



Research paper

The modulation of motor contagion by intrapersonal sensorimotor experience



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HIGHLIGHTS

- Execution is interfered when observing incongruent movements.
- Underpinned by the presence of response-specific feedback.
- Modulate the inhibition of interference through intrapersonal sensorimotor experience.
- Sensorimotor experience may relate to the sense of agency.

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ABSTRACT

Sensorimotor experiences can modify the internal models for action. These modifications can govern the discrepancies between predicted and actual sensory consequences, such as distinguishing self- and other-generated actions. This distinction may also contribute toward the inhibition of movement interference, which is strongly associated with the coupling of observed and executed actions. Therefore, movement interference could be mediated by the sensorimotor experiences underlying the self-other distinction. The present study examined the impact of sensorimotor experiences on involuntary movement interference (*motor contagion*). Participants were required to complete a motor contagion paradigm in which they executed horizontal arm movements while observing congruent (horizontal) or incongruent (vertical) arm movements of a model. This task was completed before and after a training protocol in which participants executed the same horizontal arm movements in the absence of the model stimuli. Different groups of participants trained with or without vision of their moving limb. Analysis of participants who were predisposed to motor contagion (involuntary movement interference during the observation of incongruent movements) revealed that the no vision group continued to demonstrate contagion at post-training, although the vision group did not. We propose that the vision group were able to integrate the visual afferent information with an internal model for action, which effectively refines the ability to match self-produced afferent and efferent sources of information during response-execution. This enhanced matching allows for a better distinction between self and other, which in turn, mediates the inhibition of motor contagion.

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1. Introduction

The mimicry of observed motor behaviours has been suggested to unfold because of a common relation between the neural codes

representing actions and their sensory consequences [1,2]. Because of this perception-action coupling, the observation of action can activate the neural codes that are responsible for the execution of corresponding action. This motor system activation increases the potential for observed actions to be executed by the observer; a concept referred to as *motor contagion* [3]. It is thought that this common coding can be empirically observed by the interference caused by observing movements incongruent to our own executed

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movements [4]. Neurophysiological and neuro-imaging techniques have indirectly traced these behavioural outcomes to premotor and fronto-parietal regions of the human brain [5,6]. This neural substrate seems to adhere to principles of Hebbian learning [7], and Associative Sequence Learning (ASL) theory [8,9], which highlights the formation of stimulus-response links via sensorimotor experience. That is, by repeatedly executing a movement, the motor codes representing the action and the sensory consequences of the action become refined and coupled [10]. In support of this experience-dependent coupling between perception and action, the interference on executed arm movements (e.g., horizontal) (as indicated by involuntary movement variance) caused by observing an incongruent movement (e.g., vertical) may increase after physical practice of the observed (e.g., vertical) movement [11]. Relatedly, the facilitation of congruent actions can be eliminated through short-term incongruent stimulus-response training in which the observer executes an alternative action to that being observed (e.g., close hand response execution following open hand observation) [12–14]. This incongruent sensorimotor training has been traced to the neural regions underlying typical (or congruent) mirror responses (premotor cortex, inferior parietal lobule; [15,16]).

There has been a growing interest in the inhibition of contagion. This inhibition may be governed by the medial prefrontal cortex and the temporo-parietal junction [17]; areas strongly related to social cognition [18]. It is proposed that these regions accommodate a distinction between self- and other-generated behaviours (see [19] for a review). Changes in the ability to distinguish between self- and other-generated behaviours could mediate the amount of contagion exhibited by the observer. For example, Cook and Bird [20] showed the initial priming of a prosocial attitude enhanced the mimicry of observed actions. The pro-social prime was proposed to have “blurred” the distinction between self and other, which caused a greater relation between observed and executed actions, and thus, generated contagion.

The distinction between self and other may also be drawn from lower-level processes. That is, the distinction may be determined by a discrepancy between the predicted and actual sensory consequences of executed actions [21] (see also [22]). A match between the predicted and actual sensory consequences leads one to conclude that they were responsible for the action, whereas a mismatch leads to the attribution of “other” sources. The predicted sensory consequences are driven by an internal model that can be updated through sensorimotor experience [10,23,24]. It is through repeated experience of the action and its subsequent outcomes that the performer can couple physical reafferent signals with the visual sensory consequences. To elucidate, using the ‘intentional binding’ paradigm (see [25]), where the performer binds the perceived time of an executed action and the subsequent stimulus event, researchers have quantified the distinction between self and other (also referred to as ‘sense of agency’). Of interest, it has been shown that exposure to stimulus information that is contingent upon an executed action (e.g., auditory tone following a finger response) can enhance intentional binding, and with it, the sense of agency [26]. Therefore, it is possible that in the absence of response-produced visual feedback, the motor events are rendered independent of the sensory events. In this situation, the predicted sensory consequences generated from the efference copy may be restricted to non-visual sources of afferent information. Consequently, the ability to distinguish between self- and other-generated actions based on response-produced visual information would be increased in someone trained with visual feedback of their own limb compared to without visual feedback, which would result in differences in the coupling of observed and executed actions, along with the incidence of motor contagion. In other words, the more an individual

experiences a specific sensorimotor coupling, the more likely a self-other distinction will occur and contagion will be reduced.

With this in mind, the present study was designed to examine how different sensorimotor experiences affect motor contagion. To this end, we employed a test-retest design in which participants executed cyclical horizontal arm movements during the observation of congruent (horizontal) or incongruent (vertical) movements. Contagion was indicated by an increase in movement variance in the unintended orthogonal (vertical) axis of movement during the observation of incongruent compared to congruent movements. Because this study examined the experience-dependent inhibition of contagion, it was imperative that the participants of interest were initially susceptible to contagion (e.g., [4]). During training, the participants executed horizontal arm movements either with or without vision. If response-specific visual-motor codes developed through sensorimotor experience help to distinguish self- and other-generated actions, which in turn, accommodate the inhibition of motor contagion, then less contagion would be observed after training for the group trained with vision. Meanwhile, if the absence of response-produced visual feedback causes self- and other-generated actions to appear less distinct, then contagion would continue to unfold for the group trained without vision. Although these predictions seem to conflict with the lower-level sensorimotor theories of imitation which generally predict sensorimotor experiences to enhance contagion (e.g., ASL), the present set of predictions are simply alternative outcomes based on the same stimulus-response mechanism. Whereas the sensorimotor experiences that are congruent with the observed stimulus have received most of the attention (e.g., [11]), the present study pertains to sensorimotor experiences of trained movements that are incongruent with the observed stimulus.

2. Method

2.1. Participants

Thirty-five participants (age range = 19–29 years) were randomly assigned to one of two groups (vision $n = 18$, no vision $n = 17$). All participants were self-declared right-handed, had normal or corrected-to-normal vision, and were compensated \$10 (CAD). The experimental procedures were approved by the Office of Research Ethics at the University of Toronto and conducted in accordance with the ethical guidelines and standards of the 1964 Declaration of Helsinki.

2.1.1. Apparatus, stimulus, task and procedure

The visual stimulus was displayed on a blank wall via a projector (Dell 1510X) at a viewing distance of 1.9 m. The experiment was controlled using PsychoPy [27] from a host PC with a spatial resolution of 1024×768 pixels, and refresh rate of 85 Hz. The stimuli were 30 s videos of a female adult executing straight-line cyclical horizontal (i.e., left (right)-right (left)) arm movements with an orthogonal (vertical) movement variance of 25.53 mm or vertical (i.e., up (down)-down (up)) arm movements with an orthogonal (horizontal) movement variance of 12.98 mm. The individual segments from each of the movement cycles were displaced at approximately 500 mm, and executed at a cycle rate of 0.5 Hz. The size of the visual stimuli was scaled so the individual segments of the model subtended a 500-mm amplitude for the participant's own movement.

Participants stood 1.9 m from the stimulus display and executed horizontal arm movements similar to the horizontal model stimulus. Prior to data collection, participants became familiar with the horizontal arm movements with the aid of two targets placed on the wall 1350 mm apart (to scale with the prerequisite 500-mm

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