

SECOND EDITION



Biomechanics of Human Movement

Marlene J. Adrian
John M. Cooper

S E C O N D E D I T I O N

Biomechanics of Human Movement

Marlene J. Adrian, D.P.E

Professor Emerita of Kinesiology, Rehabilitation, Bioengineering
Director of Biomechanics Research Laboratory
University of Illinois at Urbana-Champaign

John M. Cooper, Ed.D.

Professor Emeritus of Physical Education
Indiana University

**Mc
Graw
Hill** **WCB
McGraw-Hill**

Boston, Massachusetts Burr Ridge, Illinois Dubuque, Iowa
Madison, Wisconsin New York, New York San Francisco, California St. Louis, Missouri

Book Team

Editor *Scott Spoolman*
Production Editor *Jayne Klein*
Art Editor *Tina Flanagan*
Photo Editor *Rose Deluhery*
Visuals/Design Freelance Specialist *Mary L. Christianson*
Marketing Manager *Pamela S. Cooper*
Production Manager *Beth Kundert*

WCB/McGraw-Hill

A Division of The McGraw-Hill Companies

Executive Vice President/General Manager *Thomas E. Doran*
Vice President/Editor in Chief *Edgar J. Laube*
Vice President/Marketing and Sales Systems *Eric Ziegler*
Director of Production *Vickie Putman Caughron*
Director of Custom and Electronic Publishing *Chris Rogers*
National Sales Manager *Bob McLaughlin*

President and Chief Executive Officer *G. Franklin Lewis*
Senior Vice President, Operations *James H. Higby*
Corporate Senior Vice President and Chief Financial Officer *Robert Chesterman*
Corporate Senior Vice President and President of Manufacturing *Roger Meyer*

Cover and interior designs by Lesiak/Crampton Design Inc.

Cover image by © William R. Sallaz/Duomo Photography Inc.

Copyedited by Jeffrey Putnam

Copyright © 1989 by Benchmark Press, Inc.

Copyright © 1995 by Wm. C. Brown Communications, Inc.
All rights reserved

Library of Congress Catalog Card Number: 93-74411

ISBN 0-697-16242-7

No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of the publisher.

Printed in the United States of America

10 9 8 7 6 5 4 3 2

Biomechanics of Human Movement

To Charlianna Cooper, from both of us

FOREWORD

Little did Aristotle, the acknowledged father of kinesiology, realize where his practical observations on animal locomotion and human performance would lead. The study of biomechanics, as we know it today, is based on his work and those whose curiosity led them to follow in his footsteps. Those footsteps have led to what the present biomechanists consider to be the major purpose of biomechanics. That purpose is to scientifically analyze the techniques involved in the performance of human movement skills. It allows one to look at movement in terms of space, time, and direction (kinematics), or in terms of the forces responsible for causing motion (kinetics). Further, it allows one to examine the environment in which the movement is performed. No matter whether the movement is a daily movement task or whether the movement is a sport-related skill, the joy and satisfaction of performance occurs when it is done correctly, effortlessly, and safely.

When the first edition of this text was written, the 1988 Olympic Games had just been completed. Nowhere was the importance of biomechanics more evident. For the athletes and coaches, the very motto of the Olympics, "*Citius, Altius, Fortius*"—Swifter, Higher, Stronger—, implied a reliance on the knowledge inherent in the field of biomechanics. Their goal was to compete in an event in the most effective and efficient

manner possible. While this book was in revision, another Olympic Games passed. Performances were even better than the previous Olympic Games, with World and Olympic records being broken. The goal of all athletes in the Olympics was to be the best that they could be. Achieving these goals could not have been possible without the advances in the field of the sport sciences, among them biomechanics.

In a sense, Adrian and Cooper have used the motto of the Olympics as their guiding theme in writing this revised text. The first edition of the text provided a comprehensive exploration of every aspect of human movement and biomechanics. They provided the background material for understanding movement effectiveness and efficiency. However, just as the athletes from one Olympics to another strived to improve the quality of their performances, the authors also strived to improve the quality of their text. They reorganized sections of the text for better clarity, strengthened some of the material on basic biomechanical concepts, and added new information to the application section.

This text represents one of the most comprehensive undertakings in the writing of texts for biomechanics. It covers almost every aspect involved in the living human body. For the teacher or student in biomechanics, the text provides a blend of theory and practice. Learning is

enhanced with motivational tools, such as mini-laboratory learning experiences, and excellent illustrations, tables, and graphs.

Adrian and Cooper long have been recognized as pioneers and leaders in the field of biomechanics. Their experience and wealth of knowledge have added to the value of this text. There is no doubt that they will take

their place in history along with the others who have so ably promoted the study of human movement. Their enthusiasm for the field is contagious and their dedication to the field second to none.

Carole J. Zebas, P.E.D.
Past Chair, Kinesiology Academy
Past President, CSC-ACSM

PREFACE

This edition has been revised to provide the ideas, concepts, and facts for today's students of biomechanics that will enable them to adapt to changing technology, changing social demographics, and the unknown requirements of the future. This book is based on the premise that facts of today may not be facts of tomorrow. But we hope that our presentation of ideas and diversity of perspectives will provide the foundation for adapting to and optimizing our tomorrows.

New Knowledge

As we have repeatedly seen in the past, the introduction of new techniques of analysis result in new knowledge. For example, the electron microscope "saw" new information about bone morphology and the telescope "saw" errors in our thinking about the planets Pluto and Saturn. As we explored the world of kinanthropometry, we came to realize why tall golfers use the predominance of arm actions when they hit a golf ball and shorter golfers emphasize the actions of the trunk. We also see shot putters, especially shorter athletes, using a discus-style turn when putting the shot. New perspectives and greater interrelationships of a multiplicity of factors must be woven into existing knowledge. This we have tried to do in this volume.

Diversity

The amount of material is certainly more than might be discussed in one semester of class meetings. But students and teachers should not be hampered because of the size of this book. Books such as this one are resources to stimulate discussion among students and between students and teachers. The large amount of material is vital to enable students to learn the broad scope of biomechanics and all its applications. Our educational objective is to teach to the diversity of our students. Each student has unique prior experiences. Each has unique objectives and will select a vocational career that will require different aspects of biomechanics. Each student is also endowed with uniquely different cultural and familial backgrounds. With this book, we have tried to provide for the diversity and individuality of our readers. We hope it includes areas of study that will be exciting and motivating to every reader.

Suggestions on Using the Book

This book is designed to be nontraditional, although it can be used in a traditional manner. Since no two classes of students are alike, the order of presentation of material may differ from class to class. We envisage that graduate or second-course level students might wish to

start with Chapters 7 and 8 to study movement analysis. Some teachers may wish to begin with Chapter 24 as a motivating beginning; others will use it as the final session of a class to stimulate thinking for postcollege applications. An idea mentioned in one chapter may be further explored in one or more sections of the book. As the need arises, the student can explore the same concept from several perspectives, or choose to acquire only the basics. The teacher, therefore, can assign a portion of a chapter together with an application from another chapter, and recommend optional sections to read on the same general topic. It is not necessary to read the same number of pages or the same number of chapters for each successive class session. Some material is more difficult or less familiar than other material. Moreover, what is familiar to one student may not be familiar to another student.

Instructor's Manual

We would also mention that the instructor's manual is designed to provide hints for teachers in selecting appropriate key concepts, discussion topics, objectives, evaluation materials, and mini-laboratory experiences. The latter include mathematical problem-solving tasks. Some of the material is photocopy-ready for transparency displays on overhead projectors. The instructor's manual is a resource for the teachers to further enhance learning and provide additional experiences of biomechanical topics, emphasizing the problem-solving analysis approach.

Varied Presentations

The general format of the book is consistent throughout, but we believe that some variation in the presentation of material is refreshing to the student. Therefore, we have not followed a standardized style of writing. The freedom of presentation of ideas from new perspectives seems to be somewhat inconsistent, but we view it as providing the reader with one unique "feel" of each topic. This decision is congruous with the belief that change is inherently valuable for education and that the students of today are a diverse group.

Changes in This Edition

Adrian and Cooper acknowledge the pioneers' work, specifically that of Lawrence Morehouse and Ruth Glassow who wrote with us on previous editions of *Biomechanics of Human Movement*. Morehouse should be cited for his insight into the value of biomechanics as it related to sports. Glassow's pioneer work involved the synthesis of theory and application to the study of human movement. We are grateful for their outstanding foresights. We also are grateful for the contributions of those who contributed to the previous edition. We also acknowledge the many experts in biomechanics, teaching, coaching, therapy, anatomy, and related fields who have contributed to this edition.

Contributors are a Unique Source of Strength

One of the unique features of our book is the valuable insights and knowledge presented by our contributors. They have enabled us to continue to provide our readers with application concepts, knowledge, and issues in a wide spectrum of movement environments. We include a multitude of sports, activities of daily living, music and other arts, occupational tasks, rehabilitation, exercise, and developmental movement patterns. Thus, with this new edition, we have again presented a comprehensive textbook of biomechanics of human movement. This book continues to have the most complete description of analysis techniques, instrumentation systems, and methods of displaying and interpreting data in the field.

New Topics

New sports topics include soccer, team handball, and wrestling. Sections of many of the chapters have been expanded, and new research findings have replaced outdated material. We have particularly expanded the information on dance movements, dysfunctional patterns of disabled people, aging patterns, cycling, and exercise. Some sections have been rearranged and/or merged with others. All sections have been revised extensively.

Organization

The format has been redefined to include the highlighting of key concepts in each section and topics for discussion and movement pattern analysis. The material in the book's sections is consistent with Kinesiology Academy Guidelines, but goes far beyond these requirements.

The book consists of six parts:

- Part I.** Basic Biomechanical Concepts
- Part II.** Tools for Human Movement Analysis
- Part III.** Movements Across the Entire Spectrum of Life
- Part IV.** Sports Movements on Land
- Part V.** Sports Movements in Air, Ice, Snow, and Water Environments
- Part VI.** The Future

Main Authors

Marlene J. Adrian, DPE, FSM

Professor Emerita of Kinesiology, Rehabilitation, Bioengineering
University of Illinois at Urbana–Champaign
Urbana, Illinois

John M. Cooper, Ed.D., FSM

Professor Emeritus
Former Director, Biomechanics Laboratory
Indiana University
Bloomington, Indiana

Contributors

Hobie Billingsley, M.S.

Former US Olympic Diving Coach
Indiana University
Bloomington, Indiana
Consultant for Chapter 23

Connie Bothwell-Meyers, Ph.D.

University of New Brunswick
Fredericton, New Brunswick, Canada
Curling in Chapter 17

Douglas Briggs, Ph.D.

Eastern Michigan University
Ypsilanti, Michigan
Cycling in Chapter 22

Carol Brink, Ph.D.

St. Cloud State University
St. Cloud, Minnesota
Chapter 13 jointly with Lela June Stoner

Eugene W. Brown, Ph.D.

Michigan State University
East Lansing, Michigan
Soccer in Chapters 18 and 19

Dayna Daniels, Ph.D.

University of Lethbridge
Lethbridge, Canada
Chapter 23

Terence M. Freeman, Col.

US Army, West Point, New York
Team Handball in Chapter 19

Paula Richley Gieggle, M.S., PT

Outpatient Therapy, Services Manager
Carle Foundation Hospital
Urbana, Illinois
Consultant for Chapters 10 and 11

Joy Hendrick, Ph.D.

State University College at Cortland
Cortland, New York
Chapter 5

Phillip Henson, Ph.D.

Assistant Track Coach, Indiana University and Olympic Facilities Manager for the 1996 Olympics
Bloomington, Indiana
Consultant for Chapters 15, 16, and 17

Lois Klatt, PED

Concordia University
River Forest, Illinois
Rating sheets in several chapters
Field Hockey in Chapter 19

Anne Klinger, Ph.D.

Clatsop Community College
Astoria, Oregon
Consultant for Chapter 20

Sharol Laczkowski, M.S.

Fitness Expert, Student Health Center
Indiana University
Bloomington, Indiana
Power Skating and In-line Skating in Chapter 22

Cheryl Maglischo, Ed.D.

California State University
Chico, California
Jointly with Ernie Maglischo, Chapter 21

Ernie Maglischo, Ph.D.

California State University
Arizona State
Tempe, Arizona
Jointly with Cheryl Maglischo, Chapter 21

Dawn L. Orman Patel, M.S.

Indianapolis University
Indianapolis, Indiana
Badminton in Chapter 18

Michael Purcell, M.S., Kodan

Member of Kodokan Scientific Study Group, Japan
Richland, Washington
Judo in Chapter 20

Lynda Randall, PED

California State University
Fullerton, California
Clinical Diagnosis in Chapter 9

James Richards, Ph.D.

University of Delaware
Newark, Delaware
Bobsled and Luge in Chapter 22

Mary Ridgway, Ph.D.

University of Texas, Arlington
Arlington, Texas
Volleyball in Chapter 19

Paul Smith, Ph.D.

West Chester University
West Chester, Pennsylvania
Karate in Chapter 20

Lela June Stoner, Ph.D.

University of Minnesota
Minneapolis, Minnesota
Chapter 13 jointly with Carol Brink

Tonya Toole, Ph.D.

Florida State University
Tallahassee, Florida
Aging in Chapter 9

Reviewers**David A. Barlow**

University of Delaware

Cheryl Maglischo

California State University—Chico

Helen Miles

Fort Hays State University

Mary E. Ridgeway

University of Texas—Arlington

Carole J. Zebas

University of Kansas

CONTENTS IN BRIEF

PART I	BASIC BIOMECHANICAL CONCEPTS				
1	Fundamental Biomechanical Concepts	3	12	Occupational Biomechanics	243
2	Static and Dynamic Posture	21	13	Biomechanics in the Arts	257
3	The Human Structural System	43	14	Collisions and Impacts	279
4	Human Movement Assembly: Muscle-Bone Lever System	55			
5	Activation of the Muscle-Bone System	85	PART IV	SPORTS MOVEMENTS ON LAND	293
6	Mechanical Principles Related to Human Movement	105			
			15	Biomechanics of Running	295
PART II	TOOLS FOR HUMAN MOVEMENT ANALYSIS	129	16	Biomechanics of Jumping	315
			17	Biomechanics of Throwing	333
7	Tools for Assessment, Improvement, and Prediction of Movement	131	18	Biomechanics of Striking and Kicking Skills	365
8	Qualitative and Quantitative Assessment	153	19	Biomechanics of Selected Team Sports	393
			20	Biomechanics of Combatives	427
PART III	MOVEMENTS ACROSS THE ENTIRE SPECTRUM OF LIFE	177	PART V	SPORTS MOVEMENTS IN AIR, ICE, SNOW, AND WATER ENVIRONMENTS	445
9	Developmental Biomechanics	179			
10	Biomechanics of Exercise	209	21	Biomechanics of Aquatic Activities	447
11	Rehabilitative Biomechanics	227	22	Biomechanics of Rolling and Sliding Activities	471
			23	Biomechanics of Airborne and Arm-Supported Activities	501
			PART VI	THE FUTURE	525
			24	Visualizing the Future	527

CONTENTS

	<i>Foreword</i>	xv			
	<i>Preface</i>	xvii			
PART I	BASIC BIOMECHANICAL CONCEPTS	1	3	The Human Structural System	43
1	Fundamental Biomechanical Concepts	3		<i>Framework of the Skeleton</i>	<i>43</i>
	<i>What Is Human Biomechanics?</i>	<i>3</i>		<i>Joints</i>	<i>43</i>
	<i>The Person</i>	<i>4</i>		<i>Bones</i>	<i>48</i>
	<i>The Task</i>	<i>9</i>		<i>References</i>	<i>53</i>
	<i>The Environment</i>	<i>9</i>	4	Human Movement Assembly:	
	<i>The Movement</i>	<i>10</i>		<i>Muscle-Bone Lever System</i>	<i>55</i>
	<i>Temporal Aspects of Movement</i>	<i>10</i>		<i>Definition of a Lever</i>	<i>55</i>
	<i>The Why of Biomechanics?</i>	<i>16</i>		<i>Identifying Human Levers</i>	<i>55</i>
	<i>Movement Analysis Models</i>	<i>16</i>		<i>Function of Bony Levers</i>	<i>57</i>
	<i>The Search for Answers</i>	<i>19</i>		<i>Effect of Positioning of Body Segments on Resistance Arms</i>	<i>59</i>
	<i>References</i>	<i>20</i>		<i>Muscles</i>	<i>60</i>
2	Static and Dynamic Posture	21		<i>Components of Muscle Force</i>	<i>70</i>
	<i>Principles of Equilibrium</i>	<i>22</i>		<i>Muscle-Bone Lever Systems, Muscles, and Physiological Cross-Sectional Area (PCSA)</i>	<i>77</i>
	<i>Normal and Abnormal Postures</i>	<i>23</i>		<i>Body Segments</i>	<i>80</i>
	<i>Posture of Readiness</i>	<i>26</i>		<i>References</i>	<i>83</i>
	<i>Determining Center of Gravity</i>	<i>27</i>	5	Activation of the Muscle-Bone System	85
	<i>Measurement of Postural Sway</i>	<i>31</i>		<i>Central Nervous System</i>	<i>85</i>
	<i>Determining Center of Gravity in a Moving Body</i>	<i>33</i>		<i>Peripheral Nervous System</i>	<i>88</i>
	<i>References</i>	<i>41</i>		<i>Motor Units</i>	<i>89</i>
				<i>Receptors</i>	<i>90</i>
				<i>Proprioceptors</i>	<i>91</i>

<i>Volitional Contribution to Motor Action</i>	93	<i>Goniometry and Electrogoniometry</i>	141
<i>Involuntary Details of Motor Behavior</i>	94	<i>Electromyography</i>	144
<i>Inherent Motor Patterns</i>	97	<i>Dynamography</i>	145
<i>Learning Motor Patterns</i>	98	<i>Accelerometry</i>	149
<i>Perception of Movement and Position</i>	99	<i>Modeling and Simulation</i>	149
<i>Reaction Time and Movement Time</i>	100	<i>General Guidelines for Use of Tools</i>	152
<i>Neural Adaptation</i>	101	<i>References</i>	152
<i>Proprioceptive Neuromuscular Facilitation</i>	102	8 Qualitative and Quantitative Assessment	153
<i>References</i>	103	<i>Qualitative Analysis</i>	153
6 Mechanical Principles Related to Human Movement	105	<i>Quantitative Analysis</i>	154
<i>Understanding the Variables of Mechanics</i>	106	<i>Naked-Eye Observational Procedures</i>	154
<i>Understanding the Vector Quantities</i>	107	<i>Acoustical Analysis of Rhythmic Pattern of Movement</i>	156
<i>Displacements with Respect to Time</i>	110	<i>Videographic and Cinematographic Analyses</i>	162
<i>Useful Equations of Motion</i>	111	<i>Basic Dynamographic Analysis</i>	169
<i>Relationship of Newton's Three Laws of Motion to Translation</i>	112	<i>Accelerometric Analysis</i>	169
<i>Relationship of Laws of Motion to Rotary Motion</i>	114	<i>Electrogoniometric Analysis</i>	171
<i>Impulse-Momentum</i>	118	<i>Muscle Analysis</i>	172
<i>Conservation of Momentum</i>	119	<i>Composite Analysis</i>	175
<i>Principles Related to Impulse/Momentum</i>	121	<i>References</i>	176
<i>Work-Energy</i>	122	PART III MOVEMENTS ACROSS THE ENTIRE SPECTRUM OF LIFE	177
<i>Potential and Kinetic Energy of Collisions</i>	124	9 Developmental Biomechanics	179
<i>Forces in Air and Water Environments</i>	127	<i>Stage-Theory Models</i>	180
<i>References</i>	128	<i>Determinants of Walking</i>	183
PART II TOOLS FOR HUMAN MOVEMENT ANALYSIS	129	<i>Ground Reaction Forces During Walking</i>	188
7 Tools for Assessment, Improvement, and Prediction of Movement	131	<i>Motor Development of Children</i>	189
<i>Timing Devices</i>	131	<i>Immature Patterns of Fundamental Movements</i>	189
<i>Photography and Cinematography</i>	132	<i>Clinical Diagnosis of Skills for Effective Training</i>	192
<i>Videography</i>	139	<i>Biomechanics and Aging</i>	196
		<i>ADL: The Foundation of Developmental Biomechanics Related to Aging</i>	202
		<i>Guidelines for Evaluation of ADL Performances within the Life Space Environment</i>	207
		<i>References</i>	207

10	Biomechanics of Exercise	209		<i>Biomechanics of Head Injuries and Protection</i>	283
	<i>Guidelines for Biomechanical Design and Evaluation of Exercises</i>	210		<i>Falling</i>	284
	<i>Strength Exercises</i>	211		<i>Landing</i>	287
	<i>Flexibility and Stretching Exercises</i>	217		<i>Protective Equipment Used During Landings</i>	288
	<i>Neuromuscular Exercises</i>	218		<i>Is Protective Equipment Required?</i>	289
	<i>Cardiovascular Exercise</i>	219		<i>References</i>	290
	<i>Hazardous Exercise?</i>	220			
	<i>Exercise Equipment Evaluation</i>	221			
	<i>References</i>	226	PART IV	SPORTS MOVEMENTS ON LAND	293
11	Rehabilitative Biomechanics	227	15	Biomechanics of Running	295
	<i>Major Goals of Rehabilitative Biomechanics</i>	227		<i>Step and Stride</i>	296
	<i>Rehabilitation Exercises</i>	228		<i>General Mechanics of Running</i>	296
	<i>Rehabilitation Locomotion</i>	230		<i>Body Lean of a Sprinter Compared to a Distance Runner</i>	299
	<i>Supplementation Devices</i>	232		<i>Joint Actions of Supporting Limb</i>	300
	<i>Substitution Devices</i>	235		<i>Joint Actions of Swinging Limb</i>	301
	<i>Transportation Devices</i>	236		<i>Angles of Inclination of Supporting Limb</i>	302
	<i>ADL Analyses and Concerns</i>	238		<i>Additional Joint Actions</i>	302
	<i>References</i>	240		<i>Types of Terrain</i>	303
12	Occupational Biomechanics	243		<i>Track Starts and Initial Sprinting Phase</i>	304
	<i>Methodological Approaches</i>	243		<i>Overstriding and Understriding</i>	306
	<i>Occupational Biomechanical Considerations</i>	244		<i>Running Economy</i>	306
	<i>Kinetic Modeling</i>	252		<i>Fatigue Effects</i>	307
	<i>References</i>	254		<i>Speed and Efficiency</i>	308
13	Biomechanics in the Arts	257		<i>Forces and Anatomical Adjustments</i>	308
	<i>Biomechanical Principles for Artists</i>	258		<i>Gender Differences</i>	309
	<i>The Dancer</i>	259		<i>Racewalking</i>	309
	<i>The Musician</i>	267		<i>References</i>	313
	<i>The Dramatic Artist</i>	273	16	Biomechanics of Jumping	315
	<i>The Visual Artist</i>	273		<i>Standing Jumps (Pushing Off with Both Feet)</i>	316
	<i>Trends and Guidelines</i>	274		<i>Running Jumps (Single-Foot Push)</i>	320
	<i>References</i>	276		<i>References</i>	331
14	Collisions and Impacts	279	17	Biomechanics of Throwing	333
	<i>Understanding and Measuring the Forces of a Collision</i>	279		<i>Factors Affecting Flight of Objects</i>	333
	<i>Mechanics of Stopping Moving Objects</i>	279		<i>High-Velocity Throwing Concepts</i>	334
	<i>Catching</i>	280		<i>Axes of Rotation</i>	334
	<i>Protective Equipment for Catching</i>	282		<i>Throwing Patterns</i>	337
				<i>Biomechanics of Selected Throwing Skills</i>	340

	<i>Underarm Patterns: Softball Pitching, Hammer Throw, Bowling, and Curling</i>	342		<i>Using Sculling Motions Effectively</i>	459
	<i>Overarm Patterns: Football Passing, Baseball Pitching, Shot Put, and Javelin Throws</i>	352		<i>Stroke Rates and Stroke Lengths</i>	463
	<i>Injuries</i>	361		<i>Swim Starts and Turns</i>	464
	<i>References</i>	363		<i>Special Training Devices for Improving Swimming Speed</i>	467
18	Biomechanics of Striking and Kicking Skills	365	22	Biomechanics of Rolling and Sliding	468
	<i>Velocity of the Striking Instrument</i>	366		<i>Activities</i>	471
	<i>Baseball and Softball Batting</i>	366		<i>Definitions</i>	471
	<i>Racquet Sports</i>	369		<i>Commonalities of Gliding Activities</i>	471
	<i>Golf Stroke</i>	378		<i>Skating</i>	472
	<i>Kicking</i>	384		<i>Skiing</i>	477
	<i>References</i>	390		<i>Surfboarding</i>	483
19	Biomechanics of Selected Team Sports	393		<i>Skateboarding</i>	484
	<i>Basketball</i>	393		<i>Bobsled</i>	484
	<i>Team Handball</i>	408		<i>Luge</i>	486
	<i>Soccer</i>	410		<i>Bicycle Racing</i>	487
	<i>Field Hockey</i>	413		<i>References</i>	499
	<i>Volleyball</i>	416	23	Biomechanics of Airborne and Arm-Supported Activities	501
	<i>References</i>	424		<i>Basic Principles Relating to Airborne and Swinging Activities</i>	502
20	Biomechanics of Combatives	427		<i>Trampolining, Tumbling, and Diving Skills</i>	503
	<i>Answering Questions with Biomechanical Principles</i>	427		<i>Rotary Capabilities of the Human Body</i>	504
	<i>Karate</i>	428		<i>Gymnastics and Rotations</i>	505
	<i>Boxing</i>	435		<i>Determinants of Skilled Gymnastics Movements</i>	506
	<i>Wrestling</i>	436		<i>Arm-Supported Skills</i>	508
	<i>Fencing</i>	437		<i>Elements on the Parallel Bars</i>	510
	<i>Judo</i>	440		<i>Elements on the Uneven Parallel Bars and the Horizontal (High) Bar</i>	510
	<i>References</i>	443		<i>Elements on the Still Rings</i>	515
PART V	SPORTS MOVEMENTS IN AIR, ICE, SNOW, AND WATER ENVIRONMENTS	445		<i>Pommel Horse Elements</i>	517
				<i>Balance Beam</i>	518
21	Biomechanics of Aquatic Activities	447		<i>Vaulting</i>	519
	<i>Characteristics of Water</i>	447		<i>Anthropometric Considerations for All Gymnastics Events</i>	521
	<i>Floating</i>	448		<i>Biomechanics and Safety</i>	521
	<i>Resistive Drag</i>	450		<i>Risk Analysis</i>	522
	<i>Types of Resistive Drag Encountered by Swimmers</i>	450		<i>References</i>	523
	<i>Propulsive Forces</i>	455			

PART VI	THE FUTURE	525	APPENDIX		
24	Visualizing the Future	527	A	Metric-English Units	540
	<i>A Vision or Reality?</i>	528	B	Trigonometry, Vectors, and Problems	542
	<i>Teams of Movement Analysts</i>	528	C	Projectiles	547
	<i>New Fitness Equipment</i>	528	D	Maximum Moments of Force	551
	<i>Recording Movement Parameters in Sports</i>	530	E	Anthropometric Values	552
	<i>Improving the Environment to Improve Athletic Performance</i>	530	GLOSSARY		553
	<i>Expert Systems and Profiling</i>	532	INDEX		559
	<i>Solving Movement Problems</i>	532			
	<i>New Perspectives</i>	537			
	<i>References</i>	539			