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OCULOCENTRIC FRAMES OF REFERENCE FOR LIMB MOVEMENT

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INTRODUCTION

A little more than a decade ago, two of us (MF and JFS) developed a hypothesis to account for the manner in which visual and proprioceptive information could be processed in a common frame of reference in order to guide limb movements (29). The proposal generated considerable discussion and controversy (13) and spurred other investigators to tackle this problem (e.g. 2, 20, 21). With the passage of time, and since this volume is meant as a retrospective, it seemed appropriate to re-examine the hypothesis. We begin by summarizing the initial hypothesis, and our reinterpretation of the problem in light of recent experimental evidence. We will then summarize some of the electrophysiological evidence that supports a new scheme and conclude by describing some of our recent behavioral observations that led us to it.

The original hypothesis. - We originally set out to account for the first stage of the processes whereby visual information about a target's location in space would be mapped into a pattern of muscle activation adequate to bring the arm to the target. This study was actually inspired by a prior study one of us (JFS) had conducted with Carlo Terzuolo, which dealt with the question of how figural motions (such as circles and ellipses) could be produced (31). There, we proposed a simple algorithm according to which figural aspects of the motion of the hand in space (the slant of the ellipse and the plane in which it was drawn) were regulated by controlling the phasing of the oscillatory motion of the joint angles of the arm (32).

The original hypothesis was also inspired by principles developed in robotics, where the problem of controlling motion is split into two stages: a kinematic phase, in which a plan of motion is generated, and a kinetic phase, in which this plan of motion is translated into the forces required to achieve it (6, 15, 34). Our hypothesis dealt strictly with the kinematic transformations in the first stage and it was based largely on an analysis of errors in memory-guided reaching movements. When subjects were presented with visual targets, asked to close their eyes, and then to put their finger on the remembered position of the target, they made errors that were spherically symmetrical about a point close to the shoulder (28, 33). From this, we argued that information about target location originally encoded in a retinocentric frame of reference was transformed into a body-centered representation, using a spherical coordinate system centered at the shoulder. We also suggested a simple

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