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Kinematic adaptation to sudden changes in visual task constraints during reciprocal aiming

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Abstract

In a series of three experiments the visual modulation of movement during a reciprocal aiming task was examined when participants were confronted with sudden changes in visually specified task constraints. Amplitude and precision constraints were manipulated independently in Experiments 1 and 2, respectively, while their simultaneous effects were analyzed in Experiment 3. Analysis of the evolution of kinematic characteristics following a sudden change in task constraints revealed two different times scales of adaptation: a rapid adjustment occurring during the deceleration phase of the first movement following change and a more gradual adaptation, affecting the kinematic pattern as a whole, occurring over the next few movements. Overall, the results indicate that visual information with respect to the adequacy of the unfolding movement is continuously monitored, even under the least constraining conditions, and serves to modulate the pattern of movement to (a) comply with the (new) task constraints and (b) optimally tailor the pattern of movement to the situation at hand. We interpret these findings in the framework of a dynamical perspective on movement organization, with information modulating the parameters of an otherwise invariant underlying dynamical structure.

PsycINFO classification: 2330

Keywords: Reciprocal aiming; Motor control; Visual information; Task constraints; Dynamics; Aiming movements; Vision

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1. Introduction

How might visual information influence the dynamics of ongoing movement? In the present article, we investigate this question in the context of a reciprocal aiming task, yielding a continuous oscillatory movement between two visual targets. Recent research has demonstrated that visual information can affect not only movement trajectories but also the underlying dynamic organization of movement during reciprocal aiming (Bootsma, Boulard, Fernandez, & Mottet, 2002; Fernandez & Bootsma, 2002; Mottet, Guiard, Ferrand, & Bootsma, 2001). Here we examine the role of information through sudden changes in visual task conditions and infer their effects on movement dynamics.

Theoretically, visual information might modulate the dynamics of a system on at least three levels (Saltzman & Munhall, 1992; Warren, 2006). First, it could directly affect the state of the system, altering the current limb position or velocity but leaving the basic form of the oscillatory trajectory intact. Second, information might influence the parameters of the system, altering the form of the trajectory but leaving the underlying dynamic structure invariant. Such a change could occur on a fast time scale, via discrete resetting of parameter values, or on a slower time scale, via more gradual parameter dynamics. Third, information might invoke a reorganization of the dynamical structure itself, with qualitative consequences for the movement pattern. In the present experiments we probe the modulatory effects of visual information by abruptly changing the visual task conditions and measuring the time course of adaptation in movement kinematics.

Aiming tasks have been widely used to investigate the control processes implied in goal-directed behavior. The seminal work of Fitts (1954) (Fitts & Peterson, 1964) gave birth to a powerful experimental paradigm, elegantly capturing the essence of goal-directedness: aiming for a goal requires dealing with the distance D separating the desired and the current positions, in the light of the allowable error defined by the extent (or width W) of the target to be attained. Thus, Fitts' paradigm allows a precise control of task difficulty, operationalized by an index of difficulty with $\mathrm{ID} = \log_2(2D/W)$. The distance to be covered D, defined with respect to the target center, constitutes a constraint on movement amplitude, while the width W of the target to be attained constitutes a constraint on precision. When task difficulty is increased, the time necessary to perform an aiming movement increases. This systematic relation[1] has come to be known as Fitts' law and has proven to be a powerful tool in evaluating perceptuo-motor capabilities and human–computer interfaces (e.g., Soukoreff & MacKenzie, 2004).

However, not only the time required to complete an aiming movement varies as a function of task difficulty. The kinematic pattern of the movement also changes. For discrete movements, executed at low levels of difficulty, the velocity profile is symmetrically bell-shaped, with acceleration and deceleration phases of equal duration. As task difficulty increases, the velocity profile gradually loses its symmetrical character (Beggs & Howarth, 1970; Langolf, Chaffin, & Foulke, 1976; MacKenzie, Marteniuk, Dugas, Liske, & Eickmeier, 1987; Soechting, 1984). The increase in movement time provoked by an increase in task difficulty results primarily from an increase in the duration of the deceleration phase. During this phase, adjustments of the ongoing movement (i.e., discontinuities in the velocity profile) can be observed, presumably based on visual feedback

[1] Although robust in the grand majority of settings, the monotonic relation between ID and MT is not a law of nature, as violations have been reported (e.g., Kelso, Southard, & Goodman, 1979).