individuals' social and motor experience (either contingent or not to the given interaction) largely contributes to the computation of the costs of selection, implementation, and understanding of communicative signals.

2. SMC and individual differences: the case of Autism Spectrum Conditions

Pezzulo et al. [1] discuss how factors such as temporal, informational and goal demands afford SMC. This perspective highlights how different task structures and ecological factors shape the selection and implementation of communicative strategies by interactive agents. However, in interactive scenarios that require individuals to understand, predict, and complement a partner's actions, other variables are crucial for the recruitment of efficient SMC, namely individual cognitive capabilities. In fact, SMC is grounded on a large set of cognitive and motor skills, the lack of which may hamper individuals' ability and motivation to engage in coordination by selecting appropriate communication strategies. Research shows that individuals rapidly and effortlessly compute the perspective of a partner in joint action contexts, suggesting that one function of visuospatial perspective taking might be to support predictive processes and ultimately interpersonal coordination [9–11]. The implementation of adequate coordination smoothers in joint tasks, such as signaling, could be predicted by individuals' ability to represent the partner's mental states, goals, and perspective. In a recent study, Curioni et al. investigated whether the degree of individuals' autistic traits impacts their ability to coordinate in a joint action [12]. Because deficits in social communication, social interaction, perspective taking and mentalizing characterize Autism Spectrum Conditions [13], individual differences along the continuum from neurotypical development to Autism should predict individuals' ability to recruit and modulate SMC. Indeed, the results of this study show that high autistic traits predict a reduced modulation of motor behavior according to the role that individuals had in the task. These results indicate that individuals' differences in social, motor and cognitive skills predict their ability to select the communicative behavior that is most adaptive in a given social interaction. In line with suggestions [14] that the core cognitive processes of our social cognition (such as mentalizing, taking someone's perspective and predicting an agent's intention) develop within and thanks to successful motor interactions with others, we believe it is critical to consider how these processes influence the agents' ability to implement SMC and adapt it to different interactive circumstances.

3. SMC and "joint" motor representations

We have suggested that signaling may emerge to support interpersonal coordination in the long and short term as a result of social and motor learning experiences (Point 1), and that it is grounded on individuals' cognitive skills such as the ability to take the partner's perspective and understand how to modulate one's behavior to facilitate coordination (Point 2). One might thus ask how signaling can be implemented seemingly without effort or awareness when partners interact in a motor exchange.

During a joint action, the presence of a shared goal that drives and bias co-agents behaviors shapes motor planning processes [15,16] to such an extent that it can even facilitate performance in patients with impairment of motor control [17]. Shared goals allow co-agents to infer the partner's contribution, thus supporting predictions on his/her future behavior. These predictions are strictly motor in nature [18–20] and become an integral part of the agent's motor plan (that becomes "dyadic" as it specifies both one's own and the partner's contribution, [21]). Such dyadic motor plans might thus support agents' understanding of what they have to do to facilitate the partner's task during the interaction, e.g., applying signaling behaviors, and the ability to read signaling behaviors in the partner. Future research might investigate whether the presence of shared goals that specify dyadic motor plans modulates the emergence of signaling, and what "interactive" features support or prevent it. Because social and emotional variables have been shown to modulate sensorimotor simulation during a motor interaction [22,23], they might also influence the emergence of signaling. Research on this issue may shed light on the "social" nature of such a behavioral strategy.

To conclude, we argue that a neurocognitive theory of SMC and signaling would benefit from taking into account that signaling is supported by social motor representations characterizing collaborative joint actions; it serves the function of supporting interpersonal coordination in the short and long term and might be deeply influenced by contingent and life-long social learning. It remains to be further specified how the individuals' cognitive abilities, social motor experience, and the social and emotional features of each specific interaction contribute to its development and modulate its implementation.

References

[1] Pezzulo G, Donnarumma F, Dindo H, D'Ausilio A, Konvalinka I, Castelfranchi C. The body talks: sensorimotor communication and its brain and kinematic signatures. Phys Life Rev 2019;28:1–21. https://doi.org/10.1016/j.plrev.2018.06.014 [in this issue].

[2] Schilbach L, Timmermans B, Reddy V, Costall A, Bente G, Schlicht T, et al. Toward a second-person neuroscience. Behav Brain Sci 2013;36(4):393–414.

[3] Candidi M, Curioni A, Donnarumma F, Sacheli LM, Pezzulo G. Interactional leader-follower sensorimotor communication strategies during repetitive joint actions. J R Soc Interface 2015;12(110):0644.

[4] Pezzulo G. Shared representations as coordination tools for interaction. Rev Philos Psychol 2011;2(2):303–33.

[5] Michael J, Sebanz N, Knoblich G. The sense of commitment: a minimal approach. Front Psychol 2016;6:1968.

[6] Goebl W, Palmer C. Synchronization of timing and motion among performing musicians. Music Percept 2009;26(5):427–38.

[7] Chafe C, Cáceres J, Gurevich M. Effect of temporal separation on synchronization in rhythmic performance. Perception 2010;39(7):982–92.

[8] Wing AM, Endo S, Bradbury A, Vorberg D. Optimal feedback correction in string quartet synchronization. J R Soc Interface 2014;11(93):20131125.

[9] Samson D, Apperly IA, Braithwaite JJ, Andrews BJ, Bodley Scott SE. Seeing it their way: evidence for rapid and involuntary computation of what other people see. J Exp Psychol Hum Percept Perform 2010;36(5):1255.

[10] Freundlieb M, Kovács ÁM, Sebanz N. When do humans spontaneously adopt another's visuospatial perspective?. J Exp Psychol Hum Percept Perform 2016;42(3):401.

[11] Surtees A, Samson D, Apperly I. Unintentional perspective-taking calculates whether something is seen, but not how it is seen. Cognition 2016;148:97–105.

[12] Curioni A, Minio-Paluello I, Sacheli LM, Candidi M, Aglioti SM. Autistic traits affect interpersonal motor coordination by modulating strategic use of role-based behavior. Mol Autism 2017;8:23.

[13] American Psychiatric Association. Diagnostic and statistical manual of mental disorders. Fifth edition (DSM-V). Washington, DC: American Psychiatric Association; 2013.

[14] Reddy V, Uithol S. Engagement: looking beyond the mirror to understand action understanding. Br J Dev Psychol 2016;34(1):101–14.

[15] Candidi M, Sacheli LM, Aglioti SM. From muscles synergies and individual goals to interpersonal synergies and shared goals: mirror neurons and interpersonal action hierarchies: comment on "Grasping synergies: a motor-control approach to the mirror neuron mechanism" by D'Ausilio et al. Phys Life Rev 2015;12:126–8.

[16] Sacheli LM, Aglioti SM, Candidi M. Social cues to joint actions: the role of shared goals. Front Psychol 2015;6:1034.

[17] Candidi M, Sacheli LM, Era V, Canzano L, Tieri G, Aglioti SM. Come together: human-avatar on-line interactions boost joint-action performance in apraxic patients. Soc Cogn Affect Neurosci 2017;12(11):1793–802.

[18] Sacheli LM, Candidi M, Era V, Aglioti SM. Causative role of left aIPS in coding shared goals during human-avatar complementary joint actions. Nat Commun 2015;6:7544.

[19] Sacheli LM, Tieri G, Aglioti SM, Candidi M. Transitory inhibition of the left anterior intraparietal sulcus impairs joint actions: a continuous theta-burst stimulation study. J Cogn Neurosci 2018;30(5):737–51.

[20] Era V, Candidi M, Gandolfo M, Sacheli LM, Aglioti SM. Inhibition of left anterior intraparietal sulcus shows that mutual adjustment marks dyadic joint-actions in humans. Soc Cogn Affect Neurosci 2018;13(5):492–500.

[21] Sacheli LM, Arcangeli E, Paulesu E. Evidence for a dyadic motor plan in joint action. Sci Rep 2018;8(1):5027.
[22] Sacheli LM, Candidi M, Pavone EF, Tidoni E, Aglioti SM. And yet they act together: interpersonal perception modulates visuo-motor interference and mutual adjustments during a joint-grasping task. PLoS ONE 2012;7(11):e50223.
[23] Wang Y, Hamilton AF. Social top-down response modulation (STORM): a model of the control of mimicry in social interaction. Front Human Neurosci 2012;6:153.