# Contents


Contributors xiii

Introduction xv

B.M. Nigg, B.R. MacIntosh, and J. Mester

## Part I Work and Energy

Work and Energy Historical Highlights 3

Chapter 1 Mechanical Considerations of Work and Energy 5

B.M. Nigg, D. Stefanyshyn, and J. Denoth

The Concept of Mechanical Work and Energy 5
Mechanical Work 6
Mechanical Energy 8
Calculation of Mechanical Energy During Human Movement 8
The Laws of Conservation of Energy 11
Conservation of Energy 12
Summary 17
References 17

Chapter 2 Storage and Release of Elastic Energy in the Locomotor System and the Stretch-Shortening Cycle 19

R.McN. Alexander

Principles of Elasticity 19
The Properties of Body Parts 20
Springs Functioning as Catapults 25
Springs Saving Energy 27
Springs Cushioning Impacts 28
Conclusion 28
References 28

Chapter 3 Length Changes of Muscle-Tendon Units During Athletic Movements 31

J.G. Hay

Elaboration of the Concepts 31

Long Jump 32
Volleyball Block 38
Sprinting 39
Cycling 42
Summary and Potential Applications 44
References 46

Chapter 4 Work and Energy Influenced by Athletic Equipment 49
D.J. Stefanyshyn and B.M. Nigg
Energy Return 49
Minimizing the Loss of Energy 54
Additional Situations With an Unnecessary Loss of Energy 62
Situations Where a Loss of Energy is Advantageous 63
Summary 63
References 63

Chapter 5 The Three Modes of Terrestrial Locomotion 67
A.E. Minetti
Mechanics and Energetics of Locomotion 67
Slow Speed: Walking and Brachiation 69
Intermediate Speed: Running, Trotting, and Hopping 72
High Speed: Galloping and Skipping 73
Gait Transition 76
Gradient Locomotion 76
Different Gravity Conditions 77
Summary and Potential Applications 77
References 78

Chapter 6 The Pathways for Oxygen and Substrates 79
H. Hoppeler and E.R. Weibel
The Primary Concepts 79
Historical Highlights 80
Model of the Respiratory System 80
Muscle Mitochondria Set the Demand for Oxygen 85
Supply of Substrates From Cellular Stores to Mitochondria 89
Microcirculatory Supply of Oxygen and Substrates 91
Convective Transport of Oxygen and Substrates by the Heart 94
Oxygen Diffusion in the Lung 95
Conclusions 98
References 98

Chapter 7 Energy and Nutrient Intake for Athletic Performance 103
P.W.R. Lemon
Food Energy 104
Carbohydrate 105

Fat 108
Protein 110
Water 115
Minerals 117
Vitamins 121
Summary and Potential Applications 122
References 123

**Chapter 8 Intensity of Cycling and Cycle Ergometry: Power Output and Energy Cost 129**

**B.R. MacIntosh, R.R. Neptune, and A.J. van den Bogert**

Primary Concepts 129
Ergometer Cycling 131
Road Cycling 132
Kinematic Methods 134
Kinetic Methods 134
Indirect Calorimetry 138
Steady State Energetics 139
Determinants of Steady State Energy Cost of Cycle Ergometry 140
Slow Component of Oxygen Uptake 142
Supramaximal Energy Use, Anaerobic Metabolism 144
Measurement of the Energy Cost of Cycling 144
Summary 145
References 146

**Work and Energy Summary 149**

**Work and Energy Definitions 155**

## Part II Balance and Control of Movement

**Balance and Control of Movement Historical Highlights 161**

**Chapter 9 Basic Concepts of Movement Control 163**

**R. Stein, E.P. Zehr, and J. Bobet**

Review of Control Theory 163
Feedforward (Muscle) Control 164
Isometric Contractions 164
Force-Length Curve 166
Force-Velocity Curve 167
Feedback (Reflex) Control 169
Stretch Reflexes and Servo-Control 170
Servo-Assistance and Fusimotor Set 171
Inhibitory Modulation 171
Golgi Tendon Organs 172
Cutaneous Receptors 172

Central Control of Locomotion 174
References 176

**Chapter 10 Muscle Activation and Movement Control 179**
**W. Herzog**
Muscle Activation 179
Movement Control: Experimental Considerations 181
Movement Control: Theoretical Considerations 185
Applications to Sport Science 187
Final Comments 191
References 191

**Chapter 11 Power Output and Force-Velocity Properties of Muscle 193**
**B.R. MacIntosh and R.J. Holash**
The Primary Concepts 193
Shape of the Force- and Power-Velocity Relationships 194
Muscle Architecture and the Force-Velocity Relationship 197
Ways of Studying Force-Velocity Properties 200
Factors Affecting the Force- and Power-Velocity Relationships 202
A Model of Force-Velocity Properties for Mixed Fiber Types 204
Functional Implications of the Force-Velocity Properties of Muscle 207
Concluding Remarks 208
References 208

**Chapter 12 Stability and Control of Aerial Movements 211**
**M.R. Yeadon and E.C. Mikulcik**
Statement of the Problem 211
Primary Concepts 212
Elaboration of Concepts 212
Film Analysis 217
Summary and Potential Applications 220
References 221

**Chapter 13 Movement Control and Balance in Earthbound Movements 223**
**J. Mester**
Statement of the Problem 223
The Primary Concepts 223
Elaboration of Concepts 224
Bottom-Up Regulation: Building Up Posture and Balance Against Gravity 226
Top-Down Regulation: Central Input and Supervision 228
Control and Balance of Directional Earthbound Movements 229
Balance in Standing Upright Under High External Forces 233
Balance in Sitting Under Low External Forces 235
Movement Control Under Time Pressure 236

Summary and Potential Applications 238
References 238

**Balance and Control of Movement Summary** 241

**Balance and Control of Movement Definitions** 245

## Part III Load During Physical Activity

**Load During Physical Activity Historical Highlights** 249

**Chapter 14 Forces Acting on and in the Human Body** 253
**B.M. Nigg**
Definitions and General Comments 253
The Force System Analysis 261
Order of Magnitude of Forces 265
Summary 266
References 266

**Chapter 15 Force Production in Human Skeletal Muscle** 269
**W. Herzog**
Structure and Morphology of Skeletal Muscle 269
Gross Structure of Skeletal Muscle 272
Excitation-Contraction Coupling 272
The Cross-Bridge Theory 273
Muscle Force 275
History Dependence of Force Production 280
Final Comments 280
References 281

**Chapter 16 Mechanical Effects of Forces Acting on Bone, Cartilage, Ligaments, and Tendons** 283
**D.D. Anderson, D.J. Adams, and J.E. Hale**
The Primary Concepts 283
Characterizing Mechanical Properties 284
Hierarchy: A Composite Structural Theme in Musculoskeletal Tissues 288
Summary and Potential Applications 302
References 303

**Chapter 17 Biological Response to Forces Acting in the Locomotor System** 307
**K.J. Fischer**
Statement of the Problem 307
The Primary Concepts 308
Bone Adaptation 308
Articular Cartilage Adaptation 313
Tendon Adaptation 317

Ligament Adaptation 320
Summary and Potential Applications 324
References 324

**Chapter 18 Prevention of Excessive Forces With Braces and Orthotics 331**
**A. Gollhofer, W. Alt, and H. Lohrer**
The Primary Concepts 331
The Ankle Joint 331
The Knee Joint 339
Further Bracing Applications 344
Summary and Potential Application 344
Conclusions 345
References 345

**Load During Physical Activity Summary 351**

**Load During Physical Activity Definitions 355**

## Part IV Fatigue and Exercise

**Fatigue and Exercise Historical Highlights 363**

**Chapter 19 Contractile Changes and Mechanisms of Muscle Fatigue 365**
**B.R. MacIntosh and D.G. Allen**
Primary Concepts 365
Ways of Studying Fatigue 366
Contractile Consequences Associated With Fatigue 368
Cellular Mechanisms of Muscle Fatigue 372
Summary 378
References 378

**Chapter 20 Stretch-Shortening Cycle Fatigue 385**
**P.V. Komi and C. Nicol**
Muscle Fatigue During Isolated Eccentric Actions 386
Eccentrically Induced Muscle Damage and Soreness 387
Specific Functional Effects of Fatiguing SSC Exercises 392
Concluding Hypothesis 403
References 404

**Chapter 21 Muscle Fatigue Monitored by Force, Surface Mechanomyogram, and EMG 409**
**C. Orizio**
Fatigue: Local Muscle Fiber Changes and Muscle Motor Control Alterations 410

Changes in Muscle Mechanical and Electrical Signals 414
Applications 427
Concluding Remarks 428
References 428

**Fatigue and Exercise Summary 435**

**Fatigue and Exercise Definitions 439**

**Name Index 441**

**Subject Index 451**

**About the Editors 467**