Applying motor resonance to humanoid robots

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Abstract. As humanoid robots are likely to become present in our societies, it is important to understand humans' reactions to these agents and to develop neuromimetic models of robots' motor learning. Motor resonance is an emerging framework based the overlap between neural processes involved in the execution and the perception of human actions. In this review of previous works, I will present a paradigm that has demonstrated that humanoid robots cause motor resonance in humans. Motor resonance has also been applied to motor learning by imitation, demonstrating that basic forms of imitation can emerge in a simple robotic system controlled by visuomotor association network. These practical applications of motor resonance to the study and implementation of human-robot interactions provide a promising neuromimetic framework for further developments in humanoid robotics.

1 Introduction

Artificial anthropomorphic agents such as humanoid and android robots are increasingly present in our societies. For these robots to interact optimally with humans, it is important to understand humans' automatic and unconscious reactions to these agents as well as to develop neuromimetic models of robots' motor learning in order to reproduce the smoothness of human social interactions.

Following the finding that the same neural structures show an increase of activity both when executing a given action and when observing another individual executing the same action, theories of social interactions using concepts of motor resonance have flourished in the scientific literature [1]. I refer to this process as motor resonance, which is defined, at the behavioural and neural levels, as the automatic activation of motor control systems during the perception of actions.

This concept was first demonstrated at the cellular level. Mirror neurons are neurons in the macaque monkey premotor area F5 which discharge when monkeys execute distal goal-directed motor acts such as grasping, holding or tearing an object and when monkeys observe someone performing the same action [2]. Human physiological data, using brain imaging techniques which emerged in the last decades such as positron emission tomography, functional magnetic resonance imagery or electroencephalography confirm in humans what mirror neurons demonstrated: the perception of other individuals' behaviors utilizes neural bases for the control of the self's actions [1].

Motor resonance is evident in behaviors like action contagion (contagion of yawning for example), motor priming (the facilitation of the execution of an action by seeing it

done) and motor interference (the hindering effect of observing incompatible actions during execution of actions [3]). It also impacts everyday life. The chameleon describes the unconscious reproduction of “postures, mannerisms, facial expressions and other behaviors of one’s interacting partner” [4].
The main function attributed to motor resonance is action perception. It was reported that lesions of premotor cortices, involved in the control of action, impairs the perception of biological motion presented using point-light displays [5]. Another function frequently associated with resonance is imitation. Key brain regions for the human imitation are the left inferior parietal lobule [6] and the ventral premotor cortex [7], homolog of the macaque monkey area PF and F5 where mirror neurons were reported. The rest of this paper will review evidence that motor resonance is a valid framework to understand some aspects of human-robot embodied interactions, both in terms of describing the principles underlying human perception of humanoid robots action and of implementing neuromimetic principles for robot motor learning.

2 Motor Interference

A consequence of motor resonance, motor interference is the influence the perception of another individual’s actions has on the execution of actions by the self: observing an action facilitates the execution of the same action, and hinders the execution of a different action. A series of experiments was initiated by Kilner et al’s [3] study of motor interference when facing a real human being or an industrial robotic arm. Volunteers in this study produced a vertical or horizontal arm movement while watching another agent in front of them producing a spatially congruent (ie vertical when vertical, horizontal when horizontal) or a spatially incongruent (horizontal when vertical and vertical when horizontal) movement. The interference effect, measured by the increase of the variance of a movement, was found when subjects watched an arm movement spatially incompatible with the one they were producing (e.g. vertical versus horizontal, Fig. 1) [3]. This study did not find any interference effect using an industrial robotic arm moving at a constant velocity.
This experimental paradigm was adapted [8] to investigate how humanoid robots interfere with humans. Subjects performed rhythmic arm movements while observing either a human agent or humanoid robot performing either congruent or incongruent movements with comparable kinematics. We found that in contrast to the industrial robotic arm, a humanoid robot executing movements based on motion captured data caused a significant change of the variance of the movement depending on congruency [8]. The ratio between the variance in the incongruent and in the congruent conditions increases from the industrial robotic arm (r=1, no increase in incongruent condition), the humanoid robot (r~1.5) and the human (r~2). In a follow-up experiment, we found that the increase in the incongruent conditions was significant when the robot movements followed biological motion, but not an biologically invalid motion with linear velocity [9]. These results suggest that motor interference is an interesting metric for motor resonance with humanoid robots.

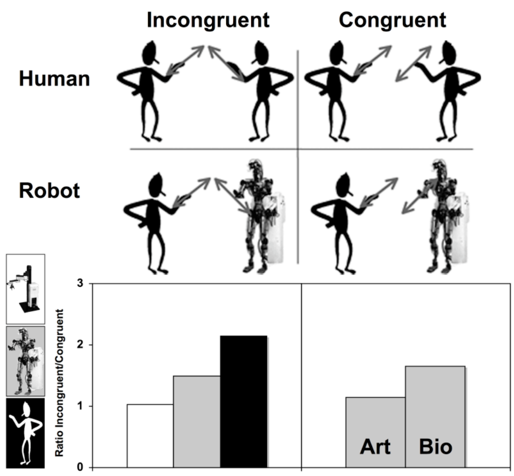

Fig. 1. top: factorial plan showing the conditions of motor interference experiments: horizontally, the spatial congruency between the two agents' movements; vertically, the agent being tested, a human or the humanoid robot DB. Bottom: summary of the experimental result. The ratio between the variance for incongruent and congruent movements is shown for three agents, an industrial robot [3], a humanoid robot [8] and a human [3, 8] on the left, and for the humanoid robot acting with artificial (ART) or biological (BIO) motion [9] on the right.

3. Imitation bootstrapping by a robotic hand

The origin of motor resonance is debated, and it has been argued that it could emerge as a result of self-observation. In a computational framework, the hypothesis is that the synchrony between motor commands sent to a visible effector like the hand and the sensory feedback, like the experience of a baby during motor babbling, can induce Hebbian-like acquisition of sensory-motor associations forming a motor resonance network. The activation of such a network when actions from another person are perceived could result in automatic and involuntary production of the associated motor output, a behaviour that would be considered as one of the simplest forms of imitation: action contagion.

We tested this proposal on a realistic experimental platform, [10]. We combined a 16 degrees of freedom robotic hand and a minimal visual retina using an associative network based on Hebbian learning. This visuomotor association network, trained by the self-observation of hand postures, was able to reproduce gestures shown with another hand, but also to generalize to new hand postures the network hadn't experienced during training. These results indicate that crucial features of human imitation, such as the generalization to new actions, can emerge from a connectionist associative network. Therefore, we suggested that behaviours as complex as imitation, including more complex forms requiring parsing an observed action into its sub-components, can be achieved in humanoid robots using realistic cognitive architectures based on recent developments on the origin and physiology of motor resonance.

4. Conclusions

Because it is a solid theoretical basis from neuroscience, motor resonance is a promising framework to describe some aspects of embodied interactions between natural and artificial agents and develop new interaction frameworks. Behavioral results, based on experimental paradigm originally developed to investigate human behavior, indicate that motor resonance is modulated by the appearance of the agent, with intermediate measure for anthropomorphic robotic devices in comparison to non anthropomorphic devices and real humans. Following a first proof of concept, robotic implementation of the developmental origin of motor resonance can be used to implement neuromimetic robotic controllers sustaining simple motor resonance in humanoid robots, including the emergence of motor behaviors. This could take the form of a visuomotor association network similar to the network used for bootstrapping hand imitation with at its core a representation of the robot's body including all its degrees of freedom, that would be connected to other controllers and parameterized in order to bias robot's actions towards resonating behaviours such as synchronization of eyes, head, or other rhythmic movements.

5. References

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