

# A Multilevel Approach to the Study of Motor Control and Learning

Second Edition

**Debra J. Rose**

*California State University, Fullerton*

**Robert W. Christina**

*University of North Carolina, Greensboro*



San Francisco Boston New York  
Cape Town Hong Kong London Madrid Mexico City  
Montreal Munich Paris Singapore Sydney Tokyo Toronto

Publisher: Daryl Fox  
Senior Acquisitions Editor: Deirdre Espinoza  
Development Manager: Claire Alexander  
Assistant Editors: Christina Pierson and Alison Rodal  
Production Supervisor: Beth Masse  
Manufacturing Buyer: Stacey Weinberger  
Senior Marketing Manager: Sandra Lindelof  
Production and Composition: The Left Coast Group  
Cover Designer: Yvo Riezebos Design  
Photo Researcher: Diane Austin  
Copyeditor: Carla Breidenbach  
Cover photo: Getty Images/Zac Macauley

Photo and art credits are found on page 421, which should be considered an extension of the copyright page.

ISBN 0-8053-6031-X

Copyright © 2006 Pearson Education, Inc., publishing as Benjamin Cummings, 1301 Sansome St., San Francisco, CA 94111. All rights reserved. Manufactured in the United States of America. This publication is protected by Copyright and permission should be obtained from the publisher prior to any prohibited reproduction, storage in a retrieval system, or transmission in any form or by any means, electronic, mechanical, photocopying, recording, or likewise. To obtain permission(s) to use material from this work, please submit a written request to Pearson Education, Inc., Permissions Department, 1900 E. Lake Ave., Glenview, IL 60025. For information regarding permissions, call (847) 486-2635.

Many of the designations used by manufacturers and sellers to distinguish their products are claimed as trademarks. Where those designations appear in this book, and the publisher was aware of a trademark claim, the designations have been printed in initial caps or all caps.

Library of Congress Cataloging-in-Publication Data

Rose, Debra J.

A multilevel approach to the study of motor control and learning/Debra J. Rose, Robert W. Christina.—2nd ed.

p.; cm.

Includes bibliographical references and index.

ISBN 0-8053-6031-X

1. Motor learning. 2. Afferent pathways.

[DNLM: 1. Motor Activity. 2. Learning. 3. Psychomotor Performance. WE 103 R795m 2006] I. Christina, Robert W. II. Title.

QP301.R65 2006

612.8'11—dc22

2005006531



10 9 8 7 6 5 4 3 2 1 DOC 08 07 06 05

www.aw-bc.com

# CONTENTS

Preface xiii

## **SECTION ONE: MOTOR CONTROL**

### **Chapter 1: Introduction to Motor Control 1**

Defining Motor Control	2
Open- and Closed-Loop Motor Control	4
Open-Loop Motor Control	4
Use of Open- versus Closed-Loop Motor Control	6
Theories of Motor Control	7
Reflex Theories	7
Hierarchical Theories	9
Dynamical and Ecological Approaches	14
Does One Theoretical Approach Better Explain How Movements Are Controlled?	19
Characteristics of Human Action	21
Flexibility	21
Uniqueness	22
Consistency and Modifiability	23
Does One Theory of Motor Control Better Explain the Characteristics of Skilled Actions?	23
The Degrees-of-Freedom Problem	26
Summary	29
Important Terminology	29
Suggested Further Reading	30
Test Your Understanding	30

### **Chapter 2: Scientific Measurement and Motor Control 31**

Psychological Measures	32
Response Outcome Measures	32
Response Process Measures	41
Neurological Measures	51
Intracellular Recordings	52
Lesions and Ablations	52
Brain Mapping and Scanning Techniques	53

Summary	55
Important Terminology	56
Suggested Further Reading	57
Test Your Understanding	57
Practical Activities	58
<b>Chapter 3: Somatosensory Contributions to Action</b>	<b>59</b>
General Properties of Sensory Receptors and Afferent Pathways	60
Adequate Stimulation	60
Intensity Coding	61
Sensory Adaptation	61
The Transmission and Integration of Sensory Input	63
Somatosensation	65
Cutaneous Receptors	66
Proprioceptors	67
Transmission of Somatosensory Input	72
Dorsal Column System	72
Spinocerebellar Tract	74
Anterolateral System	74
Somatosensory Cortex	76
Disorders of the Somatosensory System	77
Application of Theory	79
The Conscious Sensation of Movement	80
Afferent Sources of Kinesthesia	80
The Conscious Sensation of Muscular Effort	83
Practical Applications	84
The Role of Feedback in Controlling Actions	86
Knowledge of Body Position	86
Planning and Modification of Action Plans	86
Learning or Relearning Movements	87
Errors in Performance	88
Summary	88
Important Terminology	89
Suggested Further Reading	90
Test Your Understanding	90
Practical Activities	91

<b>Chapter 4: Visual and Vestibular System</b>	
<b>Contributions to Action</b>	<b>93</b>
Neuromotor Processing of Vision	94
Reception of Visual Input	94
Transmission to the Brain	96
Topographic Organization in the Visual System	97
The Control of Eye Movements	97
Two Visual Systems?	99
Two Visual Systems and Motor Control	99
Psychological Studies of Perception and Action	100
Contrasting Theories of Visual Perception	100
Visual Guidance of Action	103
Reaching and Grasping	103
Standing Balance	104
Locomotion	105
Jumping from Different Heights	107
Catching Objects	107
Hitting Objects	108
Time-to-Contact Information	108
Visual Dominance	111
Role of Vision in Performance of Sport Skills	111
Disorders of the Visual System	113
Vestibular System	114
Anatomy of the Vestibular System	114
Peripheral Sensory Reception	116
Ascending Pathways	117
Descending Pathways	118
Vestibular-Visual Interactions	119
Adaptability of the Vestibular Ocular Reflex	119
Vestibular Contributions to Equilibrium	120
Disorders of the Vestibular System	121
Summary	123
Important Terminology	124
Suggested Further Reading	125
Test Your Understanding	125
Practical Activities	126

## **Chapter 5: Developing and Executing a Plan of Action 127**

Planning the Action	128
Making the Decision to Act	128
Developing a General Plan	129
Adding Details to the Plan	129
Executing the Plan of Action	130
The Neuromotor Level of Analysis	130
The Limbic System	132
The Association Cortex	133
The Projection System	133
Motor Pathways	140
The Spinal System	144
Moment-to-Moment Control	144
Types of Motoneurons	145
Muscle Activation and Force Production	146
Musculoskeletal Contributions to Force	150
Subconscious Control of Movement	151
Solving the Motor Problem	157
Constraints on Action	158
Intrinsic Capabilities of the Performer	158
Task-Related Constraints	159
Environmental Constraints	161
Summary	162
Important Terminology	163
Suggested Further Reading	163
Test Your Understanding	163
Practical Activities	164

## **SECTION TWO: MOTOR LEARNING**

### **Chapter 6: Introduction to Motor Learning 166**

Defining Motor Learning	167
Motor Learning Is Inferred from Performance	168
Performance Is Not a Perfect Index of Motor Learning	168
Motor Learning Produces Reliable Performance Changes	169
Motor Learning May Not Lead to Performance Improvement	170
Motor Learning and Instruction, Practice, and/or Experience	171

<b>Theories of Motor Learning</b>	<b>171</b>
Adams' Closed-Loop Theory	172
Schmidt's Schema Theory	172
Ecological Theories of Perception and Action	175
How Does Motor Learning Really Occur?	176
<b>Stages of Motor Learning</b>	<b>178</b>
Fitts' Three Stages of Learning	178
A Neo-Bernsteinian Perspective	179
Gentile's Two-Stage Model	181
Benefits of the Three Models of Motor Learning	183
<b>Readiness for Motor Learning</b>	<b>184</b>
Developmental Qualities	185
Learning Styles	186
Motivational Qualities	189
<b>Summary</b>	<b>190</b>
<b>Important Terminology</b>	<b>192</b>
<b>Suggested Further Reading</b>	<b>192</b>
<b>Test Your Understanding</b>	<b>193</b>
<b>Chapter 7: How Motor Learning Is Studied</b>	<b>194</b>
<b>Approaches to the Study of Motor Learning</b>	<b>195</b>
Traditional Approach	195
Method versus Problem-Oriented Approach	197
Doctrine of Disproof Approach	198
Cooperative Approach between Basic and Applied Research	199
<b>Assessing Motor Learning in Acquisition</b>	<b>200</b>
Performance Curves	200
Setting a Criterion of Mastery	206
Over-Learning	207
Level of Automaticity	207
Limitations of Assessing Motor Learning in Acquisition	208
<b>Assessing Motor Learning in Post-Acquisition</b>	<b>209</b>
Retention Tests	209
Maintaining the Learning–Retention Distinction	210
Transfer Tests	210
Development of a Knowledge Base	217

<b>Measuring Learning-Related Changes in Perception and Cognition</b>	<b>218</b>
Expert–Novice Comparisons	212
Visual Occlusion Techniques	214
Eye Movement Recordings	215
Pattern Recognition and Memory Recall Tests	215
Development of a Knowledge Base	217
<b>Measuring Learning-Related Changes in the Dynamics of Action</b>	<b>218</b>
Measures of Metabolic and Mechanical Efficacy	218
<b>Identifying the Learning-Related Changes in Performance</b>	<b>219</b>
<b>Summary</b>	<b>220</b>
<b>Important Terminology</b>	<b>221</b>
<b>Suggested Further Reading</b>	<b>221</b>
<b>Test Your Understanding</b>	<b>221</b>
<b>Chapter 8: Setting the Stage for Motor Learning</b>	<b>223</b>
<b>Motivating People to Learn Motor Skills</b>	<b>224</b>
Goal Setting	225
Praise and Criticism	226
Success and Failure	227
Self-Esteem	227
Competition and Cooperation	228
<b>Introducing and Explaining Movement Skills</b>	<b>228</b>
Setting the Stage for the Introduction	228
Delivering the Introduction	229
Delivering the Explanation	229
Select the Best Words to Use in the Explanation	229
Where to Direct the Learners' Focus of Attention	230
Relate What Is Being Taught to the Learners' Background	231
<b>Demonstrating the Skill to Be Learned</b>	<b>233</b>
Variables That Influence the Effectiveness of Modeling	234
Evaluating the Effectiveness of a Model	242
Guidelines for Using Modeling	243
<b>Theoretical Explanations of the Modeling Effect</b>	<b>244</b>
Social Learning Theory	244
Direct Perception Approach	245



Discovery Learning	245
Applying the Principles of Discovery Learning	247
Summary	248
Important Terminology	249
Suggested Further Reading	250
Test Your Understanding	250
<b>Chapter 9: Organizing the Practice Environment</b>	<b>252</b>
Amount of Practice	253
Level of Original Learning	254
Level of Over-Learning	255
Structuring the Practice Session	256
Specificity of Practice	256
Variability of Practice	262
Organizing the Practice Schedule	264
Introducing Interference	264
Influencing Factors	265
Theoretical Accounts of the Contextual Interference Effect	270
Elaboration View	271
Action-Plan Reconstruction View	271
Spacing/Distribution of Practice	272
Techniques for Enhancing the Effectiveness of Practice	274
Guidance Techniques	274
Whole-Task versus Part-Task Practice Strategies	275
Part-Task Practice Methods	277
Attentional Cuing and Whole Practice	277
Mental Practice	278
Mental Practice Conditions	279
Variables Limiting Our Understanding of Mental Practice Effects	282
Physiological Basis of Mental Practice	284
Summary	286
Important Terminology	288
Suggested Further Reading	288
Test Your Understanding	289
Practical Activities	290

**Chapter 10: Augmented Feedback and Motor Learning 291**

Functions of Feedback in Motor Learning	293
Feedback as Information to Correct Performance Errors	293
Feedback as Positive Reinforcement to Strengthen Correct Performance	294
Feedback as Negative Reinforcement to Strengthen Correct Performance	295
Feedback as Punishment to Suppress Errors	296
Feedback as Motivation for Motor Learning	296
Form of the Feedback	297
Kinematic and Kinetic Visual Displays	298
Videotape Feedback	299
Augmented Sensory Feedback: Biofeedback	301
Precision of Augmented Feedback	303
Frequency of Augmented Feedback	303
Fading-Frequency Schedules of Knowledge of Results	305
Bandwidth Knowledge of Results	305
Reversed Bandwidth Knowledge of Results	307
Summary Knowledge of Results	307
Average Knowledge of Results	309
Self-Regulated (Controlled) Augmented Feedback Schedules	312
Theoretical Explanations of the Frequency Effect	313
Guidance Hypothesis	313
Consistency Hypothesis	313
The Timing of Knowledge of Results	314
Summary	316
Important Terminology	318
Suggested Further Reading	319
Test Your Understanding	319

**Chapter 11: Memory and Forgetting 321**

Contemporary Concepts of Memory	322
Atkinson and Shiffrin's Multistore Model	323
Levels-of-Processing Framework	325
Neurobiology of Memory	326

<b>Types of Memory</b>	<b>328</b>
Short-Term and Long-Term Memory	328
Declarative and Procedural Memory	328
The Relationship Between Learning and Memory	329
<b>How Memory and Forgetting Are Studied</b>	<b>329</b>
What Retention Test Performance Tells Us	330
Example of How the Retention of Motor Learning Is Studied	332
Controlling for Variables That Produce Contaminating Effects	334
Retention Test Measures	338
<b>Theories of Forgetting</b>	<b>341</b>
Trace Decay Theory	341
Interference Theory	342
Retrieval Theory	344
Which Theory Is Correct?	345
<b>Factors That Influence Memory Skill</b>	<b>345</b>
Characteristics of the Movement Skill	346
The Level of Original Learning	350
The Learner	350
<b>Disorders of Memory</b>	<b>352</b>
<b>Summary</b>	<b>353</b>
<b>Important Terminology</b>	<b>354</b>
<b>Suggested Further Reading</b>	<b>355</b>
<b>Test Your Understanding</b>	<b>355</b>
<b>Chapter 12: Transfer of Motor Learning</b>	<b>357</b>
<b>Transfer of Motor Learning Depends on Similarity</b>	<b>358</b>
Direction and Amount of Transfer	359
Extent of Transfer	362
Additional Factors Influencing Transfer	367
<b>Transfer of General Factors</b>	<b>370</b>
Transfer of Principles	370
Learning to Learn	371
Two-Factor Theory	371
<b>Types of Transfer</b>	<b>372</b>
Vertical Transfer	372
Lateral Transfer	374
Near and Far Transfer	379

<b>How Transfer Is Studied</b>	<b>380</b>
Experimental Design to Study Proactive Transfer	380
Experimental Design to Study Retroactive Transfer	382
Measuring Transfer	383
<b>Summary</b>	<b>386</b>
<b>Important Terminology</b>	<b>388</b>
<b>Suggested Further Reading</b>	<b>388</b>
<b>Test Your Understanding</b>	<b>389</b>
<b>References</b>	<b>391</b>
<b>Credits</b>	<b>421</b>
<b>Author Index</b>	<b>423</b>
<b>Subject Index</b>	<b>433</b>

# PREFACE

The second edition of a *Multilevel Approach to Motor Control and Learning* expands upon the goal of the first edition: to provide a textbook for upper division undergraduate and entry-level graduate students in kinesiology that addresses motor control and motor learning concepts in the same text. What continues to differentiate this text from others that address one or both of these important subject areas is its multilevel approach. The content contained in this text is not only presented at a behavioral level of analysis but at a neurological level of analysis also. The significantly expanded content at both levels of analysis in the second edition will be particularly appropriate for students interested in pursuing postgraduate studies in health care professions such as physical therapy and/or professional careers in rehabilitation settings.

The book continues to be divided into two sections: Motor Control and Motor Learning. The first section—Chapters 1 through 5—presents an in-depth discussion of the prominent motor control theories and the scientific evidence in support of each theory and/or theoretical perspective. The underlying mechanisms that contribute to motor control are explored at both a behavioral and neurological level of analysis. At the completion of this section, the reader should have acquired a strong understanding of the behavioral and neurological processes that are involved in the planning and executing of many different movement skills.

The second section—Chapters 6 through 12—focuses on the theoretical concepts that underlie the acquisition, retention, and, in some cases, forgetting of learned movement skills. The multilevel theoretical approach is followed in this section also, as the behavioral changes associated with the learning of movement skills are once again linked to the underlying neurological mechanisms. This section of the book also emphasizes practical application as issues related to how motor skills should be introduced and practiced for optimal retention and transfer are discussed.

## New to This Edition

1. A coauthor. It is a privilege and honor to be writing this second edition with my mentor, Dr. Robert Christina. Dr. Christina brings a wealth of knowledge and history of the field of motor control and learning that adds a richness and depth to the content presented in a number of chapters, but most notably the motor learning section of the book.
2. A new chapter that addresses the issue of the transfer of learning.
3. Major restructuring and reordering of chapters. The reordering of chapters provides a more cohesive discussion of the subject matter and was based on reviewer feedback and our own critical review of the first edition.
4. Expanded and updated content in all chapters. There is a more comprehensive discussion of the major theoretical approaches that have guided the research conducted in the areas of motor control and learning.

5. Addition of practical activities at the end of selected chapters. These provide the instructor with opportunities to engage the students in classroom activities that add a practical dimension to the theoretical content presented in the book.
6. Addition of more highlight boxes. Each addresses an important theoretical concept or controversy, a classic experiment, or examples of how motor control and learning theory has been applied to practice.

## **Pedagogical Features**

The pedagogical features in the second edition have been expanded to include practical activities at the end of selected chapters, additional summary boxes that emphasize important points presented in the text, and new highlights in every chapter that address pivotal research findings from sport and clinical settings, important theoretical concepts, or practical applications of research.

## **Acknowledgements**

This second edition would not have come to fruition without the significant contributions and support of my coauthor, Bob Christina, and the encouragement of so many of my colleagues in motor control and learning who adopted the first edition of this textbook over six years ago and kept asking when the second edition was going to be published. Of course, our book editors at Benjamin-Cummings kept asking us the same question, as we missed our submission deadlines on multiple occasions. Fortunately for us, Christina Pierson and Deirdre Espinoza both recognized that writing a textbook, even a second edition, is a serious undertaking and one that cannot be rushed if it is to be a product of which everyone can be proud. I would also personally like to thank my faculty colleagues in motor control and learning at Cal State-Fullerton, David Chen and Michelle Barr, who provided me with excellent feedback on the first edition based on their own personal teaching experiences using the book. Finally, I wish to thank each and every undergraduate and graduate student who I have taught in the six years since this book was first published. They have been my very best critics as the target audience for whom this book is intended. I hope that this second edition addresses many of their criticisms of the first edition.

## **Reviewers**

Laurie Lundy-Ekman, Pacific University; Jeffrey M. Haddad, University of Massachusetts–Amherst; Rachel D. Seidler, University of Michigan; Amy Haufler, University of Maryland; Shane Frehlich, California State University–Northridge; Richard Stratton, Virginia Tech; Steven J. Radlo, Western Illinois University; Ann Gentile, Teachers College, Columbia University; Daniel Corcos, University of Illinois at Chicago; Qin Lai, Wayne State University; Lori Ploutz-Snyder, Syracuse University; Gabriele Wulf, University of Nevada–Las Vegas.

Start studying Motor Learning. Learn vocabulary, terms and more with flashcards, games and other study tools. What is multilevel approach to the study of motor learning and control? A behavior level analysis-adopting information-processing approach. The environment is important factor in considering movement. Scientific measurements of motor performance and learning. changes in perception and cognition changes in performance. Measuring learning-related changes in perception and cognition