

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/234028439>

# Research Methods in Biomechanics

Book · January 2004

DOI: 10.5040/9781492595809

---

CITATIONS

334

---

READS

10,198

5 authors, including:



**Douglas Gordon Robertson**

University of Ottawa

154 PUBLICATIONS 1,746 CITATIONS

SEE PROFILE



**Joseph Hamill**

University of Massachusetts Amherst

456 PUBLICATIONS 14,828 CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:

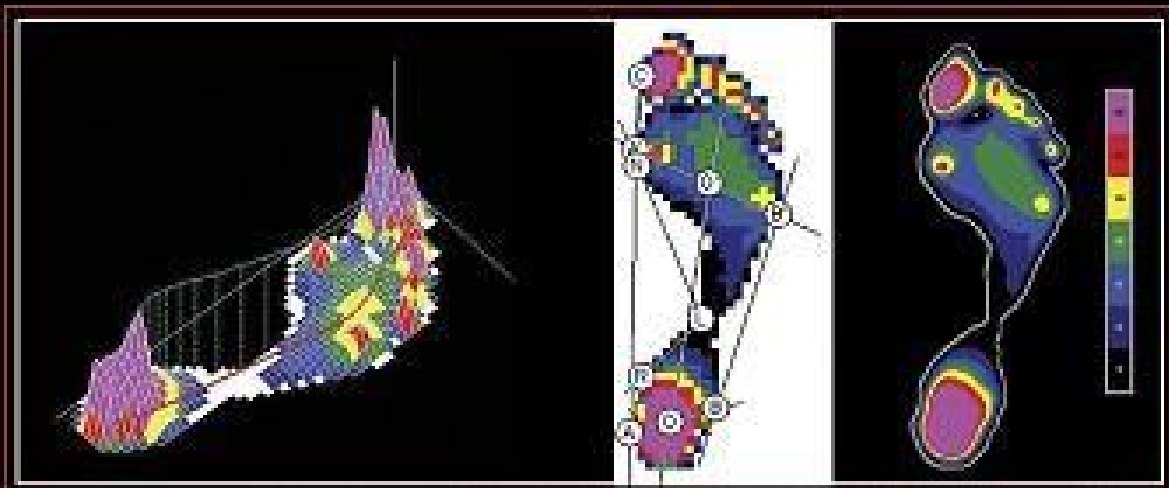


Dynamics Systems Approach in Human Movement Analysis [View project](#)



RP SHL Connexus [View project](#)

# Research Methods in Biomechanics



**D. Gordon E. Robertson**  
**Graham E. Caldwell**  
**Joseph Hamill**  
**Gary Kamen**  
**Saunders N. Whittlesey**

# **Research Methods in Biomechanics**

---

**D. Gordon E. Robertson**  
University of Ottawa

**Graham E. Caldwell**  
University of Massachusetts, Amherst

**Joseph Hamill**  
University of Massachusetts, Amherst

**Gary Kamen**  
University of Massachusetts, Amherst

**Saunders N. Whittlesey**  
University of Massachusetts, Amherst



Human Kinetics

**Library of Congress Cataloging-in-Publication Data**

Library of Congress information to come

ISBN: 0-7360-3966-X

Copyright © 2004 by D. Gordon E. Robertson, Joseph Hamill, Graham E. Caldwell, and Gary Kamen

All rights reserved. Except for use in a review, the reproduction or utilization of this work in any form or by any electronic, mechanical, or other means, now known or hereafter invented, including xerography, photocopying, and recording, and in any information storage and retrieval system, is forbidden without the written permission of the publisher.

The Web addresses cited in this text were current as of January 14, 2004, unless otherwise noted.

**Acquisitions Editor:** Loarn D. Robertson, PhD; **Developmental Editor:** Anne Rogers; **Assistant Editor:** Amanda S. Ewing; **Copyeditor:** Nancy Elgin; **Proofreader:** Erin Cler; **Indexer:** Robert Howerton; **Permission Manager:** Dalene Reeder; **Graphic Designer:** Andrew Tietz; **Graphic Artist:** Denise Lowry; **Cover:** Cover images provided by novel GmbH, www.novel.de. Copyright novel GmbH.; **Photographer (cover):** ?????????? ??????????; **Art Manager:** Kelly Hendren; **Illustrator:** Mic Greenberg; **Printer:** Edwards Brothers

Printed in the United States of America 10 9 8 7 6 5 4 3 2 1

**Human Kinetics**

Web site: [www.HumanKinetics.com](http://www.HumanKinetics.com)

*United States:* Human Kinetics, P.O. Box 5076, Champaign, IL 61825-5076  
800-747-4457  
e-mail: [humank@hkusa.com](mailto:humank@hkusa.com)

*Canada:* Human Kinetics, 475 Devonshire Road Unit 100, Windsor, ON N8Y 2L5  
800-465-7301 (in Canada only)  
e-mail: [orders@hkcanada.com](mailto:orders@hkcanada.com)

*Europe:* Human Kinetics, 107 Bradford Road, Stanningley, Leeds LS28 6AT, United Kingdom  
+44 (0) 113 255 5665  
e-mail: [hk@hkeurope.com](mailto:hk@hkeurope.com)

*Australia:* Human Kinetics, 57A Price Avenue, Lower Mitcham, South Australia 5062  
08 8277 1555  
e-mail: [liaw@hkaustralia.com](mailto:liaw@hkaustralia.com)

*New Zealand:* Human Kinetics, Division of Sports Distributors NZ Ltd., P.O. Box 300 226 Albany, North Shore City, Auckland  
0064 9 448 1207  
e-mail: [blairc@hknewz.com](mailto:blairc@hknewz.com)

*To Dr. James (Jim) G. Hay, 1936-2002,  
for his inspiring leadership in sport biomechanics education and research,  
and to all our graduate and undergraduate students  
who assisted and inspired us.*



# **CONTENTS**

Preface ix

<b><i>Introduction</i></b>	<b><i>Biomechanics Analysis Techniques: A Primer</i></b>	<b>1</b>
	What Tools Are Needed in Biomechanics? .....	1
	Applications of the Principles of Biomechanics: An Example .....	1
	Numerical Accuracy and Significant Digits .....	4
	Summary .....	4

## ***Part I Kinematics***

<b><i>Chapter 1</i></b>	<b><i>Planar Kinematics</i></b>	<b>9</b>
	Description of Position .....	9
	Degrees of Freedom .....	11
	Kinematic Data Collection .....	12
	Linear Kinematics .....	19
	Angular Kinematics .....	26
	Summary .....	34
	Suggested Readings .....	34
<b><i>Chapter 2</i></b>	<b><i>Three-Dimensional Kinematics</i></b>	<b>35</b>
	Scalars, Vectors, and Matrices .....	35
	Collection of Three-Dimensional Data .....	37
	Coordinate Systems .....	38
	Marker Systems .....	39
	Determination of the Local Coordinate System .....	42
	Transformations Between Reference Systems .....	44
	Joint Angles .....	45
	Segment Angles .....	52
	Summary .....	52
	Suggested Readings .....	52

## ***Part II Kinetics***

<b><i>Chapter 3</i></b>	<b><i>Body Segment Parameters</i></b>	<b>55</b>
	Methods for Measuring and Estimating Body Segment Parameters .....	55
	Two-Dimensional (Planar) Computational Methods .....	62
	Three-Dimensional (Spatial) Computational Methods .....	67

	Summary .....	71
	Suggested Readings .....	71
<b>Chapter 4</b>	<b><i>Forces and Their Measurement</i></b>	<b>73</b>
	Force .....	73
	Newton's Laws .....	74
	Free-Body Diagrams .....	75
	Types of Forces .....	75
	Moment of Force, or Torque .....	79
	Linear Impulse and Momentum .....	80
	Angular Impulse and Momentum .....	83
	Measurement of Force .....	86
	Summary .....	102
	Suggested Readings .....	102
<b>Chapter 5</b>	<b><i>Two-Dimensional Inverse Dynamics</i></b>	<b>103</b>
	Planar Motion Analysis .....	104
	Numerical Formulation .....	109
	General Plane Motion .....	110
	Method of Sections .....	112
	Human Joint Kinetics .....	115
	Applications .....	119
	Summary .....	123
	Suggested Readings .....	123
<b>Chapter 6</b>	<b><i>Energy, Work, and Power</i></b>	<b>125</b>
	Energy, Work, and the Laws of Thermodynamics .....	125
	Conservation of Mechanical Energy .....	128
	Ergometry: Direct Methods .....	129
	Ergometry: Indirect Methods .....	131
	Mechanical Efficiency .....	142
	Summary .....	144
	Suggested Readings .....	144
<b>Chapter 7</b>	<b><i>Three-Dimensional Kinetics</i></b>	<b>145</b>
	Laboratory Setup .....	146
	Data Required for Three-Dimensional Analysis .....	146
	Anthropometry .....	147
	Sources of Error in Three-Dimensional Calculations .....	150
	Three-Dimensional Kinetics Calculations .....	151
	Presentation of the Data .....	159
	Summary .....	159
	Suggested Readings .....	160

## ***Part III Additional Techniques***

---

<b>Chapter 8</b>	<b><i>Electromyographic Kinesiology</i></b>	<b>163</b>
	Physiology of the Electromyographic Signal .....	163



	Recording and Acquiring the Electromyographic Signal .....	166
	Analyzing and Interpreting the Electromyographic Signal .....	171
	Applications for Electromyographic Techniques .....	176
	Summary .....	181
	Suggested Readings .....	181
<b>Chapter 9</b>	<b>Muscle Modeling</b>	<b>183</b>
	The Hill Muscle Model .....	183
	Musculoskeletal Models .....	196
	Summary .....	207
	Suggested Readings .....	207
<b>Chapter 10</b>	<b>Computer Simulation of Human Movement</b>	<b>211</b>
	Overview: Modeling As a Process .....	212
	Why Simulate Human Movement? .....	213
	General Procedure for Simulations .....	214
	Free-Body Diagrams .....	214
	Differential Equations .....	216
	Model Derivation: Lagrange's Equation of Motion .....	216
	Numerical Solution Techniques .....	218
	Control Theory .....	220
	Limitations of Computer Models .....	220
	Summary .....	224
	Suggested Readings .....	225
<b>Chapter 11</b>	<b>Signal Processing</b>	<b>227</b>
	Characteristics of a Signal .....	227
	Fourier Transform .....	229
	Time-Dependent Fourier Transform .....	230
	Sampling Theorem .....	232
	Ensuring Circular Continuity .....	232
	Smoothing Data .....	234
	Summary .....	238
	Suggested Readings .....	238
Appendix A	International System of Units (System International, SI)	239
Appendix B	Selected Factors for Converting Between Units of Measure	243
Appendix C	Basic Electronics	245
Appendix D	Vector Operations	255
Appendix E	Matrix Operations	259
Appendix F	Numerical Integration of Double Pendulum Equations	261
Appendix G	Derivation of Double Pendulum Equations	263
Appendix H	Discrete Fourier Transform Subroutine	267
Appendix I	Shannon's Reconstruction Subroutine	269
Example Answers		271
Glossary		283
References		289
Index		303
About the Authors		309



# PREFACE

This book was developed with biomechanics, biomedical engineering, and kinesiology students and laboratory researchers in mind. The purpose of this book is to outline concisely and extensively the mathematical and technical tools necessary for investigating human and animal motion. In the past, such information had to be gleaned from disparate sources, including the periodical literature, or through hands-on demonstrations by professors or seasoned researchers. Our text provides students and researchers with the tools necessary to collect and analyze the mechanical characteristics of human movements using current biomechanical technologies.

The authors assume that the readers have taken an introductory course in biomechanics or Newtonian or engineering mechanics. Readers should have an understanding of vectors and elementary vector algebra and be familiar with the International System of Units (SI), although these areas are reviewed. Furthermore, readers should know the fundamental laws of mechanics, namely Newton's laws, and basic human musculoskeletal anatomy. The text examines how these laws apply to complex human motions, including the analysis of a human motion segment by segment and combining segments for limb or total body measures. Although knowledge of human anatomy is desirable, it is not essential for in-depth understanding of the analytical tools described.

The text is divided into 11 chapters in three parts. Part I describes the area called *kinematics*, which is concerned with motion description without regard to its causes. This section and part II include chapters specifically concerned with two-dimensional (2-D) and three-dimensional (3-D) analyses. Therefore, the text can be used for both intermediate and advanced courses in biomechanics, ensuring continuity of terminology from year to year. In an intermediate-level course, it is often unnecessary to perform complex 3-D methods to answer particular biomechanical questions. Therefore, suitable methods are outlined using two dimensions alone. If the motion under study is not planar, appropriate 3-D methodologies are included.

Part II pertains to the kinetic analysis of human motion—**kinetics** being the study of causes of

motion. In general, this means the quantification of forces and the work, impulse, and power produced by forces. One chapter describes how to obtain various body segment parameters, such as mass, center of gravity, and moment of inertia. Not only are segmental parameters derived, but also methods for determining the total body's center of gravity and moment of inertia. As in part I, part II contains chapters on 2-D and 3-D kinetic analyses. Furthermore, methods for measuring forces and moments of force both directly and indirectly are presented. In biomechanics, it is rarely possible to directly measure forces in muscles and ligaments. These forces are estimated using a process called inverse dynamics. A method to perform inverse dynamics is outlined systematically, with explanations about its limitations and interpretation.

Part III contains four chapters about electromyographic kinesiology, muscle modeling, computer simulation, and signal processing. Electromyography (EMG) is the field of study that records and interprets the electrical signals produced by skeletal muscles when they are recruited to produce force. This discipline offers a direct way of determining the sequence of muscle activities and, therefore, explains how the brain and peripheral nervous system act together to coordinate human movements. Muscle modeling is a method of indirectly estimating the forces produced by individual muscles during a movement sequence. This is important, because it is not possible to measure these forces directly without using surgical intervention. Computer simulation involves the process of forward dynamics, in which a model of the musculoskeletal system predicts the kinematic motion from a set of initial conditions and prescribed kinetic patterns. Simulation allows researchers to explore optimal movement patterns, the effects of possible surgical interventions, and the role of specific muscles to a motion sequence. The final chapter, on signal processing, outlines technologies used when noise is present and needs to be removed. This technological area is of special interest when smoothing displacement signals prior to double differentiation (to obtain acceleration) or to analyze

the frequency characteristics of EMG signals from muscle contractions.

The text concludes with a summary of SI units, conversion factors for converting measurements from American to SI units, an outline of basic electronics, outlines of vector and matrix mathematics,

derivations and numerical integrations of double pendulum equations, and two computer subroutines for signal analysis. The book's glossary defines biomechanical terminology, and the index provides a quick reference for finding essential biomechanical concepts outlined in the text.