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Review

Action observation and robotic agents: Learning and anthropomorphism

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ABSTRACT

The 'action observation network' (AON), which is thought to translate observed actions into motor codes required for their execution, is biologically tuned: it responds more to observation of human, than non-human, movement. This biological specificity has been taken to support the hypothesis that the AON underlies various social functions, such as theory of mind and action understanding, and that, when it is active during observation of non-human agents like humanoid robots, it is a sign of ascription of human mental states to these agents. This review will outline evidence for biological tuning in the AON, examining the features which generate it, and concluding that there is evidence for tuning to both the form and kinematic profile of observed movements, and little evidence for tuning to belief about stimulus identity. It will propose that a likely reason for biological tuning is that human actions, relative to non-biological movements, have been observed more frequently while executing corresponding actions. If the associative hypothesis of the AON is correct, and the network indeed supports social functioning, sensorimotor experience with non-human agents may help us to predict, and therefore interpret, their movements.

Contents

1. Introduction

Observation of actions activates the motor codes required for their performance. For example, it has been shown behaviourally that we automatically imitate others, when there is no intention to have done so, and no reported awareness of having done so (e.g. Chartrand and Bargh, 1999). In line with such behavioural data, neuroimaging studies have shown that observing action activates an 'action observation network', including ventral and dorsal premotor cortices, primary motor cortex, and inferior parietal lobule (Rizzolatti et al., 1996; Buccino et al., 2001; Grezes and Decety, 2001; Gazzola and Keysers, 2008; Kilner et al., 2009). Some of these areas, namely ventral premotor cortex and inferior parietal lobule, correspond to those in which 'mirror neurons' have been found in the macaque monkey: These neurons discharge not only when the monkey executes an action of a certain type (e.g. precision grip),

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but also when it observes the experimenter performing that action (Di Pellegrino et al., 1992; Gallese et al., 1996, 2002; note that neurons with similar properties have also been found in primary motor cortex and dorsal premotor cortex (Cisek and Kalaska, 2004; Dushanova and Donoghue, 2010)).

The AON is biologically tuned, such that it responds more to the observation of human, than non-human, movement (either defined by form or kinematic profile). This biological tuning may be crucial for sociocognitive functioning, which the AON is hypothesized to support (e.g. Gallese and Goldman, 1998). On the basis of such hypotheses, some have suggested that when the AON is active during the observation of non-human agents like humanoid robots, it is a sign of the ascription of human properties such as mental states to these agents (e.g. Oberman et al., 2007; Gazzola et al., 2007; Chaminade and Cheng, 2009). For example, Oberman et al. (2007) claim that 'the implication is that the human mirror neuron system may be activated as a result of the human interactant anthropomorphising these robots. Indeed, by activating the human mirror neuron system humanoid robots could potentially tap into the powerful social motivation system inherent in human life, which could lead to more enjoyable and longer lasting human-robot interactions' (p. 2195). Similarly, Gazzola et al. (2007) say 'now we know, that our mirror neuron system may be part of the reason why, when in Stars Wars, C3PO taps R2D2 on the head in a moment of mortal danger, we cannot help but attribute them human feelings and intentions, even if their physical aspect and kinematics are far from human' (p. 1683). Furthermore, Chaminade and Cheng (2009) state 'the underlying assumption is that the measure of. . . (AON activation) indicates the extent to which an artificial agent is considered as a social inter-actor' (p. 289).

This review will outline evidence of biological tuning in the AON. It will consider the AON to be a mechanism which translates an observed action into motor codes required for execution. It will therefore cover behavioural studies indicating operation of such translation processes (see Heyes, in press) and neurological studies suggesting activation of components of the motor network when observing actions, including primary motor cortex, and ventral and dorsal premotor cortices; both BA6 and BA44. This range of coverage is not assuming that activations in different components of the motor network will all necessarily signal the same processes; it simply reflects that, on the basis of present theorizing about the AON, the components cannot be divided functionally with confidence. It will examine the features of observed actions which generate biological specificity, and conclude that there is evidence for tuning to both the form and kinematic profile of observed movements, and little evidence for direct tuning to belief about identity. It will subsequently propose that biological tuning in the AON is a result of more frequent and systematic observation of human actions while executing corresponding actions. If the AON develops through learning, and it indeed supports social functions such as action understanding, sensorimotor experience with agents may help us to predict, and therefore interpret, their movements.

2. Biological tuning in the AON

Kilner et al. (2003) showed that the execution of sinusoidal arm movements in a vertical or horizontal plane was subject to interference from simultaneous observation of another human performing arm movements in the opposite plane; if participants executed vertical arm movements while observing horizontal movements, there was greater variance in the horizontal dimension, compared with conditions where they observed vertical movements (Fig. 1a). This 'interference effect' is thought to be a result of the automatic activation of motor codes which correspond to observed action, and interference between these motor codes and those required for executing the intended action. When the observed movements were made by a robotic arm, there was no interference effect. Imaging studies support these behavioural findings: A positron emission tomography (PET) study found that the observation of human grasping actions activates premotor cortex to a greater degree than the observation of similar robotic actions (Tai et al., 2004). Furthermore, in three functional magnetic resonance imaging (fMRI) studies, stronger premotor activation was found when participants observed meaningless human hand movements relative to the movements of yellow objects (Engel et al., 2008; BA6), human finger actions relative to scissor movements (Costantini et al., 2005; BA44), and humans rather than robots dancing (Miura et al., 2010; BA44 and BA6).

However, there are at least two differences between the human and non-human stimuli presented in these five experiments. First, the stimuli differ in form. Namely, the human stimuli are a flesh colour and rounded, whereas the non-biological stimuli are often more geometric. Second, the stimuli differ in kinematics. The human arms have followed an approximately minimum jerk trajectory, where the movement is slow at turning points and speeds up on straighter trajectories (Hogan, 1984). The non-biological stimuli have tended to move with constant velocity. A number of studies have controlled for one of these factors while measuring the effect of the other, to investigate whether one or both of form and kinematics generate the biological specificity within the AON.

2.1. Biological tuning evidence: influence of form

In a simple reaction time (RT) task, Brass et al. (2001) found evidence of greater AON activation when stimuli had a human, rather than square, form, and stimuli were matched for kinematics. Participants were required to make a pre-specified index finger lifting or tapping movement whenever they saw the index finger of an observed hand move. They were faster to execute this movement (e.g. finger lifting) in response to observed compatible (lifting) rather than incompatible (tapping) movements. This effect has been termed the 'automatic imitation' effect, given that it signifies primed imitative, relative to non-imitative, responses (see Fig. 1b), and for similar reasons to the interference effect, is considered to reflect automatic activation of motor codes which correspond to observed actions. Brass et al. (2001) found no evidence of an automatic imitation effect when responses were made to a square that moved up or down with the same kinematic profile as the observed finger actions. Likewise, in a paradigm akin to that employed by Kilner et al. (2003), Gowen et al. (2008) found a greater interference effect when participants observed a real human model performing movements which were incongruent with their own, relative to a point on a computer monitor moving with a similar kinematic profile. An electroencephalography (EEG) study has indicated that these behavioural effects may result from differences in processing in motor circuits: Oberman et al. (2005) found greater attenuation of *mu* frequency oscillations over sensorimotor electrodes – a signature of sensorimotor cortex activation – when participants observed videos of hand movements rather than balls which moved with the same kinematics. Additionally, a magnetoencephalography (MEG) study demonstrated differential processing in ventral premotor cortex when observing and imitating finger movements rather than points moving with similar kinematics (Kessler et al., 2006; Biermann-Ruben et al., 2008; cf. Jonas et al., 2007).

Influences of form on AON activation have also been found when the non-human stimuli are more similar to the human stimuli. Perani et al. (2001) found activation in left BA6 when participants observed real human hand grasping actions, but not when observing a virtual reality hand moving with the same kinematics. In addition, Press et al. (2005) investigated differences in processing of human and robotic form, while controlling for kinematics, by