

## Chapter 19

# Tensorial aspects of the multidimensional approach to the vestibulo-oculomotor reflex and gaze

A. Pellionisz

*Department of Physiology and Biophysics, New York University Medical Center, 550 First Avenue, New York, NY 10016, USA*

### 1. Introduction

Gaze control has recently been interpreted by tensor network theory of the CNS, which applies to multidimensional natural coordinate systems (Pellionisz & Llinás, 1979a,b, 1980, 1982a; Ostriker et al., 1985). The vestibulo-oculomotor reflex has also been described by a matrix analysis method, which reduces this system to arbitrary frames that are three-dimensional throughout (Schultheis & Robinson, 1981; Robinson, 1982; Ezure & Graf, 1984a,b) (Chapters 1 & 20). While a detailed tensorial computer model of the complex gaze system is offered elsewhere (Ostriker et al., 1985), two specific, yet important and timely tensorial aspects of the VOR and the adaptive gaze are pointed out in this paper, in order to better illuminate the differences and the similarities of these two approaches. First, it is shown mathematically how the problem of motor coordination is treated tensorially as a covariant-contravariant Eigenvector problem in *overcomplete* sensorimotor systems, through the generalized inverse of the covariant metric tensor (Pellionisz, 1983a, 1984a). Second, it is emphasized that there is a need for a hierarchical analysis of *nested sensorimotor networks* underlying gaze control, as dictated by the concept of Metaorganization, which explains the genesis and modification of neuronal networks that implement the functional geometries of the CNS (Pellionisz, 1983b, 1984c).

#### *1.1. Multidimensional approaches to the central nervous system and to the vestibulo-ocular reflex*

When Sherrington (1906) promulgated the classic concept of reflexes, he warned against its oversimplification. "The main secret of nervous coordination lies evidently in the compounding of reflexes. . . . But though the unit reaction in the integration is a reflex, not every reflex is a unit reaction, since some reflexes are compounded of simpler reflexes. A simple reflex is probably a purely abstract conception, because all parts of the nervous system are connected together and no part of it is probably ever capable of reaction without affecting and being affected by various other parts . . ." (Sherrington, 1906).

Indeed, the gaze system has been regarded since Flourens (1826) as an interconnected multi-variable system where *all* vestibular canals affect the function of *all* eye muscles (cf. the classical analyses by Helmholtz, 1896, Weiland, 1898 or Lorente de Nó, 1932). However, this complex interpretation of the whole had to be supported by a convergent triad of experimental, formal and conceptual means capable of handling such complexities. Such an experimental approach, in the form of registering the contraction of all extraocular muscles, was pioneered by Szentágothai (1950). A corresponding formal treatment, in the form of conventional vector analysis, was attempted by Krewson (1950). An outstanding concep-