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Comment

Neural correlates of action monitoring and mutual adaptation during interpersonal motor coordination
Comment on “The body talks: Sensorimotor communication and its brain and kinematic signatures” by G. Pezzulo et al.

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In their review article, Pezzulo et al. [16] make the effort to provide an integrative view on the role of sensorimotor communication (SMC) during interpersonal motor interactions. We comment on the possibility to study brain processes associated to two fundamental mechanisms supporting motor interactions, i.e. mutual adaptation and error monitoring, that lead to the emergence of SMC, by using ecological experimental set-ups. Most of the available experimental studies on motor interactions have used simplified forms of interpersonal interactions such as finger tapping, finger movements, imitation of finger/hand movements [10,21,14,12,13,4], with the advantage of using well controlled experimental set-ups that preserve critical features of realistic interactions such as interdependence, need to predict, need to monitor, need to adapt.

However, the most sophisticated form of SMC identified by Pezzulo and colleagues, i.e. the attempt to disambiguate one’s own actions among different alternatives (intentional signalling), is often unexplored in these simplified set-ups. Crucially, this ability is strictly dependent on the ability to on-line modulate subtle motion cues such as the curvature of one’s own movements [19,1] according to the behavior of a partner which emerges during realistic interactions requiring mutual adaptation and error monitoring.

The process of mutual adaptation is supported by the moment-to-moment integration of predictions regarding the effects of one’s own and the other’s actions. Most of the studies investigating the neural bases of motor interactions dealt with the possibility to highlight the neural pattern associated to synchronizing with, or imitating and complementing, the action of a partner in different contexts. Endorsing the Authors’ view that “… information asymmetry and the presence of joint goals seem the most important prerequisites for sophisticated forms of SMC (see also Fig. 3),

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hence tasks that include them can be effectively used to chart more accurately the territory of SMC.", we believe that understanding the neural mechanisms of SMC is dependent on finding specific neural systems supporting the ability to *integrate* the action of a partner with ones' own, and *monitor the joint outcome* of the interaction, which may be fundamental to open new avenues for treating motor and social disorders.

Recent studies have shown that within the posterior parietal cortex, the anterior intraparietal sulcus ((aIPS), which has been shown to code for the goal of both observed [9] and executed [3,22] actions) supports humans' ability to perform complementary motor interactions, where integration of predictions of one's own and other's movements is needed in order to coordinate efficiently [18,20]. Interestingly, inhibitory transcranial magnetic stimulation (TMS) has been used to inhibit the activity of left aIPS in one member of human–human dyads performing motor interactions implying mutual adaptation [5]. This study showed that aIPS functioning supports effective motor synchronization during human–human complementary interactions. Moreover, the less the pairs were able to mutually adapt, the more left aIPS inhibition effect was visible. Thus, the impairment induced by TMS in one participant was compensated by the pair's ability to mutually adapt, suggesting that mutual adaptation is a crucial marker of human–human motor interactions [5]. Similarly, another study showed that brain damaged patients with motor difficulties (apraxic patients) improve their motor behavior when interacting with another person [2], indicating that the real-time coupling of one's own action with the ones of another individual may be spared in patients that show motor disorders as measured through individual motor tests.

The ability to adapt to a partner's movements clearly depends on ones' ability to detect differences between what one expects the other to do and what he/she actually does. It has been shown that the same error-related EEG markers (ERN, Pe, Theta ERS) [7,8,23,15] recorded over fronto-central electrodes when human participants perform or observe motor errors, also increase when human participants are required to predict the behavior of a virtual partner that suddenly changes its motor trajectory during a real interaction [11]. This suggests that the error monitoring system is involved during motor interactions, particularly when the partner's movements are less predictable and when the task requires a continuous integration of one's own and partner's movements. Interestingly, in the previously mentioned study, aside from the classical error-related midfrontal theta activity, another source of the theta ERS generated by the observation and prediction of a violation in the expected movement was localized over occipito-temporal regions suggesting a role in visuo-motor integration during motor interactions [11].

These studies indicate that SMC, promoted in set-ups implying real-time sensorimotor coupling of observed and executed actions might be exploited to facilitate motor behavior in patients suffering from several motor and social difficulties. In this sense, the development of virtual reality scenarios (that have the advantage of allowing better control over the behavior of the virtual partner in comparison to human–human interactions) to implement motor interactions for rehabilitation purposes might take into account the notion that mutual adaptation appears as a crucial aspect of realistic motor interactions [5,17] and implement virtual partners that are able to adapt to the motor behavior of the human interactor [6]. Moreover, virtual reality scenarios offer the opportunity to boost SMC by making the kinematics of the virtual partner more informative and predictable in order to facilitate motor coordination in populations with motor and social disorders.

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