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Research Report

# The contribution of visual feedback to visuomotor adaptation: How much and when?

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A B S T R A C T

We investigated the role of visual feedback in adapting to novel visuomotor environments. Participants produced isometric elbow torques to move a cursor towards visual targets. Following trials with no rotation, participants adapted to a 60° rotation of the visual feedback before returning to the non-rotated condition. Participants received continuous visual feedback (CF) of cursor position during task execution or post-trial visual feedback (PF). With training, reductions of the angular deviations of the cursor path occurred to a similar extent and at a similar rate for CF and PF groups. However, upon re-exposure to the non-rotated environment *only* CF participants exhibited post-training aftereffects, manifested as increased angular deviation of the cursor path, with respect to the pre-rotation trials. These aftereffects occurred *despite* colour cues permitting identification of the change in environment. The results show that concurrent feedback permits automatic recalibration of the visuomotor mapping while post-trial feedback permits performance improvement via a cognitive strategy.


## 1. Introduction

Unusual force fields and optical transformations such as those created by mirrors, prisms or computer-generated rotations create problems for an inexperienced person attempting a target-directed aiming task. For example, unusual forces can push the person off course and visual rotations typically cause people to move in the wrong direction. However, after attempting the task a few times a person typically learns to deal with the altered environment: their movement paths become straight with bell-shaped velocity profiles, almost identical to those originally produced in normal conditions. The person is said to *adapt* to the altered environment. Experiments have shown that adaptation typically involves changes in the feedforward motor commands that take the alteration into account and compensate for it. Such changes in the commands can be interpreted as demonstrating that the process of adaptation involves creating or updating an internal model (e.g., Kawato, 1999). In the case of altered optical transformations, the model takes the form of a visuomotor map that transforms visual information into motor commands (Cunningham, 1989). Adaptation to a visual rotation then involves adjusting the visuomotor map so as to compensate for the magnitude and direction of rotation.

The adaptation process is driven by sensory feedback information about the discrepancy between the intended movement and the actual movement (the error). The visual and somatosensory systems are the most important sources of such information and normally both systems are likely to contribute to adaptation.

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However, it is known that vision alone can sometimes be sufficient for adaptation (Ghez et al., 1995) and somatosensory information can be sufficient for adaptation to novel force environments (Lackner and Dizio, 1994; Tong et al., 2002; Scheidt et al., 2005). In the case of altered visuomotor environments (e.g., those induced by prisms or rotations of feedback on a computer display), visual feedback concerning task performance is necessary for adaptation of aiming movements, when the success of the movement can only be determined visually. A recent study by Mazzoni and Krakauer (2006) indicated that in an out-and-back movement of a cursor, visual feedback in the first 100 ms of the movement, and a cursor depicting the reversal point of the movement, was sufficient to allow adaptation. This suggests that *continuous* visual feedback of the cursor position is not necessary for visuomotor adaptation, at least in dynamic visuomotor tasks (see also Krakauer et al., 1999; Miall et al., 2004).

It is clear that visual feedback about various features of performance can be provided to a person in an aiming task. The most natural and obvious situation is one in which the person is able to see themselves move the working point as they attempt to acquire the target (complete concurrent feedback). Various restrictions can be introduced that allows a person to see only some of their performance (e.g., Mazzoni and Krakauer, 2006). An alternative is to deny a person visual feedback *during* performance but provide it after completion of the task. Depending upon the information actually provided, this type of feedback is called knowledge of results (KR) or knowledge of performance (KP). In KR only feedback about the outcome is provided: in an aiming task it might show the relative position of target and aiming device at completion. In KP, feedback about the movement is given: in an aiming task it might show the path taken to the target.

We sought to investigate how different types of visual feedback influence adaptation to a visual rotation. In particular, we asked whether the type of visual feedback (complete concurrent feedback or post-trial feedback) would affect how participants learned to compensate for the rotation. When aiming at a target in the presence of a visual rotation, it is possible to reach the target by moving in a direction that exactly cancels out the rotation. For example, if the rotation is 60° clockwise and the target is straight ahead, a movement directed 60° to the left will be in the direction of the target. Moving in the appropriate direction could be the result of a change in the visuomotor map. Altenatively, the person might learn the cognitive strategy of always aiming in a direction 60° to the left of the target. The method of interspersing occasional catch trials (Shadmehr and Mussa-Ivaldi, 1994), in which no rotation (perturbation) is applied, amongst a sequence of rotation trials is unable to distinguish between these two possibilities because in either case it would result in identical behaviour. For this reason we adopted a different approach. If participants were informed as to whether or not there was a visual rotation, for example with a colour cue, then the cognitive strategy of always aiming in a direction 60° to the left of the target, could be adopted when appropriate. In this case, we would expect little or no errors when participants return to a non-rotated environment. If, however, learning a 60° rotation results in a change in the visuomotor map, a return to a non-rotated environment would result in aiming errors in the opposite direction of the rotation. We employed an isometric aiming task in which torques are applied to a fixed manipulandum and converted into movements of a cursor on a computer screen (Shemmell et al., 2005). This task removes potential complications due to the muscular and skeletal degrees of freedom available to participants in unconstrained reaching tasks, and eliminates the effects of anisotropic viscous and inertial properties of the limb (Pellegrini and Flanders, 1996).

## 2. Results

Participants produced isometric torques to move a cursor towards visual targets, presented on a computer screen (Fig. 1). Two groups of participants received continuous visual feedback of the cursor position (i.e., concurrent feedback, CF). One of these groups produced feedback modifications to correct errors (CF-FB), while one group only made feedforward responses (CF-FF). Two groups were provided with post-trial (PF) knowledge (feedback) of task performance (PF-KP) or task result (PF-KR) following task execution. Each group was exposed to a pre-training block (no rotation, PRE), a training period in which a 60° counterclockwise rotation was applied (ROT), followed by a post-training

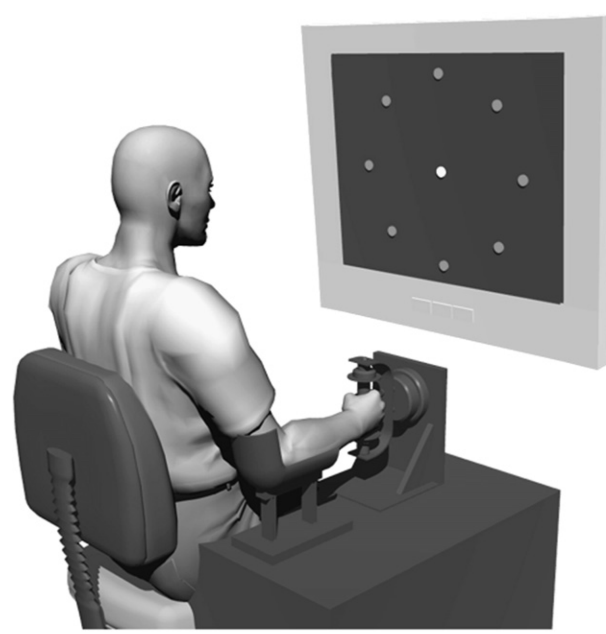

**Fig. 1 – Experimental set-up. Participants held the manipulandum and controlled cursor movement via isometric flexion–extension (up–down cursor movement) and pronation–supination (left–right cursor movement) torques of the elbow–forearm complex. Torques were measured by the force/torque transducer positioned behind the handle. When participants relaxed their arm in the restraint, zero torque was registered, and the cursor appeared at the start position in the centre of the screen (depicted as a white dot). One of eight visual targets (represented as grey dots), equally spaced around the start position, was presented on each trial.**