Comment

Sensorimotor communication at the intersection between kinematic coding and readout

Comment on "The body talks: Sensorimotor communication and its brain and kinematic signatures" by Giovanni Pezzulo, Francesco Donnarumma, Haris Dindo, Alessandro D'Ausilio, Ivana Konvalinka, Cristiano Castelfranchi

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Pezzulo et al.'s article [1] offers a sophisticated account of *sensorimotor communication* (*SMC*), conceptualized as the process of imposing a communicative intention on a pragmatic action, that is, an action performed to bring one closer to a pragmatic goal. The recognition of this form of communication as distinct from both conventionalized communication and information transfer has implications for designing and interpreting experiments aimed at understanding social exchanges.

From the SMC perspective, sensorimotor signals may be embedded in every action, from grasping an object to walking. Major open questions that follow from this account regard the operations that mediate the encoding and decoding of such signals. This commentary discusses such questions through perspectives drawn from the *intersection information framework* [2], offering some observations that potentially test and expand Pezzulo et al.'s considerations on SMC.

Pezzulo et al. [1] posit that SMC operates through subtle changes in movement kinematics. In cooperative contexts, for example, individuals may modify their movement kinematics to facilitate the recognition of their intention by other individuals. Conversely, in competitive contexts, they may use SMC to make their actions and intentions more opaque. The central idea of this commentary is that to understand SMC, *information coding* cannot be studied separately from *information readout*. We propose that what mediates SMC is the *intersection* between the two stages of information coding and readout (Fig. 1). In other words, what matters is the understanding of how information-carrying changes in movement kinematics are read out by other individuals. In what follows, we elaborate on the concepts of information coding, readout and intersection by considering an exemplar scenario in which one individual (agent A) lifts a box
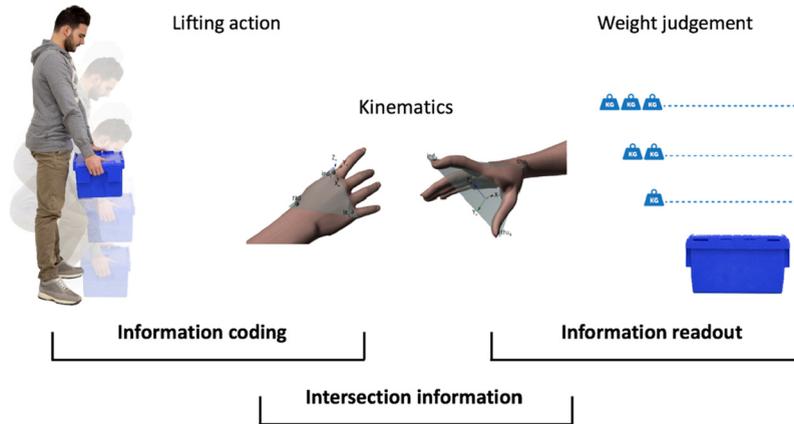

Fig. 1. *Schematic of our proposal for describing sensorimotor communication as intersection information*. We use the example of one individual lifting a box and using SMC signals to communicate to another individual information about the weight of the object being lifted. Two operations of sensorimotor communication are the encoding of weight information by the lifter's kinematics, and the readout of such information by the observer. Sensorimotor communication happens if information coding and readout intersect, that is, if the readout is able to extract effectively the weight information encoded by the kinematics.

using SMC signals to communicate to another individual (agent B) information about the weight of the object being lifted.

1. Information coding

The first stage, information coding, determines how weight information is encoded in the kinematic features of the action performed by agent A. It is well established that variations in the weight of a lifted object introduce specific changes in the reach, grasp and lift components of the lifter's action [3]. For example, when compared to light objects, heavy objects cause increased peak grasp aperture, a final finger and thumb placement on the object that more closely passed through the object center of mass, increased lift delay and reduced peak lift velocity [4]. Variations in partly different features may further specify the lifter's expectations and intentions in grasping the object [5]. For example, they may reveal whether the lifter intends to convey the impression that a box is heavier than it actually is [6]. Taken together, these findings point to a kinematic pattern encoding (through a set of kinematics features functional to the action goal), not only information about the object's real weight, but also (through a partly different set of kinematic features functional to communication) information about the lifter's intention (intended object weight).

One important observation is that SMC may not be always associated with an increase in the total amount of information encoded in the kinematics. Indeed, while in some cases SMC may increase encoded information, for example when information is intentionally communicated by amplifying functional modulations otherwise imperceptible, in other cases, the encoded information may remain the same or even decrease. This may happen when the information carried by features used to communicate is either redundant or misleading with respect to that provided by features functional to the action goal. Thus, the distinctive kinematic signature of SMC is not the total amount of information, but the distribution of information across different kinematic features. But how does this distribution contribute to SMC?

Detailed information coding analysis of lifting movement kinematics may allow the identification of the features that carry information specifying real and/or intended weight. However, determining that a kinematic feature encodes weight information would not be sufficient to establish whether or how encoded information is read out.

2. Information readout

In our example scenario, agent B observes A lifting the box and judges the weight of the box. While often accomplished in everyday life, this task is not easy and requires a detailed assessment of the observed kinematics. Having defined information coding by agent A's kinematics, the second stage is thus determining how agent B reads out kinematics carrying weight-related information. Information readout refers, in our definition, to the ability of agent B

to estimate, through observation, weight information encoded by the kinematics of agent A. Whether or not specific kinematic features of agent A are read out by B can be determined by measuring how well the considered kinematic features predict weight estimates by agent B; see [7,8] for examples of how readouts may be measured. Readout is necessary for SMC: if B cannot read out A's kinematics, neither SMC nor information transfer can take place between A and B. Therefore, only kinematic features with a non-zero readout can contribute directly to SMC. However, measuring readout is not sufficient to reveal SMC [2]. In fact, information coding and information readout could be based on distinct features. Some kinematic features used to encode weight information may be ignored by agent B. Alternatively, agent B may estimate weight using kinematic features that do not encode weight-related information. Also, agent B may be able to estimate informative kinematic features of A, but he/she may not know how to combine them correctly to extract weight information. For example, weight information may be encoded by the difference $f_1 - f_2$ of two kinematic features f_1 and f_2, but agent B may attempt to extract information from their sum $f_1 + f_2$, getting an imprecise estimate of the lifted weight. In all of these cases, the suboptimal "alignment" of the pattern of features used for coding and readout would prevent successful SMC.

3. Change of intersection information as the signature of SMC

We propose that what makes SMC possible is the effective alignment between the weight information encoded by A's kinematic features and the readout of such features by agent B. How well encoded weight information and readout are aligned, or how much of the encoded information is read out to correctly judge weight, is quantified by the concept of intersection information [2]. This concept was originally developed to investigate how sensory information encoded in neural activity is read out to inform behavioral choices [2,9]. In the extension to SMC of this concept proposed here, we define intersection information as the correspondence, in each trial, between weight information encoded by agent A's kinematics and the behavioral readout of such information by agent B. Importantly, intersection information may be either positive or negative. Positive intersection information indicates a positive correlation between how information is encoded and how it is read out: when agent's A kinematic encodes, on a given trial, a heavier weight, agent B tends to estimate the lifted object to be heavier. Negative intersection information whereby the encoded information anti-correlates with readout information could happen in two cases. The first is the correct read out of misleading encoded information. That is, agent A alters its kinematics to deceive agent B about the weight of the lifted box (e.g., so as to make it look heavier) and agent B, falling short of detecting A's deceptive intention, estimates the box to be heavier. The second is the wrong readout of correct encoded information. That is, agent B, possibly suspecting that A is trying to deceive him although A is not, overestimates (or underestimates) the real object weight.

In this framework, we propose that, operationally, SMC mode could be experimentally revealed by a change in the pattern of information encoding in the kinematics of A that leads to an increase of intersection information about weight information transmitted from A to B. The sign of intersection information could provide further information regarding the context – cooperative versus competitive – of SMC.

4. Concluding remarks

We propose that the application of the concept of intersection information to study sensorimotor communication offers multiple advantages. First, it allows a better understanding of the basic operational building blocks of communication between agents (encoding, readout, and their intersection). Second, it provides operative and quantitative measures of how and how well sensorimotor signaling is mediated by (possibly subtle) variations in movement kinematics. Third, as for other aspects of information theory [10], the concept of intersection can be developed to become dynamic and time-resolved, thereby allowing potentially the experimenter to understand and link dynamic changes in information coding and readout computations due to close loop interactions between subjects.

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