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Brief article

Sensorimotor training alters action understanding

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ABSTRACT

The discovery of 'mirror' neurons stimulated intense interest in the role of motor processes in social interaction. A popular assumption is that observation-related motor activation, exemplified by mirror neurons' matching properties, evolved to subserve the 'understanding' of others' actions. Alternatively, such motor activation may result from sensorimotor learning. Sensorimotor training alters observation-related motor activation, but studies demonstrating training-dependent changes in motor activation have not addressed the functional role of such activation. We therefore tested whether sensorimotor learning alters action understanding. Participants completed an action understanding task, judging the weight of boxes lifted by another person, before and after 'counter-mirror' sensorimotor training. During this training they lifted heavy boxes while observing light boxes being lifted, and vice-versa. Compared to a control group, this training significantly reduced participants' action understanding ability. Performance on a duration judgement task was unaffected by training. These data suggest the ability to understand others' actions results from sensorimotor learning.

1. Introduction

Whether, and to what extent, the motor system plays a role in the perception and understanding of observed actions is a matter of fierce debate within cognitive science. There is relatively unambiguous evidence that motor-related neural structures are activated by action observation, exemplified by over two decades of research on mirror neurons (motor-related neurons which fire during both action performance and observation of another performing a related action; di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992); but the function of such observation-related motor activation is still unclear. Some theorists argue that motor activation plays a causal role in the perception and understanding of others' actions ('embodied simulation'; Gallese & Sinigaglia, 2011), whereas others argue that motor activation is the consequence (not cause) of action perception and understanding (Mahon & Caramazza, 2008), or that motor activation contributes to action perception in a domain-general fashion, impacting on processes such as attention and rhythm perception that are recruited for action and non-action stimuli alike (Press & Cook, 2015).

Questions concerning the function of observation-related motor activation are orthogonal to questions concerning the origin of such activation, but empirical evidence pertaining to one question has often been used to support a position with respect to the other. For example, supporters of embodied simulation theories argue that mirror neurons within the motor system subserve the 'understanding' of others' actions (Rizzolatti, Fadiga, Gallese, & Fogassi, 1996); and that the matching properties of mirror neurons evolved specifically to subserve such 'action understanding' (Fogassi, 2014; Gallese, Rochat, Cossu, & Sinigaglia, 2009).

An alternative to such theories is that observation-related motor activation originates from sensorimotor learning in which the perceptual representation of an action is associated with the motor program for that action (Cook, Bird, Catmur, Press, & Heyes, 2014). This theory is well supported by empirical data; for example, 'counter-mirror' sensorimotor training (associative training in which observation of one action is systematically paired with performance of another action, for example performing an index finger action while observing a little finger action) has reliably been shown to change mirror neuron responses (Catmur, Walsh, & Heyes, 2007; Cavallo, Heyes, Becchio, Bird, & Catmur, 2014; de Klerk, Johnson, Heyes, & Southgate, 2015; Petroni, Baguear, & Della-Maggiore, 2010; Press et al., 2012).

However, the question of whether sensorimotor learning alters not only observation-related motor activation, but also the 'understanding' of others' actions, has not been addressed (Rizzolatti & Sinigaglia, 2010;

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Fig. 1. Screenshots from an exemplar box lifting video.

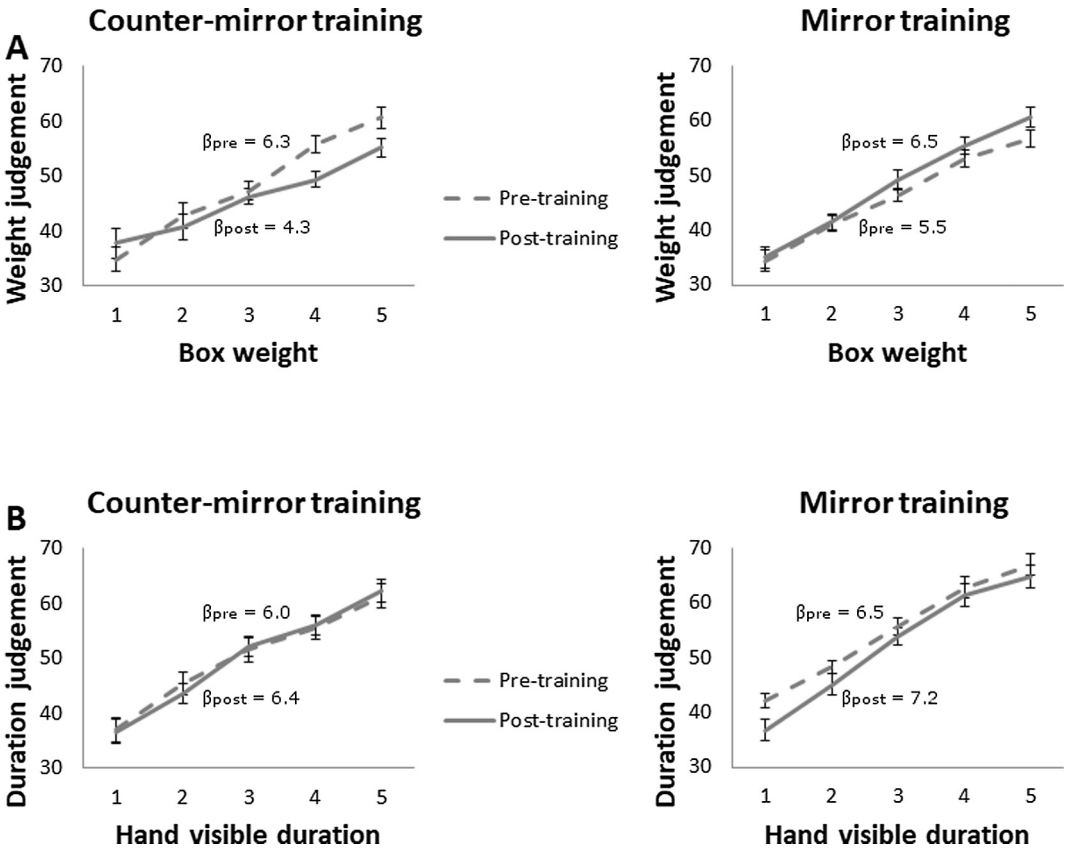

Fig. 2. Mean ± standard error of the mean performance on A. the weight judgement and B. the duration judgement tasks in the two training groups before and after training. β values indicate the regression line slope. Counter-mirror training reduced performance on the weight judgement task, whereas performance on the duration judgement task was unaffected by training.

see also Hickok, 2009). In particular, supporters of the embodied simulation account have proposed that although sensorimotor training may alter observation-related motor activation, it would not affect action understanding because 'movement mirroring' is distinct from 'goal mirroring' (Rizzolatti & Sinigaglia, 2010, p. 269). In contrast, the sensorimotor learning account predicts that any learning that alters observation-related motor activation should also alter action understanding, if action understanding relies on such activation. The present study therefore addressed this gap in the literature by testing whether sensorimotor learning, the process theorized to give rise to observation-related motor activation, alters the hypothesized function of such activation, action understanding.

The term 'action understanding' has been used to refer to various stages in processing others' actions, including: action perception (Pobric & Hamilton, 2006; Saygin, Wilson, Dronkers, & Bates, 2004); identification of the 'goal' of an action (Rizzolatti & Fabbri-Destro, 2008); and identification of the actor's underlying intentions (Iacoboni et al., 2005). As we have recently argued (Catmur, 2014, 2015), there is little empirical evidence supporting the involvement of motor processes in identifying intentions from actions; but there is some evidence that motor brain areas, including areas thought to contain mirror neurons, are involved in aspects of action perception, including the ability to discriminate between actions based on perceptual differences. The clearest demonstration of the role of motor areas in action perception utilizes a task (Runeson & Frykholm, 1981) in which participants judge a box's weight by watching videos of a hand lifting the box and placing it on a shelf. Performance on this task is disrupted by repetitive transcranial magnetic stimulation to inferior frontal gyrus (Pobric & Hamilton, 2006), consistent with the idea that motor-related areas are required to perform this task (see also Hayes, Hodges, Huys, & Williams, 2007; Moro et al., 2008; Saygin, 2007).

In the present study, we therefore use 'action understanding' to refer to perceptual discrimination between actions, as the definition where there is most evidence of a motor (and possibly therefore mirror neuron) contribution. Thus the fairest test of whether sensorimotor learning affects action understanding as well as producing observation-related motor activation is to use the definition of action understanding for which a motor contribution has been demonstrated.

Participants in the present study therefore completed an action understanding task in which they judged the weight of boxes lifted by another person, before and after 'counter-mirror' sensorimotor training. During this training, they lifted heavy boxes while observing light boxes being lifted, and vice-versa. The control group received 'mirror' sensorimotor training, wherein they lifted heavy boxes while observing