Contents

Foreword by Sir Clive Woodward xiii
Preface xv
List of Contributors xvii

Section 1  Strength and Conditioning Biology 1
1.1 Skeletal Muscle Physiology 3
Valmor Tricoli
1.1.1 Introduction 3
1.1.2 Skeletal Muscle Macrostructure 3
1.1.3 Skeletal Muscle Microstructure 3
1.1.3.1 Sarcomere and myofilaments 4
1.1.3.2 Sarcoplasmic reticulum and transverse tubules 7
1.1.4 Contraction Mechanism 7
1.1.4.1 Excitation–contraction (E-C) coupling 7
1.1.4.2 Skeletal muscle contraction 7
1.1.5 Muscle Fibre Types 9
1.1.6 Muscle Architecture 10
1.1.7 Hypertrophy and Hyperplasia 11
1.1.8 Satellite Cells 12
1.2 Neuromuscular Physiology 17
Alberto Rainoldi and Marco Gazzoni
1.2.1 The Neuromuscular System 17
1.2.1.1 Motor units 17
1.2.1.2 Muscle receptors 17
1.2.1.3 Nervous and muscular conduction velocity 18
1.2.1.4 Mechanical output production 18
1.2.1.5 Muscle force modulation 20
1.2.1.6 Electrically elicited contractions 22
1.2.2 Muscle Fatigue 22
1.2.2.1 Central and peripheral fatigue 22
1.2.2.2 The role of oxygen availability in fatigue development 23
1.2.3 Muscle Function Assessment 23
1.2.3.1 Imaging techniques 23
1.2.3.2 Surface EMG as a muscle imaging tool 24
1.2.3.3 Surface EMG for noninvasive neuromuscular assessment 25
1.3 Bone Physiology 29
Jörn Rittweger
1.3.1 Introduction 29
1.3.2 Bone Anatomy 29
1.3.2.1 Bones as organs 29
1.3.2.2 Bone tissue 30
1.3.2.3 The material level: organic and inorganic constituents 31
1.3.3 Bone Biology 32
1.3.3.1 Osteoclasts 32
1.3.3.2 Osteoblasts 32
1.3.3.3 Osteocytes 33
1.3.4 Mechanical Functions of Bone 33
1.3.4.1 Material properties 33
1.3.4.2 Structural properties 34
1.3.5 Adaptive Processes in Bone 35
1.3.5.1 Modelling 35
1.3.5.2 Remodelling 35
1.3.5.3 Theories of bone adaptation 36
1.3.5.4 Mechanotransduction 37
1.3.6 Endocrine Involvement of Bone 38
1.3.6.1 Calcium homoeostasis 38
1.3.6.2 Phosphorus homoeostasis 38
1.3.6.3 Oestrogens 38
1.4 Tendon Physiology 45
Nicola Maffulli, Umile Giuseppe Longo, Filippo Spiezia and Vincenzo Denaro
1.4.1 Tendons 45
1.4.2 The Musculotendinous Junction 46
1.4.3 The Osteotendinous Junction 46
1.4.4 Nerve Supply 46
1.4.5 Blood Supply 46
1.4.6 Composition 47
1.4.7 Collagen Formation 47
1.4.8 Cross-Links 47
1.4.9 Elastin 48
1.4.10 Cells 48
1.4.11 Ground Substance 48
1.4.12 Crimp 48

1.5 Bioenergetics of Exercise 53
Ron J. Maughan
1.5.1 Introduction 53
1.5.2 Exercise, Energy, Work, and Power 53
1.5.3 Sources of Energy 54
1.5.3.1 Phosphagen metabolism 55
1.5.3.2 The glycolytic system 56
1.5.3.3 Aerobic metabolism: oxidation of carbohydrate, lipid, and protein 57
1.5.4 The Tricarboxylic Acid (TCA) Cycle 57
1.5.5 Oxygen Delivery 58
1.5.6 Energy Stores 58
1.5.7 Conclusion 60

1.6 Respiratory and Cardiovascular Physiology 63
Jeremiah J. Peiffer and Chris R. Abbiss
1.6.1 The Respiratory System 63
1.6.1.1 Introduction 63
1.6.1.2 Anatomy 63
1.6.1.3 Gas exchange 63
1.6.1.4 Mechanics of ventilation 66
1.6.1.5 Minute ventilation 67
1.6.1.6 Control of ventilation 68
1.6.2 The Cardiovascular System 68
1.6.2.1 Introduction 68
1.6.2.2 Anatomy 68
1.6.2.3 The heart 70
1.6.2.4 The vascular system 71
1.6.2.5 Blood and haemodynamics 72
1.6.3 Conclusion 74

1.7 Genetic and Signal Transduction Aspects of Strength Training 77
Henning Wackerhage, Arimantas Lionikas, Stuart Gray and Aivaras Ratkevicius
1.7.1 Genetics of Strength and Trainability 77
1.7.1.1 Introduction to sport and exercise genetics 77
1.7.1.2 Heritability of muscle mass, strength, and strength trainability 77
1.7.2 Signal Transduction Pathways that Mediate the Adaptation to Strength Training 79
1.7.2.1 Introduction to adaptation to exercise: signal transduction pathway regulation 79
1.7.2.2 Human protein synthesis and breakdown after exercise 80
1.7.2.3 The AMPK–mTOR system and the regulation of protein synthesis 81
1.7.2.4 Potential practical implications 82
1.7.2.5 Myostatin–Smad signalling 83
1.7.2.6 Signalling associated with muscle protein breakdown 83
1.7.2.7 Satellite-cell regulation during strength training 84
1.7.2.8 What we have not covered 84

1.8 Strength and Conditioning Biomechanics 89
Robert U. Newton
1.8.1 Introduction 89
1.8.1.1 Biomechanics and sport 89
1.8.2 Biomechanical Concepts for Strength and Conditioning 89
1.8.2.1 Time, distance, velocity, and acceleration 90
1.8.2.2 Mass, force, gravity, momentum, work, and power 90
1.8.2.3 Friction 91
1.8.3 The Force–Velocity–Power Relationship 91
1.8.4 Musculoskeletal Machines 92
1.8.4.1 Lever systems 92
1.8.4.2 Wheel-axle systems 93
1.8.5 Biomechanics of Muscle Function 93
1.8.5.1 Length–tension effect 93
1.8.5.2 Muscle angle of pull 93
1.8.5.3 Strength curve 94
1.8.5.4 Line and magnitude of resistance 95
1.8.5.5 Sticking region 95
1.8.5.6 Muscle architecture, strength, and power 95
1.8.5.7 Multiarticulate muscles, active and passive insufficiency 96
1.8.6 Body Size, Shape, and Power-To-Weight Ratio 96
1.8.7 Balance and Stability 96
1.8.7.1 Factors contributing to stability 96
1.8.7.2 Initiating movement or change of motion 97
1.8.8 The Stretch–Shortening Cycle 97
1.8.9 Biomechanics of Resistance Machines 98
1.8.9.1 Free weights 98
1.8.9.2 Gravity-based machines 98
1.8.9.3 Hydraulic resistance 99
1.8.9.4 Pneumatic resistance 99
1.8.9.5 Elastic resistance 100
1.8.10 Machines vs Free Weights 100
1.8.11 Conclusion 100

Section 2 Physiological adaptations to strength and conditioning 103
2.1 Neural Adaptations to Resistance Exercise 105
Per Aagaard
2.1.1 Introduction 105
2.1.2 Effects of Strength Training on Mechanical Muscle Function 105
2.1.2.1 Maximal concentric and eccentric muscle strength 105
2.1.2.2 Muscle power 106
2.1.2.3 Contractile rate of force development 107
2.1.3 Effects of Strength Training on Neural Function 107
2.1.3.1 Maximal EMG amplitude 108
2.1.3.2 Contractile RFD: changes in neural factors with strength training 109
2.1.3.3 Maximal eccentric muscle contraction: changes in neural factors with strength training 110
2.1.3.4 Evoked spinal motor neuron responses 114
2.1.3.5 Excitability in descending corticospinal pathways 116
2.1.3.6 Antagonist muscle coactivation 116
2.1.3.7 Force steadiness, fine motor control 119
2.1.4 Conclusion 119

2.2 Structural and Molecular Adaptations to Training 125
Jesper L. Andersen
2.2.1 Introduction 125
2.2.2 Protein Synthesis and Degradation in Human Skeletal Muscle 125
2.2.3 Muscle Hypertrophy and Atrophy 127
2.2.3.1 Changes in fibre type composition with strength training 128
2.2.4 What is the Significance of Satellite Cells in Human Skeletal Muscle? 131
2.2.5 Concurrent Strength and Endurance Training: Consequences for Muscle Adaptations 132

2.3 Adaptive Processes in Human Bone and Tendon 137
Constantinos N. Maganaris, Jörn Rittweger and Marco V. Narici
2.3.1 Introduction 137
2.3.2 Bone 137
2.3.2.1 Origin of musculoskeletal forces 137
2.3.2.2 Effects of immobilization on bone 138
2.3.2.3 Effects of exercise on bone 140
2.3.2.4 Bone adaptation across the life span 140
2.3.3 Tendon 141
2.3.3.1 Functional and mechanical properties 141
2.3.3.2 In vivo testing 143
2.3.3.3 Tendon adaptations to altered mechanical loading 143
2.3.4 Conclusion 147

2.4 Biochemical Markers and Resistance Training 155
Christian Cook and Blair Crewther
2.4.1 Introduction 155
2.4.2 Testosterone Responses to Resistance Training 155
2.4.2.1 Effects of workout design 155
2.4.2.2 Effects of age and gender 156
2.4.2.3 Effects of training history 156
2.4.3 Cortisol Responses to Resistance Training 156
2.4.3.1 Effects of workout design 156
2.4.3.2 Effects of age and gender 157
2.4.3.3 Effects of training history 157
2.4.4 Dual Actions of Testosterone and Cortisol 157
2.4.5 Growth Hormone Responses to Resistance Training 157
2.4.5.1 Effects of workout design 158
2.4.5.2 Effects of age and gender 158
2.4.5.3 Effects of training history 158
2.4.6 Other Biochemical Markers 158
2.4.7 Limitations in the Use and Interpretation of Biochemical Markers 159
2.4.8 Applications of Resistance Training 159
2.4.9 Conclusion 160

2.5 Cardiovascular Adaptations to Strength and Conditioning 165
Andrew M. Jones and Fred J. DiMenna
2.5.1 Introduction 165
2.5.2 Cardiovascular Function 165
2.5.2.1 Oxygen uptake 165
2.5.2.2 Maximal oxygen uptake 165
2.5.2.3 Cardiac output 165
2.5.2.4 Cardiovascular overload 166
2.5.2.5 The cardiovascular training stimulus 167
2.5.2.6 Endurance exercise training 167
2.5.3 Cardiovascular Adaptations to Training 167
2.5.3.1 Myocardial adaptations to endurance training 167
2.5.3.2 Circulatory adaptations to endurance training 170
2.5.4 Cardiovascular-Related Adaptations to Training 172
2.5.4.1 The pulmonary system 172
2.5.4.2 The skeletal muscular system 173
2.5.5 Conclusion 174

2.6 Exercise-induced Muscle Damage and Delayed-onset Muscle Soreness (DOMS) 179
Kazunori Nosaka
2.6.1 Introduction 179
2.6.2 Symptoms and Markers of Muscle Damage 179
CONTENTS

2.6.2.1 Symptoms 179  
2.6.2.2 Histology 179  
2.6.2.3 MRI and B-mode ultrasound images 180  
2.6.2.4 Blood markers 180  
2.6.2.5 Muscle function 181  
2.6.2.6 Exercise economy 182  
2.6.2.7 Range of motion (ROM) 182  
2.6.2.8 Swelling 182  
2.6.2.9 Muscle pain 183  
2.6.3 Relationship between Doms and Other Indicators 184  
2.6.4 Factors Influencing the Magnitude of Muscle Damage 184  
2.6.4.1 Contraction parameters 185  
2.6.4.2 Training status 185  
2.6.4.3 Repeated-bout effect 185  
2.6.4.4 Muscle 186  
2.6.4.5 Other factors 186  
2.6.5 Muscle Damage and Training 187  
2.6.5.1 The importance of eccentric contractions 187  
2.6.5.2 The possible role of muscle damage in muscle hypertrophy and strength gain 187  
2.6.5.3 No pain, no gain? 188  
2.6.6 Conclusion 188  
2.7 Alternative Modalities of Strength and Conditioning: Electrical Stimulation and Vibration 193  
Nicola A. Maffiuletti and Marco Cardinale  
2.7.1 Introduction 193  
2.7.2 Electrical-Stimulation Exercise 193  
2.7.2.1 Methodological aspects: ES parameters and settings 193  
2.7.2.2 Physiological aspects: motor unit recruitment and muscle fatigue 194  
2.7.2.3 Does ES training improve muscle strength? 195  
2.7.2.4 Could ES training improve sport performance? 196  
2.7.2.5 Practical suggestions for ES use 196  
2.7.3 Vibration Exercise 197  
2.7.3.1 Is vibration a natural stimulus? 200  
2.7.3.2 Vibration training is not just about vibrating platforms 201  
2.7.3.3 Acute effects of vibration in athletes 201  
2.7.3.4 Acute effects of vibration exercise in non-athletes 202  
2.7.3.5 Chronic programmes of vibration training in athletes 202  
2.7.3.6 Chronic programmes of vibration training in non-athletes 203  
2.7.3.7 Applications in rehabilitation 203  
2.7.3.8 Safety considerations 203  
2.8 The Stretch–Shortening Cycle (SSC) 209  
Anthony Blazevich  
2.8.1 Introduction 209  
2.8.2 Mechanisms Responsible for Performance Enhancement with the SSC 209  
2.8.2.1 Elastic mechanisms 209  
2.8.2.2 Contractile mechanisms 212  
2.8.2.3 Summary of mechanisms 216  
2.8.3 Force Unloading: A Requirement for Elastic Recoil 216  
2.8.4 Optimum MTU Properties for SSC Performance 217  
2.8.5 Effects of the Transition Time between Stretch and Shortening on SSC Performance 218  
2.8.6 Conclusion 218  
2.9 Repeated-sprint Ability (RSA) 223  
David Bishop and Olivier Girard  
2.9.1 Introduction 223  
2.9.1.1 Definitions 223  
2.9.1.2 Indices of RSA 223  
2.9.2 Limiting Factors 223  
2.9.2.1 Muscular factors 224  
2.9.2.2 Neuromechanical factors 227  
2.9.2.3 Summary 229  
2.9.3 Ergogenic aids and RSA 229  
2.9.3.1 Creatine 230  
2.9.3.2 Carbohydrates 230  
2.9.3.3 Alkalizing agents 230  
2.9.3.4 Caffeine 231  
2.9.3.5 Summary 232  
2.9.4 Effects of Training on RSA 232  
2.9.4.1 Introduction 232  
2.9.4.2 Training the limiting factors 235  
2.9.4.3 Putting it all together 235  
2.9.5 Conclusion 235  
2.10 The Overtraining Syndrome (OTS) 243  
Romain Meeusen and Kevin De Pauw  
2.10.1 Introduction 243  
2.10.2 Definitions 243  
2.10.2.1 Functional overreaching (FO) 243  
2.10.2.2 Nonfunctional overreaching (NFO) 244  
2.10.2.3 The overtraining syndrome (OTS) 244  
2.10.2.4 Summary 244  
2.10.3 Prevalence 244  
2.10.4 Mechanisms and Diagnosis 245  
2.10.4.1 Hypothetical mechanisms 245  
2.10.4.2 Biochemistry 245
3.5.2.5 IGF 306
3.5.2.6 Leptin 307
3.5.2.7 Research on hormones in sporting environments 307
3.5.2.8 Methodological considerations 308
3.5.3 Metabolic Monitoring 308
3.5.3.1 Muscle biopsy 308
3.5.3.2 Biochemical testing 309
3.5.4 Immunological and Haematological Monitoring 309
3.5.4.1 Immunological markers 309
3.5.4.2 Haematological markers 310
3.5.5 Practical Application 310
3.5.5.1 Evaluating the effects of training 310
3.5.5.2 Assessment of training workload 311
3.5.5.3 Monitoring of fatigue 311
3.5.5.4 Conclusions and specific advice for implementation of a biochemical monitoring programme 311

3.6 Body Composition: Laboratory and Field Methods of Assessment 317
Arthur Stewart and Tim Ackland
3.6.1 Introduction 317
3.6.2 History of Body Composition Methods 317
3.6.3 Fractionation Models for Body Composition 317
3.6.4 Biomechanical Imperatives for Sports Performance 318
3.6.5 Methods of Assessment 319
3.6.5.1 Laboratory methods 319
3.6.5.2 Field methods 323
3.6.6 Profiling 330
3.6.7 Conclusion 330

3.7 Total Athlete Management (TAM) and Performance Diagnosis 335
Robert U. Newton and Marco Cardinale
3.7.1 Total Athlete Management 335
3.7.1.1 Strength and conditioning 335
3.7.1.2 Nutrition 335
3.7.1.3 Rest and recovery 336
3.7.1.4 Travel 336
3.7.2 Performance Diagnosis 336
3.7.2.1 Optimizing training-programme design and the window of adaptation 337
3.7.2.2 Determination of key performance characteristics 338
3.7.2.3 Testing for specific performance qualities 339
3.7.2.4 What to look for 339
3.7.2.5 Assessing imbalances 339
3.7.2.6 Session rating of perceived exertion 340

Section 4 Practical applications 345
4.1 Resistance Training Modes:
A Practical Perspective 347
Michael H. Stone and Margaret E. Stone
4.1.1 Introduction 347
4.1.2 Basic Training Principles 348
4.1.2.1 Overload 348
4.1.2.2 Variation 348
4.1.2.3 Specificity 348
4.1.3 Strength, Explosive Strength, and Power 348
4.1.3.1 Joint-angle specificity 349
4.1.3.2 Movement-pattern specificity 350
4.1.3.3 Machines vs free weights 351
4.1.3.4 Practical considerations: advantages and disadvantages associated with different modes of training 355
4.1.4 Conclusion 357

4.2 Training Agility and Change-of-direction Speed (Cods) 363
Jeremy Sheppard and Warren Young
4.2.1 Factors Affecting Agility 363
4.2.2 Organization of Training 363
4.2.3 Change-of-Direction Speed 364
4.2.3.1 Leg-strength qualities and Cods 366
4.2.3.2 Technique 366
4.2.3.3 Anthropometrics and Cods 369
4.2.4 Perceptual and Decision-Making Factors 370
4.2.5 Training Agility 371
4.2.6 Conclusion 374

4.3 Nutrition for Strength Training 377
Christopher S. Shaw and Kevin D. Tipton
4.3.1 Introduction 377
4.3.2 The Metabolic Basis of Muscle Hypertrophy 377
4.3.3 Optimal Protein Intake 377
4.3.3.1 The importance of energy balance 378
4.3.4 Acute Effects of Amino Acid/Protein Ingestion 379
4.3.4.1 Amino acid source 379
4.3.4.2 Timing 381
4.3.4.3 Dose 382
4.3.4.4 Co-ingestion of other nutrients 382
CONTENTS

4.3.4.5 Protein supplements 383
4.3.4.6 Other supplements 383
4.3.5 Conclusion 383

4.4 Flexibility
William A. Sands
4.4.1 Definitions 389
4.4.2 What is Stretching? 390
4.4.3 A Model of Effective Movement: The Integration of Flexibility and Strength 393

4.5 Sensorimotor Training
Urs Granacher, Thomas Muehlbauer, Wolfgang Taube, Albert Gollhofer and Markus Gruber
4.5.1 Introduction 399
4.5.2 The Importance of Sensorimotor Training to the Promotion of Postural Control and Strength 400
4.5.3 The Effects of Sensorimotor Training on Postural Control and Strength 401
4.5.3.1 Sensorimotor training in healthy children and adolescents 401
4.5.3.2 Sensorimotor training in healthy adults 401
4.5.3.3 Sensorimotor training in healthy seniors 401
4.5.4 Adaptive Processes Following Sensorimotor Training 402
4.5.5 Characteristics of Sensorimotor Training 402
4.5.5.1 Activities 402
4.5.5.2 Load dimensions 403
4.5.5.3 Supervision 405
4.5.5.4 Efficiency 405
4.5.6 Conclusion 406

Section 5 Strength and Conditioning special cases 411
5.1 Strength and Conditioning as a Rehabilitation Tool
Andreas Schlimberger
5.1.1 Introduction 413
5.1.2 Neuromuscular Effects of Injury as a Basis for Rehabilitation Strategies 414
5.1.3 Strength and Conditioning in Retraining of the Neuromuscular System 415
5.1.3.1 Targeted muscle overloading: criteria for exercise choice 415
5.1.3.2 Active lengthening/eccentric training 417
5.1.3.3 Passive lengthening/eccentric stretching 419
5.1.3.4 Training of the muscles of the lumbopelvic hip complex 421
5.1.3.5 Training of sport-specific movements 422
5.1.4 Conclusion 423

5.2 Strength Training for Children and Adolescents
Avery D. Faigenbaum
5.2.1 Introduction 427
5.2.2 Risks and Concerns Associated with Youth Strength Training 427
5.2.3 The Effectiveness of Youth Resistance Training 429
5.2.3.1 Persistence of training-induced strength gains 429
5.2.3.2 Programme evaluation and testing 429
5.2.4 Physiological Mechanisms for Strength Development 430
5.2.5 Potential Health and Fitness Benefits 430
5.2.5.1 Cardiovascular risk profile 431
5.2.5.2 Bone health 431
5.2.5.3 Motor performance skills and sports performance 432
5.2.5.4 Sports-related injuries 432
5.2.6 Youth Strength-Training Guidelines 432
5.2.6.1 Choice and order of exercise 433
5.2.6.2 Training intensity and volume 434
5.2.6.3 Rest intervals between sets and exercises 434
5.2.6.4 Repetition velocity 435
5.2.6.5 Training frequency 435
5.2.6.6 Programme variation 435
5.2.7 Conclusion 435
Acknowledgements 435

5.3 Strength and Conditioning Considerations for the Paralympic Athlete
Mark Jarvis, Matthew Cook and Paul Davies
5.3.1 Introduction 441
5.3.2 Programming Considerations 441
5.3.3 Current Controversies in Paralympic Strength and Conditioning 442
5.3.4 Specialist Equipment 443
5.3.5 Considerations for Specific Disability Groups 443
5.3.5.1 Spinal-cord injuries 443
5.3.5.2 Amputees 445
5.3.5.3 Cerebral palsy 446
5.3.5.4 Visual impairment 447
5.3.5.5 Intellectual disabilities 448
5.3.5.6 Les autres 449
5.3.6 Tips for More Effective Programming 449

Index 453