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Priming of complex action via movement contingent sensory effects

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ABSTRACT

Objectives: The aim of the present study was to examine whether movement contingent sensory effects could be used to prime and facilitate motor performance on a ball-tossing task.
Design: The ball-tossing task was performed across two consecutive days, and consisted of an acquisition phase and a test phase. During the acquisition phase, participants ($N = 30$) practiced an underhanded ball tossing task to a near and far target ($N = 360$ total, $n = 180$ each distance). Tosses that landed near the target immediately produced an auditory feedback tone upon landing, with unique tones for both the near and far target. In the test phase, the auditory tones preceded the toss and served as imperative stimuli for the tossing task.
Method: The test phase consisted of three tossing conditions (corresponding, non-corresponding, and control) in which the participants responded to the tones by tossing the ball to either the corresponding or non-corresponding target associated with the tones during learning.
Results: Findings indicated that both accuracy and consistency of ball tossing improved when the toss was preceded by the corresponding auditory feedback associated with the successful execution of the action during learning.
Conclusions: The present study extends previous research by showing that complex actions consisting of multiple degrees of freedom can be primed via movement contingent sensory effects. Furthermore, this study demonstrates that movement-effect priming can impact distal measures of motor performance (e.g., accuracy of tossing), as opposed to the features of movement production (e.g., response selection, initiation, and execution).

1. Introduction

Humans move in order to bring about desired effects in the environment (e.g., lift a cup to one's mouth; shoot a basketball through a hoop). It is not surprising then that the perceptual consequences of movement are thought to play an important role in the planning, execution, and control of goal directed actions (Elsner & Hommel, 2001; Koch, Keller, & Prinz, 2004; Kunde, Koch, & Hoffmann, 2004). To this end, research has shown that when a movement is consistently associated with a specific sensory effect during learning (i.e., movement contingent sensory effect), the movement effect can subsequently be used to prime and facilitate performance of that action (Elsner & Hommel, 2001, 2004; Greenwald, 1970, 1972; Hommel, 1996). Although the research surrounding the influence of movement effects on priming performance is robust, to date, the research has largely been based on reaction times of relatively simple actions (e.g., button presses). Consequently, the extent to which such studies can inform the priming of more complex and rich human

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motor skills is unclear (Wulf & Shea, 2002).

Anticipation of the outcome and perceptual consequences of an action has been considered as an essential component underlying goal directed actions (Elsner & Hommel, 2001; Kunde, Elsner, & Kiesel, 2007; Prinz, 1997). In essence, the ability to reliably obtain a movement goal requires that we know and can anticipate the consequences of our actions. Otherwise, we would rely simply on chance that the movements selected would bring about the desired outcome (Kunde et al., 2007). Therefore, during the initial stages of action control, movements are believed to be planned and controlled based on their intended outcome and effects (Hommel & Elsner, 2009; Kunde et al., 2004; Prinz, 1997). Evidence for this contention is widespread. For instance, Rosenbaum et al. (1990) observed that participants adopted different postures while grasping an object depending on the intended future placement of the object (e.g., end-state comfort). Differences in the initial grasping postures reflected constraints imposed by the anticipation of the future movement goal. Similarly, the research on external focus of attention highlights the influence of both anticipation and movement effects on motor performance (Beilock, Carr, MacMahon, & Starkes, 2002; Gray, 2004; Jackson, Ashford, & Norsworthy, 2006; Land, Tenenbaum, Ward, & Marquardt, 2013; Wulf, 2007). Across a variety of tasks (e.g., golf putting, basketball free throws, tennis serves), improved performance has been associated with attention directed at the anticipated perceptual effects of one's movement (i.e., external focus; trajectory of a golf shot) as compared to attention directed at the kinematics and technique of the movement itself (i.e., internal focus; movement of the arm during putting) (see Wulf (2013) for an overview). These findings emphasize the influence that an action's intended outcome can have on motor planning and action control (Prinz, 1997).

The link between movement and its ensuing effect has long been considered as theoretically important (Harless, 1861; James, 1890; Lotze, 1852), with the fundamental question being: How can anticipation and thoughts of goals lead to selecting and producing actions that appropriately fulfill the movement objective (Prinz, Aschersleben, & Koch, 2009)? Seeking to provide a theoretical basis to this question, ideomotor theory posits that motor patterns become automatically and intrinsically connected to their internal and external sensory consequences (Kunde et al., 2007). More specifically, internal representations of motor patterns become associated with representations of their perceivable environmental and bodily consequences (i.e., movement effects) that stem from the movement itself (Shin, Proctor, & Capaldi, 2010). Importantly, the internal association between a movement and its perceptual consequences within memory are proposed to be bidirectionally linked. As such, the intention or focus on a given anticipated movement effect can have a generative function for initiating the motor action that produces the anticipated effect or goal.

Effect-based theories of action control (e.g., ideomotor theory) have seen renewed interest in recent years (Hommel, 2004). For instance, based on the ideomotor framework, Elsner and Hommel (2001) proposed a two-stage model for the acquisition of voluntary action control. In stage one of the model, action-effect representations are developed via contingencies established between the action and its resultant sensory effects over the course of practice. More specifically, a bidirectional link between the motor commands (i.e., cognitive output signals to the motor system) and their reafferences (i.e., internal and external sensory feedback produced by the action) is established through repeated co-occurrences. Interestingly, evidence suggests that temporal overlaps (< 1 s) between movements and resultant sensory effects are sufficient for integration within the action-effect representation (Elsner & Hommel, 2001, 2004). Given this bidirectional encoding, Stage 2 of the model refers to the selection and initiation of voluntary action guided by anticipation of the action's sensory feedback. That is to say, anticipation of the intended goal and its effects will cue forth the relevant motor commands (i.e., efferences) previously associated with the anticipated effects (i.e., reafferences).

According to Greenwald (1970), empirical support of the proposed ideomotor mechanism can be investigated using an experimental paradigm that features both a learning phase and test phase. During the learning phase, an action becomes associated with a contingent response over repeated practice. During a subsequent test phase, the learned response acts as an imperative stimulus cuing the associated action. If it is the case that the response effect becomes bidirectionally integrated with the action representation, then the presentation of the response effect should act as a prime or cue for the movement itself.

Based on this paradigm, ample research exists supporting the contentions of ideomotor theory (Elsner & Hommel, 2001, 2004; Greenwald, 1970, 1972; Hommel, 1996). For example, Elsner and Hommel (2001) had participants perform a key pressing task in which each key press would produce a corresponding audible tone (e.g., high or low pitch tone). In a subsequent test phase, the auditory tones were used as imperative stimuli within a choice-reaction time task. That is, the participants would respond to the auditory tone by pressing the corresponding key that initially produced the tone during the acquisition phase. Results indicated that reaction times during the choice-reaction test depended on the associations learned during acquisition. Specifically, reaction times were faster when responses were cued by the auditory tones associated with the response during the learning phase, whereas, reaction times were slower when the required response was cued by the alternative auditory stimulus. In a subsequent free-choice experiment, results indicated that the auditory tones biased the selection of action (i.e., which key was pressed), thus affecting the frequency of responses. These findings support the contention that learned movement effects can be used to activate and prime the corresponding movement.

While the research surrounding the influence of action effects on performance is robust; to date, the research has been isolated to examining relatively simple actions (e.g., button press) with a few degrees of freedom (Elsner & Hommel, 2001, 2004; Hommel, 1996; Koch et al., 2004; Kunde et al., 2004; Kunde, 2001, 2003). Furthermore, this research has primarily been based on reaction-time paradigms. Thus, the ecological validity and practical implication of these studies has been limited. The extent to which such studies can inform more complex and rich human motor skills comprising of multiple degrees of freedom is unclear (Wulf & Shea, 2002). Consequently, the purpose of the present study is to determine whether movement contingent sensory effects can cue and facilitate a more complex motor response (e.g., tossing a ball) in a similar manner as has been demonstrated with simple actions in previous research. Importantly, examining a more complex action allows for investigation of performance variables other than simple reaction times or response selection. Specifically, the present study considers the influence of movement-effect priming on the more distal characteristics of performance, namely the accuracy and consistency of toss performance as opposed to features of the