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Short communication

Effect of task-specific execution on accuracy of imagined aiming movements

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HIGHLIGHTS

- A common ideomotor network may link action imagination and execution.
- Imagined movement times (MTs) have been shown to decrease after execution.
- Present work studied how specificity of execution experience affects imagined MT.
- Imagined MT was reduced more when execution was specific to the imagined task.

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ABSTRACT

Ideomotor theory states that the neural codes that represent action and the perceptual consequences of those actions are tightly bound in a common code. For action imagination, bound action, and perceptual codes are thought to be internally activated at a sub-threshold level through action simulation. In support of this hypothesis, previous research revealed that imagined movement times (MTs) for reciprocal aiming movements were closer to actual execution MTs after the participants gained experience executing the task. The current study examined the task-specific nature of the effects of experience on imagination by determining if improvements in accuracy in the imagination of reciprocal aiming movements occur only with experience of the reciprocal aiming task or with any aiming task. To this end, one group of participants executed a reciprocal pointing task, whereas a second group executed a discrete aiming task with comparable accuracy requirements before and after imagining reciprocal aiming movements. Influence of task specificity on imagination was assessed by evaluating the changes in imagined MTs before and after execution. Consistent with previous findings, there was a reduction in imagined MTs following task execution. Critically, there was a significant time by group interaction revealing a significant pre/post reduction in imagined MTs for the group that executed the reciprocal aiming movements, but not for the group that executed the discrete aiming movements. These data support ideomotor accounts of action imagination because it appears that the imagination of a movement is affected by task-specific experience with that movement.

1. Introduction

We are not only able to plan and execute actions, but we are also able to perceive and imagine these same actions. There has been an interest in the commonalities across these processes for more than a century [1]. More recent experimental research has elucidated the potential behavioral and neurophysiologic similarities across imagined, perceived, and executed action. The results of this research suggest that an ideomotor or common coding network may underlie these processes, see [2,3] for reviews. Ideomotor theory is based on the premise that the neural codes that represent and generate an action are tightly coupled with the codes that represent the perceptual consequences of that action. Perception can therefore be seen not only as the consequence of action, but also directly associated with its cause [4]. Binding and refining of action and consequence codes may occur through physical practice or familiarization with the task [5]. This experience-driven refining and binding of the perception and action codes allows one to efficiently activate the action codes needed to bring out a selected consequence and to accurately predict the perceptual outcomes once a specific action has been selected, see [4] for review.

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Furthermore, common coding theory consolidates ideomotor theory with recent neurophysiologic and behavioral evidence to explain the link between action execution, perception, and imagination. The main tenet of this approach is that these processes share a common representational network or neural code [6]. Essentially, perception and imagination are processes in which ideomotor codes are run at a sub-threshold level such that by perceiving or imagining movement, one is also activating the motor code for that movement. This tenet has been supported by considerable neurophysiological evidence that has demonstrated activation of the motor system in action observation and imagination, see [7] for review.

Additional support for a common ideomotor network is found in several behavioral studies utilizing Fitts' law [8]. Fitts' law describes a linear relationship between the difficulty of a task and the movement time necessary to complete that task accurately, known as the speed–accuracy trade-off. This linear relationship can be described by the formal equation: $MT = a + b(ID)$, where MT is movement time, ID is the index of difficulty and "a" and "b" are constants relating to an individual's base MT and the unit increase in MT as a function of ID. Essentially, as a task becomes more difficult, an individual will need to increase their MT to maintain accuracy. Fitts' reciprocal aiming task requires an individual to move as quickly and accurately as possible between pairs of targets that vary in width and amplitude. The ID of the task is related to the width of the targets and the amplitude between them and is calculated using the equation: $ID = \log_2(2\,A/W)$, where A is the movement amplitude and W is the target width. Effectively, as targets became narrower and/or farther apart, there is an increase in the ID and, consequently, an increase in MT to maintain accuracy.

Fitts' law has been shown to hold not only in execution, but also in imagination and perception of movement. Decety and Jeannerod [9] used mental chronometry to demonstrate similarity in speed–accuracy trade-offs between real and imagined movements. In this experiment, participants were asked to imagine themselves walking through gates of three different widths, placed at three different apparent distances. Both real and imagined walking times conformed to Fitts' speed–accuracy trade-off. Subsequently, Sirigu et al. demonstrated that imagined manual aiming movements also scaled to Fitts' law [10]. These studies demonstrated that there is a relationship between actual and imagined movements. Finally, it has also been shown that Fitts' law holds in the perception of aiming movements [11]. In support of the hypothesis that common codes underlie action perception, the accuracy of these perceptions has been shown to improve following execution of the perceived movements [12]. This experience-driven improvement in action perception demonstrates that experience with a task may allow for the enhanced integration and refinement of action and consequence codes.

To specifically examine the relationship between action execution, perception, and imagination, Wong et al. [13] had participants both perceive and imagine reciprocal aiming movements before and after executing the same movements. Although they did not find a change in perceived MTs following execution at the group level [cf 12], there were changes in perception on the individual level, consistent with previous findings. Further, imagined MTs were reduced, closer to execution MTs, after having executed the task. Critically, a control group who completed a non-aiming (button pressing) motor task in between imagination sessions did not show a significant decrease in imagined MTs. These control group results suggest that the decreases in imagined MTs following task execution could not simply be attributed to an effect of time, mental practice, or generalized motor system activation. Overall, these results support a common ideomotor network for the imagination and execution of action because participants were able to more accurately imagine their movements following task execution, likely due to experience-based refinement or enhanced binding of action and consequence codes.

The purpose of the current study was to test if improvements in action imagination following task experience are influenced by task-specificity. As discussed, ideomotor theory predicts that binding of action and consequence codes occurs following experience with a task and its associated effects. Therefore, a reduction in imagined MTs (approaching execution MTs) may only occur following execution of a reciprocal aiming task and not following practice of any other aiming task. To evaluate the potential task-specific nature of the effect of experience on action imagination, the current study compared changes in imagined MT of a reciprocal aiming task before and after execution of two different aiming tasks, both with inherent speed–accuracy demands. The critical manipulation was that separate groups of individuals physically completed either the reciprocal aiming movement that was imagined or a discrete aiming task with comparable accuracy requirements. It was hypothesized that if improvement in the timing of action imagination occurs only via task-specific, experience-driven binding of ideomotor codes, then there should be a larger reduction of imagined MTs for the group that executed the reciprocal task compared to the group that executed the discrete task. Alternatively, if the effects of execution on imagined MTs are due to an effect of time, generalized motor system activation, motor imagery practice, or experience with any aiming task that involves a speed–accuracy trade-off, then there should be no group differences in the effect of execution on imagined MTs.

2. Materials and methods

2.1. Participants

Twenty-four right-handed individuals (8 men and 16 women) aged 18–44 years old participated in the study and received monetary compensation for their time. All participants had normal or corrected-to-normal vision and were naive to the purpose of the study. Handedness was determined by self-report of hand preference on tasks of daily living. Participants provided informed consent and the procedures of the study were approved by Office of Research Ethics at the University of Toronto.

2.2. Design, apparatus, and tasks

The design of the current study was based on the study of Wong et al. [13]. In the action imagination and continuous execution tasks, the same set of nine posters was used. Each poster consisted of a pair of identical black target strips pasted onto a white poster board (57 cm [l] × 72.5 cm [w]). The targets were all 15 cm in length and one of three different widths (2, 4, or 8 cm). The center-to-center distance between the targets varied (4, 8, 16, 32, or 64 cm), generating three posters with IDs 2–4 for each of the three target widths. In the discrete execution task, nine different posters with the same target widths and movement amplitudes were used. For these posters, however, the right side rectangular target was replaced with a small circular home position, from which participants began their reaching movements.

2.2.1. Action imagination task

Participants sat in front of a table in view of an optoelectric motion tracking system (Optotrack Certus, Northern Digital Inc.). An infrared emitting diode (IRED) was attached to the participant's right index finger. One of the nine poster boards was clamped onto the table in front of the participant. The order of the posters was randomized. The participants were asked to imagine the look and feel of executing ten movements between the two targets as quickly and accurately as possible (i.e., one movement was from the right