Human Movement Science 30 (2011) 846–868

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Neuro-cognitive mechanisms of decision making in joint action: A human–robot interaction study

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ARTICLE INFO

Article history:
Available online 3 January 2011

PsycINFO Classification:
2340
3040
4140
4160

Keywords:
Motor planning
Decision making
Dynamic neural fields
Joint action

ABSTRACT

In this paper we present a model for action preparation and decision making in cooperative tasks that is inspired by recent experimental findings about the neuro-cognitive mechanisms supporting joint action in humans. It implements the coordination of actions and goals among the partners as a dynamic process that integrates contextual cues, shared task knowledge and predicted outcome of others' motor behavior. The control architecture is formalized by a system of coupled dynamic neural fields representing a distributed network of local but connected neural populations. Different pools of neurons encode task-relevant information about action means, task goals and context in the form of self-sustained activation patterns. These patterns are triggered by input from connected populations and evolve continuously in time under the influence of recurrent interactions. The dynamic model of joint action is evaluated in a task in which a robot and a human jointly construct a toy object. We show that the highly context sensitive mapping from action observation onto appropriate complementary actions allows coping with dynamically changing joint action situations.

1. Introduction

As an exquisitely social species humans are experts in cooperating with others when trying to achieve the goals of a common task (Sebanz, Bekkering, & Knoblich, 2006). In our everyday social interactions we continuously monitor the actions of our partners, interpret them in terms of their

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doi:10.1016/j.humov.2010.08.012

outcomes and adapt our own motor behavior accordingly. Imagine for instance the joint action task of preparing a dinner table. The way a co-actor grasps a certain object (e.g., a coffee cup) or the context in which the motor act is executed (e.g., the cup may be empty or full) transmits to the observer important information about the co-actor's intention. Depending on the grip type, for instance, she/he may want to place the cup on the table or, alternatively, may have the intention to hand it over. Knowing what the other is going to do should facilitate motor programmes in the observer that serve the achievement of shared goals. Fluent and efficient coordination of actions among co-actors in a familiar task requires that the preparation of an adequate complementary action is a rather automatic and unconscious process. Since in sufficiently complex situations several possible complementary behaviors may exist this process necessarily includes a decision-making operation.

The long-term goal of our research group is to build robots that are able to interact with users in the same way as humans interact with each other in common tasks. Our research strategy to achieve this challenging objective is to develop and test control architectures that are strongly inspired by neuro-cognitive mechanisms underlying human joint action. We believe that implementing a human-like interaction model in an autonomous robot will greatly increase the user's acceptance to work with an artificial agent since the co-actors will become more predictable for each other (for a survey of challenges for socially interactive robots see Fong, Nourbakhsh, and Dautenhahn (2003)). Such an interdisciplinary approach constitutes not only a promising line of research towards human-centered robots but also offers unique possibilities for researchers from neuroscience and cognitive science. Synthesizing cooperative behavior in an artificial but naturally inspired cognitive system allows them in principle to test their theories and hypothesis about the mechanisms supporting social interactions (Dominey & Warneken, in press).

The focus of this paper is on flexible action planning and decision formation in cooperative human–robot interactions that take into account the inferred goal of the co-actor and other task constraints. An impressive range of experimental evidence accumulated over the last two decades supports the notion that a close perception-action linkage provides a basic mechanism for real-time social interactions (Newman-Norlund, Noordzij, Meulenbroek, & Bekkering, 2007; Wilson & Knoblich, 2005). A key idea is that action observation leads to an automatic activation of motor representations that are associated with the execution of the observed action. It has been suggested that this resonance of motor structures supports an action understanding capacity (Blakemore & Decety, 2001; Fogassi et al., 2005; Rizzolatti, Fogassi, & Gallese, 2001). By internally simulating action consequences using his own motor repertoire the observer may predict the consequences of others' actions. Direct physiological evidence for such a perception-action matching system came with the discovery of the mirror neurons first described in premotor cortex of macaque monkey (for a review see Rizzolatti and Craighero (2004)). Mirror neurons are a particular class of visuomotor neurons that are active both during the observation of goal-directed actions such as reaching, grasping, holding or placing an object and during the execution of the same class of actions. Although action understanding is the dominant hypothesis about the functional role of the motor resonance mechanism it has been suggested that it may also contribute to motor planning and action preparation. Typically it is assumed that a direct activation of the corresponding motor program explains the evidence found in many behavioral experiments for a tendency of an automatic imitation of observed actions (e.g., Brass, Bekkering, & Prinz, 2001, for a review see Wilson & Knoblich, 2005). Such a tendency is of course not beneficial for cooperative joint action which normally requires the facilitation of a complementary motor behavior. Recent findings in neuroimaging and behavioral studies provide evidence however that goal and context representations may link an observed action to a different but functionally related motor response (Newman-Norlund, van Schie, van Zuijlen, & Bekkering, 2007; van Schie, van Waterschoot, & Bekkering, 2008). These studies clearly demonstrate that the mapping between action observation and action execution is much more flexible than previously thought.

Here we present a dynamic model that implements such a flexible perception-action linkage as a means to achieve an efficient coordination of actions and decisions between co-actors in a joint action task. We report results of our ongoing evaluation of the model as part of the control architecture of a humanoid robot that assembles together with a human user a toy object from its components (Bicho, Louro, Hipolito, & Erlhagen, 2008, 2009).