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Comment

Sensorimotor communication beyond the body: The case of driving. Comment on "The body talks: sensorimotor communication and its brain and kinematic signatures" by G. Pezzulo et al.

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Pezzulo et al. ([1], this issue) draw attention to the important phenomenon of what they call sensorimotor communication (SMC), in which an action both achieves some practical, non-communicative goal, but also serves as a form of communication through the manner in which the goal is achieved. As Pezzulo et al. point out, the communicative content of such actions can be remarkably flexible; but, equally, repeated similar SMC actions can fairly rapidly lead to conventionalized meanings. But how far do the principles underlying SMC apply more broadly – beyond movements of the body?

We suggest that the reach of SMC is very broad. Indeed, the propensity to communicate is so powerful that this can occur even when opportunities to communicate are very limited. In this commentary, we note how driving provides a surprisingly rich domain for SMC and a domain which highlights the considerable practical importance of SMC.

Consider two vehicles, A and B, are heading towards a single-lane bridge from opposite directions. Suppose that A is marginally further from the bridge and slows abruptly; by slowing abruptly, A does not merely let B go first, but *signals* to B that this is A's intention. This facilitates the interaction, because B now is informed that A has seen B and is giving "permission" for B to proceed. Conversely, suppose A were to move to the center of the road well before reaching the bridge: this would convey A's intention to cross first, with the expectation that B should retreat. Of course, the drivers might also use explicit communicative signals [2], such as flashing headlights, hooting or waving. But such interactions frequently proceed without any such explicit communication.

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What is the connection between the action and communicative function of SMC? This becomes clearer by considering an 'ideal' case of successful communication.

First, notice that a successful communicative signal, S, between two agents, A and B, requires both agents mutually recognizing the same meaning for S in a given context. That is, A's interpretation of S, $M_A(S)$, is the same as B's interpretation of S, $M_B(S)$. To the extent that these meanings differ, A and B will misunderstand each other. Crucially, not only must the agents mutually recognize this meaning itself, but also the fact that $M_A(S) = M_B(S)$, such that this is common ground between A and B [3]. That is, not only do A and B agree on the interpretation of S, but they know that they do, and they know that they know this, and so on. From this point of view, the purpose of a communicative signal (whether SMC or not) is to put new information, conveyed by the meaning of that signal, into common ground.

Second, note that the bridge crossing scenario above, and the examples of collaborative tasks, music, and dance considered by Pezzulo et al., can be viewed as examples of joint action [4–7], in which two or more people coordinate their actions to achieve a common goal. In the bridge-crossing case, of course, the people have the common goal of both safely crossing the bridge without collision. But their interests may also conflict: here, for example, each driver may prefer to go first.

Finally, we need a mechanism for resolving conflicting interest and achieving the common goal. Such situations may seem to require negotiation between the parties to decide which option should be chosen. But in the types of cases Pezzulo et al. and we are considering, there is no possibility for the linguistic exchange of offer and counter-offer that might normally be involved in such negotiation. What the agents can do, however, is simulate what the outcome *would* be were such bargaining to occur [8]. If such bargaining has an 'obvious' outcome, then purely *virtual* bargaining is sufficient. Both agents can implement what they would have agreed, short-circuiting the need for actual negotiation. So, for example, if one vehicle will arrive at the bridge sooner, then (all else being equal) the parties would surely agree that it should go first; if, though, the later vehicle is an ambulance with its siren on, both parties would agree that it should take precedence, and so on.

Putting these three elements together we can sketch how SMC, combining both action and communicative functions, can arise. By choosing a particular action (e.g., moving to the center of the road), one party can *change* what the most natural agreement is. Once one vehicle is in the center of the road, both parties might agree that this vehicle will most naturally go first, to avoid awkwardly swerving to the side; if one vehicle slows abruptly, both parties might agree that the other should go first, to avoid the first vehicle awkwardly having to pick up speed. So a choice of action can shift the subsequent natural agreement, but it can also thereby communicate the intention to make this very shift.

Note, of course, that the very same action could be made without intentional communication, and coordination may still succeed. For example, one vehicle might slow to pass through a puddle; or move to the center of the road to avoid a pedestrian (or simply in anticipation of crossing the bridge, having absent-mindedly failed to notice the on-coming driver).

How can these cases be distinguished empirically? One approach is by examining the other aspects of the interaction. For example, if one driver 'communicatively' slows for another, the other is likely to acknowledge this, by making eye contact and smiling, waving, or briefly flashing headlights; and the first driver will see this as confirming a successful interaction. If the first driver merely slowed through a puddle, then the second driver's thanks may be perceived as bizarre or even ironic. Conversely, if the second driver doesn't realize the slowing was intentional and fails to acknowledge when acknowledgment is expected, the second driver will be perceived as impolite.

Such an approach may be conservative at detecting intentional communication and imperfectly reliable. However, we can prominently see it play out in documented interactions between human-driven and automated vehicles. In one illustrative case, a car on autopilot ignored an 'invitation' to change lanes by the human driver of another car, because it failed to recognize the latter car's change in speed (to open up a gap) as a communicative gesture; mere moments later, however, as the human-driven car rescinded the 'offer' by starting to close the gap, the automated car moved out in front of it, which the human occupant quickly recognized as rude [9]. The perceived rudeness of this act, in this case, resides not in the maneuver itself (which was apparently executed safely), but rather reveals the intentionally communicative aspect of the human driver's movements (which was missed by the artificial intelligence).

Indeed, we suggest that human social intelligence is exquisitely tuned to finding the implicit 'bargains' involved in joint actions in general [10], and SMC in particular. We suggest that examples from driving, the focus of our own recent experimental work, illustrate how SMC applies far beyond the body. It also illustrates the profound practical significance of SMC in this domain: autonomous vehicles that interact with human-driven vehicles but without such

subtle interpretative reasoning, risk being perceived as driving impolitely or bizarrely and, more importantly, may fail to coordinate smoothly and safely with human drivers and road users.

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