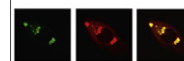


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## Research Report

# Motor preparation is delayed for both directly and indirectly cued movements during an anticipation-timing task

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### ABSTRACT

Previous investigations comparing direct versus indirectly cued movements have consistently shown that indirectly cued movements take longer to prepare (Neely and Heath, 2010. *Brain Res.* 1366, 129–140) and involve the recruitment of additional brain areas (Connolly et al., 2000. *J. Neurophysiol.* 84, 1645–1655). This increase in processing time has been associated with the additional cognitive transformations required of the task (Neely and Heath, 2010. *Brain Res.* 1366, 129–140). In the present study we investigated whether differences between direct versus indirectly cued movements are also reflected in the time course of motor preparation. Participants performed a targeting task, moving directly to the location of a visual cue (i.e., directly cued movement) or to a location that differed by 60°, 90°, or 120° with respect to the visual cue provided (i.e., indirectly cued movements). Participants were instructed to initiate their movements concurrently with an anticipated go-signal. To examine the time course of motor preparation, a startling acoustic stimulus (SAS, 124 dB) was randomly presented 150 ms, 500 ms, or 1000 ms prior to the go-signal. Results from the startle trials revealed that the time course of motor preparation was similar regardless of the angle of rotation required and hence whether it was a direct or indirectly cued trial. Specifically, motor preparation was delayed until less than 500 ms prior to movement initiation for both direct and indirectly cued movements. These findings indicate that similar motor preparation strategies are engaged for both types of cued movements, suggesting that the time to prepare a motor response may be similar regardless of whether a cognitive transformation is required.

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## 1. Introduction

Many movements in everyday life involve an established relationship between a target goal and the movement required to reach the given target. For example, a visual stimulus may be the movement goal, directly cuing the location of the

target (e.g., when reaching for a cup of coffee). In other instances, the visual stimulus indirectly corresponds to the required movement such that the actual movement is made towards a different location than that indicated visually (e.g., when controlling a cursor on a screen by moving a computer mouse). Direct versus indirectly cued movements

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have been shown to differ with regards to the cognitive demands associated with them. Specifically, indirectly cued movements are proposed to incur greater cognitive demands (as seen by the additional recruitment of frontoparietal areas (Connolly et al., 2000)), resulting in longer response times (Heath et al., 2009a; Maraj and Heath, 2010; Rosenbaum, 1980).

To study the sensorimotor processes underlying movement initiation to direct versus indirectly cued movements in the laboratory, researchers have used a visuomotor mental rotation (VMR) task (Georgopoulos and Massey, 1987; Neely and Heath, 2010). Typically, the VMR task requires participants to point from a central home position to a location that deviates from a visual cue by a predetermined/instructed angle of rotation. Initial research using this VMR task has demonstrated that reaction time (RT) increases linearly as the angle of rotation is increased from 5° to 140° (Georgopoulos and Massey, 1987). To account for this increase in RT, Georgopoulos and Massey (1987) proposed a mental rotation model (MRM), suggesting that during indirectly cued movements, participants mentally rotate a movement vector from its starting position (i.e., a movement directed to the visual cue) through increasing angular degrees until the movement goal is obtained. In support of the MRM, single-cell recordings in monkeys during the response preparation phase of a VMR task revealed that the weighted vector sum of neural activity (i.e., the population vector) in the motor cortex initially reflected the location of the visual cue; however, over time the population vector rotated to reflect the direction of the mentally rotated movement goal (Georgopoulos et al., 1989; see Georgopoulos and Pellizzer, 1995 for a review). Thus, these results suggest that the transformation of the visual cue and preparation of the corresponding response occur simultaneously, and as such, differences in the time required for motor preparation lead to RT differences between direct and indirectly cued movements (see Georgopoulos and Pellizzer, 1995 for a review).

In contrast to the MRM, Cisek and Scott (1999) proposed the response substitution hypothesis (RSH) to explain observed changes in neural activity and increases in RT with increasing angles of rotation during a VMR task. According to the RSH, the onset of a visual cue in a VMR task elicits two distinct neural responses, one to the visual cue and the other to the (rotated) movement goal. During indirectly cued movements, the initial motor activity related to the visual location of the stimulus (i.e., a directly cued response) must then be inhibited, and replaced with that of the rotated movement goal in order for the movement to be initiated as required. In accordance with the RSH, Olk and Kinstone, 2003 have suggested that increased latencies associated with indirectly cued antisaccades are primarily due to oculomotor inhibition. Furthermore, additional results from the antisaccade literature suggest that the cognitive transformation of the target and motor preparation of the indirectly cued responses are two distinct processes during a VMR task, whereby the transformation occurs very rapidly following stimulus presentation (Zhang and Barash, 2000). Taken together, these results support the RSH hypothesis that indirectly cued movements result in longer RTs because of an *additional cognitive transformation* and inhibition of the stimulus-driven response directed to the visual cue.

Although the two neural models (i.e., MRM and RSH) differ in their explanation for how indirectly cued movements are carried out within the VMR task, they both highlight the notion that there is initial activation related to the location of the visual cue. Given that indirectly cued movements are not initiated to the location of the visual cue, the cognitive transformation or response related activity required to achieve the correct movement goal takes longer and requires additional processing time compared to directly cued trials. While some studies have investigated the timeline of cognitive/motor transformations in pro/antisaccade tasks (see Munoz and Everling, 2004 for a review), the time required for these additional cognitive and/or motor processes and when they occur during preparation of a targeted limb response in a VMR task remains unclear. Specifically, it is unclear if the observed increases in RT associated with indirectly cued movements during a VMR task arise due to 1) more time being required to complete non-motoric processes (e.g., visual/cognitive transformations) or 2) increased time associated with motor-related processes (e.g., preparing the desired response). In the current study we investigated whether differences in RT between direct versus indirectly cued movements during a VMR task arise due to differences in the time required to prepare (i.e., activate) motor-related neural structures between the two movement types. In other words, we asked if it takes longer for participants to activate motor-related neural structures in an indirectly cued movement in comparison to a directly cued movement.

In order to determine whether a buildup of response related activity in motor structures requires different amounts of time for direct versus indirectly cued movements, we instructed participants to initiate their movements concurrent with an anticipated go-signal, and then used a “startle” technique to probe motor preparation at various intervals preceding the go-signal (see Carlsen et al., 2012 for a review). The startle technique involves the presentation of a loud (>120 dB), startling acoustic stimulus (SAS) during the motor preparatory phase. Previous research has shown that when a person is startled, the typical reaction consists of a fast, reflexive response, characterized by a general symmetrical flexion of the body including activation of the sternocleidomastoid (SCM) muscle (Brown et al., 1991; Landis et al., 1939; Wilkins et al., 1986). However, if a person is startled when preparing to react to a go-signal in a directly cued simple RT task, the SAS not only gives rise to the typical startle response, but also involuntarily triggers the release of the planned voluntary movement. Specifically, a startle can result in a response that is produced at a significantly shorter latency (<80 ms from SAS onset) compared to trials in which the SAS is not presented (Carlsen et al., 2003, 2004a, 2004b, 2007, 2009a; Castellote et al., 2007; Cressman et al., 2006; MacKinnon et al., 2007; Maslovat et al., 2008, 2009; Valls-Solé et al., 1995, 1999, 2005). Importantly, this early response initiation suggests that if an action is sufficiently “prepared” the SAS can act to directly trigger it, thus allowing one to examine motor preparation. This early initiation of a planned movement in conjunction with an observed startle reflex response (e.g., SCM activity) is termed the StartReact effect (Carlsen et al., 2012).

The startle technique not only provides insight into the components of a movement that are prepared (Carlsen

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