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Utilization of visual feedback of the hand according to target view availability in the online control of prehension movements

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ABSTRACT

The aim of this study was to investigate the role of online vision of a target object and the participant's moving hand in the early phase of reach-to-grasp movements. We designed an experiment that separately manipulated the visibility of a moving hand and the target object by using two liquid crystal shutter plates placed in the same horizontal plane (25 cm above the experimental table). When target view was available immediately after movement onset, the effect of hand view in the early phase of movement was very limited. The effect of hand view appeared when target view in the early phase of movement was not available. This was even the case for the condition where the temporal range of non-availability of target view after movement initiation was 150 ms. Therefore, online vision (of target and hand) for controlling grasping was utilized in a flexible fashion that depended on the visual environment.

1. Introduction

The reach-to-grasp movement is a fundamental human skill used in daily life. It serves as a form of interaction with the external world and has been a research focus for the last three decades (see Castiello & Begliomini, 2008; Grafton, 2010; Rosenbaum, Chapman, Weigelt, Weiss, & van der Wel, 2012

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for recent reviews). In early studies, Jeannerod (1981, 1984) proposed that this movement consists of two components: a transport component, which is thought to be involved in directing the arm to the spatial location of the target, and a manipulation component, which is involved in grasping a three-dimensional object. The behavioral aspects of grasping indicate that the fingers first open gradually and form the appropriate configuration for the target object to be grasped ("preshaping"). The fingers then open wider than the size of the target object and stop opening at a point about 60–70% into the movement (i.e., the peak grip aperture; PGA). They then enclose the object, and finally touch its surface (e.g., Jeannerod & Marteniuk, 1992). The PGA is highly correlated with the target size (Marteniuk, Leavitt, MacKenzie, & Athènes, 1990).

Proper performance of this movement requires visuomotor transformation, indicating that online vision is essential for goal-directed movements. Since Woodworth's pioneering work (Woodworth, 1899), many researchers have investigated how online vision affects the control of goal-directed movements (e.g., Beggs & Howarth, 1970; Keele & Posner, 1968; Vince, 1948; Zelaznik, Hawkins, & Kisselburgh, 1983). Previous studies on goal-directed movements focused on: (i) which source of vision was critical for the control of movement, and (ii) how that source affected the movement kinematics. In aiming and reaching tasks, visual feedback of the hand position came to be viewed as important in the later phase of the movement (e.g., Beaubaton & Hay, 1986; Carlton, 1981; Chua & Elliott, 1993), in line with the notion that sensory feedback is too slow for appropriate control of the hand trajectory due to the inherent delay of the sensorimotor loop (Gerdes & Happee, 1994; Hollerbach, 1982). However, in addition to a rather classical study by Bard, Hay, and Fleury (1985), more recent investigations have challenged this notion. For example, Saunders and Knill (2003) demonstrated that visual feedback of hand position in the early phase of reaching was used in a continuous fashion to correct movement (see also Bedard & Proteau, 2004; Ma-Wyatt & McKee, 2007; Sheth & Shimojo, 2002). This observation has been interpreted as evidence for an internal forward model (e.g., Kawato, 1999; Miall & Wolpert, 1996), which uses an efferent copy of the motor command to predict the current state of an effector, which could compensate for sensory delays in feedback processing (Desmurget & Grafton, 2000). Sarlegna et al. (2003) focused on the relative contributions of viewing the hand and the target for the online control of reaching, and demonstrated a predominant role of target position and a lesser contribution of visual information relative to hand position (see also Berkinblit, Fookson, Smetanin, Adamovich, & Poizner, 1995). Recently, Elliott et al. (2010) presented a multiple-process model of limb control in aiming action. They assumed that at least three types of online regulation were operative: (a) early efferent control based on a comparison of efferent copy to efferent outflow; (b) early and continuing afferent control based on a comparison of the early dynamic properties of the limb movement (visual and proprioceptive) to the expected sensory consequences; and (c) late visual control based on a comparison of limb and target position as the limb enters central vision.

Reach-to-grasp movements show a significantly larger PGA when online vision from the entire visual field is absent during prehension (Bradshaw & Elliott, 2003; Fukui & Inui, 2006; Jakobson & Goodale, 1991; Wing, Turton, & Fraser, 1986). Furthermore, when participants were prevented from seeing their hands during movement, this affected both movement duration and finger aperture (e.g., Berthier, Clifton, Gullapalli, McCall, & Robin, 1996; Gentilucci, Toni, Chieffi, & Pavesi, 1994). Specifically, movement duration was longer and PGA was larger when participants were prevented from seeing their moving hands (but see Connolly & Goodale, 1999; Jeannerod, 1984). One possible reason for a larger PGA when online vision is lacking is that the greater margin of hand aperture allows for error in movement and prevents collision of the fingers with the target object (e.g., Edwards, Wing, Stevens, & Humphreys, 2005; Haggard & Wing, 1995; Rand, Lemay, Squire, Shimansky, & Stelmach, 2007; Wing et al., 1986). Therefore, PGA has been regarded as an indicator of the influence of online vision on grasping.

In a previous study (Fukui & Inui, 2006), we investigated: (i) whether online vision in the early phase of movement influences the control of reach-to-grasp movements, and (ii) how vision of the target object and of the participant's moving limb in the early phase affects the online control of movement. We used liquid crystal shutter goggles and liquid crystal shutter plates to manipulate the duration of online vision during the movement. In addition, we used the liquid crystal shutter plates to manipulate views of the target and the hand. We found that: (i) the presence or absence of vision in