

Action control: Independent effects of memory and monocular viewing on reaching accuracy

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Abstract

Evidence suggests that perceptual networks in the ventral visual pathway are necessary for action control when targets are viewed with only one eye, or when the target must be stored in memory. We tested whether memory-linked (i.e., open-loop versus memory-guided actions) and monocular-linked effects (i.e., binocular versus monocular actions) on action arise from a common mechanism as suggested by evidence from neuropsychology and psychophysics. Participants viewed targets with either one eye or two (vision: monocular versus binocular) and then reached to touch targets in open-loop and memory-guided conditions (condition: open-loop versus 0, 500, 1000, and 1500 ms delays). Results showed that memory-linked and monocular-linked increases in radial and variable movement error were additive (i.e., main effects of vision and condition, but no interaction). This suggests that the two effects on visuomotor control arise from separate mechanisms, in contrast to evidence from psychophysics and neuropsychology suggesting a common underlying mechanism.

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1. Introduction

The control of reaching movements requires a transformation of target information from visual to motor co-ordinates. Considerable evidence indicates that these visuomotor transformations take place in the posterior parietal cortex (PPC; see Cohen & Andersen, 2002) and operate independently from the perceptual networks in the inferotemporal cortex that underlie conscious perception of the visual world (Goodale & Milner, 1992). It has become increasingly clear, however, that the control of action depends on consciously perceived features of target objects in quite specific situations (Goodale, Westwood, & Milner, 2004).

Mounting evidence from human psychophysics and neuropsychology indicates that actions to remembered (as compared to visible) targets are sensitive to the consciously perceived size of the object (for review, see Goodale et al., 2004). The same appears to be true of actions carried out with monocular (as compared to binocular) vision (e.g., Marotta, DeSouza, Haffenden, & Goodale, 1998). We (Goodale et al., 2004) have suggested that the visuomotor networks of the dorsal stream operate in real time, and are engaged for action control when targets are visible at the time the action is required (i.e., visually guided reaching). These networks cannot be engaged in delayed reaching situations because the target is not visible when the action is required. In this situation, action control accesses a stored representation of the target—a representation that is delivered by the perceptual mechanisms in the ventral visual pathway. Similar arguments have been put forward to account for the

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dependence of monocular actions on conscious visual perception; that is, the visuomotor networks in the PPC presumably depend on binocular cues to compute target distance, and cannot therefore be engaged in monocular viewing conditions.

In the present investigation, we tested whether the effects of memory and monocular viewing on visuomotor control are indeed mediated by the same mechanism; namely, a transition in action control from the dorsal to ventral visual pathway. If so, then combining memory and monocular vision in a reaching task should not produce greater effects on movement accuracy than either manipulation alone (i.e., an interaction of memory and monocular vision). If not, then memory and monocular effects should combine in an additive fashion (i.e., main effects of memory and monocular vision, but no interaction).

2. Methods

2.1. Participants

Fifteen undergraduate and graduate students (6 male, 9 female; mean age = 24.3 years) were recruited from Indiana University. All participants were right-handed and right-eye dominant as established by self-report (handedness) and a standard eye-dominance test (sighting a distant target through a circle made by the participant's index finger and thumb). Participants provided informed consent in accord with the Office of Human Research, Indiana University.

2.2. Apparatus and stimuli

Target LEDs were mounted beneath a smooth, darkened acrylic surface resting atop a standard wooden table. Two targets were positioned along the midsagittal axis, at distances of 24 and 26 cm from a home position, where the index finger of the reaching (right) hand rested. All light sources in the reaching environment were extinguished, leaving a completely darkened room.

The timing of visual events was implemented using computer-controlled liquid-crystal visual occlusion spectacles. In monocular conditions the left eye was patched. Movement kinematics (velocity, acceleration, endpoint position, reaction time, and movement time) were computed off-line from 3D position data collected at 200 Hz using an Optotrak 3020 system (NDI, Waterloo, ON, Canada). A single IRED was attached to the dorsal surface of the nail of the right index finger. The home position was a telegraph-style switch that allowed visual events to be yoked to movement onset where applicable (see below). No explicit feedback was ever given to participants about the accuracy of any movement.

2.3. Procedure

In this investigation participants were instructed to complete discrete goal-directed reaching movements to target LEDs. The experimental session began with 8–10 practice trials designed to familiarize participants with the reaching task and the darkened aiming environment. Following practice, participants completed 160 reaching movements in the experiment proper. Manipulated variables were target location (near, 24 cm; far, 26 cm), vision (monocular; binocular) and condition (open-loop, OL; 0-ms delay, D0; 500-ms delay, D500; 1000-ms delay, D1000; and 1500-ms delay, D1500). Eight reaches were carried out in each of the 20 cells in the design. The 10 vision-condition combinations (e.g., binocular open-loop, . . . , monocular 1500 ms delay) were presented in randomly ordered blocks of 16 trials, within which each target location appeared eight times in random order. Instructions were to reach 'quickly and accurately' to the location of the target after the auditory 'go' signal.

2.3.1. Conditions

In all conditions, participants viewed the target for 2000 ms (with either binocular or monocular vision). In the open-loop condition an auditory signal followed the initial 2000 ms viewing period; vision was occluded when the finger lifted off the home position, and remained occluded until the beginning of the next trial. In the delay conditions, vision was occluded after the initial 2000 ms viewing period. An auditory signal was given 0, 500, 1000, or 1500 ms after visual occlusion; vision remained occluded until the beginning of the next trial.

2.4. Dependent measures

Reaction time (RT: from cue to movement onset) and movement time (MT: from movement onset to offset) were derived from kinematic profiles. Radial error (RE) was computed from the 2D reaching endpoints as the vector distance from target centre to the IRED position, thus encompassing both amplitude and direction errors. Variable error was calculated as the standard deviation of reaching endpoints about the mean endpoint position in the amplitude (VE_A : anteroposterior) and direction (VE_D : mediolateral) axes. Peak velocity was computed as the maximum positive value of the first time derivative of finger position.

Dependent measures were analyzed using repeated measures ANOVAs with factors target (near, far), vision (binocular, monocular), and condition (open-loop, 0, 500, 1000, and 1500 ms delays), $\alpha = .05$. Main effects were evaluated using Tukey's HSD test ($\alpha = .05$). Significant interactions were analyzed using simple-effects analysis ($\alpha = .05$) and Tukey's HSD test.

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