

HANDBOOK OF HUMAN FACTORS AND ERGONOMICS

FIFTH EDITION

EDITED BY
GAVRIEL SALVENDY
WALDEMAR KARWOWSKI



WILEY

HANDBOOK OF HUMAN FACTORS
AND ERGONOMICS

HANDBOOK OF HUMAN FACTORS AND ERGONOMICS

Fifth Edition

Edited by
Gavriel Salvendy
and
Waldemar Karwowski
*University of Central Florida
Orlando, Florida*

WILEY

This book is printed on acid-free paper.

Copyright © 2021 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, 222 Rosewood Drive, Danvers, MA 01923, (978) 750-8400, fax (978) 646-8600, 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 www.wiley.com/go/permissions.

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 the 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 the author shall be liable for damages arising herefrom.

For general information about our other products and services, 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 publishes in a variety of print and electronic formats and by print-on-demand. Some material included with standard print versions of this book may not be included in e-books or in print-on-demand. If this book refers to media such as a CD or DVD that is not included in the version you purchased, you may download this material at <http://booksupport.wiley.com>. For more information about Wiley products, visit www.wiley.com.

Library of Congress Cataloging-in-Publication Data is Available:

9781119636083 (hardback)

9781119636106 (epdf)

9781119636090 (epub)

Cover Design: Wiley

Cover Image: © alvarez/Getty Images; SciePro/Getty Images;

John Gress Media Inc/Shutterstock.com; Scharfsinn/Shutterstock.com;

Bloomicon/Shutterstock.com

CONTENTS

About the Editors	ix
Contributors	xi
Foreword	xxi
Preface	xxiii
1. Human Factors Function	1
1. The Discipline of Human Factors and Ergonomics <i>Waldemar Karwowski and Wei Zhang</i>	3
2. Human Systems Integration and Design <i>Guy A. Boy</i>	38
2. Human Factors Fundamentals	55
3. Sensation and Perception <i>Robert W. Proctor and Janet D. Proctor</i>	57
4. Selection and Control of Action <i>Robert W. Proctor and Kim-Phuong L. Vu</i>	91
5. Information Processing <i>Christopher D. Wickens and C. Melody Carswell</i>	114
6. Decision-Making Models, Decision Support, and Problem Solving <i>Mark R. Lehto and Gaurav Nanda</i>	159
7. Mental Workload <i>G.M. Hancock, L. Longo, M.S. Young, and P.A. Hancock</i>	203
8. Social and Organizational Foundation of Ergonomics: Multi-Level Systems Approaches <i>Pascale Carayon</i>	227
9. Emotional Design <i>Feng Zhou, Yangjian Ji, and Roger Jianxin Jiao</i>	236
10. Cross-Cultural Design <i>Tom Plocher, Pei-Luen Patrick Rau, Yee-Yin Choong, and Zhi Guo</i>	252
3. Design of Equipment, Tasks, Jobs, and Environments	281
11. Three-Dimensional (3D) Anthropometry and Its Applications in Product Design <i>Liang Ma and Jianwei Niu</i>	283
12. Basic Biomechanics and Workplace Design <i>William S. Marras and Waldemar Karwowski</i>	303

13. The Changing Nature of Task Analysis <i>Erik Hollnagel</i>	358
14. Workplace Design <i>Nicolas Marmaras and Dimitris Nathanael</i>	368
15. Job and Team Design <i>Frederick P. Morgeson and Michael A. Campion</i>	383
16. Design, Delivery, Evaluation, and Transfer of Effective Training Systems <i>Tiffany M. Bisbey, Rebecca Grossman, Kareem Pantou, Chris W. Coultas, and Eduardo Salas</i>	414
17. Situation Awareness <i>Mica R. Endsley</i>	434
4. Design for Health, Safety, and Comfort	457
18. Sound and Noise: Measurement and Design Guidance <i>John G. Casali</i>	459
19. Vibration and Motion <i>Neil J. Mansfield and Michael J. Griffin</i>	494
20. Human Errors and Human Reliability <i>Peng Liu, Renyou Zhang, Zijian Yin, and Zhizhong Li</i>	514
21. Occupational Safety and Health Management <i>Jeanne Mager Stellman, Sonalee Rau, and Pratik Thaker</i>	573
22. Managing low-Back Disorder Risk in the Workplace <i>William S. Marras and Waldemar Karwowski</i>	597
23. Manual Materials Handling: Evaluation and Practical Considerations <i>Fadi A. Fathallah and Ira Janowitz</i>	630
24. Warnings and Hazard Communications <i>Michael S. Wogalter, Christopher B. Mayhorn, and Kenneth R. Laughery, Sr.</i>	644
25. Use of Personal Protective Equipment <i>Grażyna Bartkowiak, Krzysztof Baszczyński, Anna Bogdan, Agnieszka Brochocka, Anna Dąbrowska, Rafał Hrynyk, Emilia Irzmańska, Danuta Koradecka, Emil Kozłowski, Katarzyna Majchrzycka, Krzysztof Makowski, Anna Marszałek, Magdalena Młynarczyk, Rafał Młyński, Grzegorz Owczarek, and Jan Żera</i>	668
5. Human Performance Modeling	685
26. Mathematical Modeling in Human–Machine System Design and Evaluation <i>Changxu Wu and Yili Liu</i>	687
27. Modeling and Simulation of Human Systems <i>Gunther E. Paul</i>	704
28. Human Supervisory Control of Automation <i>Thomas B. Sheridan</i>	736
29. Digital Human Modeling in Design <i>Vincent G. Duffy</i>	761
30. Extended Reality (XR) Environments <i>Kay M. Stanney, Hannah Nye, Sam Haddad, Kelly S. Hale, Christina K. Padron, and Joseph V. Cohn</i>	782
31. Neuroergonomics <i>Hasan Ayaz and Frédéric Dehais</i>	816

6. System Evaluation	843
32. Accident and Incident Investigation <i>Patrick G. Dempsey</i>	845
33. Human Factors and Ergonomics Audits <i>Colin G. Drury and Patrick G. Dempsey</i>	853
34. Cost/Benefit Analysis for Human Systems Investments <i>William B. Rouse and Dennis K. McBride</i>	880
7. Human–Computer Interaction	893
35. Data Visualization <i>Sumanta N. Pattanaik and R. Paul Wiegand</i>	895
36. Representation Design <i>John M. Flach, Kevin B. Bennett, Jonathan W. Butler, and Michael A. Heroux</i>	947
37. Collecting and Analyzing User Insights <i>Matthias Peissner, Kathrin Pollmann, and Nora Fronemann</i>	960
38. Usability and User Experience: Design and Evaluation <i>James R. Lewis and Jeff Sauro</i>	972
39. Website Design and Evaluation <i>Kim-Phuong L. Vu, Robert W. Proctor, and Ya-Hsin Hung</i>	1016
40. Mobile Systems Design and Evaluation <i>June Wei and Siyi Dong</i>	1037
41. Human Factors in Ambient Intelligence Environments <i>Constantine Stephanidis, Margherita Antona, and Stavroula Ntoa</i>	1058
42. Human-Centered Design of Artificial Intelligence <i>George Margetis, Stavroula Ntoa, Margherita Antona, and Constantine Stephanidis</i>	1085
43. Cybersecurity, Privacy, and Trust <i>Abbas Moallem</i>	1107
44. Human–Robot Interaction <i>Jessie Y.C. Chen and Michael J. Barnes</i>	1121
45. Human Factors in Social Media <i>Qin Gao and Yue Chen</i>	1143
8. Design for Individual Differences	1187
46. Design for All in Digital Technologies <i>Constantine Stephanidis</i>	1189
47. Design for People Experiencing Functional Limitations <i>Gregg C. Vanderheiden, J. Bern Jordan, and Jonathan Lazar</i>	1216
48. Design for Aging <i>Jia Zhou and Qin Gao</i>	1249
49. Design of Digital Technologies for Children <i>Panos Markopoulos, Janet C. Read, and Michail Giannakos</i>	1287
9. Selected Applications	1305
50. Human Factors and Ergonomics Standards <i>Waldemar Karwowski, Redha Taiar, David Rodrick, Bohdana Sherehiy, and Robert R. Fox</i>	1307

51. Data Analytics in Human Factors	1351
<i>Matt Holman, Guy Walker, Melissa Bedinger, Annie Visser-Quinn, Kerri McClymont, Lindsay Beevers, and Terry Lansdown</i>	
52. Human Factors and Ergonomics in Design of A ³ : Automation, Autonomy, and Artificial Intelligence	1385
<i>Ben D. Sawyer, Dave B. Miller, Matthew Canham, and Waldemar Karwowski</i>	
53. Human Factors and Ergonomics in Health Care	1417
<i>Pascale Carayon, Kathryn Wust, Bat-Zion Hose, and Megan E. Salwei</i>	
54. Human Factors and Ergonomics in Digital Manufacturing	1438
<i>Dieter Spath and Martin Braun</i>	
55. Human Factors and Ergonomics in Aviation	1460
<i>Steven J. Landry</i>	
56. Human Side of Space Exploration and Habitation	1480
<i>Kevin R. Duda, Dava J. Newman, Joanna Zhang, Nicolas Meirhaeghe, and H. Larissa Zhou</i>	
57. Human Factors and Ergonomics for Sustainability	1512
<i>Klaus Fischer, Andrew Thatcher, and Klaus J. Zink</i>	
Index	1529

ABOUT THE EDITORS

Gavriel Salvendy is University Distinguished Professor at the University of Central Florida and founding president of the Academy of Science, Engineering, and Medicine of Florida. He is also professor emeritus of Industrial Engineering at Purdue University and was the Founding Head (2001–2011) of the Department of Industrial Engineering at Tsinghua University, China. From 1984 to 1999, he was the NEC Corporation’s private chair holder at Purdue University. He is the author of nearly 600 research publications including over 320 journal papers. He has been the major professor to 68 PhD students. His main research deals with the human aspects of design, operation, and management of advanced engineering systems. In 1990, he became the first member of the Human Factors and Ergonomics Society to be elected to the National Academy of Engineering (NAE). In 1995, he received an Honorary Doctorate from the Chinese Academy of Sciences. He is the fourth person in all fields of science and engineering in the 45 years of the Academy ever to receive this award. In 2006, he received the Friendship Award presented by the People’s Republic of China. The award is the highest honor the Chinese government confers on foreign experts. In 2007, he received the American Association of Engineering Societies’ John Fritz Medal, which is the engineering profession’s highest award. Special issues of the journals *Ergonomics* (2003), *Computers in Industry* (2010) and *Intelligent Manufacturing* (2011) were published in honor of Gavriel Salvendy. He is Honorary Fellow and life member of the Ergonomics Society and Fellow of the Human Factors and Ergonomics Society, Institute of Industrial and Systems Engineers, and the American Psychological Association. He earned his Ph.D. in Engineering Production at the University of Birmingham, United Kingdom.

Waldemar Karwowski is Pegasus Professor and Chairman, Department of Industrial Engineering and Management Systems, University of Central Florida, USA. He holds an M.S. in Production Engineering and Management from the University of Technology Wroclaw, Poland, and a Ph.D. in Industrial Engineering from Texas Tech University, USA. He was awarded D.Sc. in management science by the Institute for Organization and Management in Industry, Warsaw, and received the National Professorship title from the President of Poland (2012). Three Central European universities also awarded him Doctor Honoris Causa degrees. Dr. Karwowski served on the Board on Human Systems Integration, National Research Council, USA (2007–2011). He currently is Co-Editor-in-Chief of *Theoretical Issues in Ergonomics Science* journal, Editor-in-Chief of *Human-Intelligent Systems Integration* journal, and Field Chief Editor of the *Frontiers in Neuroergonomics* journal. Dr. Karwowski has over 550 research publications, including over 200 journal papers focused on ergonomics and safety, human performance, neuro-fuzzy systems, nonlinear dynamics, human-centered AI, and neuroergonomics. He is Fellow of the Ergonomics Society (UK), the Human Factors and Ergonomics Society (HFES), the Institute of Industrial and Systems Engineers (IISE), and the International Ergonomics Association (IEA), and has served as President of both HFES (2006–2007) and the IEA (2000–2003). He received the William Floyd Award from the Chartered Institute of Ergonomics & Human Factors, the United Kingdom in 2017, and the David F. Baker Distinguished Research Award, Institute of Industrial and Systems Engineers, Atlanta, USA, in 2020.

CONTRIBUTORS

Margherita Antona
Principal Researcher, HCI Lab
Institute of Computer Science – FORTH
Heraklion, Crete, Greece

Hasan Ayaz
Provost Solutions Fellow Associate Professor
School of Biomedical Engineering, Science and Health
Systems
Department of Psychology, College of Arts and Sciences
Drexel Solutions Institute
Drexel University

Michael J. Barnes
Senior Research Psychologist
U.S. Army Research Laboratory
Adelphi, Maryland

Grażyna Bartkowiak
Assistant Professor and Head of the Laboratory
Department of Personal Protective Equipment
Central Institute for Labour Protection – National
Research Institute
Warsaw, Poland

Krzysztof Baszczyński
Assistant Professor and Head of the Laboratory
Department of Personal Protective Equipment
Central Institute for Labour Protection – National
Research Institute
Warsaw, Poland

Melissa Bedinger
Research Associate
Institute for Infrastructure and Environment
School of Energy, Geoscience, Infrastructure and Society
Heriot-Watt University
Edinburgh, UK

Lindsay Beevers
Professor of Water Management
Institute for Infrastructure and
Environment
School of Energy, Geoscience, Infrastructure
and Society
Heriot-Watt University
Edinburgh, UK

Kevin B. Bennett
Professor
Human Factors and Industrial
Organizational PhD Program
Wright State University
Dayton, Ohio

Tiffany M. Bisbey
Graduate Student
Department of Psychological Sciences
Rice University
Texas

Anna Bogdan
Associate Professor and Vice-Dean General and
Scientific Affairs
Faculty of Building Services, Hydro and Environmental
Engineering
Warsaw University of Technology
Warsaw, Poland

Guy A. Boy
FlexTech Chair Institute Professor
CentraleSupélec, Paris Saclay
University
ESTIA Institute of Technology
Paris, France

Martin Braun
Senior Researcher at Fraunhofer Institute for Industrial
Engineering (IAO)
Lecturer at Institute for Human Factors and Technology
Management (IAT)
University of Stuttgart
Stuttgart, Germany

Agnieszka Brochocka
Assistant Professor and Head of the Laboratory
Department of Personal Protective Equipment
Central Institute for Labour Protection – National
Research Institute
Warsaw, Poland

Jonathan W. Butler
Senior UX/UI Designer
Mile Two, LLC
Dayton, Ohio

Michael A. Campion
Herman C. Krannert Distinguished Professor of
Management
Krannert Graduate School of Management
Purdue University
West Lafayette, Indiana

Matthew Canham
Research Professor
Institute for Simulation and Training
University of Central Florida
Orlando, Florida

Pascale Carayon
Leon and Elizabeth Janssen Professor in the College of
Engineering
Department of Industrial & Systems Engineering
Wisconsin Institute for Healthcare Systems Engineering
University of Wisconsin-Madison
Madison, Wisconsin

C. Melody Carswell
Professor Emeritus of Psychology
University of Kentucky
Lexington, Kentucky

John G. Casali
Grado Chaired Professor; Director, Auditory Systems
Laboratory
Department of Industrial and Systems Engineering

Virginia Tech
Blacksburg, Virginia
Founder and Chief Technology Officer
Hearing, Ergonomics & Acoustics Resources (H.E.A.R.)
LLC

Jessie Y.C. Chen
Senior Research Scientist (ST) for Soldier Performance
U.S. Army Research Laboratory
Adelphi, Maryland

Yue Chen
Postdoctoral Researcher
Department of Industrial Engineering
Tsinghua University
Beijing, China

Yee-Yin Choong
Research Scientist
National Institute of Standards and Technology
Gaithersburg, Maryland

Joseph V. Cohn
Chief, Research Program Administration Division
Defense Health Agency

Chris W. Coultas
Director of Science & Research; Senior Consultant
Leadership Worth Following, LLC

Anna Dąbrowska
Research Associate
Department of Personal Protective Equipment
Central Institute for Labour Protection – National
Research Institute
Warsaw, Poland

Frédéric Dehais
Professor
ISAE-SUPAERO, Université de Toulouse
School of Biomedical Engineering, Science and Health
Systems
Drexel University

Patrick G. Dempsey
Chief, Workplace Health Branch
Pittsburgh Mining Research Division
National Institute for Occupational Safety
and Health
Pittsburgh, Pennsylvania

Siyi Dong
Researcher
Center for Research on Zhejiang Digital Development
and Governance
Doctoral Candidate
School of Management
Zhejiang University
China

Colin G. Drury
SUNY Distinguished Professor Emeritus
Department of Industrial and Systems Engineering
University at Buffalo: SUNY
Buffalo, New York

Kevin R. Duda
Group Lead, Space & Mission Critical Systems
Systems Engineering Directorate
The Charles Stark Draper Laboratory, Inc.

Vincent G. Duffy
Professor
School of Industrial Engineering and
Department of Agricultural and Biological Engineering
Purdue University
West Lafayette, Indiana

Mica R. Endsley
President
SA Technologies
Marietta, Georgia

Fadi A. Fathallah
Professor
Department of Biological and Agricultural
Engineering
University of California, Davis
California

Klaus Fischer
FOM University of Applied Science
Mannheim, Germany

John M. Flach
Senior Cognitive Systems Engineer
Mile Two, LLC
Emeritus Professor
Psychology Department
Wright State University
Dayton, Ohio

Robert R. Fox
General Motors Technical Fellow for Ergonomics
Global Ergonomics & Virtual Human Simulation
General Motors Company

Nora Fronemann
Team Lead User Experience
Fraunhofer Institute for Industrial Engineering IAO
Germany

Qin Gao
Associate Professor
Department of Industrial Engineering
Tsinghua University
Beijing, China

Michail N. Giannakos
Professor and Head of the Learner-Computer Interaction
Lab
Department of Computer Science
Norwegian University of Science and
Technology
Trondheim, Norway

Michael J. Griffin
Professor
Human Factors Research Unit
Institute of Sound and Vibration Research
University of Southampton
Southampton, UK

Rebecca Grossman
Associate Professor of Industrial/Organizational
Psychology
Department of Psychology
Hofstra University
New York

Zhi Guo
Senior User Researcher
Institute of Human Factors and Ergonomics
Department of Industrial Engineering
Tsinghua University
Beijing, China

Sam Haddad
Engineering Director
Augmented Reality Technical Fellow
Design Interactive, Inc.
Oviedo, Florida

Kelly S. Hale
Principal Member of Technical Staff
User Experience and Performance Division
Draper

G. M. Hancock
Assistant Professor
Department of Psychology
California State University, Long Beach
Long Beach, California

P. A. Hancock
Provost Distinguished Research Professor
Department of Psychology and Institute for Simulation
& Training
University of Central Florida
Orlando, Florida

Michael A. Heroux
Director of Design
Mile Two, LLC
Dayton, Ohio

Erik Hollnagel
Senior Professor of Patient Safety
University of Jönköping
Sweden
Visiting Professorial Fellow
Macquarie University

Matt Holman
Doctoral Student in Human Factors
School of Energy, Geoscience, Infrastructure and
Society
Heriot-Watt University
Edinburgh, UK

Bat-zion Hose
Doctoral Student and Research Assistant
Department of Industrial & Systems Engineering
Wisconsin Institute for Healthcare Systems
Engineering
University of Wisconsin-Madison
Madison, Wisconsin

Rafał Hrynyk
Department of Personal Protective Equipment
Central Institute for Labour Protection – National
Research Institute
Warsaw, Poland

Ya-Hsin Hung
Postdoctoral Research Assistant
Department of Psychological Sciences
Purdue University
West Lafayette, Indiana

Emilia Irzmańska
Assistant Professor and Head of
the Laboratory
Department of Personal Protective
Equipment
Central Institute for Labour Protection – National
Research Institute
Warsaw, Poland

Ira Janowitz
Consultant in Ergonomics (Ret.)

Yangjian Ji
Professor
School of Mechanical Engineering
Zhejiang University
China

Roger Jianxin Jiao
Associate Professor
The George W. Woodruff School of Mechanical
Engineering
Georgia Institute of Technology
Atlanta, Georgia

J. Bern Jordan
Co-PI, Trace Center
Assistant Research Scientist,
College of Information Studies
University of Maryland
Baltimore, Maryland

Waldemar Karwowski
Pegasus Professor and Department Chair
Department of Industrial Engineering
and Management Systems
University of Central Florida
Orlando, Florida

Danuta Koradecka
Professor and Director
Central Institute for Labour Protection – National
Research Institute
Warsaw, Poland

Emil Kozłowski
Research Associate
Department of Vibroacoustic Hazards
Central Institute for Labour Protection - National
Research Institute
Warsaw, Poland

Steven J. Landry
Professor and Peter and Angela Dal Pezzo Chair and
Department Head
The Harold & Inge Marcus Department of Industrial and
Manufacturing Engineering
The Pennsylvania State University
Pennsylvania

Terry Lansdown
Associate Professor
Psychology
School of Social Sciences
Heriot-Watt University
Edinburgh, UK

Kenneth R. Laughery, Sr.
Professor Emeritus
Psychology Department
Rice University
Houston, Texas

Jonathan Lazar
Associate Director, Trace Center
Professor, College of Information Studies
University of Maryland
Baltimore, Maryland

Mark R. Lehto
Professor
School of Industrial Engineering
Purdue University
West Lafayette, Indiana

James R. Lewis
Distinguished User Experience Researcher
MeasuringU
Denver, Colorado

Zhizhong Li
Professor
Department of Industrial Engineering
Tsinghua University
Beijing, China

Peng Liu
Associate Professor
Zhejiang University
Hangzhou, China

Yili Liu
Arthur F. Thurnau Professor
Department of Industrial and Operations
Engineering
University of Michigan
Ann Arbor, Michigan

Luca Longo
Assistant Professor
School of Computer Science
College of Sciences & Health
Technological University Dublin
Ireland

Liang Ma
Associate Professor
Department of Industrial Engineering
Tsinghua University
Beijing, China

Katarzyna Majchrzycka
Associate Professor and Department Head
Department of Personal Protective
Equipment
Central Institute for Labour Protection – National
Research Institute
Warsaw, Poland

Krzysztof Makowski
Department of Personal Protective
Equipment
Central Institute for Labour Protection – National
Research Institute
Warsaw, Poland

Neil J. Mansfield
Professor of Human Factors Engineering
Head of Department of Engineering
Nottingham Trent University
Nottingham, UK

George Margetis
Postdoctoral Researcher, HCI Lab
Institute of Computer Science – FORTH
Heraklion, Crete, Greece

Panos Markopoulos
 Professor of Design for Behaviour Change
 Vice-Dean
 Department of Industrial Design
 Eindhoven University of Technology
 Eindhoven, the Netherlands

Nicolas Marmaras
 Professor of Ergonomics and Dean of the
 School
 School of Mechanical Engineering
 National Technical University of Athens
 Athens, Greece

William S. Marras
 Honda Chair Professor and Director
 College of Engineering
 Spine Research Institute
 Department of Integrated Systems Engineering
 The Ohio State University
 Columbus, Ohio

Anna Marszałek
 Assistant Professor
 Department of Ergonomics
 Central Institute for Labour Protection - National
 Research Institute
 Warsaw, Poland

Christopher B. Mayhorn
 Professor and Head
 Psychology Department
 North Carolina State University
 Raleigh, North Carolina

Dennis K. McBride
 Chief Strategy Officer
 Source America

Kerri McClymont
 Doctoral Student in Civil Engineering
 Institute for Infrastructure and Environment
 School of Energy, Geoscience, Infrastructure and Society
 Heriot-Watt University
 Edinburgh, UK

Nicolas Meirhaeghe
 Doctoral Candidate
 Harvard-MIT Division of Health Sciences and
 Technology

Bioastronautics Training Program
 Massachusetts Institute of Technology
 Cambridge, Massachusetts

Dave B. Miller
 Postdoctoral Associate
 Department of Industrial Engineering and Management
 Systems
 University of Central Florida
 Orlando, Florida

Magdalena Młynarczyk
 Assistant Professor
 Head of the Laboratory of Thermal Load
 Department of Ergonomics
 Central Institute for Labour Protection - National
 Research Institute
 Warsaw, Poland

Rafał Młyński
 Assistant Professor
 Department of Vibroacoustic Hazards
 Central Institute for Labour Protection - National
 Research Institute
 Warsaw, Poland

Abbas Moallem
 Adjunct Professor
 Department of Industrial Engineering and Dept. of
 Applied Data Science
 San Jose State University
 San Jose, California

Frederick P. Morgeson
 Eli Broad Professor of Management
 The Broad College of Business
 Michigan State University
 East Lansing, Michigan

Gaurav Nanda
 Assistant Professor of Practice
 School of Engineering Technology
 Purdue University
 West Lafayette, Indiana

Dimitris Nathanael
 Assistant Professor
 School of Mechanical Engineering
 National Technical University of Athens
 Athens, Greece

Dava J. Newman
Apollo Program Professor of Astronautics
Harvard-MIT Health, Sciences and
Technology
MacVicar Faculty Fellow
Department of Aeronautic and Astronautics
Massachusetts Institute of Technology
Cambridge, Massachusetts

Jianwei Niu
Associate Professor
Department of Logistics Engineering, School of
Mechanical Engineering
University of Science and Technology Beijing
Beijing, China

Stavroula Ntoa
Postdoctoral Researcher, HCI Lab
Institute of Computer Science – FORTH
Heraklion, Crete, Greece

Hannah Nye
Senior User Experience Designer
Extended Reality Design Lead
Design Interactive, Inc.

Grzegorz Owczarek
Assistant Professor and Head of the
Laboratory
Department of Personal Protective
Equipment
Central Institute for Labour Protection - National
Research Institute
Warsaw, Poland

Christina K. Padron
Director of DOD Programs
Dynepic, Inc.

Kareem Panton
Graduate Student
Department of Psychology
Hofstra University
New York

Sumanta N. Pattanaik
Associate Professor
Department of Computer Science
University of Central Florida
Orlando, Florida

Gunther E. Paul
Associate Professor
Principal Research Fellow OHS
Australian Institute of Tropical Health
and Medicine
James Cook University
North Queensland, Australia

Matthias Peissner
Head of Research Area Human-Technology
Interaction
Fraunhofer Institute for Industrial
Engineering IAO
Stuttgart, Germany

Tom Plocher
Principal Investigator
Moai Technologies, LLC

Kathrin Pollmann
User Experience Researcher
Fraunhofer Institute for Industrial
Engineering IAO
Stuttgart, Germany

Janet D. Proctor
Senior Academic Advisor
Psychological Sciences
College of Health and Human Sciences
Purdue University
West Lafayette, Indiana

Robert W. Proctor
Distinguished Professor
Department of Psychological Sciences
Purdue University
West Lafayette, Indiana

Pei-Luen Patrick Rau
Professor, Department of Industrial Engineering
Vice Dean, Tsinghua Global Innovation
Exchange (GIX) Institute
Tsinghua University
Beijing, China

Sonalee Rau
Department of Health Policy & Management
Mailman School of Public Health
Columbia University
New York

Janet C. Read
 Professor of Child Computer Interaction
 School of Psychology and Computer Science
 University of Central Lancashire
 Preston, UK

David Rodrick
 Health Scientist Administrator
 Center for Quality Improvement
 and Patient Safety
 Agency for Healthcare Research
 and Quality

William B. Rouse
 Research Professor
 McCourt School of Public Policy
 Georgetown University
 Washington, DC

Eduardo Salas
 Allyn R. & Gladys M. Cline Professor of Psychology
 and Department Chair
 Department of Psychological Sciences
 Rice University
 Houston, Texas

Megan E. Salwei
 Postdoctoral Research Fellow
 Department of Biomedical Informatics
 Center for Research and Innovation in Systems
 Safety
 Vanderbilt University Medical Center
 Nashville, Tennessee

Jeff Sauro
 Founding Principal
 MeasuringU
 Denver, Colorado

Ben D. Sawyer
 Assistant Professor
 Department of Industrial Engineering
 and Management Systems
 University of Central Florida
 Orlando, Florida

Bohdana Sherehiy
 Senior Consultant
 EurekaFacts
 Washington, DC

Thomas B. Sheridan
 Ford Professor of Engineering and Applied Psychology
 Emeritus
 Department of Mechanical Engineering
 Professor of Aeronautics and Astronautics Emeritus
 Massachusetts Institute of Technology
 Cambridge, Massachusetts

Dieter Spath
 Professor
 Institute for Human Factors and Technology
 Management (IAT)
 University of Stuttgart
 Head of Fraunhofer Institute for Industrial Engineering
 (IAO)
 President of Acatech – German National Academy of
 Science and Engineering
 Stuttgart, Germany

Kay M. Stanney
 CEO & Founder
 Design Interactive, Inc.
 Oviedo, Florida

Jeanne Mager Stellman
 Professor Emerita and Special Lecturer
 Department of Health Policy & Management
 Mailman School of Public Health
 Columbia University
 New York

Constantine Stephanidis
 Professor of HCI
 Department of Computer Science
 University of Crete
 Head of HCI Lab and Ambient Intelligence
 Program
 Institute of Computer Science – FORTH
 Heraklion, Crete, Greece

Redha Taiar
 Professor
 Department of Sport Sciences
 Université de Reims Champagne Ardenne
 Reims, France

Pratik Thaker
 Corporate Director
 Environmental Health & Safety
 New York-Presbyterian Hospital
 New York

Andrew Thatcher
Chair of Industrial/Organisational
Psychology
Department of Psychology
University of the Witwatersrand
Johannesburg, South Africa

Gregg Vanderheiden
Founder and Director, Trace Center
Professor, College of Information Studies
University of Maryland
Baltimore, Maryland

Annie Visser-Quinn
Research Associate
Institute for Infrastructure & Environment
School of Energy, Geoscience, Infrastructure
and Society
Heriot-Watt University
Edinburgh, UK

Kim-Phuong L. Vu
Professor
Department of Psychology
California State University Long Beach
Long Beach, California

Guy Walker
Professor of Human Factors and EGIS Leader of
Pioneering Education
School of Energy, Geoscience, Infrastructure
and Society
Heriot-Watt University
Edinburgh, UK

June Wei
Professor
Department of Management and MIS
College of Business
University of West Florida
Pensacola, Florida

Christopher D. Wickens
Adjunct Professor of Psychology
Colorado State University
Professor Emeritus of Aviation and
of Psychology
University of Illinois at Champaign Urbana
Institute of Aviation and Department
of Psychology
Urbana, Illinois

R. Paul Wiegand
Assistant Professor
Computer Science & Quantitative Methods
Winthrop University
Rock Hill, South Carolina

Michael S. Wogalter
Professor Emeritus
Psychology Department
North Carolina State University
Raleigh, North Carolina

Changxu Wu
Professor
Department of Industrial Engineering
Tsinghua University
Beijing, China

Kathryn Wust
Doctoral Student and Research Assistant
Department of Industrial & Systems Engineering
Wisconsin Institute for Healthcare
Systems Engineering
University of Wisconsin-Madison
Madison, Wisconsin

Zijian Yin
Doctoral Student
Department of Industrial Engineering
Tsinghua University
Beijing, China

Mark S. Young
Visiting Professor
Loughborough Design School
Loughborough University
Loughborough, UK

Jan Żera
Professor and Head of the Electroacoustics
Division
Institute of Radioelectronics and Multimedia
Technology
Faculty of Electronics and Information Technology
Warsaw University of Technology
Warsaw, Poland

Joanna Zhang
Associate Systems Engineer
Northrop Grumman

Renyou Zhang
Postdoctoral Research Associate
Department of Industrial Engineering
Tsinghua University
Beijing, China
Assistant Professor
Department of Safety Engineering
Beijing Institute of Petrochemical Technology

Wei Zhang
Professor
Department of Industrial Engineering
Tsinghua University
Beijing, China

Feng Zhou
Assistant Professor
Dept. of Industrial and Manufacturing Systems
Engineering
University of Michigan-Dearborn
Dearborn, Michigan

Jia Zhou
Associate Professor
School of Management Science and
Real Estate
Chongqing University
China

H. Larissa Zhou
Doctoral Student in Materials Science/Mechanical
Engineering
NASA Space Technology Research Fellow
Harvard University, School of Engineering and Applied
Sciences
Cambridge, Massachusetts

Klaus J. Zink
Senior Research Professor and Scientific
Director
Institute for Technology and Work
University of Kaiserslautern
Kaiserslautern, Germany

FOREWORD

Review of the fourth edition and comment on the fifth edition by Donald A. Norman, Director and Co-Founder, University of California, San Diego Design Lab.

This review was written by me for my Website (www.jnd.org): hence the informal writing style. Although it is not in the format I would have provided had I done a normal foreword for this Handbook. I have given permission to reprint it here. I could write it more substantively, with more words and deeper analysis, but the message would stay the same: This is an essential book for professionals and students alike. Maybe the message is even stronger in this shorter, less formal format.

I'm often asked for reading suggestions, especially for references to the literature on Human Factors and Ergonomics. In the past few months, I have been reading chapters of one book that has it all: Gavriel Salvendy's massive tome, the *Handbook of Human Factors and Ergonomics*. It is huge, with over 1,500 pages and 61 chapters. It takes 2 pages just to list the advisors, 10 pages to list the authors of the chapters. It is also expensive: \$250.

Buy it. The articles are all excellent. They all reflect up-to-date reviews of the areas they cover. They are wonderful self-study material, wonderful references, and would make excellent material in multiple courses. Yes, it is obscenely expensive, but this one book is the equivalent of 10 normal books. Consider it as essential piece of professional equipment. Buy it. Use it.

If you don't know human factors, this is a great way to find the parts relevant to your work. And even if you are an expert, this book will be valuable because it is unlikely that you are expert at all the topics covered here, yet very likely you will need some of the ones you are not (yet) expert at. I follow my own advice. I consider myself an expert (I am a Fellow of the Human Factors Society), but I still learn each time I read from these pages. So, yes, grit your teeth and buy the book.

The 5th edition has new – and very important – chapters written by the authorities in each topic. It has kept up with the times and become even more valuable as both a text and a reference.

Review of the fifth edition by Thomas B. Sheridan, Ford Professor Emeritus of Engineering and Applied Psychology, Massachusetts Institute of Technology

The fifth edition of the Handbook of Human Factors and Ergonomics is the most authoritative and comprehensive reference work in the field.

From the Foreword to the second edition by John F. Smith, Jr., Chairman of the Board, Chief Executive Officer and President, General Motors Corporation

The publication of this second *Handbook of Human Factors and Ergonomics* is very timely. It is a comprehensive guide that contains practical knowledge and technical background on virtually all aspects of physical, cognitive, and social ergonomics. As such, it can be a valuable source of information for any individual or organization committed to providing competitive, high-quality products and safe, productive work environments.

From the Foreword to the first edition by E. M. Estes, Retired President, General Motors Corporation

Regardless of what phase of the economy a person is involved in, this handbook is a very useful tool. Every area of human factors from environmental conditions and motivation to the use of new communications systems, robotics, and business systems is well covered in the handbook by experts in every field.

PREFACE

The *Handbook of Human Factors and Ergonomics* (HFE) provides scientifically-based practical information applied to the design of systems, including hardware, software, facilities, and environments for effective human use, safety, and comfort, which results in high quality and productive work performance, and products and services which customers like. The Handbook's first four editions have received strong endorsements from captains of industry and leading scientists worldwide. Some of the previous editions have also been published in Japanese and Russian and won the Institute of Industrial Engineers' Joint Publishers Book of the Year Award.

The HFE discipline is well recognized worldwide, with over 50 scientific societies working under the umbrella of the International Ergonomics Association. HFE professionals play a critical role in the design and operation of products, processes, and systems to benefit humankind. When HFE is effectively implemented, it can improve the quality, productivity, safety, and well-being of people worldwide.

The 57 chapters were authored by 142 experts from four continents. In creating this Handbook, the authors gathered information from 10,193 references and presented 619 figures and 269 tables to provide theoretically based and practically oriented HFE knowledge for practitioners, educators, and researchers.

The chapters have been completely revised and updated, and 17 new chapters have been included to account for the rapidly expanding theory, methods, and applications of the HFE discipline. These new chapters discuss the following subjects:

- Human Systems Integration and Design
- Emotional Design
- Three-Dimensional (3D) Anthropometry and Its Applications in Product Design
- Manual Materials Handling: Evaluation and Practical Considerations
- Modeling and Simulation of Human Systems
- Neuroergonomics
- Representation Design
- Mobile Systems Design and Evaluation
- Human-Centered Design of Artificial Intelligence
- Cybersecurity, Privacy, and Trust
- Human–Robot Interaction
- Human Factors in Social Media
- Design of Digital Technology for Children
- Data Analytics in Human Factors
- Human Factors and Ergonomics in Design of A³: Automation, Autonomy, and Artificial Intelligence
- Human Side of Space Exploration and Habitation
- Human Factors and Ergonomics for Sustainability.

The main aim of this Handbook is to serve the needs of the human factors and ergonomics researchers, practitioners, educators, and others who need to apply HFE knowledge to the effective design and operation of products, services and systems utilized for the benefit of mankind. The many contributing authors came through magnificently. We thank them all most sincerely for agreeing so willingly to create this Handbook with us.

GAVRIEL SALVENDY AND WALDEMAR KARWOWSKI

October 2020

- USOS. *See* United States Orbital Segment
 US Rehabilitation Act, 1192
 UTAUT. *See* Unified Theory of
 Acceptance and Use of Technology
 Utility function
 assessment, 183
 determination, 885, 886, 889–890
 elicitation, variable probability method
 (usage), 183f
 example, 889f
 parameters, assessment, 885, 886
 UX. *See* User experience
 UXAmI Observer, 1066
- V**
 Validity, defining/types, 860–861
 Value
 function, 524f
 functional value, 952, 953–955
 global allocation, inequality, 1521
 trees, 182, 182f
 visual attention factor, 117
 Values
 data values, 130
 overestimation, 121
 Value Sensitive Design (VSD), 1401
 Value Survey Module (VSM), usage, 253
 VAMR. *See* Virtual, augmented, and
 mixed reality
 Variable probability method, usage, 183f
 Variables inspection, 856
 Variable specifications, principles, 698
 Variance analysis, usage, 408
 Vascular disorders, hand-arm vibration
 (impact), 507–508
 VDTs. *See* Visual display terminals
 VDV. *See* Vibration dose value
 Vector field visualization, 931
 Velocity dynamics (first-order system),
 response, 144
 Verbal language, interpreter/translator
 usage, 261
 Vergence angle (eyes), 65
 Verne, Jules, 718
 Vertebrae tolerance, 311–312
 Vertebrate retina, neural
 structures/interconnections, 66f
 Vertical factor (VF), variation, 327f
 Vertical zone, graphic representation, 613f
 VESARS. *See* Virtual Environment
 Situation Awareness Review System
 Vestibular eye movements, 76
 Vestibular system, 75–76
 Vestibulo-ocular reflex, 499
 VF. *See* Vertical factor
 VHCD. *See* Virtual HCD
 Vibrating observer, vision interference,
 499
 Vibration, 494. *See also* Hand-arm
 vibration; Whole-body vibration
 anti-vibration gloves, usage
 (requirement), 509
 axes, usage, 496f
 defining, 460
 DHM CASIMIR vibration model, 726f
 direction, 495–496
 duration, 496
 effect, model, 501f
 EU Physical Agents Directive, 502,
 504, 511
 evaluation, 502
 frequency, 495
 human body responses, biomechanical
 models, 504–505
 human exposures, instrumentation, 496
 injuries, tools/processes (association),
 508t
 magnitude, 495
 measurement, 495–496
 perception, age-related changes, 1256
 severity, evaluation (International
 Standard 2631-1), 502
 sinusoidal vibration, displace-
 ment/velocity/acceleration
 waveforms, 495f
 syndrome, 507
 variables, effects, 501
 Vibration dose value (VDV), 502, 504t
 Vibration-induced white finger (VWF),
 507–508, 508t
 Vibrotaction, 77
 Video-based biomechanical models, 611
 Videogames, multitasking (relationship),
 106
 Vigilance, 527
 Violin plot, 918–919, 920f
 Virtual assistants, 1126f
 Virtual, augmented, and mixed reality
 (VAMR), 1122, 1124, 1124f, 1130
 Virtual environment, 123
 haptic glove/gesture control, usage,
 1131f
 Virtual Environment Situation Awareness
 Review System (VESARS),
 444–445
 Virtual HCD (VHCD), 42, 50–51
 Virtual interfaces, 1131
 Virtuality continuum, 783f, 789f
 Virtual Physiological Human (VPH)
 initiative, 715
 Virtual prototyping
 capabilities/limitations, 769f
 Virtual Reality (VR), 751, 783, 1443
 benefit, 790–791
 design principles, 791
 systems, 785–786, 786f
 technology, 785–786
 VR-based simulation training,
 effectiveness, 1135
 Virtual reality/augmented reality
 (VR/AR), combination, 1065
 Virtual Solder (Research) project, 767,
 769, 772
 Vision, 64–72
 activities, interference, 498–500
 color vision/specification, 70–72
 color vision, universality, 265
 decline, 1254–1255
 enhanced flight vision systems
 (EFVSSs), usage, 1475
 scotopic vision, 65
 synthetic vision systems (SVSSs), usage,
 1475
 trichromatic vision, 70
 Visual accommodation, age-related
 changes, 1255
 Visual acuity, 69–70
 Visual analytics, 188, 1092–1093
 Visual attention, factors, 116–117
 Visual displays, 1130, 1312
 Visual display terminals (VDTs), 1312,
 1338
 Visual feedback, 102–103
 Visual impairments, 1226
 Visual intelligence, impact, 1444
 Visualization. *See* Data visualization
 ball-stick visualizations, 933f
 geovisualization, 925–926
 medical visualization, 940
 medical volume visualization, software
 (usage), 942t
 molecule visualization, 932, 933f,
 942t
 network visualization, 931–932
 non-traditional disciplines,
 visualization, 943–944
 persuasiveness, increase, 130
 scientific visualization, 940, 941t
 software, usage, 942t
 spatial visualization/orientation factors,
 1134
 three-dimensional (3D) visualization,
 940–941
 uncertainty visualization, 932–933
 usage, 898
 vector field visualization, 931
 volume visualization, 9029
 wind velocity field, 931f, 932f
 Visual media, narrative/storytelling
 (usage), 898
 Visual metaphors, finding, 903
 Visual output, 1231–1232
 Visual pathways, 67–68
 Visual perception, 68–72, 80–81
 Visual predictive analytics, 1092–1094
 Visual processes, 901
 Visual representation, 953–957
 Visual scanning, avoidance, 133
 Visual search
 models, 119
 usage, 855
 Visual selective attention, 116–117

- Visual system, 64–68, 68f
enhancement, 1475
- V-Model, 706
- Voice
gesture, interaction, 265–266
interaction, 266
technology system, 1264–1265
- Volatility, uncertainty, complexity, ambiguity (VUCA), 1445, 1445t, 1449
- Volume visualization, 929
direct volume rendering, 930–931, 931f
isosurface rendering, 929, 930f
slice view, 929, 930f
- Voluntary task switching, 147–148
- von Helmholtz, Hermann, 75
- VPH. *See* Virtual Physiological Human
- VR. *See* Virtual Reality
- VSD. *See* Value Sensitive Design
- VSM. *See* Value Survey Module
- VUCA. *See* Volatility, uncertainty, complexity, ambiguity
- VWF. *See* Vibration-induced white finger
- W**
- W3C Web Application Security Working Group, 1027–1028
- W3C Web Security Context Working Group, user interface guidelines, 1027–1028
- WAFOS. *See* Workload, anxiety, fatigue, and other stressors
- WAI. *See* Web Accessibility Initiative
- Warnings, 644, 645–646
application, design, 658–661
auditory warnings, 651, 655–656
background, 645
beliefs/attitudes, 656
briefness/completeness, 658–659
color, usage, 650
compliance, cost, 656–657
components, checklist, 658
criteria, 645
design, 652, 658, 659t, 660
dynamic warnings, 661
environmental stimuli, 651
explicitness, 654
exposure, habituation, 655
external/environmental factors, 657
flat-screen displays, usage, 661
formatting, 651
individual tailoring, 662
message content, 653
pictorial symbols, usage, 650, 652
placement, 651
positioning, prioritization, 659–660
presentation, 661–662
principles, 658–661
print, legibility, 651
purpose, 645
receiver knowledge, 660
reminders, role, 655
signal word panels, examples, 652f
systems, 649
testing, 660–661
timing/content, 645–646
Waypoint operation, 1125
- WCAG. *See* Web Content Accessibility Guidelines
- WCED. *See* World Commission on Economic Development
- WDQ. *See* Work Design Questionnaire
- Weak AI, intention, 1442
- Wearable Coach™, cost/benefit analysis, 887, 888t
- Wearable computing, development, 284
- Wearable devices, 1051, 1069
- Wearable robotics, usage, 619–621
- Web Accessibility Initiative (WAI), 1246
- Web Accessibility in Mind (WebAIM), 1246
- Web Content Accessibility Guidelines (WCAG), 1027, 1031, 1191–1192, 1225
- Web design, 266–268, 268t
- WebGL powered libraries, usage, 942t
- Website
accessibility, 1026, 1030–1031
animation, 1025
automated accessibility checker, example, 1031f
back button/history, usage, 1022
browsers, usage, 1024
browsing, 1022–1023
characteristics, comparison, 267
cognitive walkthrough, 1029–1030
components, 1018
content, 1018–1022, 1027
cross-cultural designs, 1026
design, 1029, 1029t
design/evaluation, 1016, 1019
disability accessibility, 1026–1027
elements (accessibility check), manual/automated tools (usage), 1032t
error messages, 1024, 1024f
global site design, 1023–1024
goals, 1016–1017
heuristic evaluation, 1029
home page, 1025
human trust, 1109–1110
index, 1022
information, 1018–1025
labels/tags, usage, 1020–1021
landing page, 1025
linear information structures, usage, 1021
links, importance, 1025
navigation, 1021–1022
older adult usage, 1026
organizational schemes, 1020
organizational structure, 1021
orphan pages, avoidance, 1022
outlines, 1022
page, design/layout, 1025
pop-up windows, 1024
pull-down menus, usage, 1022
representative tasks, sample, 1030
representative users, sample (data coding/analysis), 1030
scrolling/paging, 1024
search, 1023
searching, 1022–1023
secondary windows, 1024
simple search, advanced search (contrast), 1022
site maps, 1021
static links, list, 1022
table of contents layout, 1022
text, graphics/images (contrast), 1025
universal access, design, 1026
usability, 1028–1032
user agents, 1024
web server log files, usage, 1019
- Website users
diary, usage, 1019
ethnographic studies, 1019
interactions, interviews/surveys/questionnaires (usage), 1018–1019
naturalistic observation, 1019
- Weighted additive (WADD)
relative accuracy/effort, trade-off, 175
strategy, requirements, 193
- Weighted aggregation (MWL aggregation strategy), 216
- Welding shield, augmented system module (inclusion), 671f
- Well-being
clinician well-being, HFE systems approach, 1430–1431
mental well-being, age-related changes, 1261
quality of life, relationship, 1069–1070
social media, impacts, 1166–1168
- Western reasoning styles, 256t
- Westin, Alan, 1110
- “What if?” scenarios/analyses, 883, 887
- What You See Is What You Get (WYSIWYG), 948, 1196, 1199
- Where’s Waldo* (Handford), 901
- Whiting, S.E., 845
- Whole-body vibration, 496–505
acceleration frequency weightings, 497f
activities interference, 498–502
discomfort, 496, 498t
duration, effects, 498
earth-moving machine whole-body vibration z-axis acceleration, 503f
evaluation, frequency weightings (application), 498t

- exposure measurement, vibration axes (usage), 496f
- frequency/direction, effects, 497–498
- frequency weighting curves, application guide, 497f
- magnitude, effects, 496
- occurrence, 494
- protection, 505
- seating dynamics, 505
- “Why It Happened” (example), 529t
- Widgets, adaptation, 1197t–1199t, 1206f
- Wiener, Norbert, 1387
- Window, icon, menu, pointing device (WIMP), 263, 786
- Wind shear, problem, 1462
- Wind velocity field, visualization, 931f, 932f
- Winograd, Terry, 40
- WIP. *See* Work in progress
- Wireless bidirectional link, usage, 1239f
- Wireless networks, development (increase), 1049
- Wireless Sensor Networks (WSN), 1115
- WISE. *See* Workplace improvement in small enterprises
- Wizard of Oz (WoZ), 991, 1124
- Word cloud, sample, 920f
- Word spacing (WS), 1267
- Work
 - analysis, 953–957
 - artifacts, spatial arrangement, 372
 - changes, 359
 - comfort, maintenance, 676
 - days absent, 575t
 - gainful works, effects, 1456
 - individual designs, team designs (contrast), 399
 - individualized design, 401–402
 - intensity exposure, LBP risk (relationship), 600f
 - knowledge work, 1457
 - low-back disorder (LBD), assessment methods/identification, 609–613
 - low back pain (LBP) problem, magnitude, 598–599
 - physical aspects, 765–766
 - psychosocial work stressors, effect (pooled odds ratios), 315t
 - relationships, problems (job stressor category), 230
 - risk factors, epidemiology, 599–600
 - semi-skilled work, 1456–1457
 - specialist work, 1457
 - standing work, bench heights (recommendation), 320f
 - surface height, sitting posture (relationship), 371
 - sustainable work systems, 1513–1514
 - system design/implementation, HFE principles, 1426–1429
 - tasks, requirements, 1449
 - work-positioning system, 682f
 - work-related musculoskeletal disorders, 313f, 346–348
 - work-related stress, reduction, 586
- Work activities
 - digitization, impact, 1450–1451
 - simplification, 1450
 - spine evaluation, 606f
- Work design, 229, 317–318, 1439
 - cooperation/communication, 1454
 - differential work design, 1453–1454
 - heterarchic organizational concepts, 1456
 - human-centered work design, concepts/strategies, 1450–1457
 - learning/competence development, 1454–1455
 - measures, 1454–1456
 - organizational forms, development, 1455–1456
 - paradigm shift, 1449
- Work Design Questionnaire (WDQ), 384, 388t–390t
- Work domain
 - agency constraints, 953
 - agent constraints, 956–957
 - analysis, 951–952
 - functional value, 952
 - hard constraints, 955–956
 - process constraints, 952, 956
 - surface constraints, 953, 957
- Workers
 - agricultural workers, spine (sustained flexion), 636f
 - compensation systems, 575–576
 - container handling, 631f
 - custom-made handles, usage, 641f
 - differences, 397–399
 - lumbar flexion, direct measurement/EMG, 637f
 - needs/values, change (creation), 399
 - sustained bent posture, 630f
- Working conditions, differentiation, 1445
- Working memory, 131–132
 - age-related changes, 1259
 - capacity, considerations, 133, 1134–1135
 - chunk capacity, excess (avoidance), 132
 - constraints, design implications, 132–133
 - dynamic working memory, 133–134
 - impact, 438
 - learning/training, relationship, 132
 - model, 522f
- Working persons, 369, 369f
- Working postures, 369–372, 374t
- Work in progress (WIP) buffer, 957, 973
- Workload. *See* Cognitive workload; Mental workload
 - assessment, 204–206, 220
 - compound measurement approaches, 214
 - evaluation, application realms, 220
 - history, 204
 - management, 1427
 - matrix, measures (representation), 220f
 - multimodal workload, balancing, 1394–1395
 - profiles, 1357–1358
 - role, 220
 - subjective workload curve, 208f
 - theoretical foundation, 204–206
 - vibration effect, model, 501f
- Workload, anxiety, fatigue, and other stressors (WAFOS), 441
- Workload Profile, 243
- Workplace
 - assessment, 612–613
 - characteristics, 669
 - design, 601, 618–619
 - driving workplace, 374f
 - dynamic moment exposure, 612
 - dynamic motion assessment, 334–335
 - interdependencies, 368f
 - lighting, ISO standards, 1323
 - low-back disorder (LBD) risk, management, 597
 - low back pain (LBP), impact, 598t
 - protective gloves, usage, 678–679
 - respiratory protective devices, selection, 668–669
 - safety inspection, process, 854–855
 - stress reduction, biomechanical principles (application), 313–326
 - survey, 864t, 872t–873t
 - TWA, 471
- Workplace design, 303, 368
- Workplace health, 229
 - factors, WHO categories, 229
- Workplace improvement in small enterprises (WISE), 866
- Work Process Analysis Model (WPAM), 562
- Work protection factor (WPF), 669
- Workspace design (older adults), 1270–1271
- Workstations
 - computer monitors, placement, 380f
 - constraints/requirements, identification, 373
 - design, 372–375
 - ergonomic design, process, 372f
 - human factors engineering, 1338–1339
 - improvements/final design, 375
 - layout, 375–380
 - modules, 378–380, 378f, 380f
 - orientations, alternatives, 380f
 - prototype, 374–375

- Workstations (*continued*)
 resources/high-level requirements, decisions, 373
 simulation, server-based simulation (contrast), 717
 standing-sitting workstation, 369–370, 370f
 user needs, identification, 373
- Work systems
 constraints/requirements, identification, 373
 design, 228–230
 social/psychosocial aspects, 229
 structural changes, 1445–1446
- Work teams
 advantages/disadvantages, 396t
 effectiveness, organizational context (creation), 405
 job design, relationship, 396t
- World Alliance for Patient Safety (WHO launch), 1421
- World Commission on Economic Development (WCED), 1512–1513
- World Health Organization (WHO), IEA cooperation, 27
- World Patient Safety Day, WHO establishment, 1421
- World Wide Web Consortium (WWWC), Web Accessibility Initiative, 1225
- WPAM. *See* Work Process Analysis Model
- WPF. *See* Work protection factor
- Wright brothers, impact, 1460
- Wrists
 anatomical structures, 322f
 anatomy/loading, 322
 gloves, usage, 323–324
 grip design, 323
 OCRA assessment scores, 342
 position, grip strength, 323f
 postural classification scheme, 338t
 trauma, 322
- WSN. *See* Wireless Sensor Networks
- Wundt illusion, 121
- X**
 XAI. *See* Explainable AI
 XR. *See* Extended reality
 XYZ tristimulus coordinate system, 71
- Y**
 Yerkes-Dodson law, 237
 Youth (cognitive control/attention), social media (iapct), 1166
- Z**
 Zeiller, Paul, 718, 720
 Zero Harm culture, ensuring, 574, 586
 Zero-order system (position dynamics), response, 144
 Zones of convenient reach (ZCRs), 259