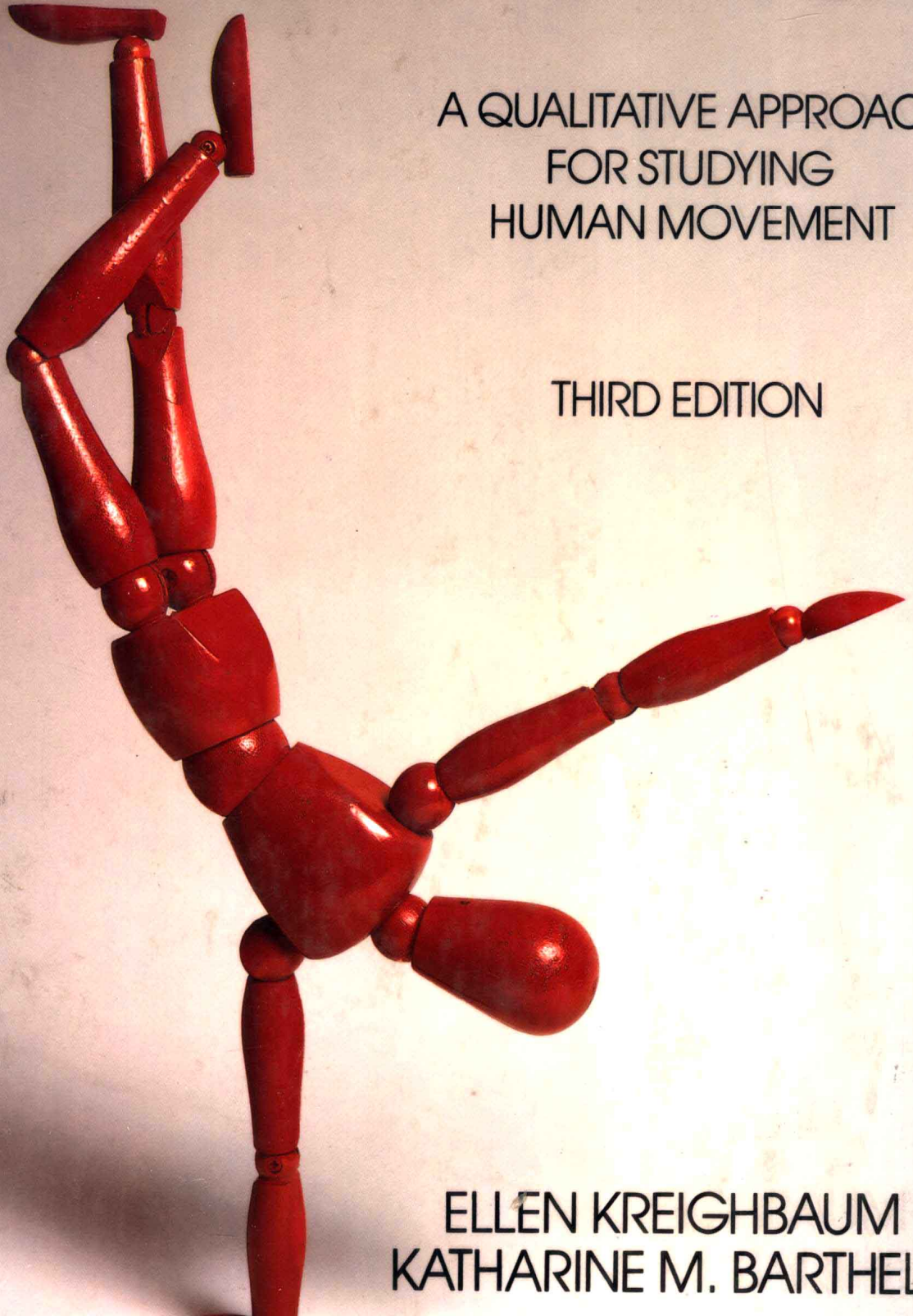


BIOMECHANICS

A QUALITATIVE APPROACH
FOR STUDYING
HUMAN MOVEMENT

THIRD EDITION



ELLEN KREIGHBAUM
KATHARINE M. BARTHELS

BIOMECHANICS

THIRD EDITION

Macmillan Publishing Company
New York

Editor: Robert Miller
Production Supervision: Kirsten Stigberg/Publication Services, Inc.
Text Design: Sheree Goodman
Cover Designers: Katharine M. Barthels and Sheree Goodman
Illustrations: Katharine M. Barthels and Ellen Kreighbaum

This book was set in Palatino by Publication Services, Inc.,
and printed and bound by R.R. Donnelley & Sons.
The cover was printed by Phoenix Color Corp.

Copyright © 1990 by Macmillan Publishing Company,
a division of Macmillan, Inc.

Printed in the United States of America

All rights reserved. No part of this book may be reproduced or
transmitted in any form or by any means, electronic or mechanical,
including photocopying, recording, or any information storage and
retrieval system, without permission in writing from the Publisher.

Earlier editions copyright © 1981 and 1985 by Burgess Publishing Company.

Macmillan Publishing Company
866 Third Avenue, New York, New York 10022

Collier Macmillan Canada, Inc.

Library of Congress Cataloging-in-Publication Data

Kreighbaum, Ellen.

Biomechanics : a qualitative approach for studying human movement
/ Ellen Kreighbaum, Katharine M. Barthels. —3rd ed.

p. cm.

Includes bibliographical references.

ISBN 0-02-366310-3

1. Human mechanics. 2. Biomechanics. I. Barthels, Katharine M.
II. Title.

QP303.K72 1990

612'.76—dc20

89-12667

CIP

Printing: 5 6 7 Year: 4 5 6

*The authors dedicate this text to their parents, who guided, influenced,
and instilled attitudes necessary to pursue such a task;
to professional colleagues, who inspired and encouraged their questioning;
and to their students, whose comments and criticisms were an integral
part of the text development, and who provided the main reason for its writing.*

Foreword

Authoring a textbook is like becoming a parent. It is a mixture of joy, a measure of heartache, considerable pride, and lots of work! It begins in rapture, sometimes planned, often not. If the timing and conditions are right, conception takes place, followed by a finite period of gestation when the myriad parts develop and are integrated into a complete functioning organism capable of life on its own. At birth (or publication of the first edition, whichever side of the simile you choose to adopt), the organism is, at the same time, complete and incomplete. It has the basic framework and all the organs necessary for survival, but it is yet an infant.

The first revision can be likened to adolescence when the awkwardness of rapid growth occurs and must be accommodated. The second revision signals the arrival of early adulthood where self-identity has been achieved and responsible contribution becomes the accepted calling.

Ellen Kreighbaum and Kathy Barthels, in the creation of this textbook, have been good parents. Their basic conception was magnificent, that of producing a source book for students, teachers, and researchers which emphasizes the qualitative aspect of studying human movement. It fulfilled a need in the field of movement analysis that had been largely ignored. The addition of concept modules and enhanced understanding sections in the first revision (second edition) *provided necessary growth, development, and strength*. This, the second revision (third edition) of the textbook, marks its status as a fully developed body of knowledge. Its uniqueness remains the authors' dedication to presenting a way of analyzing movement that is purposely qualitative. New to this edition are requisite refinements, knowledge updates, the dedication of a separate chapter for biomechanical analysis, and the addition of a new chapter on instruments that facilitate the analysis process.

Just as an adult retains certain identifiable features of his or her childhood, the same is true of this treatise on biomechanics. The authors have remained true to their "original intent and perspective," that of "promoting an understanding of biomechanical principles that govern the effectiveness of human movement

skills" within a "conceptual" and "qualitative" framework. Three foundational features of the original work remain clearly evident in this new edition. They are:

1. The importance of biomechanical principles. Principles are accepted basic rules that guide action. They attempt to explain why the body moves in certain ways, why it obeys the laws of physics/mechanics. They provide insight and allow generalizing to take place in the application of knowledge.
2. The belief that knowledge of such principles can improve performance. The insight gained from understanding biomechanical principles speeds motor skill learning. The principles provide goals to be achieved in the performance. They offer a template against which performance can be compared.
3. The importance of a conceptual/qualitative approach in learning these principles. How one learns new concepts frequently is as important as what those new concepts are. The emphasis here is always on getting the "idea" or the "big picture" first, then filling in the details. It's not that the details are unimportant. They are essential. It's just that, in the initial stages of understanding a complex body of knowledge, too many details can sometimes impede progress. In skilled motor performance, it's the old "paralysis by analysis" phenomenon.

New features are also evident in this mature organism. Of particular interest are the following:

1. A separate chapter for biomechanical analysis which brings to life the application of the principles of this science.
2. The addition of a chapter on instruments that facilitate the analysis process.

It is an honor for me to present this complete work to you. I do it confidently and proudly as one announcing the graduation of a prized student. I have watched her grow and have even played a small part in her development. She has helped many others along the way, including me. She now takes her place as a competent and complete contributor in the ever improving and expanding field of biomechanical analysis.

Orwyn Sampson

*Biomechanics Instructor
United States Air Force Academy*

Preface

The revision of this text was undertaken for the following reasons: (1) to present an expanded and more thorough analysis system for explicit use by the teacher and coach, (2) to update material and expand the references and suggested readings sections following each chapter, and (3) to modify organization and content in response to readers' comments and suggestions.

The third edition of this text is in keeping with the original intent and perspective of the authors. Thus, it is focused on promoting an understanding of the biomechanical principles that govern the effectiveness of human movement skills. Furthermore, the focus is on presenting appropriate biomechanical information within conceptual frameworks that are based on the common overall performance objective of those skills being analyzed. In keeping with the AAHPERD Kinesiology Academy Guidelines and Standards, the conceptual, qualitative approach has been maintained to facilitate the student's grasp of the ideas presented.

In particular, the analysis section has been expanded greatly and has been developed into a separate chapter. Chapter 9, *Observing and Analyzing Performance*, presents a complete format for analysis. The teacher or coach is led through the initial steps of identifying the overall performance objective of the skill, the mechanical principles governing the accomplishment of that objective, and the identification of the critical features of performance that the coach can observe. Using this format, the practitioner should be able to identify and correct misplaced, unnecessary, or detrimental aspects of performance. The analysis chapter is placed after the modules and chapters dealing with anatomy or basic mechanics and before the chapters dealing with movement performances.

The text has remained qualitative as much as possible. Where necessary, equations are used with numerical examples so that the student can obtain a feel for the relative importance of the concept being presented. For those who use quantitative material in their classes, these relationships are presented in the appendixes for convenient reference. Furthermore, the third edition includes

a chapter on biomechanics instrumentation in which the tools for quantitative analysis are described thoroughly. For those who incorporate data collection in their laboratory experiences, the chapter should serve as a valuable overview of those instruments used currently in biomechanics laboratories and at data collection sites.

The organization of the text into modules and chapters has been maintained from the second edition. The modules present basic biomechanical (anatomical or mechanical) material necessary for the understanding of groups of mechanically similar skills that follow in the chapters. For example, basic musculoskeletal information in Modules A and B and basic mechanical concepts of forces and torques in Modules C, D, and E are presented before the application of these concepts to the upper extremity, lower extremity, and trunk in Chapters 3–6. The authors firmly believe in the necessity of synthesizing anatomy and mechanics and applying them to the biological structure. Thus, we have not consented to organizing the text into an anatomy section followed by a mechanics section and finally an application section as many textbooks are prone to do. While this may be more difficult for some initially, the final result will encourage a unification of the bio- and the mechanics and, we hope, will minimize the dichotomy of the two, which has been prevalent in the past.

The module and chapter organization also facilitates ease of use for instructors who have many different approaches to teaching kinesiology or biomechanics. One may begin a course at any chapter or module. The modules and chapters that contain prerequisite information to this starting point are listed at the beginning of that chapter or module. Thus, the instructor need assign only those prerequisites to present the material in the chosen order. With this organizational scheme, virtually any order of presentation is possible. An anatomically based course could use Modules A–E and Chapters 1–7. A mechanically based course could use Modules C–K and Chapters 1 and 8–17.

The Understanding sections have been maintained and revised, and expanded where appropriate. These sections can be used for assignments, as a springboard for class discussion, or for laboratory work. The answers and points of discussion for the questions in the Understanding sections are given in the *Instructor's Manual*. Also included is useful information and direction for the instructor such as sources of biomechanics information from the literature, from professional organizations, and from professional meetings.

A further source of information is in the expanded and detailed lists of References and Suggested Readings, which follow each module and chapter. While some of these sources may exceed the level of understanding for some, they are important and useful for becoming familiar with the leading edge of the frontiers of biomechanics. They may also be important sources for reports and assignments.

Finally, the illustrations and photographs have been modified in some cases and expanded in others. In this edition, as in the last two editions, the authors have created their own illustrations and photographs. The authors believe that the application of a concept can be enhanced with the use of a quality illustra-

tion, and thus the illustrations should be used as a source of information as well as an example of concepts presented in the text.

Contributions from several individuals to the production of this edition are appreciated. We wish to thank *sincerely the following people*:

Brigitte Kohler, who did the final inking of the authors' original illustrations in the first edition, most of which are included in this edition

Bob Schwarzkopf, Jeannie Zumwalt, Don Jensen, and Rozan Pitcher, who served as subjects for some of the illustrations or for photographs

Carol Sanford, Marge Burgess, and Raeann Magyar, who assisted in various ways to complete the third edition

Orwyn Samson, who graciously consented to write the foreword to the third edition and whose comments and suggestions have been used to revise and improve the text.

E.K.

K.B.

Contents

CHAPTER 1

THE STUDY AND ANALYSIS OF HUMAN MOVEMENT	1
1.1 Kinesiology and Biomechanics: Areas of Study	2
1.2 Approaches for Studying Movement	5
<i>Understanding the Study of Human Movement</i>	7

CONCEPT MODULE A

THE SKELETAL SYSTEM AND ITS ARTICULATIONS	9
A.1 The Skeletal System	9
A.2 Articulations	21
<i>Understanding the Skeletal-Articular Structures</i>	27

CONCEPT MODULE B

THE LINK SYSTEM AND ITS MOVEMENTS	33
B.1 The Link System and Its Movements	33
<i>Understanding the Body's Link System and Its Movements</i>	48
B.2 Anthropometric Characteristics of the Body	49
<i>Understanding Anthropometric Measures</i>	60

CHAPTER 2

NEUROMUSCULAR ASPECTS OF MOVEMENT	63
2.1 Functional Aspects of the Muscular System	64
2.2 Types and Functions of Muscular Tension	68
<i>Understanding the Characteristics of the Muscular System and Muscular Tension</i>	70

2.3	Functional Aspects of the Neuromuscular System	74
2.4	Factors Influencing the Effectiveness of Muscular Tension	75
	<i>Understanding the Neuromuscular System and Factors Affecting Muscular Tension</i>	83
2.5	Functional Aspects of the Sensorimotor System	84
	<i>Understanding the Sensorimotor System</i>	88

CONCEPT MODULE C

LOOKING AT MOVEMENT: SOME MECHANICAL CONCEPTS		93
C.1	The Movement of a System Within a Frame of Reference	94
C.2	Types of Motion	97
C.3	Force	99
C.4	Pressure	99
C.5	Mass, Gravity, and Weight	100
C.6	Center of Gravity	101
	<i>Understanding a System and How It Moves</i>	103
C.7	Work	104
C.8	Power	105
C.9	Energy	106
	<i>Understanding Work, Power, and Energy</i>	107

CONCEPT MODULE D

FORCES AND MOVEMENT	109
D.1 Forces Acting on a System	109
D.2 Reaction Forces	110
D.3 Friction Force	113
D.4 Centripetal and Centrifugal Forces	116
D.5 Elastic Force	118
<i>Understanding Different Kinds of Force</i>	119
D.6 Internal and External Forces	120
D.7 Motive and Resistive Forces	124
<i>Understanding Motive and Resistive Forces</i>	127
D.8 Force Diagrams and Vectors	127
<i>Understanding Force Vectors</i>	135

CONCEPT MODULE E

TORQUE	137
E.1 Torque and Rotary Motion	137
E.2 The Effect of Two or More Torques on a System: Vector Composition	141

E.3	Systems in Linear and Rotary Motion	143
	<i>Understanding Torque</i>	144
E.4	Torque and the Body's Center of Gravity Location	147
	<i>Understanding the Center of Gravity</i>	153

CHAPTER 3

BIOMECHANICS OF THE MUSCULOSKELETAL SYSTEM	157
3.1 Leverlike Arrangements	158
<i>Understanding Torques on the Musculoskeletal System</i>	165
<i>Understanding Applications to Musculoskeletal Structures</i>	171
3.2 Wheel and Axlelike Arrangements	181
3.3 Pulleylike Arrangements	183
3.4 General Considerations of Musculoskeletal Machines	183
<i>Understanding Musculoskeletal Machines</i>	185

CHAPTER 4

BIOMECHANICAL RELATIONSHIPS IN THE UPPER EXTREMITY	187
4.1 The Shoulder Girdle Complex	188
4.2 The Shoulder Joint	193
<i>Understanding the Shoulder Girdle–Shoulder Joint Complex</i>	199
4.3 The Elbow Joint	200
4.4 The Radioulnar Joint	203
4.5 The Wrist Joint	206
<i>Understanding the Elbow, Radioulnar, and Wrist Joints</i>	206

CHAPTER 5

BIOMECHANICAL RELATIONSHIPS IN THE LOWER EXTREMITY	210
5.1 The Hip Joint	211
5.2 The Knee Joint	217
<i>Understanding the Hip and Knee Joints</i>	227
5.3 The Tibiofibular Joint	227
5.4 The Ankle and Foot	229
<i>Understanding the Ankle and Foot</i>	233
5.5 Biomechanics of the Lower Extremity During Locomotion	234
5.6 Lower Extremity Postures	235
5.7 Lower Extremity Misalignments in Dance	244
5.8 Analyzing Lower Extremity Misalignments	246
<i>Understanding Postural Alignments</i>	249

CHAPTER 6

BIOMECHANICAL RELATIONSHIPS IN THE TRUNK	255
6.1 The Skull	255
6.2 The Thorax	256
6.3 The Vertebral Column	256
<i>Understanding the Trunk</i>	270

CHAPTER 7

APPLICATION OF BIOMECHANICS TO NEUROMUSCULAR FITNESS ACTIVITIES	275
7.1 Aspects of Fitness	276
7.2 Resistance Devices Used in Training	278
<i>Understanding Resistance Devices</i>	286
7.3 Strength	286
7.4 Muscular Power	293
<i>Understanding Muscular Strength and Power</i>	294
7.5 Muscular Endurance	295
<i>Understanding Muscular Endurance</i>	296
7.6 Flexibility	297
<i>Understanding the Biomechanical Aspects of Flexibility</i>	305

CHAPTER 8

BODY BALANCE AND STABILITY CONTROL	310
8.1 Balance, Equilibrium, and Stability	310
<i>Understanding Balance, Equilibrium, and Stability</i>	319
8.2 Controlling Balance in Static Positions	320
8.3 Controlling Balance During Movement	321
<i>Understanding Balance Control</i>	333

CONCEPT MODULE F

LINEAR MOVEMENT RESPONSES TO APPLIED FORCES	334
F.1 Linear Speed and Velocity	335
F.2 Linear Acceleration	335
<i>Understanding Linear Motion Changes</i>	342
F.3 The Relationship of Force, Mass, and Linear Acceleration	342
F.4 Centripetal Force and Radial Acceleration	348
<i>Understanding Force and Motion Relationships</i>	349

CONCEPT MODULE G**LINEAR MOMENTUM AND KINETIC ENERGY 352**

- G.1** Linear Momentum 352
- G.2** Linear Impulse 353
- G.3** Conservation of Linear Momentum 358
- G.4** Kinetic Energy 360
 - Understanding Momentum and Energy* 362

CHAPTER 9**OBSERVING AND ANALYZING PERFORMANCE 363**

- 9.1** The Nature of Skills 363
 - Understanding the Nature of Skills* 367
- 9.2** Overall Performance Objective of a Skill 367
- 9.3** The Analysis Process 369
 - Understanding the Analysis Process* 376

CHAPTER 10**ANALYSIS OF PROJECTILE-RELATED ACTIVITIES 378**

- 10.1** Properties of Motion Related to Projectiles 379
- 10.2** Projecting for Vertical Distance 382
- 10.3** Projecting for Vertical Distance with a Horizontal Component 385
 - Understanding Projections for Vertical Distance* 389
- 10.4** Projecting for Horizontal Distance 389
 - Understanding Projections for Horizontal Distance* 401
- 10.5** Projecting for Accuracy 402
 - Understanding Projections for Accuracy and Speed* 411

CONCEPT MODULE H**FLUID FORCES 414**

- H.1** Fluid Drag Force 415
 - Understanding Fluid Drag Force* 426
- H.2** Fluid Lift Force 427
 - Understanding Fluid Lift Force* 432

CHAPTER 11**APPLICATION OF AERODYNAMICS IN SPORT 434**

- 11.1** Effects of Drag on the Body and Objects in Sport 435
 - Understanding Drag Force in Sport* 445

11.2	Effects of Lift in Sport	445
	<i>Understanding Lift Force in Sport</i>	451
11.3	Lift Force Produced by Spin: The Magnus Effect	452
	<i>Understanding the Magnus Effect</i>	459

CHAPTER 12

APPLICATION OF HYDRODYNAMICS IN SWIMMING 463

12.1	Buoyancy and Flotation	464
	<i>Understanding Buoyancy and Flotation</i>	475
12.2	Resistive Forces in Swimming Skills	475
	<i>Understanding Resistance in Swimming Skills</i>	483
12.3	Propulsive Forces in Swimming Skills	483
	<i>Understanding Propulsion in Swimming Skills</i>	503
12.4	Swimming Speed and Efficiency	504
	<i>Understanding Speed and Efficiency</i>	508

CONCEPT MODULE I

ROTARY MOVEMENT RESPONSES TO APPLIED TORQUES 513

I.1	Angular Speed and Velocity	514
I.2	Linear Velocity of a Point on a Rotating Body	515
I.3	Angular Acceleration	517
	<i>Understanding Rotary Motion</i>	520
I.4	The Relationship of Torque, Rotational Inertia, and Angular Acceleration	520
	<i>Understanding Torque and Motion Relationships</i>	527

CONCEPT MODULE J

ANGULAR MOMENTUM 530

J.1	Angular Momentum	530
J.2	Angular Impulse	531
J.3	Conservation of Angular Momentum Within a System	534
J.4	Vector Resolution of Angular Momentum	538
	<i>Understanding Angular Momentum</i>	539

CHAPTER 13

ANALYSIS OF ACTIVITIES IN WHICH THE BODY ROTATES FREE OF SUPPORT 542

13.1	The Human Body in Rotary Motion	543
	<i>Understanding the Body Rotating Free of Support</i>	549

13.2	Initiating Rotations	550
	<i>Understanding the Initiation of Rotation in the Air</i>	562
13.3	Analysis of Rotations While Airborne	562
	<i>Understanding Airborne Rotations</i>	572

CHAPTER 14

ANALYSIS OF ACTIVITIES IN WHICH THE BODY ROTATES WHILE SUPPORTED

		575
14.1	The Human Body in Supported Rotary Motion	576
14.2	Conservation of Angular Momentum in a Supported System	578
14.3	Applications of Angular Momentum Principles to a Supported Body	581
	<i>Understanding the Rotation of a Body Supported</i>	593

CONCEPT MODULE K

THROWLIKE AND PUSHLIKE MOVEMENT PATTERNS

		596
K.1	Introduction and Terminology	597
	<i>Understanding Segmental Movement Concepts</i>	599
K.2	Throwlike Patterns: Sequential Segmental Rotations	599
	<i>Understanding Sequential Segmental Rotations</i>	610
K.3	Lever Versus Wheel–Axle Rotations	611
	<i>Understanding Lever and Wheel–Axle Rotations</i>	614
K.4	Pushlike Patterns: Simultaneous Segmental Rotations	615
K.5	The Throw–Push Continuum	619
	<i>Understanding Pushlike Patterns</i>	621

CHAPTER 15

PERFORMANCE ANALYSIS OF THROWLIKE MOVEMENTS

		624
15.1	Biomechanics of Throwlike Patterns	625
15.2	Analysis of Sport Skills Using the Kinetic Link Principle	628
15.3	Comparisons of Similar Skills Within the Same Pattern	634
15.4	Performance Errors: Teaching and Coaching Applications	637
15.5	Developmental Patterns: Teaching Implications	639
	<i>Understanding Applications of the Kinetic Link Principle</i>	642

CHAPTER 16

PERFORMANCE ANALYSIS OF PUSHLIKE MOVEMENTS

		646
16.1	Force Activities	647

16.2	Power Activities	649
	<i>Understanding Jumping Mechanics</i>	652
16.3	Accuracy Activities	660
 CHAPTER 17		
INTRODUCTION TO BIOMECHANICS INSTRUMENTATION		665
17.1	Research In and Out of the Laboratory	666
17.2	Overview of Instrumentation and Its Uses	666
17.3	Clocks and Timers	668
17.4	Stroboscopy	670
17.5	Cinematography and Computer-Assisted Analysis	670
17.6	Videography and Computer-Assisted Analysis	678
17.7	Force-Measuring Instrumentation	686
17.8	Accelerometry	689
17.9	Electrogoniometry	689
17.10	Electromyography	690
17.11	Using Microcomputers for Collecting and Analyzing Data	691
	<i>Understanding Biomechanics Instrumentation</i>	693
 GLOSSARY		697
 APPENDIX I		
METRIC AND BRITISH UNITS AND CONVERSIONS		703
 APPENDIX II		
LIST OF SYMBOLS AND EQUATIONS		705
 APPENDIX III		
ANTHROPOMETRIC PARAMETERS		709
 APPENDIX IV		
METHODS OF CALCULATING THE CENTER OF GRAVITY		714
 APPENDIX V		
MATHEMATICS REVIEW AND TRIGONOMETRY		722
 APPENDIX VI		
MUSCLES AND MOVEMENTS		733
 INDEX		741