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Full Length Article

The action-specific effect of execution on imagination of reciprocal aiming movements

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ABSTRACT

Past research has shown that the movement times of imagined aiming movements were more similar to actual movement times after the individual has experienced executing the movements. The purpose of the present study was to determine if experience with a set of movements altered the imagination of movements that were not experienced. Participants imagined a series of reciprocal aiming movements in different movement difficulty contexts (created by altering target width and movement amplitude) before and after actually executing a series of aiming movements. The range of difficulties of the imagined movements included difficulty contexts that were within (Experiment 1) or outside (Experiment 2) the range of difficulty experienced during execution. It was found that imagined movement times of movements within the range of movement difficulties experienced were more consistent with Fitts' Law after movement experience, whereas imagination of more difficult movements was not altered by experience. It is suggested that execution did not enhance imagination of more difficult movements because the relative contributions of motor planning and control to the more difficult movements were different from those in the experienced movements. Thus, the enhancement of imagination through experience might only occur when mechanisms underlying the executed and imagined movements are similar.

1. Introduction

Imagining a simple action, such as picking up a glass, is closely related to executing that same action, with the exception that motor output is absent. Indeed, Decety and Jeannerod (1995) defined motor imagery as a "dynamic state during which a subject mentally simulates a given action" (p. 127). Converging evidence from several sources indicate that many of the principles associated with action execution also pertain to motor imagery (Jeannerod, 1995, 2004). For example, past research has revealed that motor imagery and execution involve activation of very similar cerebral structures (Crammond, 1997; Jeannerod, 2001; Sirigu et al., 1995). These similarities have led some researchers to hypothesize that a common ideomotor network may underlie the processes of action execution and imagination, and maybe even perception (Hommel, 2009; Jeannerod, 2001; Prinz, 1997). In this ideomotor approach, it is hypothesized that the neural codes that are responsible for generating actions are tightly coupled with the neural codes that represent the perceptual consequences of that action (for reviews see Hommel, 2009; Prinz, 1997; Shin, Proctor, & Capaldi, 2010). In action imagination, these neural codes are run at a sub-threshold level such that individuals can effectively simulate a given action via the thought or perception of its perceptual effects (Grosjean, Shiffrar, & Knoblich, 2007; Jeannerod, 2001). It is this common ideomotor network that may link the processes of action execution, imagination and perception.

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Furthermore, the coupling or binding of action and effect codes is suggested to occur through experience and/or training. Once these corresponding codes are integrated, the activation of one code will lead to the excitation of the other (Shin et al., 2010). Elsner and Hommel (2001) demonstrated this action-effect integration through experience across a series of studies. During the training phase of one task, the researchers had participants perform a choice reaction time task in which they made arbitrary left and right keyboard presses. A specific effect tone followed each response – a high tone followed a left key press and a low tone followed a right key press. It was predicted that the constant pairing of a response with an effect tone would lead to binding between that specific response and a specific tone. Following the training, subjects were presented with a free-choice task where the effect tones were randomly presented prior to the moment in which the participant was to choose to execute a left or right key press. The critical finding of the studies was that participants were more likely to choose and execute a compatible response to the task-irrelevant tone effects. That is, left key responses were made more often after a high tone and right key responses were made more often following a low tone was presented. The authors concluded that this finding indicated that participants formed an association between the codes for the motor pattern underlying the action and the perceptual code representing the consequence of the action, lending support for a bidirectional relationship between actions and their perceptual effects. Comparable effects of action-effect binding have been reported for visual (Kunde, 2001), temporal (Kunde, 2003), semantic (Koch & Kunde, 2002), and other relations between actions and effects.

Similar training effects have been observed or intuited from studies of action imagination and execution in aiming movements. In these behavioral studies, paradigms exploiting Fitts' law have been utilized because this equation accurately characterizes the speed-accuracy trade-off that occurs during rapid aiming movements and, hence, provides a solid platform upon which to form predictions. Fitts' law describes the logarithmic relationship between the speed and accuracy of movements as a function of the difficulty of the movement (Fitts, 1954). Specifically, while performing a reciprocal pointing task, participants increase their movement times (MTs) to maintain accuracy and precision across movements of increasing difficulty. This speed-accuracy relationship can be described by the formal equation: $MT = a + b\left(\log_2 \frac{2A}{W}\right)$, where a and b are constants related to an individual's base MT and the unit increase in difficulty as function of movement difficulty, respectively. The $\left(\log_2 \frac{2A}{W}\right)$ component of the equation quantifies the difficulty of the movement, and has been termed the index of difficulty (ID). This ID is related to the width of the target (W) and the movement amplitude (A) (centre-to-centre distance between the targets). Effectively, as either movement amplitude increases or target width decreases, actors need to increase their MTs to maintain accuracy.

This speed-accuracy trade-off has been observed in imagined movements as well. For instance, Sirigu et al. (1995) had a patient with a unilateral lesion of the motor cortex both execute and imagine moving a pen back and forth between a starting position and a target. Critically, the target width was manipulated in accordance with Fitts' law. They found that executed and imagined MTs were linearly related to ID, conforming to Fitts' law (see also Decety & Jeannerod, 1995). Most interestingly, motor imagery was impaired for the same movements which the patient had difficulties executing overtly. In neurotypical adults, Fitts' speed-accuracy trade-off has consistently been shown in imagined pointing movements (Cerritelli, Maruff, Wilson, & Currie, 2000; Macuga, Papailiou, & Frey, 2012; Papaxanthis, Schieppati, Gentili, & Pozzo, 2002; Young, Pratt, & Chau, 2009) and, more recently, researchers have revealed accuracy-dependent activation of the right cerebellum and superior parietal lobule when imagining a Fitts'-type task (Lorey et al., 2010). These results provide evidence that Fitts' law is present in imagined movements. On the larger theoretical level, the presence of Fitts' law in imagined movements and, in particular, the similarity in imagined and executed MTs is consistent with an ideomotor account of action imagination. The similarity in imagined and executed MTs is consistent with the ideomotor account because, according to this account, the same action-effect codes that enable execution are also engaged at a sub-threshold level during action imagination.

More recently, Wong, Manson, Tremblay, and Welsh (2013) conducted a further testing of the ideomotor account by investigating the relationship between action execution and imagination of a reciprocal aiming task.[1] Consistent with previous work, these authors used MT as a common measure of actual and imagined movements. In addition to assessing the relationship between execution and imagination, the study was designed to examine the effect that execution (i.e., task experience) had on imagined MTs. To achieve this latter goal, participants performed the action imagination task before and after executing the same movements. Based on previous work showing that executing a movement and experiencing the perceptual consequences of the movement enhances the association between the codes representing them (e.g., Elsner & Hommel, 2001; see also Heyes, 2001), they predicted that motor experience should lead to a refinement of the action and effect codes and an enhancement of the link between those codes. The consequence of these refinements and enhancements would be that MTs in the imagination task would be more similar to actual execution MTs following task experience. The critical finding of the study was that imagined MTs were indeed more similar to execution MTs after experience with the aiming task. A control group who completed a non-aiming task in between imagination sessions did not show a change in imagined MTs suggesting that time, repeated experience with the imagination and perception tasks, and motor system activation was not responsible for the change in MTs. The authors suggested that the reduction in imagined MTs following task experience was due to enhanced action-effect binding, specific to the experience with the task. Specifically, it was thought that the tighter coupling of action and effect codes (brought about via experience) meant that participants could more effectively and realistically simulate actions that were closer to their actual MTs. This enhanced imagination resulted in an imagination experience

[1] Note that action perception was also examined this Wong et al. (2013) study. Because the present research focuses on imagination, the results of the perception task will not be discussed further. It should be noted, however, that the results for the perception task were consistent with those of the action imagination task and, as such, supported the hypothesis that a common representational network underlies action execution, imagination, and perception. Please read Wong et al. (2013) for more details.