Human and Robotic Action Observation Elicit Automatic Imitation

Clare Press
Dept of Psychology
University College London
26 Bedford Way, London. WC1H
OAP.
c.press@ucl.ac.uk

Geoffrey Bird
Institute of Cognitive
Neuroscience
University College London
17 Queen Square, London.
WC1N 3AR.
g.bird@ucl.ac.uk

Rüdiger Flach
Dept of Psychology
University College London
26 Bedford Way, London. WC1H
OAP.
r.flach@ucl.ac.uk

Cecilia Heyes
Dept of Psychology
University College London
26 Bedford Way, London. WC1H
OAP.
c.heyes@ucl.ac.uk

Abstract

Recent behavioural and neuroimaging studies found that observation of biological action, but not of robotic action, elicits imitation and activates the 'mirror neuron system' in the premotor cortex (Kilner, Paulignan, and Blakemore, 2003; Castiello, Lusher, Mari, Edwards, and Humphreys, 2002; Meltzoff, 1995; Tai, Scherfler, Brooks, Sawamoto, and Castiello, 2004). This implies that the actions of other people and of mechanical devices are processed in categorically different ways. However, if the mirror system develops through learning (Heyes, 2001), generalisation should result in some activation when observing robotic action. We asked subjects to perform a prespecified action on presentation of a human hand or a robotic device in the final posture of the same action or the opposite action (Heyes, Bird, Johnson, and Haggard, 2004; Stürmer, Ascherschleben, and Prinz, 2000). Both the human and the robotic stimuli elicited automatic imitation: the prespecified action was initiated faster when it was cued by the same action than when it was cued by the opposite action. 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 point to the shape of the human hand as a source of features distinguishing human from robotic action. They also suggest, as one would expect if the mirror neuron system develops through learning, that to varying degrees both human and robotic action can be 'simulated' by the premotor cortex (Gallese and Goldman, 1998).

1 Introduction

A number of studies have shown that action perception can influence action production. For example, in a reaction time (RT) paradigm Brass, Bekkering, and Prinz (2001) asked participants to execute a prespecified action (moving their index finger up or down) as soon as they saw another person's index finger begin to move up or down. An 'automatic imitation' effect was obtained such that upward movements were executed faster in response to upward movements than to downward movements, and vice versa for the execution of downward movements. Thus, even when the executed movement is simple, and has been prepared in advance, action perception can influence action production.

Interactions between action perception and production are thought to be mediated by structures

in the premoter and parietal cortices. The most widely-cited evidence in support of this view comes from electrophysiological studies of 'mirror neurons' in the premotor cortex (e.g. Gallese, Fadiga, Fogassi, and Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese, and Fogassi, 1996) and inferior parietal lobule (Fogassi, Gallese, Fadiga, and Rizzolatti, 1998; Gallese, Fogassi, Fadiga, and Rizzolatti, 2002) of the macaque monkey. These cells fire both when the monkey performs an action and when it watches another monkey perform the same action. Functional magnetic resonance imaging (fMRI) has indicated areas with similar properties in the human premotor cortex and parietal lobes (e.g. Iacoboni et al., 1999; Buccino et al., 2001).

Evidence is accumulating that activation in 'mirror neuron' circuits, and behavioural phenomena like automatic imitation, occur when the stimulus action is biological, but not when it is robotic. For example, Castiello (2002) required participants to reach out and grasp an object after observing a human or a robot hand reaching for and grasping a similar object. When the stimulus hand was human, but not when it was robotic, the size of the object grasped by the stimulus hand influenced aspects of participants' action such as maximum grip aperture and time to reach peak velocity. Furthermore, using positron emission tomography (PET), Tai et al. (2004) found significant activation in the left premotor cortex when participants observed grasping actions performed by a human model, but not when the same actions were performed by a robotic model.

These results can be interpreted in at least two ways. First, they may indicate that the actions of other people and of mechanical devices are processed in categorically different ways. If this hypothesis is correct, one would not expect observation of robotic action to give rise to automatic imitation even when the robotic stimuli are as perceptually salient as human action stimuli. Second, results such as those of Castiello (2002) may indicate that, whereas both human and robotic movement stimuli give rise to motor activation, human movement stimuli typically receive more motor processing than robotic movement stimuli. According to this hypothesis, the difference between the two stimulus types is quantitative rather than qualitative. If it is correct, equally salient human and robotic movement stimuli should both elicit automatic imitation, and the human stimuli should have a stronger effect on performance.

The Associative Sequence Learning (ASL) model of imitation supports the second, quantitative hypothesis over the first, qualitative hypothesis. It suggests that the capacity to imitate is learned in a Hebbian fashion; through experience which causes concurrent activation of visual and motor representations of the same action. Hand movements are perceptually transparent (Heyes and Ray, 2000), and therefore self-observation is likely to provide much of the experience contributing to hand movement imitation. However, insofar as robotic hands are visually similar to human hands, one would expect them to benefit from generalization of the 'training' received during self-observation.

The present study aimed to determine whether human and robotic stimulus hands, matched on a range of physical dimensions, would both elicit automatic imitation, but to different degrees.

2 Procedure and Results

We presented participants with four hand types; human naturalistic, human schematic, robotic naturalistic and robotic schematic (see Figure 1). In order to control kinematic variables we used static rather than moving stimuli. In addition, schematic stimuli were matched for size, luminance and colour, and only differed in shape. Naturalistic stimuli were matched as far as possible on these dimensions.
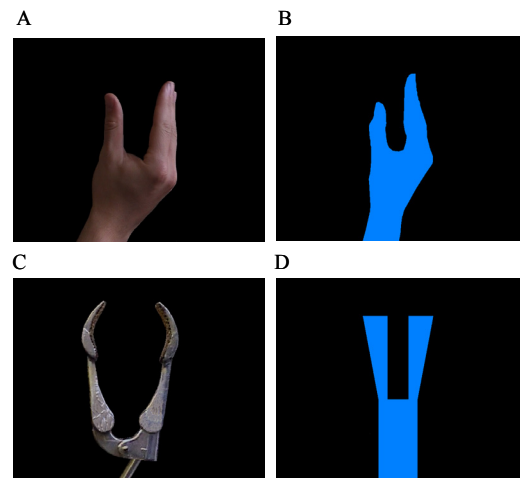

Figure 1. Experimental stimuli: A human naturalistic, B human schematic, C robotic naturalistic, D robotic schematic. Images depict hand in a neutral posture (warning stimulus).

Within a block, participants made the same response (opening or closing) in every trial. They were instructed to execute this movement as soon as a hand in a neutral posture on the computer screen

(the warning stimulus) was replaced by an opened or closed hand (the imperative stimulus). On compatible trials, the posture of the stimulus hand matched the end-point of the participant's response, and on incompatible trials, the stimulus hand was presented in the alternative posture. To control for spatial compatibility effects, the orientation of the participant's responding hand was orthogonal to that of the stimulus hand. Reaction times were recorded using EMG from the first dorsal interosseus muscle of the right hand.

The results showed that responding was faster on trials where stimulus movement type was compatible with response movement type, supporting previous findings of automatic imitation (e.g. Brass, Bekkering, and Prinz, 2001). There was a larger effect of automatic imitation with human stimuli than with robotic stimuli. This finding supported previous research suggesting human stimuli activate mirror systems to a greater extent than robotic stimuli (e.g. Tai et al., 2004). As some of our human and robotic stimuli were matched on all physical dimensions other than shape, the shape of a hand seems to be sufficient to modulate automatic imitation.

However, we still observed some automatic imitation with robotic hand stimuli. This implies both human and robotic action can be 'simulated' by the premotor cortex to varying degrees (Gallese et al., 1998), and is consistent with what one would expect if the mirror neuron system develops through learning (Heyes, 2001).

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