



# Informing, Coordinating, and Performing: A Perspective on Functions of Sensorimotor Communication

Cordula Vesper<sup>1,2\*</sup> and Vassilis Sevдалис<sup>3</sup>

<sup>1</sup>Department of Linguistics, Cognitive Science and Semiotics, Aarhus University, Aarhus, Denmark, <sup>2</sup>Interacting Minds Centre, Aarhus University, Aarhus, Denmark, <sup>3</sup>Department of Public Health, Sport Science, Aarhus University, Aarhus, Denmark

## OPEN ACCESS

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### \*Correspondence:

Cordula Vesper  
cvesper@cc.au.dk

### Specialty section:

This article was submitted to  
Cognitive Neuroscience, a section of  
the journal *Frontiers in Human  
Neuroscience*

**Received:** 25 January 2020

**Accepted:** 20 April 2020

**Published:** 26 May 2020

### Citation:

Vesper C and Sevдалис V (2020)  
Informing, Coordinating, and  
Performing: A Perspective on  
Functions of Sensorimotor  
Communication.  
*Front. Hum. Neurosci.* 14:168.  
doi: 10.3389/fnhum.2020.00168

Sensorimotor communication is a form of communication instantiated through body movements that are guided by both instrumental, goal-directed intentions and communicative, social intentions. Depending on the social interaction context, sensorimotor communication can serve different functions. This article aims to disentangle three of these functions: (a) an informing function of body movements, to highlight action intentions for an observer; (b) a coordinating function of body movements, to facilitate real-time action prediction in joint action; and (c) a performing function of body movements, to elicit emotional or aesthetic experiences in an audience. We provide examples of research addressing these different functions as well as some influencing factors, relating to individual differences, task characteristics, and situational demands. The article concludes by discussing the benefits of a closer dialog between separate lines of research on sensorimotor communication across different social contexts.

**Keywords:** sensorimotor communication, joint action, nonverbal communication, action prediction, dance, music, sport, aesthetics

## INTRODUCTION

Humans have an intrinsic ability to interact socially with others. From an early age, and before cultivating the language faculty, humans are able to understand others and to be understood by others through pre- and nonverbal cues, such as pointing gestures and gaze direction (Tomasello, 2019). Later in life, this ability becomes particularly relevant in social contexts where the environment prevents verbal exchange (e.g., due to background noise) or where linguistic forms of communication are not appropriate (e.g., in sport and performing art contexts). In such cases, individuals express meaning through their actions and body movements. Nonverbal forms of communication are pertinent in human cultures worldwide (Matsumoto, 2006) and occur in various contexts, from complementing or replacing verbal communication in everyday interactions (Vesper and Richardson, 2014; Peeters et al., 2015; Vesper et al., 2017b; Pezzulo et al., 2019) to supporting complex interpersonal interactions and producing art through dance and music (Sevдалис and Keller, 2011a, 2014; D'Ausilio et al., 2015; MacRitchie et al., 2017; Bishop et al., 2019).

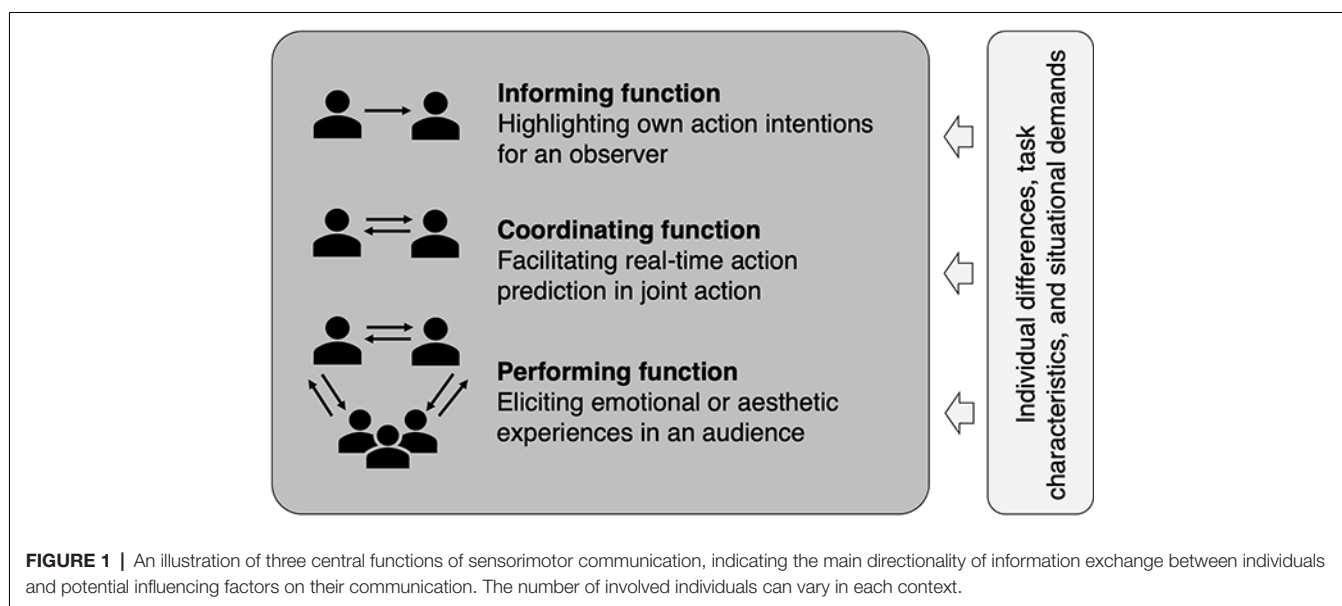
In the past decades, considerable attention has been placed on understanding the foundations of cognitive and social processes within human actions and embodied interactions (Gallese, 2007).

Within an embodied cognition framework, bodily movements and sensorimotor experiences are considered pivotal in shaping cognitive functions such as learning, memory, and perception (Wilson, 2002; Barsalou, 2008). One consequence of the embodied nature of cognition is that individuals employ their sensorimotor skills when observing the actions of other individuals (Blakemore and Frith, 2005; Wilson and Knoblich, 2005; Grafton, 2009; Schubert and Semin, 2009). This action simulation or motor resonance is regarded as a fundamental mechanism for social cognition, bridging the gap between self and other (Prinz, 1990; Jeannerod, 2006; Vesper et al., 2010; Herwig et al., 2013). Specifically, the direct matching between action and perception can act as a foundation for the coupling of individual minds and the emergence of sensorimotor communication between them.

In contrast to many predominantly communicative actions such as gesturing while speaking, sensorimotor communication is instantiated through actions that are guided by both communicative, social intentions and by instrumental, goal-directed intentions. To illustrate how this double nature of sensorimotor communication can serve different functions, consider the following example: While continuously playing her musical instrument and producing a desired complex sound pattern (an instrumental action goal), an ensemble musician can inform another performer about her intention to enter a specific musical passage by exaggerating the movement of her upper body (a communicative action goal). A second musician can understand this intention and respond by slowing down the musical tempo so that they play together in synchrony. For an observing audience, the musicians' coordinated movements can elicit aesthetic experiences and emotional reactions. The musicians' expertise, their experience with each other's playing style, and their shared musical and cultural backgrounds can all influence their resulting performance (cf. Keller, 2014).

A multitude of research studies identified kinematic parameters such as movement amplitude or grasp size that are modified depending on an agent's action intention (for an overview and discussion, see Ansuini et al., 2014). Previous research on sensorimotor communication examined how such kinematic parameters are modified in joint action to be informative for a co-actor. To that end, a computational model linked movement modifications to internal predictive processes and postulated that sensorimotor communication serves the purpose of facilitating prediction for an observer (Pezzulo et al., 2013). Moreover, a recent framework classified various forms of verbal and nonverbal information exchange (Pezzulo et al., 2019). With this article, we intend to complement such accounts by focusing on the functions that sensorimotor communication serves within different social interaction contexts. In particular, we distinguish three central functions—informing, coordinating, and performing—that differ in the directionality of information flow between individuals, as illustrated in **Figure 1**.

Accordingly, the section “Informing Function: Highlighting Own Action Intentions for an Observer” introduces movements that provide relevant information to another person, by highlighting an individual's action intentions. The section “Coordinating Function: Facilitating Real-Time Action Prediction in Joint Action” continues with movements that allow close coordination between multiple individuals' actions, by facilitating mutual predictions in real-time. The section “Performing Function: Eliciting Emotional or Aesthetic Experiences in an Audience” addresses movements that support performance in contexts such as music and dance, by conveying dynamic expressive nuances that elicit emotional and aesthetic experiences in an audience. These three functions of sensorimotor communication can be influenced by several factors related to individual differences (e.g., in self-report measures of empathy or sensorimotor expertise), specific task characteristics (e.g., when interacting individuals have



asymmetric access to task-relevant information), or situational demands (e.g., in a music performance context). To conclude, the section “Final Remarks” discusses the potential benefits of a closer dialog between separate lines of research addressing sensorimotor communication.

## **INFORMING FUNCTION: HIGHLIGHTING OWN ACTION INTENTIONS FOR AN OBSERVER**

The first function of sensorimotor communication, that we address in this article, is providing another person with information about one’s intended body movements. It is well established that individual observers are sensitive to information about others’ movement intentions, allowing them to predict what another person will do next (Graf et al., 2007; Becchio et al., 2012; Cavallo et al., 2016). For example, observers can reliably distinguish different social intentions towards another person, such as giving instructions or requesting information (Manera et al., 2010). Factors such as movement complexity, amount of visual information about the movement, and exposure duration to the movement have frequently been related to higher recognition rates (Pollick et al., 2003; Dahl and Friberg, 2007; Sevdalis and Keller, 2009, 2010).

Given this evidence, it could be argued that movements are informative *per se*. In many social contexts, however, movement information is not just passively transmitted as a byproduct of acting; instead, individuals often deliberately modify their movements to make their action intention visible to others. Thus, movements are intentionally modified to be (even more) informative. This function of sensorimotor communication occurs most prominently in situations where making another person aware of one’s intention is explicitly desired, such as during teaching and demonstration. For instance, a dance teacher might exaggerate movement cues to make her pupils understand what is most important to imitate, while she continues to perform the dance movement itself. Empirical research reveals the flexibility with which certain features of an action can be modified to fulfill the informative function of sensorimotor communication. As an example, individuals, who teach an observer a particular musical sequence, exaggerate kinematic features such as amplitude and velocity so that they become informative about where in space the movement is directed towards (McEllin et al., 2018). Similarly, in child-directed action, it has been shown that adults tend to modify movement cues to teach a child, for example, how to use a novel tool (“motionese”; Brand et al., 2002). This sensorimotor communication is thought to support learning by highlighting and separating the relevant action steps (Koterba and Iverson, 2009; Williamson and Brand, 2014). Even minimal modifications are sufficient for supporting the recognition of intentions. For instance, movements produced in a joint action context often contain sufficient information, so that even individuals unrelated to a specific interaction context can predict the actors’ movement goals from simple static images (Vesper and Richardson, 2014) or temporal cues (Vesper et al., 2017b).

Although most research has investigated communicative action modulations in cooperative contexts, they also occur in competitive contexts, where movements are intentionally modified to be less informative or misleading. One domain is competitive sports, where players might encounter deceptive body movements from their opponents. By deliberately providing “fake” information about one’s action intention, players can attempt to disturb an opponent’s prediction processes (Cañal-Bruland, 2017), misleading them about the upcoming action and, therefore, eliciting an inappropriate response. In cases such as handball, rugby, and basketball, expert performers have demonstrated a perceptual advantage in correctly disambiguating others’ movement intentions (Cañal-Bruland and Schmidt, 2009; Sebanz and Shiffrar, 2009; Brault et al., 2012; Mori and Shimada, 2013), highlighting the role of action expertise in sensorimotor communication.

## **COORDINATING FUNCTION: FACILITATING REAL-TIME ACTION PREDICTION IN JOINT ACTION**

Beyond merely providing information, body movements can also support real-time coordination between multiple individuals’ actions. In joint action settings, it is often not only necessary to understand the partner’s immediate action intention, that is, what this person is going to do next, but also to be able to perform an appropriate complementary action at the right time, that is, to choose which respective action to perform and when to act. In other words, the real-time constraints and mutual influences between co-actors place a high burden on joint planning and performance. Sensorimotor communication, here, plays the role of a “coordination smoother” (Vesper et al., 2010), a way of simplifying coordination.

One of the most studied contexts of this coordinative function of sensorimotor communication is that of achieving synchrony between two individuals’ actions. In a study with expert pianists playing duets, it was observed that restricting access to shared auditory information made the players visually enhance their finger movement height, which, in turn, allowed them to maintain precise temporal coordination with each other (Goebel and Palmer, 2009). Sensorimotor communication, in this case, compensated for missing auditory information through another (here: visual) modality. Similar findings were obtained in a joint sequence coordination task, where those persons in a dyad who received prior information about upcoming target locations, deliberately modulated their movement amplitude while interacting (Vesper and Richardson, 2014). In particular, they moved to relatively far targets with a higher amplitude and a different velocity profile than to relatively close locations. This modulation allowed the co-actors, who did not receive prior information, to anticipate the location of the correct target and their partners’ movements more efficiently. The impact of sensorimotor communication on the outcome of a joint action was directly tested in a study that modulated the type of perceptual information shared between co-actors (Vesper et al., 2016). Pairs of participants synchronized the

endpoints of simple target-directed movements. Compared to a condition without visual access to each other's movements, participants exaggerated the amplitude of their movements in a condition with visual access. This in turn, allowed them to be more synchronized. Other action features besides movement amplitude are modulated for communication, including grasp position on an object (Schmitz et al., 2018), grasp aperture while moving towards an object (Sacheli et al., 2013), and the speed with which to approach a target location (Vesper et al., 2017b).

Individual differences in co-actors' social skills or their interaction roles can influence the execution of body movements. Several studies demonstrated that leader/follower relationships influence how dyads or larger groups approach a task, and how well they manage to adjust their movements and achieve fine temporal and spatial coordination with each other (Konvalinka et al., 2010; Glowinski et al., 2013; Badino et al., 2014; Curioni et al., 2019). The assignment of leadership roles can also alter the duration of gaze towards the co-performer in duetting pianists (e.g., before tempo changes), affecting how well they achieve musical synchronization (Kawase, 2014). Coordination of music and body movement can also be influenced by familiarity with a co-performer's musical part and previous rehearsals (Williamson and Davidson, 2002; Ragert et al., 2013; Keller, 2014). Similar effects likely extend into movement performance in contexts that foster sensorimotor communication. One study tested the influence of inter-individual differences on the emergence of new communication systems (Volman et al., 2012). Their findings suggest that individuals tend to differ in their ability to understand another person's movement intentions, which, in turn, can affect the success with which dyads manage to creatively invent non-conventional ways of communicating.

## PERFORMING FUNCTION: ELICITING EMOTIONAL OR AESTHETIC EXPERIENCES IN AN AUDIENCE

In the interaction contexts described in the previous sections, the focus is on informing or transferring task-relevant information to another individual or completing tasks together. In contrast, many situations, such as dance and music performances, can generate more complex interactions, where performers engage in deliberate modulations of their bodily movements to convey meaning to an audience, such as eliciting emotions, aesthetical experiences, or narratives in an observer's mind. As illustrated in **Figure 1**, this transforms the overall interactive structure by adding more roles (i.e., performer and audience) and, possibly, more people (although this does not exclude contexts with only one performer, more than two performers, or varying sizes of the audience).

Performers' movements are potent carriers of aesthetic significance and often convey spatial and temporal expression dynamics in visual and auditory modalities, which influence the experience of observers (Vines et al., 2006; MacRitchie et al., 2013). For example, musical performances are judged as more

interesting when, in addition to hearing the music, observers can see the musicians playing in an expressive compared to an inexpressive manner (Broughton and Stevens, 2009). Similarly, dance movements depicting greater displacement of a dancer's body in space are associated with higher liking ratings from spectators (Calvo-Merino et al., 2008). In contrast to static movement displays, dynamic displays of movements across time provide audiences with information that allow them to infer information about a performer's intended artistic expression which, for example, allows them to differentiate between expressive and inexpressive motion cues in performing musicians or dancers (Sevdalis and Keller, 2012; MacRitchie et al., 2017). Moreover, aesthetic responses to dance movements can be intensified by dance performers' interpersonal synchrony (Vicary et al., 2017). Thus, body movements are effective channels for the communication of performers' intentions for expression, as well as for inducing aesthetic experiences in an observing audience.

Various factors can influence how accurately others' intentions about expression intensity and aesthetic significance can be perceived in performance contexts. One important factor is performers' and observers' sensorimotor expertise, which can emerge from the long-term cultivation of a sensorimotor skill and deliberate practice. In the field of music, for example, expert pianists, organ players, and orchestral conductors were shown to be able to reliably distinguish whether recordings of music performances involve previously executed actions of themselves or other individuals (Keller et al., 2007; Gingras et al., 2011; Wöllner, 2012a). Another important factor, apart from long-term or domain-specific expertise, is incidental sensorimotor experience with an action or an interaction partner, which can be beneficial in a communication process. When observers were asked to identify the intended expression intensity of non-expert dancers, recognition accuracy differed depending on whether the observers had motor experience (observing their own dancing movements), visual experience (observing movements of a dancing partner), or no experience with the displayed actions (observing the dancing movements of a stranger; Sevdalis and Keller, 2011b). A further example of individual characteristics that may influence sensorimotor communication is trait-like individual differences, for example, related to empathy. Individuals scoring higher on empathy in self-report questionnaires were found to be more accurate in estimating performers' intentions for expression, whether they were observing ensemble musicians (Wöllner, 2012b) or dancers (Sevdalis and Keller, 2012; Sevdalis and Raab, 2014; Sevdalis and Raab, 2016).

## FINAL REMARKS

The present article illustrates the complexity that research on sensorimotor communication in social interaction needs to address: Studying only simple information exchange may not suffice to fully understand how body movements are used to facilitate coordination between individuals; studying only coordination of body movements in a dyadic setting may not suffice to understand the dynamics of interaction

between co-performers' expressions and an audience's aesthetic responses; focusing only on complex applied performance contexts may not benefit from basic research that addresses low-level sensorimotor processes. Thus, to investigate such complexity, future research will benefit from a multidisciplinary dialog across fields as varied as human movement science, joint action, communication studies, and performance psychology (Vesper et al., 2010, 2017a; D'Ausilio et al., 2015; Sevdalis and Wöllner, 2016).

To date, despite the considerable potential of crosstalk between different fields that focus on communicative actions, the systematic investigation of movements still receives less attention compared to the study of other cognitive processes (Rosenbaum and Feghhi, 2019). Accordingly, to complement the literature on basic motor processes in sensorimotor communication (e.g., Pezzulo et al., 2013; Vesper and Richardson, 2014; Vesper et al., 2017b), we aim to extend the discussion to studies illustrating how movements serve as carriers of meaning and expression dynamics in performing arts contexts (Sevdalis and Keller, 2011a, 2014; Sevdalis and Wöllner, 2016). We hope our proposed schema in **Figure 1** will support the systematic assessment of different parameters in human social interaction, such as individuals' goals that necessitate certain body movements, the contexts in which the movements are embedded, or the particular characteristics of the individuals executing and perceiving these movements. In particular, future research could directly compare contexts that differ only in the function that sensorimotor communication has, and, thereby, specify which influencing factors are particularly relevant to which context.

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## AUTHOR CONTRIBUTIONS

CV and VS contributed equally to the conceptual development and writing of the article.

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**Conflict of Interest:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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