Contents

Preface ix

Acknowledgments xi

Chapter 1 What Muscle Parameters Are Controlled by the Nervous System? 1

Spring Properties of an Isolated Muscle 7
Muscle and Its Reflexes 9
Spring Properties of an Intact Muscle 15
Merton's Servo-Hypothesis of Motor Control 21
The α-Model 23
The λ-Model 26
The Notion of Shifting Invariant Characteristics 33
Preprogramming in Motor Control 37

Chapter 2 Analysis of Joint Compliance 49

Equations of Mass-Spring Systems 49
At Least Three Springs! 52
Introducing Central Control 56
Reconstruction of Static Joint Compliant Characteristics 58
How to Reconstruct Joint Compliant Characteristics During Voluntary Movements 59
Shifting Joint Compliant Characteristics During Slow Movements 65
Shifting Joint Compliant Characteristics During Fast Movements 71
N-Shaped Virtual Trajectories 74
Virtual Trajectories of Oscillatory Movements 75

Chapter 3 The Equilibrium-Point Hypothesis and Movement Dynamics 81

Phase Plane and Activation Zones 81
Is λ a Measure of α-Motoneuron Membrane Depolarization? 86
Muscle Reactions to Length Changes 90
Reciprocal and Renshaw Inhibition 95
How Do the Electromyograms Emerge? 98

Chapter 4 Patterns of Single-Joint Movements **103**

Kinematic and Electromyographic Patterns of Single-Joint Isotonic Movements 103
Kinetic and Electromyographic Characteristics of Single-Joint Isometric Contractions 116
Hypotheses and Models 120
Excitation Pulse and the Dual-Strategy Hypothesis 127

Chapter 5 Emergence of Electromyographic Patterns **139**

Basic Assumptions and Notions of the Model 140
Initiation of an Isotonic Movement 145
Termination of an Isotonic Movement 152
Initiation of an Isometric Contraction 159
Divergence of Isometric and Isotonic Patterns 160
Correspondence of the Model to the Data 164
Standard Motor Programs Can Lead to Different Peripheral Patterns 166

Chapter 6 Issues of Variability and Motor Learning **173**

Is There a Motor Program? 173
Variability of Single-Joint Movements 182
Variability in the λ-Language 190
Relation to Motor Learning 199

Chapter 7 Multijoint Movements **205**

The Bernstein Problem 205
Kinematic Characteristics of Multijoint Movements 210
Attempts to Solve the Bernstein Problem 222
The Problem of Postural Stability 234
Problems of Multilimb Coordination 239

Chapter 8 Optimization **245**

System Dynamics and Cost Functions 246
Minimizing Indices of Performance 247
Minimizing "Effort" and Maximizing "Comfort" 252
Relativistic Motor Control 255

Chapter 9 Examples of Motor Disorders **263**

Spasticity 265
Motor Disorders in Parkinson's Disease 274
General Characteristics of Movements in Down Syndrome 283
Some General Implications for Rehabilitation 290

Chapter 10 Language and Movement **293**

On the Laws of Coordination 294
Deep Structure 297
Transformation 299
Surface Structure 301
Tonic Stretch Reflex—An Example of Transformation 307
Concluding Comments 308

Chapter 11 What to Do Next? **311**

Epilogue 315
References 319
Index 371