

S./124

Occupational Biomechanics

Fourth Edition

Don B. Chaffin

Gunnar B. J. Andersson

Bernard J. Martin

BCU Cluj-Napoca



EDFIZ201400021

*Allych
PC
Scen
Fil*



**WILEY-
INTERSCIENCE**

A JOHN WILEY & SONS, INC., PUBLICATION

Copyright © 2006 by John Wiley & Sons, Inc. All rights reserved.

Published by John Wiley & Sons, Inc., Hoboken, New Jersey.

Published simultaneously in Canada.

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, scanning, or otherwise, except as permitted under Section 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher, or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, (978) 750-8400, fax (978) 750-4470, or on the web at www.copyright.com. Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, (201) 748-6011, fax (201) 748-6008, or online at <http://www.wiley.com/go/permission>.

Limit of Liability/Disclaimer of Warranty: While the publisher and author have used their best efforts in preparing this book, they make no representations or warranties with respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives or written sales materials. The advice and strategies contained herein may not be suitable for your situation. You should consult with a professional where appropriate. Neither the publisher nor author shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages.

For general information on our other products and services or for technical support, please contact our Customer Care Department within the United States at (800) 762-2974, outside the United States at (317) 572-3993 or fax (317) 572-4002.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic format. For information about Wiley products, visit our web site at www.wiley.com.

Library of Congress Cataloging-in-Publication Data:

Chaffin, Don B.

Occupational biomechanics / Don B. Chaffin, Gunnar B.J. Andersson,
Bernard J. Martin.—4th ed.

p. cm.

Includes bibliographical references and index.

ISBN-13: 978-0-471-72343-1 (cloth)

ISBN-10: 0-471-72343-6 (cloth)

1. Work—Physiological aspects. 2. Human mechanics. I. Andersson,
Gunnar, 1942-. II. Martin, Bernard J. III. Title.

[DNLM: 1. Biomechanics. 2. Human Engineering. 3. Occupational
Health. WE 103 C433o 2006]

QP303.C44 2006

612.7—dc22

2005035007

Printed in the United States of America.

10 9 8 7 6 5 4 3

Contents

Foreword	xi
Preface	xiii
Acknowledgments	xv
1. Occupational Biomechanics as a Specialty	1
1.1 Definition of Occupational Biomechanics / 1	
1.2 Historical Development of Occupational Biomechanics / 2	
1.2.1 Kinesiological Developments / 4	
1.2.2 Developments in Biomechanical Modeling / 4	
1.2.3 Developments in Anthropometry / 5	
1.2.4 Methods for Evaluating Mechanical Work Capacity / 5	
1.2.5 Developments in Bioinstrumentation / 5	
1.2.6 Developments in Motion Classification and Time Prediction Systems / 5	
1.3 The Need for an Occupational Biomechanics Specialty / 6	
1.3.1 Epidemiological Support for Occupational Biomechanics / 6	
1.3.2 Social and Legal Support for Occupational Biomechanics / 6	
1.3.3 Ergonomic Support for Occupational Biomechanics / 7	
1.4 Who Uses Occupational Biomechanics? / 7	
1.5 Organization of The Book / 8	
Review Questions / 8	
References / 8	
2. The Structure and Function of the Musculoskeletal System	11
2.1 Introduction / 11	
2.2 Connective Tissue / 11	
2.2.1 Ligaments, Tendons, and Fascia / 11	
2.2.2 Cartilage / 13	
2.2.3 Bone / 13	
2.3 Skeletal Muscle / 17	
2.3.1 The Structure of Muscles / 17	
2.3.2 The Molecular Basis of Muscle Contraction / 19	
2.3.3 The Energy Metabolism of Muscle / 20	
2.3.4 The Nerve Impulse Causing Muscle Contraction / 21	
2.3.5 Mechanical Aspects of Muscle Contraction / 21	
2.3.6 Muscle Fatigue / 25	

2.3.7	Quantification and Prediction of Fatigue / 26	
2.3.8	Age and Gender Sensitivity to Fatigue / 28	
2.3.9	The Action of Muscles / 28	
2.4	Joints / 30	
2.4.1	The Synovial Joint / 30	
2.4.2	Joint Lubrication / 31	
2.4.3	Osteoarthritis / 32	
2.4.4	Intervertebral Discs / 32	
	Review Questions / 33	
	References / 33	
3.	Anthropometry in Occupational Biomechanics	37
3.1	Measurement of Physical Properties of Body Segments / 37	
3.1.1	Body-segment Link Length Measurement Methods / 37	
3.1.2	Body-segment Volume and Weight / 39	
3.1.3	Body-segment Locations of Center of Mass / 40	
3.1.4	Body-segment Inertial Property Measurement Methods / 42	
3.2	Anthropometric Data for Biomechanical Studies in Industry / 45	
3.2.1	Segment Link Length Data / 45	
3.2.2	Segment Weight Data / 46	
3.2.3	Segment Mass-center Location Data / 48	
3.2.4	Segment Moment-of-Inertia and Radius-of-Gyration Data / 48	
3.3	Summary of Anthropometry in Occupational Biomechanics / 49	
	Review Questions / 49	
	References / 51	
4.	Mechanical Work Capacity Evaluation	53
4.1	Introduction / 53	
4.2	Joint Motion: Methods and Data / 53	
4.2.1	Methods of Measuring Joint Motion / 54	
4.2.2	Normal Ranges of Joint Motion / 56	
4.2.3	Factors Affecting Range-of-Motion Data / 57	
4.3	Muscle Strength Evaluation / 58	
4.3.1	Definition of Muscular Strength / 58	
4.3.2	Static and Dynamic Strength-Testing Methods / 60	
4.3.3	Population Muscle Strength Values / 64	
4.3.4	Personal Factors Affecting Strength / 68	
4.4	Summary and Limitations of Mechanical Work-Capacity Data / 70	
	Review Questions / 71	
	References / 71	
5.	Bioinstrumentation for Occupational Biomechanics	75
5.1	Introduction / 75	
5.2	Human Motion Analysis Systems / 75	
5.2.1	Basis for Measuring Human Motion / 75	
5.3	Muscle Activity Measurement / 84	
5.3.1	Applied Electromyography / 84	
5.3.2	Mechanomyography / 88	
5.3.3	Intramuscular Pressure / 88	
5.4	Muscle Strength Measurement Systems / 89	

5.4.1	Localized Static Strength Measurement Systems / 89	
5.4.2	Whole-Body Static Strength Measurement System / 90	
5.4.3	Whole-Body Dynamic Strength Measurement System / 91	
5.5	Intradiscal Pressure Measurement / 91	
5.5.1	Measurement Concept / 91	
5.5.2	Intradiscal Pressure Measurement System / 92	
5.5.3	Applications and Limitations in Occupational Biomechanics / 93	
5.6	Intra-Abdominal (Intragastric) Measurements / 93	
5.6.1	Measurement Development / 93	
5.6.2	Measurement System / 93	
5.6.3	Applications and Limitations in Occupational Biomechanics / 94	
5.7	Seat Pressure Measurement Systems / 95	
5.8	Stature Measurement System / 97	
5.9	Force Platform System / 97	
5.10	Foot and Hand Force Measurement System / 98	
5.11	Measurement of Vibration in Humans / 99	
	Review Questions / 100	
	References / 100	
6.	Occupational Biomechanical Models	109
6.1	Why Model? / 109	
6.2	Planar Static Biomechanical Models / 110	
6.2.1	Single-body-segment Static Model / 110	
6.2.2	Two-body-segment Static Model / 113	
6.2.3	Static Planar Model of Nonparallel Forces / 115	
6.2.4	Planar Static Analysis of Internal Forces / 116	
6.2.5	Multiple-Link Coplanar Static Modeling / 119	
6.3	Three-Dimensional Modeling of Static Strength / 121	
6.4	Dynamic Biomechanical Models / 124	
6.4.1	Single-segment Dynamic Biomechanical Model / 124	
6.4.2	Multiple-segment Biodynamic Model of Load Lifting / 126	
6.4.3	Coplanar Biomechanical Models of Foot Slip Potential While Pushing a Cart / 128	
6.5.	Special-Purpose Biomechanical Models of Occupational Tasks / 130	
6.5.1	Low-back Biomechanical Models / 130	
6.5.2	Biomechanical Models of the Wrist and Hand / 146	
6.5.3	Modeling Muscle Strength / 150	
6.6	Future Developments in Occupational Biomechanical Models / 153	
	Review Questions / 154	
	References / 155	
7.	Methods of Classifying and Evaluating Manual Work	161
7.1	Traditional Methods / 161	
7.1.1	Historical Perspective / 161	
7.2	Traditional Work Analysis System / 163	
7.2.1	MTM: An Example of a Predetermined Motion–Time System / 163	
7.2.2	Benefits and Limitations in Contemporary Work Analysis Systems / 165	
7.3	Contemporary Biomechanical Job Analysis / 166	
7.3.1	Identification of Musculoskeletal Injury Problems / 166	
7.3.2	Analyzing Biomechanical Risk Factors / 168	
7.3.3	Specialized Biomechanical Risk Factor Evaluation / 170	

7.3.4	Emgs in Job Evaluation / 179	
7.4	Future Impact of Occupational Biomechanics on Work Analysis Systems / 179	
	Review Questions / 180	
	References / 181	
8.	Manual Material-Handling Limits	183
8.1	Introduction / 183	
8.2.	Lifting Limits in Manual Material Handling / 184	
8.2.1	Scope of NIOSH Work Practices Guide for Manual Lifting / 186	
8.2.2	Basis and Structure of the 1994 NIOSH-Recommended Weight-Lifting Limit / 187	
8.2.3	Example of NIOSH RWL Procedure / 188	
8.2.4	Comments on the Status of the NIOSH Lifting Guide / 189	
8.2.5	Alternative Recommendations for Evaluating Manual Lifting Tasks / 190	
8.3	Pushing and Pulling Capabilities / 191	
8.3.1	Foot-slip Prevention During Pushing and Pulling / 193	
8.4	Asymmetric Load Handling / 194	
8.4.1	Toward a Comprehensive Manual Material-Handling Guide / 197	
8.5	Recommendations for Improving Manual Material-Handling Tasks / 198	
8.6	Summary of Manual Material-handling Recommendations and Evaluation Methods / 202	
	Review Questions / 203	
	References / 203	
9.	Guidelines for Work in Sitting Postures	207
9.1	General Considerations Related to Sitting Postures / 207	
9.2	Anthropometric Aspects of Seated Workers / 209	
9.3	Comfort / 211	
9.4	The Spine and Sitting / 211	
9.4.1	Clinical Aspects of Sitting Postures / 211	
9.4.2	Radiographic Data / 212	
9.4.3	Disc Pressure Data During Sitting / 213	
9.4.4	Muscle Activity / 214	
9.4.5	Sitting Postures and The Spine / 216	
9.5	The Shoulder and Sitting / 216	
9.6	The Legs and Sitting / 217	
9.7	The Sitting Workplace / 218	
9.7.1	The Office Chair / 218	
9.7.2	The Table in a Seated Workplace / 221	
9.7.3	Visual Display Terminal Workstations / 222	
9.8	Summary / 223	
	Review Questions / 223	
	References / 223	
10.	Biomechanical Considerations in Machine Control and Workplace Design	227
10.1	Introduction / 227	
10.1.1	Localized Musculoskeletal Injury in Industry / 227	
10.2	Practical Guidelines for Workplace and Machine Control Layout / 231	
10.2.1	Structure–Function Characteristics of the Shoulder Mechanism / 231	

10.2.2	Shoulder-Dependent Overhead Reach Limitations / 234	
10.2.3	Shoulder- and Arm-Dependent Forward Reach Limits / 235	
10.2.4	Neck–Head Posture Work Limitations / 239	
10.2.5	Torso Postural Considerations In Workbench Height Limitations / 241	
10.2.6	Biomechanical Considerations In The Design Of Computer Workstations / 242	
10.3	Summary / 243	
	Review Questions / 244	
	References / 244	
11.	Hand-Tool Design Guidelines	249
11.1	The Need for Biomechanical Concepts in Design / 249	
11.2	Shape and Size Considerations / 251	
11.2.1	Shape for Avoiding Wrist Deviation / 251	
11.2.2	Shape for Avoiding Shoulder Abduction / 252	
11.2.3	Shape to Assist Grip / 253	
11.2.4	Size of Tool Handle to Facilitate Grip / 254	
11.2.5	Finger Clearance Considerations / 255	
11.2.6	Gloves / 256	
11.3	Hand-Tool Weight and Use Considerations / 256	
11.4	Force Reaction Considerations in Powered Hand-Tool Design / 257	
11.5	Keyboard Design Considerations / 258	
11.5.1	Posture Stress / 259	
11.5.2	Keying Exertion Force Repetition / 259	
11.6	Summary / 260	
	Review Questions / 260	
	References / 260	
12.	Guidelines for Whole-Body and Segmental Vibration	265
12.1	Definitions and Measurement / 265	
12.1.1	Definitions / 265	
12.1.2	Measurement of Vibration / 267	
12.2	General Effects of Vibration on Human Beings / 269	
12.3	Whole-Body Vibration / 269	
12.3.1	Effects of Low-Frequency Vibration / 269	
12.3.2	Effects of Middle-Frequency Vibration / 270	
12.3.3	Biomechanical Effects on the Spine / 272	
12.3.4	Physiological Responses / 273	
12.4	Hand-Arm Vibration / 274	
12.4.1	Transmission of Vibration in the Upper Extremity / 274	
12.4.2	Hand-Arm Vibration Syndrome / 275	
12.5	Sensorimotor Effects / 276	
12.6	Vibration Exposure Criteria / 278	
12.6.1	Whole-Body Vibration Recommendations / 278	
12.6.2	Hand–Arm Vibration Recommendations / 279	
12.7	Control and Prevention / 280	
	Review Questions / 280	
	References / 281	

13. Worker Selection, Training, and Personal Protective Device Consideration	285
13.1 Worker Selection / 285	
13.1.1 Introduction To Worker Selection / 285	
13.1.2 History And Physical Examination / 288	
13.1.3 Radiographic Preplacement Examination / 289	
13.1.4 Quantitative Physical Preplacement Screening / 289	
13.2 Preplacement Training / 291	
13.2.1 General Content of Training / 291	
13.2.2 How Workers Should Be Trained / 293	
13.3 Biomechanical Aspects of Back Belts / 294	
13.3.1 Passive Stiffness Effects of Back Belts / 294	
13.3.2 Abdominal Pressure Effects of Back Belts / 295	
13.3.3 Reduced Torso Mobility Effects Due to Back Belts / 296	
13.4 Job Rotation and Psychosocial Stress / 296	
13.5 Summary / 297	
Review Questions / 297	
References / 297	
14. Summary	301
References / 303	
Appendix A	305
Part 1: Anatomical and Anthropometric Landmarks as Presented by Webb and Associates / 305	
Part 2: Glossary of Anatomical and Anthropometric Terms / 308	
Appendix B Population Weight and Mass-Center Data	313
Table B.1 Segment Weight Values Derived from Regression Equations Using Total Body Weight as the Independent Variable / 314	
Table B.2 Anatomical Location of Segment Centers of Gravity (Center of Mass) / 315	
Table B.3 Segment Moments of Inertia / 316	
Table B.4 Joint Center Locations and Link Definitions / 317	
Appendix C Terms and Units of Measurement in Biomechanics	319
Appendix D NIOSH 1994 Tables	331
Appendix E Push and Pull Fore Tables	335
Appendix F Data Gathering—Job Risk Factors	337
Appendix G Some General Web Sites that Complement References in Text	349
Index	351