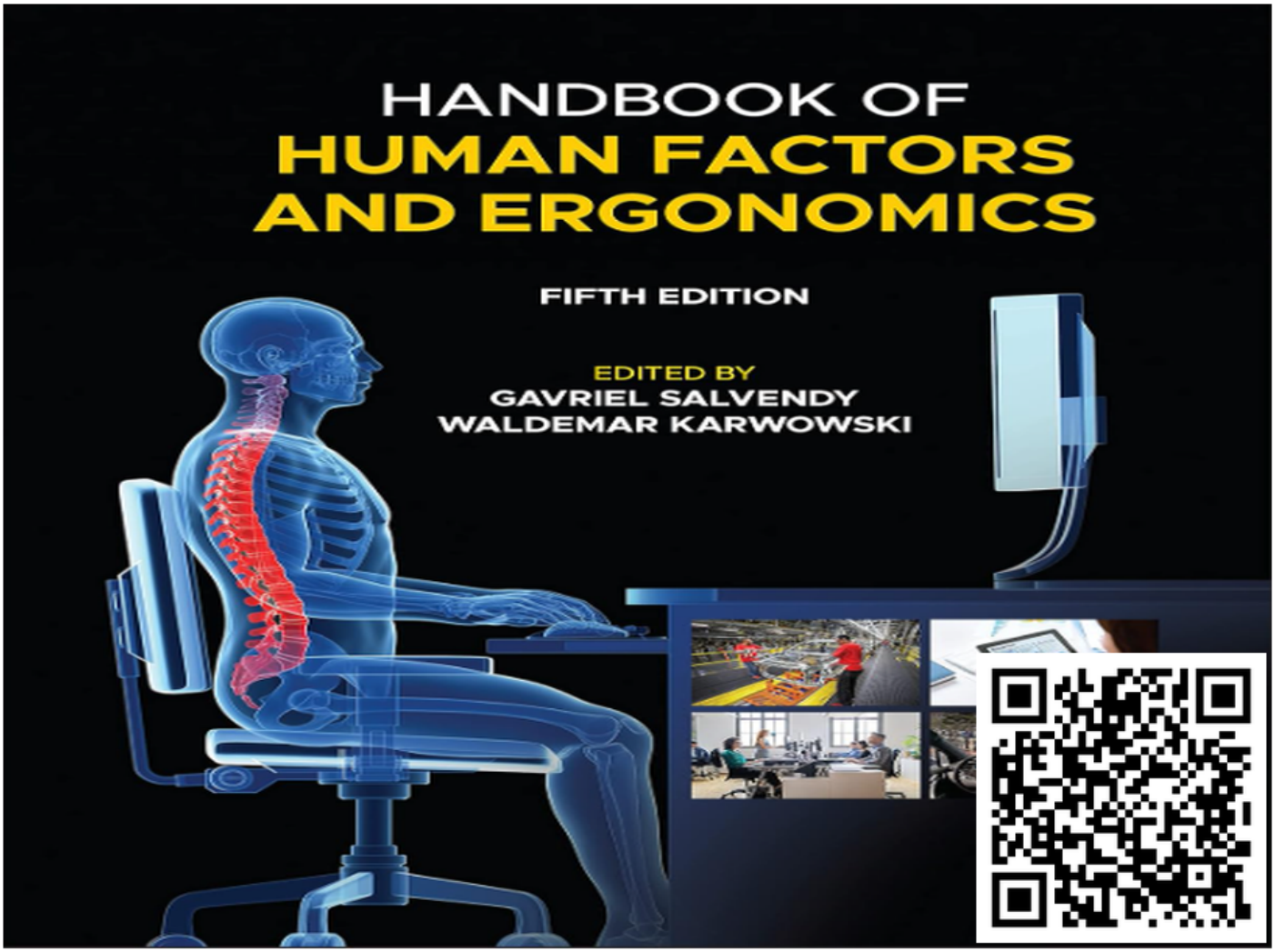

HANDBOOK OF HUMAN FACTORS AND ERGONOMICS

FIFTH EDITION

EDITED BY
GAVRIEL SALVENDY
WALDEMAR KARWOWSKI

WILEY

HANDBOOK OF HUMAN FACTORS AND ERGONOMICS

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Fifth Edition

Edited by
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and
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WILEY

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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.

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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 A^3: 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

PART 1

HUMAN FACTORS FUNCTION

CHAPTER 1

THE DISCIPLINE OF HUMAN FACTORS AND ERGONOMICS

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The purpose of science is mastery over nature.

F. Bacon *(Novum Organum*, 1620)

1 INTRODUCTION

Over the last 70 years, human factors, a term that is used here synonymously with ergonomics and denoted as human factors ergonomics (HFE), has been evolving as a unique and independent discipline that originated with a focus on the nature of human–artifact interactions. Such interactions are viewed from the unified perspective of the science, engineering, design, technology, and management of human-compatible systems, including a variety of natural and artificial products, processes, and living environments (Karwowski, 2005). The various dimensions of such defined ergonomics discipline are shown in Figure 1. The International Ergonomics Association (IEA, 2003) defines ergonomics (or human factors) as *the scientific discipline concerned with the understanding of the interactions among humans and other elements of a system and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance*. Human factors professionals contribute to the design and evaluation of tasks, jobs, products, environments, and systems in order to make them compatible with the needs, abilities, and limitations of people. HFE discipline promotes a holistic, human-centered approach to systems design that considers the physical, cognitive, neural, social, emotional, organizational, developmental, ecological, environmental, and other factors relevant for the socio-economic development and well-being of the global society (Ayaz & Dehais, 2018; Bridger, 2006; Chapanis, 1995, 1999; Drury, 2008; Edholm & Murrell, 1973; Falzon, 2014; Grandjean, 1986; Hancock, 2017; Jaworek, Marek, & Karwowski, 2020; Karwowski, 2001; Kroemer, 2017; Moray, 2000; Parasuraman, 2003; Salvendy, 1997; Sanders & McCormick, 1993; Stanton et al., 2004; Vicente, 2004; Wilson, 2014; Wilson & Corlett, 1995).

Historically, *ergonomics* (*ergon* + *nomos*), or "the study of work," was originally and proposed and defined by the Polish scientist B. W. Jastrzebowski (1857a–d) as the scientific discipline with a very broad scope and wide subject of interests

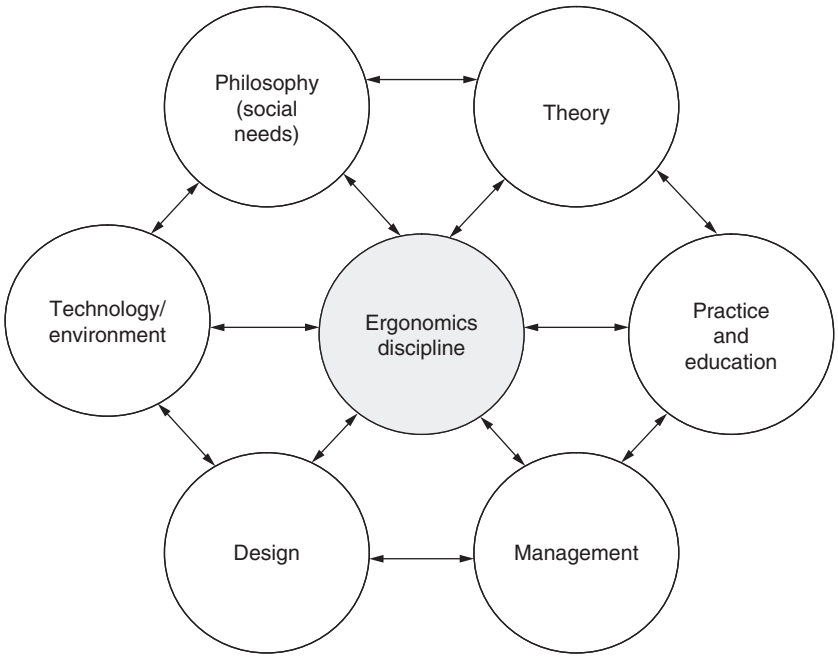

Figure 1 General dimensions of ergonomics discipline. (*Source:* Karwowski, 2005. © 2005 Taylor & Francis.)

and applications, encompassing all aspects of human activity, including labor, entertainment, reasoning, and dedication (Karwowski, 1991, 2001). In his paper published in the journal *Nature and Industry* (1857a–d), Jastrzebowski divided work into two main categories: the *useful work*, which brings improvement for the common good, and the *harmful work* that brings deterioration (discreditable work). Useful work, which aims to improve things and people, is classified into physical, aesthetic, rational, and moral work. According to Jastrzebowski, such work requires utilization of the motor forces, sensory forces, forces of reason (thinking and reasoning), and the spiritual force. The four main benefits of useful work are exemplified through the property, ability, perfection, and felicity.

The contemporary ergonomics discipline, independently introduced by Murrell in 1949 (Edholm & Murrell, 1973), was viewed at that time as an applied science, the technology, and sometimes both. British scientists had founded the Ergonomics Research Society in 1949. The development of ergonomics internationally can be linked to a project initiated by the *European Productivity Agency* (EPA), a branch of the *Organization for European Economic Cooperation*, which first established a Human Factors Section in 1955 (Kuorinka, 2000). Under the EPA project, in 1956, specialists from European countries visited the United States to observe human factors research. In 1957, the EPA organized a technical seminar on "Fitting the Job to the Worker" at the University of Leiden, The Netherlands, during which a set of proposals was presented to form an international association of work scientists. A steering committee consisting of H.S. Belding, G.C.E. Burger, S. Forssman, E. Grandjean, G. Lehman, B. Metz, K.U. Smith, and R.G. Stansfield, was charged to develop a specific proposal for such an association. The committee decided to adopt the name International Ergonomics Association (Koningsveld, 2019). At the meeting in Paris in 1958, it was decided to proceed with forming the new association. The steering committee designated itself the Committee for the International Association of Ergonomic Scientists and elected G.C.E. Burger as its first president, K.U. Smith as treasurer, and E. Grandjean as secretary. The Committee for the International Association of Ergonomic Scientists met in Zurich in 1959 during a conference organized by the EPA and decided to retain the name International Ergonomics Association. On April 6, 1959, at the meeting in Oxford, E. Grandjean declared the founding of the IEA (Koningsveld, 2019). The committee met again in Oxford, later in 1959 and agreed upon the set of bylaws or statutes of the IEA. These were formally approved by the IEA General Assembly at the first International Congress of Ergonomics held in Stockholm in 1961.

Historically, the most often cited domains of specialization within HFE have been the physical, cognitive, social, and organizational ergonomics and the area of human–computer interaction. Physical ergonomics is mainly concerned with human anatomical, anthropometric, physiological, and biomechanical characteristics as they relate to physical activity (Chaffin, Anderson, & Martin, 2006; Karwowski & Marras, 1999; Kroemer et al., 1994; Marras, 2008; National Research Council, 2001; Pheasant, 1986). Cognitive ergonomics focuses on mental processes such as perception, memory, information processing, reasoning, and motor response as they affect interactions among humans and other elements of a system (Diaper & Stanton, 2004; Hollnagel, 2003; Vicente, 1999). Organizational ergonomics (also known as macroergonomics) is concerned with the optimization of sociotechnical systems, including their organizational structures, policies, and processes (Hendrick & Kleiner, 2001, 2002a, 2002b; Holman et al., 2003; Nemeth, 2004; Reason, 1997). Examples of the relevant topics include communication, crew resource management, design of working times, teamwork, participatory work design, community ergonomics, computer-supported cooperative work, new work paradigms, virtual organizations, telework, and quality management. The above traditional domains as well as new domains are listed in Table 1.

According to the above discussion, the paramount objective of HFE is to understand the interactions between people and everything that surrounds us and, based on such knowledge, to optimize the human well-being and overall system performance. Table 2 provides a summary of the specific HFE objectives as originally discussed by Chapanis (1995). According to National Academy of Engineering (2004), in the future, ongoing developments in engineering will *expand toward tighter connections between technology and the human experience, including new products customized to the physical dimensions and capabilities of the user, and ergonomic design of engineered products*.

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