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Research Report

Robotic movement elicits automatic imitation

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Abstract

Recent behavioural and neuroimaging studies have found that observation of human movement, but not of robotic movement, gives rise to visuomotor priming. This implies that the 'mirror neuron' or 'action observation–execution matching' system in the premotor and parietal cortices is entirely unresponsive to robotic movement. The present study investigated this hypothesis using an 'automatic imitation' stimulus–response compatibility procedure. Participants were required to perform a prespecified movement (e.g. opening their hand) on presentation of a human or robotic hand in the terminal posture of a compatible movement (opened) or an incompatible movement (closed). Both the human and the robotic stimuli elicited automatic imitation; the prespecified action was initiated faster when it was cued by the compatible movement stimulus than when it was cued by the incompatible movement stimulus. However, even when the human and robotic stimuli were of comparable size, colour and brightness, the human hand had a stronger effect on performance. These results suggest that effector shape is sufficient to allow the action observation–matching system to distinguish human from robotic movement. They also indicate, as one would expect if this system develops through learning, that to varying degrees both human and robotic action can be 'simulated' by the premotor and parietal cortices.

Theme: Neural basis of behaviour
Topic: Cognition

Keywords: Action observation; Imitation; Learning; Mirror-neuron system; Visuomotor priming; Stimulus–response compatibility

1. Introduction

In humans and monkeys, observation of human action gives rise to matching motor activation; to activity in the premotor and parietal cortices normally associated with execution of the observed action. Visuomotor priming of this kind has been demonstrated using a variety of neurophysiological techniques, including single cell recording [14,34,40], functional magnetic resonance imaging (fMRI) [5,18,19,24], positron emission tomography (PET) [16,17], electroencephalography (EEG) [3,9,29] and transcranial magnetic stimulation (TMS) [2,30,35]. At the behavioural level, visuomotor priming takes the form of 'automatic imitation' [23]; in the absence of instruction to imitate, movement observation facilitates execution of the observed movement and/or interferes with performance of an alternative movement. For example, research using stimulus–response compatibility (SRC) paradigms has shown that responses to human body movement stimuli (e.g. a video image of a hand opening) are faster and more accurate when they involve execution of the same movement (hand opening) than when they involve execution of an alternative movement (hand closing) and that this compatibility effect is present even when the identity of the stimulus movement (open or close) is task-irrelevant [4,12,23,36,41].

It has been suggested that visuomotor priming is part of a 'simulation' process which enables individuals to recognise the actions of others and thereby to apprehend their mental states [13,15,25]. For example, Kilner et al. [27, p.525], referring to Gallese [13], note: 'it has been proposed that the

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mirror system might have evolved to facilitate communication, empathy, and the understanding of other people's mental states. Simulating other people's actions would trigger an action representation from which the underlying goals and intentions could be inferred on the basis of what our own goals and intentions would be for the same action'. This hypothesis about the function of visuomotor priming is consistent with evidence that patients with Moebius syndrome, involving congenital paralysis of the facial muscles, are impaired in the recognition of facial expressions of emotion [10,11].

It is generally assumed that humans and some other animals have mental states, whereas machines do not. If this is correct, and if the function of visuomotor priming is to support inferences about mental states, visuomotor priming by mechanical movements could be maladaptive. It may result in false attribution of mental states to machines. Therefore, the simulation hypothesis is also consistent with recent reports that observation of the movements of mechanical devices, even when they are robotic (i.e. similar in appearance to human movements), does not give rise to visuomotor priming [7,14,27,28,39]. Single-cell recording has shown that 'mirror neurons' in area F5 of the monkey premotor cortex fire when the monkey grasps an object and when it observes a human hand grasping the same object, but not when the monkey sees the object grasped by a mechanical pincer [14]. Similarly, PET has detected significant activation in the left premotor cortex when human participants observed manual grasping actions performed by a human model, but not when they were performed by a robotic hand/arm [39].

The results of behavioural studies also indicate that robotic movements do not support visuomotor priming. In a task involving the separation of two parts of an object, Meltzoff [28] reported that 18-month-old infants completed the task after observing a demonstration by a human adult, but not after a demonstration performed by a mechanical device. In a series of experiments with healthy adults, Castiello et al. [7] found that components of manual grasping movements, such as maximum grip aperture and time to reach peak velocity, are affected by prior observation of a human model grasping an object of the same or different size and are not influenced by prior observation of a robotic hand/arm performing the same tasks. Similarly, Kilner et al. [27] showed that performance of sinusoidal arm movements in a vertical or horizontal plane was subject to interference from simultaneous observation of another human performing incompatible arm movements, i.e. movement in the opposite plane. However, when the model was a full-size robot – with head, trunk, arms and legs – rather than a human, execution of the prespecified movements was unimpaired by simultaneous observation of incompatible responding.

These findings imply that the system which mediates visuomotor priming – the 'mirror neuron' [33] or 'action observation–execution matching' [6] system – distinguishes categorically between biological movement of a human model and mechanical movement of a robot and that it is entirely unresponsive to the latter. On the assumption that robots do not have mental states or that the system evolved in a robot-free environment, lack of responsiveness to robotic movement is consistent with the hypothesis that the function of visuomotor priming is to support inferences about mental states [13,15,25]. However, there are both empirical and theoretical grounds for further more systematic investigation of the hypothesis that robotic movement does not support visuomotor priming.

The empirical evidence is inconclusive because the studies which have reported visuomotor priming for human but not for robotic stimuli have involved very little stimulus control. Typically, they have used just one token of the robotic stimulus type (one movement pattern performed by a single robot), and the appearance of this robotic movement token differed from that of the human movement tokens on a number of dimensions, e.g. shape, kinematics, size, colour and luminance. It is possible, therefore, that the robotic stimuli in these experiments failed to support visuomotor priming because they were insufficiently salient or, being less variable than the human movement stimuli, were more readily habituated. This would be implausible if all studies comparing visuomotor priming by human and robotic stimuli had similar results, but there is an exception. One study of object grasping found equivalent effects on movement duration, deceleration time and maximum grip aperture of observing a robotic hand and a human hand [[6], Experiment 1].

Recent theoretical work also suggests that further investigation of robotic movement stimuli is required. Analyses of behavioural data on imitation [20,22,23] and of the physiological properties of cortical areas involved in visuomotor priming [26] have converged on an associative learning hypothesis. This hypothesis suggests that the potential for visuomotor priming is learned through experience in which the individual contiguously observes and executes the same actions. For example, visuomotor priming of hand movements depends on cortical links established during visual observation of ones' own hand while performing such movements. Stimulus generalisation is a ubiquitous feature of associative learning [31]; the effects of training with a stimulus, X, are not only present in behaviour toward X, but also in behaviour elicited by other stimuli to the extent that those stimuli have physical characteristics in common with X. Therefore, if the associative learning hypothesis is correct, one would not expect robotic movement stimuli to be uniformly incapable of supporting visuomotor priming. Instead, one would expect robotic movements to support visuomotor priming to the extent that they resemble the human movements observed during acquisition of the cortical connections that mediate priming.

The present study investigated these predictions of the associative learning hypothesis by comparing the visuomo-