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Perturbation of object location during bimanual prehension: The role of visual feedback

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ABSTRACT

In this series of studies on the coordination of the two hands during a bimanual perturbation task, 10 right-handed volunteers were asked to reach to grasp and lift two illuminated cubic objects. Upon initiation of the reach a perturbation could occur by extinguishing one or both objects and illuminating new objects located directly away from the start position in the para-sagittal plane (Experiment 1) or toward the start position in the para-sagittal plane (Experiment 2). In Experiment 2 we also manipulated position of the targets within the visual span by having the targets move toward the midline or away from the midline. Dependent measures included kinematic data for the reach movement as well as the timing of eye movements. Results of both experiments indicated little interference between the hands when one object was perturbed while the other remained stationary. We hypothesize that when visual feedback about limb movement is available, participants can independently reorganize the trajectory of the perturbed limb with minimal interference on the non-perturbed limb. Furthermore, results of Experiment 2 indicated that the position of the targets within the visual span at the final target location dictates the number of eye movements made to acquire both targets and can lead to asynchronies at movement termination in a task-dependent manner. Finally, we found that when targets were perturbed away from the body movement time results indicated a right-hand advantage for dealing with a single perturbation. In contrast, perturbations toward the body abolished the movement time advantage. We suggest that differences in the use of visual feedback when working in the upper versus lower visual fields may influence hand advantages.

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1. Introduction

Target perturbation tasks have been suggested to be ideally suited for the investigation of coordination between the hands during bimanual performance (Diedrichsen, Nambisan, Kennerley, & Ivry, 2004). Furthermore, these paradigms can be applied to the investigation of the role of visual information for movement control (Paulignan, Jeannerod, MacKenzie, & Marteniuk, 1991). Although the role of on-line visual information has been extensively studied for the performance of unimanual movements (see for example Carlton (1992)), the role of this type of sensory feedback for the performance of bimanual prehension has been relatively unstudied (Bingham, Hughes, & Mon-Williams, 2008; Bruyn & Mason, 2009; Riek, Tresilian, Mon-Williams, Coppard, & Carson, 2003). Coordinated bimanual movements present an interesting challenge to the visuomotor system because it is not possible to direct central vision towards both targets at the same time (Bingham et al., 2008; Riek et al., 2003). Thus, visual attention must be divided between the two targets/hands. This inability to direct focal vision to both targets simultaneously becomes increasingly important when one target is unexpectedly displaced.

In a target perturbation paradigm the participant is required to alter their original movement plan either prior to or after movement onset in response to a change in the physical characteristics of the target or location of the target within the environment. Studies using such visual perturbations in unimanual movements have manipulated the distance required to achieve the target (Gentilucci, Castiello, Chieffi, & Scarpa, 1992; Scarpa & Castiello, 1994), the direction of the reaching movement (Paulignan, Jeannerod et al., 1991; Paulignan, MacKenzie, Marteniuk, & Jeannerod, 1991), the size of the target to be grasped (Castiello, Bennett, & Paulignan, 1992; Castiello, Bennett, & Stelmach, 1993; Castiello & Jeannerod, 1991; Paulignan, Jeannerod et al., 1991), object shape (Jeannerod, 1981) and the depth structure of the target (Castiello, Bonfiglioli, & Bennett, 1998). Results of studies using perturbation paradigms have indicated increased movement times to displaced targets and double-peaks in kinematic recordings. However, results have also indicated that kinematic adjustments in movement characteristics can occur in as little as 100–150 ms (Paulignan, Jeannerod et al., 1991; Paulignan, MacKenzie et al., 1991), which includes both the reaction time to the displaced target and the time necessary to load the mass–spring system (Feldman, Adamovich, Ostry, & Flanagan, 1990; Flanagan, Ostry, & Feldman, 1993).

Recently, Diedrichsen and colleagues (2004) and Mason (2008) have extended the perturbation paradigm with the goal of investigating the role of visual information in bimanual aiming and prehension. Results from both studies indicated that when one target was displaced, the hand reaching to that target adjusted efficiently to the displacement. Furthermore, perturbation in the trajectory of the other hand was also noted for both aiming and prehension movements, although interference between the hands was more subtle and transient in aiming (Diedrichsen et al., 2004) when compared to reaching (Mason, 2008). Diedrichsen et al. (2004) and Mason (2008) both concluded that when the perturbation of one object occurs during the performance of a bimanual prehension task, visual information is used to independently update the control process for the limb moving to the perturbed object. Additionally, Mason (2008) concluded that execution-time interference causes the limb moving to the non-perturbed target to be inappropriately adjusted in response to the perturbation.

Although the results of both Diedrichsen et al. (2004) and Mason (2008) provide preliminary evidence of independent, visual control of the two limbs during bimanual perturbation tasks, the nature of the use of visual feedback can only be inferred from the results. In particular neither study specifically monitored eye movements to determine the pattern of eye movements used during bimanual perturbation tasks and whether these eye movements corresponded to key kinematic features of movement reorganization.

For unimanual aiming tasks, it is known that there is a strong relationship between eye and hand movements (Starkes, Helsen, & Elliott, 2002). In particular, studies have indicated that the primary eye movement almost always precedes the initiation of hand movement (Helsen, Starkes, Elliott, & Ricker, 2000). Furthermore, research has indicated that the primary saccade reaches the target location at approximately the same time the hand reaches peak acceleration (Helsen, Starkes, Elliott, & Buekers, 1998; Helsen et al., 2000; Helsen, Starkes, & Martinus, 1997) or stated another way, at approximately