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Differential effects of a visual illusion on online visual guidance in a stable environment and online adjustments to perturbations

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ABSTRACT

In the reported, experiment participants hit a ball to aim at the vertex of a Müller–Lyer configuration. This configuration either remained stable, changed its shaft length or the orientation of the tails during movement execution. A significant illusion bias was observed in all perturbation conditions, but not in the stationary condition. The illusion bias emerged for perturbations shortly after movement onset and for perturbations during execution, the latter of which allowed only a minimum of time for making adjustments (i.e., approx.170 ms). These findings indicate that allocentric information is exploited for online control when people make rapid adjustments in response to a sudden change in the environment and not when people guide their limb movements to interact with a stable environment.

1. Introduction

People make goal-directed actions, such as hitting, catching or reaching to bring about changes in their environment. Often this environment is relatively stable and predictable while the action is performed. In these situations performers can evaluate the task requirements in advance and execute the movements without the need for further visual control of the spatio-temporal unfolding of the movements (Plamondon, 1995; Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979). Yet, for more than a century, researchers have tried to establish that even during execution, movements are under instantaneous or online visual guidance (Woodworth, 1899). Indeed, many studies have shown that visual information about the target, hand, and eye position is used online both in relatively stable environments and in more dynamic environments. Online visual control ensures the required accuracy of a movement outcome especially when adjustments in the ongoing movements are needed in response to perturbations in the environment (Caljouw, van der Kamp, & Savelsbergh, 2006; Pelisson, Prablanc, Goodale, & Jeannerod, 1986; Pisella et al., 2000; Prablanc & Martin, 1992; Prablanc, Pelisson, & Goodale, 1986; Saunders & Knill, 2003). Rapid online adjustments of goal-directed movement to sudden displacement of a target object are thought to be controlled ‘automatically’ by an ancient visuomotor system (Milner & Goodale, 1995, 2008). From an evolutionary perspective, one early function for vision was online movement control (i.e., action). For example, catching prey requires the fast pick up of instantaneous information about the motion of the prey in relation to the predator’s own displacements.

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Vision for perception, on the other hand, is a relatively newcomer in the evolutionary landscape. It enables humans to obtain knowledge about objects, events and places and retain this knowledge for longer periods of time, for instance, to plan actions or to interact with other humans (see Milner & Goodale, 1995, 2008; van der Kamp, Rivas, Van Doorn, & Savelsbergh, 2008). When the vision for action system cannot readily gain access to visual information for online control, this vision for perception system strongly contributes in movement control, for example, when acting on previously perceived, remembered target objects (Gentilucci, Chieffi, Deprati, Saetti, & Toni, 1996; Westwood & Goodale, 2003). Yet, there are also circumstances that are thought to be particularly favorable for the more ancient visuomotor system. Pisella et al. (2000) showed that rapid implicit adjustments in movement execution occur before individuals can adjust the movements intentionally. Thus, when performing rapid aiming movements, participants made adjustments to a change in target location even when instructed to interrupt the movement in response to target motion. Pisella et al.'s findings support the proposal by Milner and Goodale (1995, 2008) of a vision for action system, dedicated to the fast online control of movement in dynamic environments, that can operate well before conscious processes can influence the movement.

Apart from the different time scales at which information is used and can be retained, the functions of vision for action and vision for perception also impose different constraints on the type of information that is used to determine relevant object properties (Milner & Goodale, 1995, 2008). Perception requires information about objects in relation to their surrounding (i.e., allocentric or contextual information), whereas for controlling actions information about objects in relation to the actor or effector is required (i.e., egocentric or context-independent information). An important, but controversial, piece of evidence indicating that visual information used for perception does not provide a necessary basis for the visual guidance of action and vice versa comes from studies using pictorial illusions. For instance, with the Müller–Lyer illusion the perception of the length of a horizontal line is strongly influenced by the surrounding visual context, that is, the orientation of the fins on each end of the line. Yet, this allocentric information is usually not involved when guiding actions, such as pointing to or grasping a bar embedded in the illusion (Bruno, Bernardis, & Gentilucci, 2008; Otto-de Haart, Carey, & Milne, 1999; van Doorn, van der Kamp, de Wit, & Savelsbergh, 2009; van Doorn, van der Kamp, & Savelsbergh, 2007, but see Franz, Gegenfurtner, Bulthoff, & Fahle, 2000; Smeets, Brenner, de Grave, & Cuijpers, 2002).

Thus, there are situations in which visually guided movement to stationary objects is genuinely unaffected by perceptual illusions, providing strong evidence for the existence of a vision for action system that exploits egocentric information during online movement control.

Milner and Goodale's two-visual systems model posits a fundamental distinction between vision for perception and vision for action in terms of the type of information used (allocentric versus egocentric) and the speed at which they operate (slow versus fast). In this respect, vision for action is the most rapid system and considered optimal for quickly adjusting movements in flight in response to a sudden change in target location. Yet, the logical assertion that adjustments to location perturbations are based on egocentric information has not been proven unequivocally. The aforementioned studies of actions directed at illusions show support for the pick up of egocentric information when the target is unperturbed during movement execution, the movements are well-practiced and executed under full vision. However, the proposition that the vision for action system is the dedicated system for dealing with target perturbations, especially under normal viewing conditions where instantaneous information about the changing properties of objects can readily be accessed, faces some empirical challenges from perturbation studies of Elliott and co-workers using pictorial illusions (Grierson & Elliott, 2009a, 2009b; Handlovsky, Hansen, Lee, & Elliott, 2004; Mendoza, Elliott, Meegan, Lyons, & Welsh, 2006). In a recent experiment, for example, Grierson and Elliott (2009a) perturbed the perceived (but not the actual) distance to the endpoint of a shaft embedded in a Müller–Lyer illusion configuration by reversing the direction of the fins immediately after movement onset. Contrary to predictions derived from the purported characteristics of the vision for action system, this change in configuration had a biasing effect on movement outcome. The observed adjustment of the movement in response to a change in the visual target surroundings (i.e., the tail configuration) is indicative for the use of allocentric information and was interpreted to counter the two-visual system model.

Although the studies of Elliott and co-workers suggest an impact of allocentric information on adjusting movements during execution, it can be questioned whether the task employed was purely subserved by the vision for action system. In this respect, a pertinent observation in the perturbation trials was the presence of an early decrease in peak acceleration, and subsequently, peak velocity and peak deceleration. Grierson and Elliott (2009a) argued that this early kinematic difference reflected a nonspecific detection of a change in the environment that prompts a conservative movement adjustment, a strategy which would allow the participants to spent more time in deceleration thereby enhancing the time for making late adjustments. Consequently, this strategic slowing may elicit the slower vision for perception system to contribute to visuomotor control, resulting in the exploitation of allocentric information for movement control.

To further explore the assertion that rapid adjustments in response to perturbations are based on egocentric information, we set-up a goal-directed hitting task that is more favorable for the rapid vision for action system. Participants had to propel a ball to a target embedded in a Müller–Lyer configuration that was visible throughout the entire trial. The perturbations of the illusion configuration not only occurred at movement onset (as per the illusion perturbation studies of Elliott and co-workers), but also during the final phase of the hitting movement. Slowing the movement to enhance the time for online adjustments is not a successful strategy in this task because participants have to control the impact velocity at ball contact in order to propel the ball to the required landing location. Although fast hitting movements are traditionally seen as ballistic in nature, rapid adjustments during movement execution are possible. Previous work involving a similar hitting task (Caljouw et al., 2006) showed that when the required physical landing location unexpectedly jumped forward, the