

TWELFTH EDITION

MOTOR LEARNING AND CONTROL

Concepts and Applications

RICHARD A. MAGILL

Teachers College, Columbia University, and New York University

DAVID I. ANDERSON

San Francisco State University

**Mc
Graw
Hill**



MOTOR LEARNING AND CONTROL: CONCEPTS AND APPLICATIONS, TWELFTH EDITION

Published by McGraw Hill LLC, 1325 Avenue of the Americas, New York, NY 10121. Copyright © 2021 by McGraw Hill LLC. All rights reserved. Printed in the United States of America. Previous editions © 2017, 2014, and 2011. No part of this publication may be reproduced or distributed in any form or by any means, or stored in a database or retrieval system, without the prior written consent of McGraw Hill LLC, including, but not limited to, in any network or other electronic storage or transmission, or broadcast for distance learning.

Some ancillaries, including electronic and print components, may not be available to customers outside the United States.

This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 LCR 24 23 22 21 20

ISBN 978-1-260-24070-2 (bound edition)

MHID 1-260-24070-3 (bound edition)

ISBN 978-1-260-83866-4 (loose-leaf edition)

MHID 1-260-83866-8 (loose-leaf edition)

Product Developers: *Elisa Odoardi*

Marketing Manager: *Meredith Leo Digiano*

Content Project Managers: *Danielle Clement, Katie Reuter*

Buyer: *Laura Fuller*

Design: *Egzon Shagiri*

Content Licensing Specialist: *Jacob Sullivan*

Cover Image: *Darren Greenwood/Design Pics*

Compositor: *MPS Limited*

All credits appearing on page or at the end of the book are considered to be an extension of the copyright page.

Library of Congress Cataloging-in-Publication Data

Magill, Richard A, author. | Anderson, David, 1965 December 21-author.

Motor learning and control : concepts and applications / Richard A

Magill, Teachers College, Columbia University, and New York University,

David I Anderson, San Francisco State University.

Twelfth edition. | New York, NY : McGraw-Hill Education,

[2021] | Includes bibliographical references and index.

LCCN 2019053994 | ISBN 9781260240702 (hardcover) |

ISBN 9781260838763 (ebook)

LCSH: Motor learning—Textbooks.

LCC BF295 .M36 2021 | DDC 152.3/34—dc23

LC record available at <https://lccn.loc.gov/2019053994>

The Internet addresses listed in the text were accurate at the time of publication. The inclusion of a website does not indicate an endorsement by the authors or McGraw Hill LLC, and McGraw Hill LLC does not guarantee the accuracy of the information presented at these sites.

mheducation.com/highered

Detailed Contents

Preface vii
Dedication xv

UNIT ONE Introduction to Motor Skills and Abilities 1

1 The Classification of Motor Skills 2	<i>Error Measures 32</i>
Application 2	<i>Kinematic Measures 37</i>
Discussion 3	<i>Kinetics 41</i>
<i>Skills, Actions, Movements, and</i>	<i>EMG 42</i>
<i>Neuromotor Processes 5</i>	<i>Brain Activity Measures 44</i>
<i>One-Dimension Classification Systems 9</i>	<i>Measuring Coordination 48</i>
<i>Gentile's Two-Dimensions Taxonomy 14</i>	
2 The Measurement of Motor Performance 26	
Application 26	
Discussion 27	
<i>Reaction Time 28</i>	
3 Motor Abilities 53	
Application 53	
Discussion 53	
<i>Ability and Motor Ability 54</i>	

UNIT TWO Introduction to Motor Control 69

4 Neuromotor Basis for Motor Control 70	<i>A Complementary Theory: The OPTIMAL Theory</i>
Application 70	<i>of Motor Learning 110</i>
Discussion 71	<i>The Present State of the Control Theory</i>
<i>The Neuron 71</i>	<i>Issue 112</i>
<i>The Central Nervous System 73</i>	
<i>The Neural Control of Voluntary Movement 82</i>	
5 Motor Control Theories 87	
Application 87	
Discussion 89	
<i>Theory and Professional Practice 89</i>	
<i>Motor Control Theory 90</i>	
<i>Open-Loop and Closed-Loop Control Systems 94</i>	
<i>Two Theories of Motor Control 96</i>	
6 Sensory Components of Motor Control 116	
Application 116	
Discussion 117	
<i>Touch and Motor Control 117</i>	
<i>Proprioception and Motor Control 120</i>	
<i>Vision and Motor Control 128</i>	
<i>Investigating the Role of Vision in Motor</i>	
<i>Control 132</i>	
<i>The Role of Vision in Motor Control 134</i>	

7 Performance and Motor Control Characteristics of Functional Skills 145

Application 145

Discussion 146

Speed-Accuracy Skills 146

Prehension 152

Handwriting 157

Bimanual Coordination Skills 158

Catching a Moving Object 160

Striking a Moving Object 163

Locomotion 166

8 Action Preparation 179

Application 179

Discussion 180

Action Preparation Requires Time 180

Task and Situation Characteristics Influencing Preparation 180

Performer Characteristics Influencing Preparation 189

What Occurs During Preparation? 191

UNIT THREE Attention and Memory 205

9 Attention as a Limited Capacity Resource 206

Application 206

Discussion 207

Attention and Multiple-Task

Performance 208

The Dual-Task Procedure for Assessing

Attention Demands 214

Focusing Attention 215

Attention and Automaticity 219

Visual Selective Attention 220

Visual Search and Motor Skill

Performance 224

Training Visual Search Strategies 231

10 Memory Components, Forgetting, and Strategies 235

Application 235

Discussion 236

Memory Structure 236

Working Memory 237

Long-Term Memory 242

Remembering and Forgetting 244

Assessing Remembering and Forgetting 244

The Causes of Forgetting 247

Movement Characteristics Related to Memory

Performance 250

Strategies That Enhance Memory

Performance 251

Practice-Test Context Effects 256

UNIT FOUR Introduction to Motor Skill Learning 261

11 Defining and Assessing Learning 262

Application 262

Discussion 262

Performance Distinguished From Learning 263

General Performance Characteristics of Skill

Learning 263

Learning Assessment Techniques 265

Practice Performance May Misrepresent

Learning 275

12 The Stages of Learning 279

Application 279

Discussion 280

The Fitts and Posner

Three-Stage Model 280

Gentile's Two-Stage Model 282

Bernstein's Description of the Learning

Process 284

Performer and Performance Changes Across the Stages of Learning 285

A Performer Characteristic That Does Not

Change Across the Stages of Learning 297

Expertise 298

13 Transfer of Learning 305

Application 305

Discussion 306

What Is Transfer of Learning? 306*Why Is Transfer of Learning Important?* 307*Why Does Positive Transfer of Learning Occur?* 309*Negative Transfer* 313*Learning How to Learn as an Example of Transfer* 315*Bilateral Transfer* 316**UNIT FIVE Instruction and Augmented Feedback 325****14 Demonstration and Verbal Instructions 326**

Application 326

Discussion 327

Demonstration 327*Verbal Instructions and Cues* 340*How Essential Is Augmented Feedback for Skill Acquisition?* 357*The Content of Augmented Feedback* 360*Types of Knowledge of Performance* 366*Timing Issues Related to Augmented Feedback* 373*The KR-Delay and Post-KR Intervals for Terminal Augmented Feedback* 376*Frequency of Presenting Augmented Feedback* 380*Techniques That Reduce Augmented Feedback Frequency* 382**15 Augmented Feedback 352**

Application 352

Discussion 353

The Feedback Family 354*Types of Augmented Feedback* 354*The Roles of Augmented Feedback in Skill Acquisition* 356**UNIT SIX Practice Conditions 391****16 Practice Variability and Specificity 392**

Application 392

Discussion 393

The Future Performance Benefit of Practice Variability 393*Implementing Practice Variability* 394*Organizing Variable Practice* 397*Accounting for the Contextual**Interference Effect* 407*Practice Specificity* 408**18 Whole and Part Practice 433**

Application 433

Discussion 434

Skill Complexity and Organization 434*Practicing Parts of a Skill* 436*An Attention Approach to Involving Part Practice in Whole Practice* 447**17 The Amount and Distribution of Practice 417**

Application 417

Discussion 418

Overlearning and Learning Motor Skills 419*The Overlearning Strategy Can Lead to Poor Test Performance* 421*Overlearning and Other Practice Variables* 422*The Distribution of Practice* 423*Defining Massed and Distributed Practice* 423*The Length and Distribution of Practice**Sessions* 424*The Intertrial Interval and Practice**Distribution* 428**19 Mental Practice 451**

Application 451

Discussion 452

Two Roles for Mental Practice 452*Mental Practice Aids Skill Acquisition* 453*Mental Practice Aids Performance**Preparation* 458*Why Is Mental Practice Effective?* 459*Mental Practice and Imagery Ability* 461

Glossary 465

References 475

Name Index 513

Subject Index 533



Preface

This twelfth edition primarily updates the previous edition by adding more recent research and interpretations of the concepts and theoretical views associated with those concepts that were in the eleventh edition. Similar to the previous editions this new edition continues its two most distinctive features as an introductory motor learning and control textbook: its overall approach to the study of motor learning and control and the organization of the implementation of that approach. In every edition of this book, the overall approach has been the presentation of motor learning and control “concepts” to identify the common theme of each chapter. The concepts should be viewed as generalized statements and conclusions synthesized from collections of research findings. Following the concept statement is a description of a real-world application of the concept, which is then followed by discussions of specific topics and issues associated with the concept. An important part of these discussions are summaries of research evidence, on which we base our present knowledge of each topic and issue, as well as the implications of this knowledge for practitioners. The benefit of this organizational scheme is the presentation of motor learning and control as a set of principles and guidelines for practitioners, which are based on research evidence rather than on tradition or “how things have always been done.”

Our goal for this edition continues to be to provide an introductory study of motor learning and control for students who aspire to become

practitioners in various professions. As in previous editions, the achievement of this goal involves the inclusion of research examples that demonstrate the evidence-based foundation for the motor learning and control concepts. It is important to note that the research examples are just that—examples; the intent of the discussion of research about a specific topic, therefore, is not to present an extensive review of the research literature or to investigate the various controversial views that may exist on a topic.

NEW TO THIS EDITION

New Research

Because an important goal of this book is to provide research evidence to support the various concepts and applications, it is essential to regularly update the research to maintain the book’s relevance. As in previous editions, each chapter of the twelfth edition includes updated research in the text, the *A Closer Look* boxes, and in the *Related Readings* sections. Research related to motor learning and control continues to increase, as evidenced by the ever-expanding amount of research articles and chapters published each year. Because of the availability of this new information, it is essential that an introductory textbook provide the most up-to-date evidence available to support the numerous concepts and applications that can be derived from this research. But, the caveat here is to not overwhelm the reader with a litany of research studies.

It is with this point in mind that we have as a primary intent to present examples of research studies that provide empirical support for the concepts discussed rather than to provide exhaustive reviews of the available research.

NEW OR EXPANDED TOPICS IN SPECIFIC CHAPTERS

Chapter 1: The Classification of Motor Skills

- Updated and added new research relevant to the concept discussed in this chapter

Chapter 2: The Measurement of Motor Performance

- Clarified situations in which discrimination reaction time is important
- Clarified the distinction between consistency and bias in error measures
- Described additional tools for recording movement kinematics
- Added a new figure showing the four types of EEG waves
- Expanded the description of transcranial magnetic stimulation (TMS)
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 3: Motor Abilities

- Updated and added new research relevant to the concept discussed in the chapter
- Expanded discussion of research evidence related to the relative independence of static and dynamic balance

Chapter 4: Neuromotor Basis for Motor Control

- Updated several figures within the chapter
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 5: Motor Control Theories

- Added section describing and discussing the OPTIMAL theory of motor learning and control

- Included discussion of OPTIMAL theory in section on “The Present State of the Control Theories Issue”
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 6: Sensory Components of Motor Control

- Updated several figures within the chapter and added a figure on the knee jerk reflex
- Updated the definition of proprioception
- Provided additional information on how muscle spindles encode joint angle
- Added new research about how sensory neuropathy patients control movement
- Added new research showing tendon vibration can improve and impair motor performance
- Described technological innovations related to the temporal occlusion procedure
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 7: Performance and Motor Control Characteristics of Functional Skills

- Added new information to section on the role of visual information in the speed-accuracy trade-off
- Added text about the role of vision in prehension
- Added section to “A Closer Look” (on the Constraint-Induced movement therapy intervention strategy) describing and discussing the HABIT (Hand-Arm Bimanual Intensive Therapy) strategy to include therapeutic strategies for improving bimanual coordination skills for people with cerebral palsy (CP)
- Added to section on handwriting information about the role of sensory feedback
- Expanded discussion of “Why do spontaneous gait transitions occur?” to update prevalent hypotheses
- Expanded discussion in “A Closer Look” (Visual Cues Can Aid Walking with Parkinson’s Disease”) to update research evidence supporting the visual cueing benefit
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 8: Action Preparation

- Added a new example in the “A Closer Look” section on applying Hick’s Law to a sport performance situation
- Added new information about reaction time in the sprint start
- Related the “A Closer Look” section on the performance expectancy phenomenon to the OPTIMAL theory of motor learning
- Clarified how research on piano playing provides evidence for the preparation of movement sequences
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 9: Attention as a Limited Capacity Resource

- Updated the Closer Look box on how cell phone use influences driving
- Updated and expanded discussion of neural characteristics associated with automaticity of motor skill performance
- Expanded discussion of research evidence related to attention allocation and vision while driving a car
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 10: Memory Components, Forgetting, and Strategies

- Added information about a proposed fourth subsystem in working memory
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 11: Defining and Assessing Learning

- Updated and added new research relevant to the concept discussed in the chapter

Chapter 12: The Stages of Learning

- Added a new section on brain changes in elite athletes
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 13: Transfer of Learning

- Added “dance” to list of activities in Introduction to which the transfer of learning concept applies
- Revised section “Using Gentile’s Taxonomy to Develop Skills” by deleting section heading and connecting discussion to previous section “Sequencing Skills to be Learned”
- Added discussion to “A Closer Look” on “Bilateral Transfer Training for Using an Upper-Extremity Prosthesis” to update research evidence supporting the experiment described
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 14: Demonstration and Verbal Instructions

- Updated “A Closer Look” section on clinical implications of a mirror neuron system with an example of feedforward video self-modeling in stroke rehabilitation
- Added information on the brain areas that are active during action observation
- Added information about self-observation in the section on novices observing novices
- Updated information on the frequency of observing demonstrations
- Updated information on auditory modeling
- Provided an additional example of the potential downsides of viewing a demonstration
- Added information about how visual cueing can enhance the effectiveness of demonstrations
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 15: Augmented Feedback

- Updated and expanded discussion in “A Closer Look” on augmented feedback as motivation
- Added surgical skills learning example to discussion of “Augmented Feedback May Not Be Needed for Skill Acquisition”
- Expanded discussion of why beginners ask for KR after good trials during practice

- Added sub-section “Manual Guidance as Augmented Feedback” to section “Types of Knowledge of Performance”
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 16: Practice Variability and Specificity

- Updated information on how performance errors benefit learning
- Added information about using the contextual interference effect to enhance learning of perceptual-cognitive skills
- Added information about how the contextual interference effect might encourage refinement of error detection and correction processes
- Provided an additional example of research on the especial skills effect
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 17: The Amount and Distribution of Practice

- Clarified use of term “procedural skills”
- Related research on treadmill training and falls risk to discussion of “The Overlearning Strategy Can Lead to Poor Test Performance”
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 18: Whole and Part Practice

- Updated and added new research relevant to the concept discussed in the chapter

Chapter 19: Mental Practice

- Revised discussion in section “Mental Practice as Part of a General Preparation Strategy that Aids Learning” by including more recent research involving learning to shoot free throws in basketball; deleted Figure 19.2 and related discussion
- Added specific reference in discussion of “Brain Activity Hypothesis” for reading a

review of research on neural plasticity related to imagery

- Updated and added new research relevant to the concept discussed in the chapter

SUCCESSFUL FEATURES

Motor Learning and Control: Concepts and Applications continues to offer the following features from the previous editions that have helped enhance student learning.

Concepts

Each chapter begins with a concept statement to present a principle or conclusion that describes the focus of the chapter. The goal of these statements is to provide students a guide for understanding the chapter content, which provides the discussion of issues and research that led to the concept statement.

Application

Following the concept statement, the application section describes in practical terms the relevance of the chapter concept and content to everyday experiences and professional practice.

Application Problem to Solve

This feature, which follows the application section at the beginning of each chapter, presents a specific application problem for students to work on as they engage in reading the discussion section of the chapter.

Discussion

This section presents the specific information from which the concept statement was derived. It includes the key topics and issues relevant to the chapter concept along with summaries and examples of research that provide evidence to support the various points presented in the chapter.

A Closer Look Boxes

Each chapter contains several boxes. The title for each box indicates its content. These boxes typically serve one of several purposes: to provide more detail about a research study than is provided in the

text; to describe a situation that applies a point in the discussion to a professional practice situation; or to describe a relevant issue that allows the student to explore a topic beyond the limits of the text.

Summary

Each chapter concludes with a summary that presents the main ideas addressed in the discussion section. Using this tool, the student can return easily to a topic in the chapter for clarification or study.

Points for the Practitioner

This feature describes how the chapter topic relates to the practice or performance setting. It encourages students to think about how they will use this information in practical ways.

Related Readings

For students who want to know more about a particular topic, this list at the end of each chapter offers carefully selected research journal articles, books, and book chapters for further exploration.

Study Questions

A set of questions appears at the end of each chapter to encourage students to review and analyze the chapter content.

Specific Application Problem as a Study Question

The final study question presents an application problem to solve as a culminating experience for the student to use the information presented in the chapter. This problem differs from the one located at the beginning of the chapter by describing a situation students might experience in their future professional experience.

Definition Boxes

Key terms, which are highlighted in the text in boldface type, are defined in corresponding boxes

for easy reference. Other important terms in the text appear in italics for emphasis.

Lab Links

The previous four editions included, as part of McGraw-Hill's Online Learning Center for this book, a laboratory manual of laboratory experiences for most chapters. These experiences are available for this edition as well. In the twelfth edition, these laboratory experiences are identified by "Lab Links" boxes in the margins.

Glossary

At the end of the book, all the key terms defined in the definition boxes are included in a comprehensive glossary. This glossary is useful as a quick reference and a helpful review to prepare for examinations.

Name Index

In addition to the regular subject index, this book features a name index, which identifies and locates all the names referred to in the book. Included in this list are the names of important people who have been or are leaders in the field of motor learning and control.

DIGITAL RESOURCES

The twelfth edition of *Motor Learning and Control* is now available online with Connect, McGraw-Hill Education's integrated assignment and assessment platform. Connect also offers SmartBook for the new edition, which is the first adaptive reading experience proven to improve grades and help students study more effectively. All of the title's website content is also available on Connect, including access to the full course Instructor's Manual, Test Bank, and PowerPoint slides, and Student Lab Manual.



FOR INSTRUCTORS

You're in the driver's seat.

Want to build your own course? No problem. Prefer to use our turnkey, prebuilt course? Easy. Want to make changes throughout the semester? Sure. And you'll save time with Connect's auto-grading too.

65%
Less Time
Grading



Laptop: McGraw-Hill; Woman/dog: George Doyle/Getty Images

They'll thank you for it.

Adaptive study resources like SmartBook® 2.0 help your students be better prepared in less time. You can transform your class time from dull definitions to dynamic debates. Find out more about the powerful personalized learning experience available in SmartBook 2.0 at www.mheducation.com/highered/connect/smartbook

Make it simple, make it affordable.



Connect makes it easy with seamless integration using any of the major Learning Management Systems—Blackboard®, Canvas, and D2L, among others—to let you organize your course in one convenient location. Give your students access to digital materials at a discount with our inclusive access program. Ask your McGraw-Hill representative for more information.

Padlock: Jobalou/Getty Images

Solutions for your challenges.



A product isn't a solution. Real solutions are affordable, reliable, and come with training and ongoing support when you need it and how you want it. Our Customer Experience Group can also help you troubleshoot tech problems—although Connect's 99% uptime means you might not need to call them. See for yourself at **status.mheducation.com**

Checkmark: Jobalou/Getty Images

SUPPORT ^{AT}
every step

FOR STUDENTS

Effective, efficient studying.

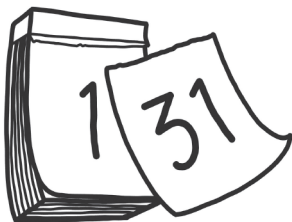
Connect helps you be more productive with your study time and get better grades using tools like SmartBook 2.0, which highlights key concepts and creates a personalized study plan. Connect sets you up for success, so you walk into class with confidence and walk out with better grades.

Study anytime, anywhere.

Download the free ReadAnywhere app and access your online eBook or SmartBook 2.0 assignments when it's convenient, even if you're offline. And since the app automatically syncs with your eBook and SmartBook 2.0 assignments in Connect, all of your work is available every time you open it. Find out more at www.mheducation.com/readanywhere

"I really liked this app—it made it easy to study when you don't have your textbook in front of you."

—Jordan Cunningham,
Eastern Washington University



Calendar: owattaphotos/Getty Images

No surprises.

The Connect Calendar and Reports tools keep you on track with the work you need to get done and your assignment scores. Life gets busy; Connect tools help you keep learning through it all.

Learning for everyone.

McGraw-Hill works directly with Accessibility Services Departments and faculty to meet the learning needs of all students. Please contact your Accessibility Services office and ask them to email accessibility@mheducation.com, or visit www.mheducation.com/about/accessibility for more information.

Top: Jenner Images/Getty Images, Left: Hero Images/Getty Images, Right: Hero Images/Getty Images



ACKNOWLEDGMENTS

The creation of a new edition of a textbook requires the support of colleagues, friends, and loved ones. Each of us wants to identify specific sources of support, without which we could not have completed this twelfth edition.

Richard wants to acknowledge students and colleagues throughout the world who have told or sent him their ideas and suggestions concerning ways to make the book work better for them in the classes they teach. He greatly appreciates their interest in assisting his efforts to develop this new edition. On a more personal level, he again acknowledges and thanks his wife, Susan Koff, for her support, encouragement, suggestions, and patience. He is dedicating this edition to her for her constancy in “being there.”

David would like to acknowledge support from Alvin Alvarez, Dean of the College of Health and Social Sciences at San Francisco State University, as well as support from the Office of Research and Sponsored Programs. He is indebted to the many colleagues and collaborators from across the world who have inspired his work and shaped his perspective on motor learning and control. Finally, he would like to thank his wife Suzanne and daughter

Torre for patiently enduring the many intrusions into “family time” that were necessary to complete this book. David is dedicating the book to his wife, Suzanne Diane Anderson, for her love and the unparalleled personal and professional support she has provided over many, many years.

A new edition of a book would not be possible without the effort and encouragement of the developmental and production editors at McGraw-Hill. We thank them for their direction, suggestions, and patience. We also thank the many undergraduate and graduate students who have been in our classes. It is difficult to express how much we have learned from them and how they have influenced much of the content of this book.

We also greatly appreciate the feedback from the following reviewers: Rhonda Fleming, Limestone College; Dr. Raisbeck, UNCG; Gunars Cazars, University of West Alabama; and Anthony Mayo, San Francisco State University.

Richard A. Magill
New York City, New York

David I. Anderson
San Francisco, California



From Richard:

To my wife

Susan R. Koff

From David:

To my wife

Suzanne D. Anderson



