Lecture Notes in Electrical Engineering 318

Shengzhao Long
Balbir S. Dhillon
Editors

Proceedings of the 14th International Conference on Man–Machine–Environment System Engineering

MMESE

Springer

Lecture Notes in Electrical Engineering

Volume 318

About this Series

"Lecture Notes in Electrical Engineering (LNEE)" is a book series which reports the latest research and developments in Electrical Engineering, namely:

- Communication, Networks, and Information Theory
- Computer Engineering
- Signal, Image, Speech and Information Processing
- Circuits and Systems
- Bioengineering

LNEE publishes authored monographs and contributed volumes which present cutting edge research information as well as new perspectives on classical fields, while maintaining Springer's high standards of academic excellence. Also considered for publication are lecture materials, proceedings, and other related materials of exceptionally high quality and interest. The subject matter should be original and timely, reporting the latest research and developments in all areas of electrical engineering.

The audience for the books in LNEE consists of advanced level students, researchers, and industry professionals working at the forefront of their fields. Much like Springer's other Lecture Notes series, LNEE will be distributed through Springer's print and electronic publishing channels.

More information about this series at http://www.springer.com/series/7818

Shengzhao Long · Balbir S. Dhillon
Editors

Proceedings of the 14th International Conference on Man–Machine–Environment System Engineering

Springer

Editors
Shengzhao Long
Astronaut Research and Training
Center of China
Beijing
China

Balbir S. Dhillon
University of Ottawa
Ottawa, ON
Canada

ISSN 1876-1100 ISSN 1876-1119 (electronic)
ISBN 978-3-662-44066-7 ISBN 978-3-662-44067-4 (eBook)
DOI 10.1007/978-3-662-44067-4

Library of Congress Control Number: 2014944335

Springer Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Xuesen Qian' Estimation

Grandness Scientist Xuesen Qian' Sky-high Estimation for the Man–Machine–Environment System Engineering

龙升照同志：

我收到您主编的《人机环境系统工程研究进展（第一卷）》，翻看了之后，感到非常高兴，1985年秋提出的一个想法，现在8年之后已赫然成书，500多页的巨卷！而且研究范围已大大超出原来航天，内容涉及航空、航天、航海、兵器、电子、能源、交通、电力、煤炭、冶金、体育、康复、管理……等领域！你们是在社会主义中国开创了这门重要现代科学技术！

此致

敬礼！

钱学森

1993.10.22

Xuesen Qian' Letter

Grandness Scientist Xuesen Qian' Congratulatory Letter to the 20th Anniversary Commemorative Conference of Man–Machine–Environment System Engineering Foundation

龙升照同志:

你的来信已收到。欣悉人-机-环境系统工程创立 20 周年纪念大会暨第五届全国人-机-环境系统工程学术会议即将召开，我向你们表示最热烈的祝贺!

20 年来，你们在人-机-环境系统工程这一新兴科学领域进行了积极的开拓和探索，并取得了非常可喜的成绩，我感到由衷的高兴。

希望你们今后再接再励，大力推动人-机-环境系统工程理论及应用的蓬勃发展，为中国乃至世界科学技术的进步作出积极贡献!

祝

工作顺利!

钱学森

2001年6月26日

Preface

In 1981, under the directing of the great scientist Xuesen Qian, an integrated frontier science—Man–Machine–Environment System Engineering (MMESE)—came into being in China. Xuesen Qian gave high praise to this emerging science. In the letter to Shengzhao Long, he pointed out, "**You are creating this very important modern science and technology in China**!" in October 22, 1993.

In the congratulation letter to the commemoration meeting of 20th anniversary of establishing the MMESE, the great scientist Xuesen Qian stated, "You have made active development and exploration in this new emerging science of MMESE, and obtained encouraging achievements. I am sincerely pleased and hope you can do even more to make prosper development in the theory and application of MMESE, and **make positive contribution to the progress of science and technology in China, and even in the whole world**" in June 26, 2001.

October 22nd, which is the day that the great scientist Xuesen Qian gave high praise to MMESE, was determined to be Foundation Commemoration Day of MMESE by the second conference of the fifth MMESE Committee on October 22, 2010. On this very special day, the great scientists Xuesen Qian pointed out in the letter to Shengzhao Long, "**You are creating this very important modern science and technology in China**!" And the conference also determined that the annual Conference on MMESE would be held from October 21st to 24th to cherish the memory of the great contributions that the great scientist Xuesen Qian had made to the MMESE!

The 14th International Conference on MMESE will be held in Guilin, China on October 21st–24th of this year; hence, we will dedicate *Proceedings of the 14th International Conference on Man–Machine–Environment System Engineering* to our readers.

Proceedings of the 14th International Conference on Man–Machine–Environment System Engineering is the academic showcases of the 14th International Conference on MMESE joint held by MMESE Committee of China and Beijing KeCui Academe of MMESE in Guilin, China. The conference proceedings is consisted of 52 more excellent papers selected from more than 400 papers. Due to limitations on space, some excellent papers have been left out, we feel deeply sorry for that. Crudeness in contents and possible incorrectness are inevitable due to the somewhat pressing editing time and we hope you kindly point them out promptly, and your valuable comments and suggestions are also welcomed.

Proceedings of the 14th International Conference on Man–Machine–Environment System Engineering will be published by Springer-Verlag, German. Springer-Verlag is also responsible for the related matters on index of Index to EI and CPCI-S (ISTP), so that the world can know the research quality and development trend of MMESE theory and application. Therefore, the publication of *Proceedings of the 14th International Conference on Man–Machine–Environment System Engineering* will greatly promote the vigorous development of MMESE in the world, and realize the grand object of **making positive contribution to the progress of science and technology in China, and even in the whole world** proposed by Xuesen Qian.

We would like to express our sincere thanks to Springer-Verlag, German for their full support and help of during the publishing process.

Beijing, July 2014 Shengzhao Long

Program and Technical Committee Information

General Chairman

Professor Shengzhao Long, Astronuat Research and Training Center of China

Program Committee Chairman

Professor Balbir S. Dhillon, University of Ottawa, Canada

Technical Committee Chairman

Professor Enrong Mao, College of Engineering, China Agricultural University, China

Program and Technical Committee Members

Professor J.G. Kreifeldt, Tufts University, USA
Professor Yanping Chen, University of Management and Technology, USA
Professor Hongfeng Gao, University of California, USA
Professor Xiangshi Ren, Kochi University of Technology, Japan
Professor Kinhuat Low, Nanyang Technological University, Singapore
Senior Engineer Baoguo Luan, CH-AUTO Technology Co. Ltd, China
Professor Baoqing Xia, Weapon Industrial Hygiene Research Institute, China
Professor Chunhui Wang, Astronaut Research and Training Center of China, China

Professor Fang Jie, China North Vehicle Research Institute, China
Senior Engineer Fong Zhou, AVIC Aerospeace Life-support Industries Ltd, China
Professor Guangtao Ma, Shenyang Jianzhu University, China
Professor Guansheng Huang, Beijing Special Vehicle Institute, China
Professor Guohua Jiang, Astronaut Research and Training Center of China
Professor Guohua Shi, Engineering Academy of the Second Artillery, China
Professor Haiming Wu, Weapon Industrial Hygiene Research Institute, China
Professor Hao Li, Astronaut Research and Training Center of China, China
Professor Hongjun Xue, Northwestern Polytechnical University, China
Professor Honglei Zhang, Air Defense Forces Academy, China
Senior Engineer Jiajun Sun, Petrochina Changqing Oilfield Company, China
Professor Junfeng Liu, Educational Technology Center of Dalian, China
Professor Lijing Wang, Beijing University of Aeronautics and Astronautics, China
Professor Long Ye, Beijing Jiaotong University, China
Professor Xiaochao Guo, Institute of Aviation Medicine, Air Force, China
Professor Xingwei Wang, Institute of Aviation Medicine, Air Force, China
Professor Ying Jin, Astronaut Research and Training Center of China, China
Professor Yonghua Tao, Naval Medical Research Institute, China
Professor Yongqing Hou, China Academy of Space Technology, China
Professor Yuhong Shen, Quartermaster Research Institute of the General Logistics Department of CPLA, China
Professor Zhibing Pang, Air Defense Forces Academy, China

Contents

Biography of Editor in Chief

Prof. Shengzhao Long He is the founder of the Man–Machine–Environment System Engineering (MMESE), the Chairman of the MMESE Committee of China, the Chairman of the Beijing KeCui Academy of MMESE and the Former Director of Ergonomics Lab of Astronaut Research and Training Center of China. In October 1992, he is honored by the National Government Specific Allowance.

Graduated from the Shanghai Science and Technology University in 1965, China. In 1981, directing under famous Scientist Xuesen Qian, founded MMESE theory. In 1982, proposed and developed Human Fuzzy Control Model using fuzzy mathematics. From August of 1986 to August of 1987, conducted research in Man–Machine System as a visiting scholar at Tufts University, Massachusetts, U.S.A. In 1993, organized MMESE Committee of China. Published "Foundation of Theory and Application of Man–Machine–Environment System Engineering"(2004) and "Man–Machine–Environment System Engineering"(1987). Edited "Proceedings of the 1st–13th Conference on Man–Machine–Environment System Engineering"(1993–2013). e-mail: shzhlong@sina.com

Dr. Balbir S. Dhillon He is a professor of Engineering Management in the Department of Mechanical Engineering at the University of Ottawa, Canada. He has served as a Chairman/Director of Mechanical Engineering Department/Engineering Management Program for over 10 years at the same institution. He has published over 345 (i.e., 201 journal + 144 conference proceedings) articles on reliability, safety, engineering management, etc. He is or has been on the editorial boards of nine international scientific journals. In addition, Dr. Dhillon has written 34 books on various aspects of reliability, design, safety, quality, and engineering management published by Wiley (1981), Van Nostrand (1982), Butterworth (1983), Marcel Dekker (1984), Pergamon (1986), etc. His books are being used in over 85 countries and many of them are translated into languages such as German, Russian and Chinese. He has served as General Chairman of two international conferences on reliability and quality control held in Los Angeles and Paris in 1987.

Professor Dhillon has served as a consultant to various organizations and bodies and has many years of experience in the industrial sector. At the University of Ottawa, he has been teaching reliability, quality, engineering management, design, and related areas for over 29 years and he has also lectured in over 50 countries, including keynote addresses at various international scientific conferences held in North America, Europe, Asia, and Africa. In March 2004, Dr. Dhillon was a distinguished speaker at the Conference/Workshop on Surgical Errors (sponsored by White House Health and Safety Committee and Pentagon), held at the Capitol Hill (One Constitution Avenue, Washington, D.C.).Professor Dhillon attended the University of Wales where he received a BS in electrical and electronic engineering and an MS in mechanical engineering. He received a Ph.D. in industrial engineering from the University of Windsor. e-mail: dhillon@genie.uottawa.ca

Part I
Research on the Man Character

Chapter 1
Performance of Ergonomics from 2001 to 2012

Jie Li, Menglu Li, Xiaohong Guo and Aleksandar Jovanovic

Abstract The objective of this paper is to conduct a quantitative and qualitative analysis of the international journal of *Ergonomics*. Articles published in *Ergonomics* from 2001 to 2012 have been downloaded from the Science Citation Index-Expanded database. The bibliometrics methods have been used to analyse the publication output with respect to authors, countries, institutes and keywords of these documents. The results show that authors such as Van Dieen JH published the most papers in this journal; the analysis of institutes and countries has shown that Vrije University Amsterdam and USA are the most productive in each category. The analysis of the keywords revealed that "electromyography" has been the most-frequently author-used keywords, followed by "biomechanics", "ergonomics" and "posture", reflecting the hot topics and main attention of *Ergonomics*.

Keywords Scientometrics · Bibliometric · Ergonomics · Knowledge mapping

1.1 Introduction

The term "ergonomics" is derived from two Greek words "ergon", meaning work, and "nomoi", meaning natural laws (http://www.ergonomics.org/). These days, ergonomics has been applied in a variety of areas, including safety, computers, automobiles, cockpits, machinery and factories [1–4]. In addition, many

J. Li · A. Jovanovic (✉)
Steinbeis Advanced Risk Technologies, Willi-Bleicher-Straße 19, 70174 Stuttgart, Germany

J. Li (✉) · X. Guo (✉)
School of safety and Environmental Engineering, Capital University of Economics and Business, Beijing 100070, China
e-mail: li.jie@risk-technologies.com

M. Li (✉)
Auburn University, 3323 Shelby Building, Auburn, AL 36830, USA
e-mail: mzl0049@auburn.edu

S. Long and B.S. Dhillon (eds.), *Proceedings of the 14th International Conference on Man–Machine–Environment System Engineering*,
Lecture Notes in Electrical Engineering 318, DOI 10.1007/978-3-662-44067-4_1

ergonomics-related journals and magazines are published around the world. In fact, there are totally 16 journals listed in the JCR 2012 (for more detailed information, please visit http://blog.sciencenet.cn/blog-554179-752558.html); these journals are all indexed by SSCI or SCI. *Ergonomics* is one of the most important journals in ergonomics topics which are published in England by Taylor and Francis Ltd and indexed by SCI and SSCI. According to the JCR Social Sciences Edition 2012, *Ergonomics* is 3 out of 16 in ergonomics journals and 23 out of 73 journals in psychology and applied. However, according to the JCR Science Edition 2012, *Ergonomics* is 9 out of 44 in categories of engineering, industrial, and 47 out of 75 in the subject categories of psychology. *Ergonomics* has an impact factor of 1.674 in 2013. Recently, the research shows that bibliometrics methods have become an effective way to analyse the performance of Journals [5–7]. In this study, scientometrics method was used to help outline a profile of the *Ergonomics* from 2001 to 2012, including annual distribution of articles, authors, institutes, countries and keywords of the journal.

1.2 Data and Method

The data were retrieved on 30 August 2013, from the Science Citation Index-Expanded (SCI-E) database with an online version published by Thomson Reuters, which has been operated by Thomson Scientific, Philadelphia, PA, USA. The retrieval strategies were arranged as Publication Name = (Ergonomics), Time span = (2001–2012). Totally, 1544 documents, including articles (1289, 83. 484 %), book reviews (177, 11.464 %), proceedings papers (81, 5.246 %), editorial materials (35, 2.267 %), reviews (22, 1.425 %), corrections (12, 0.777 %) and biographical items (8, 0.518 %), have been published in *Ergonomics*. As articles represented the majority of peer-reviewed document in the journal, therefore, 1,289 articles were downloaded for further analysis (including 81 proceedings articles published in *Ergonomics*). The bibliometrics method has been used in this study which includes basic statistics, geographic distribution and co-words analysis. Also, tools for scientometrics analysis including Histcite [8], VOSviewer [9] and SATI [10] have been used for the data analysis.

1.3 Results and Discussion

1.3.1 Publication Output

Articles published in *Ergonomics* from 2001 to 2012 are shown in Fig. 1.1. The number of papers published annually in the journal of *Ergonomics* varies from 68 to 129 and the average number of papers published in *Ergonomics* is more than

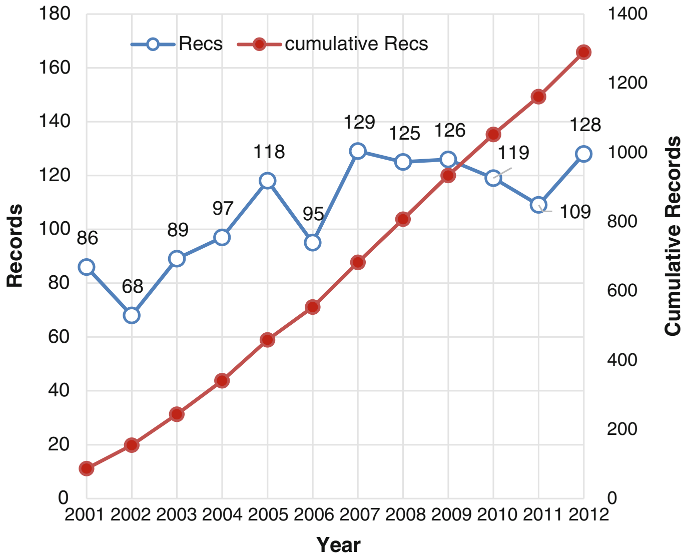


Fig. 1.1 Annual distribution of articles published in *Ergonomics* from 2001 to 2012

107, with standard deviation of 20.02. As a monthly journal, the papers published in Ergonomics did not change significantly over time.

1.3.2 Authors' Analysis

There are 3,039 authors from all the 1,289 articles. The top 10 most productive authors are displayed in Fig. 1.2. Out of 3,039 authors, Van Dieen JH has contributed the most number with 25 articles ranking the first place, followed by Stanton NA (22), Nussbaum MA (18), Chang WR (16), Frings-Dresen MHW (16), Callaghan JP (15), Kingma I (14), Chan AHS (12), Sauer J (12), Walker GH (12), Johnson PW (11) and Sluiter JK (11). They are all core authors who have published articles in *Ergonomics*.

1.3.3 Institute Analysis

The contributions of different institutes were assessed herein by the institutes' affiliations with at least one author in the published papers. The top 20 institutes with a paper quantity of more than 15 are ranked by the number of their published articles. According to Table 1.1, Vrije University Amsterdam has published 40 articles, ranking first, followed by University Waterloo with 37 articles, and

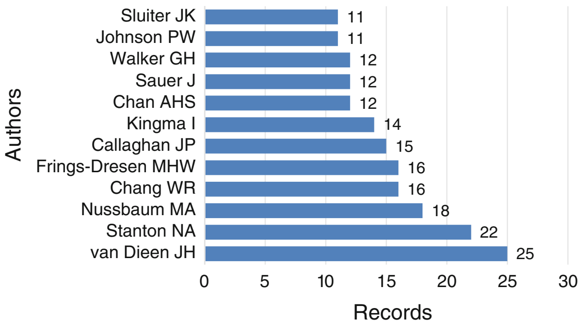


Fig. 1.2 Top 10 most productive authors of *Ergonomics* during 2001–2012

Table 1.1 Top 20 most productive Institutes of *Ergonomics* during 2001–2012

No.	Institution	Country	Recs	Percentage	LCS	GCS
1	Vrije University Amsterdam	Netherlands	40	3.1	67	542
2	University Waterloo	Canada	37	2.9	62	376
3	Liberty Mutual Res Inst Safety	USA	32	2.5	25	193
4	University Nottingham	UK	28	2.2	64	397
5	Liverpool John Moores University	UK	27	2.1	12	438
6	NIOSH	USA	26	2	64	452
7	University Cincinnati	USA	25	1.9	45	273
8	University Amsterdam	Netherlands	24	1.9	31	320
9	University Michigan	USA	23	1.8	46	217
10	University Loughborough	UK	22	1.7	40	202
11	Delft University Technol	Netherlands	21	1.6	18	180
12	University Southampton	UK	20	1.6	24	105
13	Brunel University	UK	19	1.5	84	295
14	Virginia Tech	USA	19	1.5	12	92
15	Finnish Inst Occupat Hlth	Finland	18	1.4	80	442
16	Hong Kong Polytech University	China	18	1.4	30	157
17	Massey University	New Zealand	18	1.4	32	178
18	Ohio State University	USA	17	1.3	31	152
19	University Wisconsin	USA	17	1.3	24	158
20	University Washington	USA	16	1.2	54	252

Note Rec is number of the articles, Percentage is percentage of articles, LCS is local citation score, which means the number of cited times cited by other papers in local database. GCS is global citation score that means the number of cited times cited by other papers in web of science (until 30 August 2013)

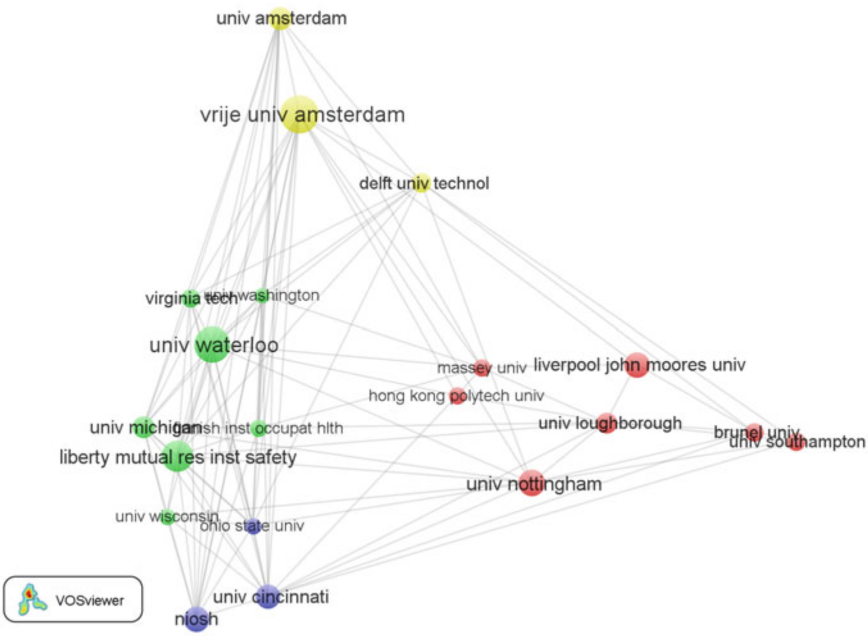


Fig. 1.3 Bibliographic coupling of key institutions in *Ergonomics*

Liberty Mutual Res Inst Safety with 32 article ranking third that makes up the three of the most powerful institutions in *ergonomics*. The GCS of the Vrije University Amsterdam (542) also is the highest, followed by NIOSH (452), Finnish Inst Occupat Hlth (442) and Liverpool John Moores University (438). Moreover, Finnish Inst Occupat Hlth (24.5) has the highest AVGS, followed by NIOSH (17.4) and Liverpool John Moores University (16.2), are the leading institutes in paper quantity.

The VOSviewer software has been used to analyse the bibliographic coupling of the 20 most productive institutions (see in Fig. 1.3). From the software, four major clusters of institutions have been generated. Cluster 1 includes Brunel Univ, Hong Kong Polytech Univ, Liverpool John Moores Univ, Massey Univ, Univ Loughborough, Univ Nottingham and Univ Southampton; the cluster 2 includes Finnish Inst Occupat Hlth, Liberty Mutual Res Inst Safety, Univ Michigan, Univ Washington, Univ Waterloo, Univ Wisconsin and Virginia Tech. The cluster 3 includes Niosh, Ohio State Univ and Univ Cincinnati; the cluster 4 includes Delft Univ Technol, Univ Amsterdam and Vrije Univ Amsterdam. Institutions in same cluster have more cooperation and the close ergonomics topics. The institutes of Vrije University Amsterdam, University Waterloo, Liberty Mutual Res Inst Safety, University of Nottingham, Liverpool john Moores University, NIOSH and University of Cincinnati are in the core status of correspondent cluster. Furthermore, institutions including Vrije University Amsterdam, University of Waterloo,

Fig. 1.4 The spatial distribution of *Ergonomics* papers during 2001–2012. To explore the map in an interactive way, please visit: https://www.google.com/fusiontables/DataSource?docid=15CoDtAs5PEscK7Zgae9Y9m9yq2MVHHoDrsTuoec8

Liberty Mutual Res Inst Safety, University of Nottingham and NIOSH have cooperated with other institutes frequently and have an important role in their cluster group.

1.3.4 Spatial Distribution Analysis

The outputs of different countries or territories are presented in Fig. 1.4, and the detailed information of top 10 countries are listed in Table 1.2. The most productive country is USA, followed by UK, Canada and the Netherlands. Furthermore, these countries also have the high citation rates that have been evaluated by TLCS and TGCS. Finland ranked the first place when compared in terms of AGCS (AGCS is the average citation frequency of article, which implies the quality of the articles). It means that these countries/territories published the most high-quality papers in this journal and have the highest strength in ergonomics research. The number of publications in other countries is all below 100.

1.3.5 Keywords Research

In this part, Statistical Analysis Toolkit for Informetrics[1] (SATI) has been used to analyse the frequency of the keywords and make the 100 × 100 Co-occurrence matrix (Valued) of the *ergonomics* keywords. Keywords matrix has been used in

[1] Statistical Analysis Toolkit for Informetrics can freely get from http://sati.liuqiyuan.com/.

Table 1.2 Top 10 most productive countries/territories of *Ergonomics* papers during 2001–2012

No.	Country	Recs	Percentage	TLCS	TGCS	AGCS
1	USA	368	28.5	613	3,608	9.80
2	UK	230	17.8	383	2,726	11.85
3	Canada	129	10	195	1,100	8.53
4	the Netherlands	104	8.1	146	1,266	12.17
5	Australia	97	7.5	141	862	8.89
6	Sweden	63	4.9	152	878	13.94
7	Germany	56	4.3	79	463	8.27
8	Peoples R China	51	4	70	381	7.47
9	New Zealand	39	3	53	328	8.41
10	France	38	2.9	46	301	7.92

Keywords/Year	Totally	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Totally
Electromyography	47	3	2	3	4	5	4	8	4	4	2	5	3	47
Biomechanics	45	5	2	2	4	2	6	4	2	4	4	4	6	45
Ergonomics	44	4	2	3	2	3	2	4	5	6	0	6	7	44
Posture	43	3	2	1	5	3	3	6	5	2	5	7	1	43
Performance	42	2	2	2	4	1	3	4	2	8	4	4	6	42
Musculoskeletal Disorders	38	2	0	2	2	5	2	3	5	6	4	2	5	38
Emg	29	4	3	1	4	1	3	1	3	4	1	2	2	29
Lifting	29	1	4	0	3	3	0	3	2	3	6	2	2	29
Workload	24	0	5	0	2	3	0	2	1	5	1	3	2	24
Driving	23	1	1	4	1	2	2	7	0	3	0	0	2	23
Children	23	1	0	2	4	1	0	3	5	2	4	1	0	23
Load Carriage	23	1	0	3	5	0	2	3	2	1	4	1	1	23
Keywords/Year	Totally	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Totally

Fig. 1.5 Annual distribution of the keywords in *Ergonomics*

Ucinet to get NET file, and Gephi[2] was used to draw the network of the keywords distribution. The most-frequent keywords and their annual distribution are displayed in Fig. 1.5. The high-frequency words including “electromyography (47)”, “biomechanics (45)”, “ergonomics (44)”, “posture (43)”, “performance (42)”, “musculoskeletal disorders” (38), “EMG (29)”, “lifting (29)”, “workload (24)”, “driving (23)”, “children (23)” and “load carriage (23)” are shown in the Fig. 1.5. These high-frequency keywords are reflecting the main topics which Ergonomics focus on. In addition, Fig. 1.5 also reveals that “electromyography” and “driving” were the hot research topics in 2007; “performance” was a hot topic in 2009; “posture” is a hot topic in 2011; “biomechanics” is a hot topic in 2006 and 2012. Each word demonstrates the trend of different research areas in *Ergonomics*. From the network of the keywords in journal of Ergonomics (See Fig. 1.6), it has been

[2] The Open Graph Viz Platform can freely get from https://gephi.org/.

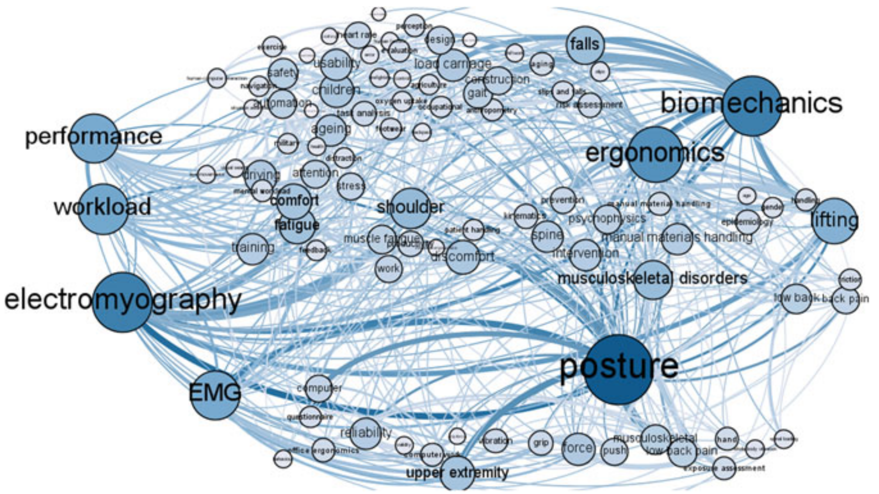


Fig. 1.6 Network of the keywords in journal of *Ergonomics*

shown that “electromyography”, “biomechanics”, “ergonomics”, “posture”, “performance”, “musculoskeletal disorders”, “EMG”, “lifting”, “workload” and “driving” have a high degree in the network. It means these keywords have played an important role in connection with each topic in *Ergonomics*.

1.4 Conclusions

In this study, bibliometrics methods have been used to analyse the performance of the journal of *Ergonomics* from 2001 to 2012. The results of publications outputs, authors, countries/territories, institutes and keywords distribution are explained in this paper. The analysis of the authors shows that Van Dieen JH, Stanton NA, Nussbaum MA and Chang WR are the most productive authors who publish more articles in *Ergonomics*. The articles published in *Ergonomics* reveal that Vrije University Amsterdam, University Waterloo and Liberty Mutual Res Inst Safety are the key institutes. Moreover, USA, UK, Canada and the Netherlands are the most productive countries. Finally, keywords of “electromyography (47)”, “biomechanics (45)”, “ergonomics (44)”, “posture (43)”, and “performance (42)” are the hot topics, which are the *Ergonomics’* focus.

Acknowledgment The study has been supported by the Joint Education Graduate Cooperation Program between Capital University of Economics and Business (CUEB) and Steinbeis Advanced Risk Technologies.

References

1. Chaffin DB (1975) Ergonomics guide for the assessment of human static strength. Am Ind Hyg Assoc J 36(7):505–511
2. Turner JA, Karasek RA Jr (1984) Software ergonomics: effects of computer application design parameters on operator task performance and health. Ergonomics 27(6):663–690
3. Hendrick HW (1991) Ergonomics in organizational design and management. Ergonomics 34(6):743–756
4. Wilson JR (1997) Virtual environments and ergonomics: needs and opportunities. Ergonomics 40(10):1057–1077
5. Arunachalam S, Markanday S (1981) Science in the middle-level countries: a bibliometric analysis of scientific journals of Australia, Canada, India and Israel. J Inf Sci 3(1):13–26
6. Ramos-Rodríguez AR, Ruíz-Navarro J (2004) Changes in the intellectual structure of strategic management research: a bibliometric study of the strategic management journal, 1980–2000. Strateg Manag J 25(10):981–1004
7. Wang M-H, Yu T-C, Ho Y-S (2010) A bibliometric analysis of the performance of water research. Scientometrics 84(3):813–820
8. Garfield E (2009) From the science of science to scientometrics visualizing the history of science with HistCite software. J Informetr 3(3):173–179
9. Van Eck NJ, Waltman L (2010) Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 84(2):523–538
10. Liu Q, Ye Y (2012) A study on mining bibliographic records by designed software SATI: case study on library and information science. J Inf Res Manage 1:50–58

Chapter 2
Perceived Fatigue Evaluating Model in Health Men Performing Backpack Load-Carriage Exercises

Yuhong Shen, Jiewen Zheng, Chenming Li, Yafei Guo and Pengfei Ren

Abstract *Objectives* This study aimed to develop a fatigue model for human load carriage during endurance exercise using quantification of perceived pains and physiological parameters. *Methods* Heart rate, skin contact pressure, and perceived pains and corresponding locations of five healthy participants were measured during treadmill tests on non-consecutive days under three different conditions of backpack payloads (29, 31.5, and 34 kg). *Results* All participants could complete the trials without resting using 29, 31.5, and 34 kg payloads for 50 min. The slopes for heart rate regression equations in three-payload conditions became steeper as the payload increased. The trends of root mean square (RMS) of skin contact pressure in back, shoulder, and hip regions are all changing smoothly. But the overall amplitudes of RMS of pressure in shoulder region in all three-payload conditions are higher comparing with other two regions. Perceived fatigue intensity results showed that shoulder region was the most discomfort region on the body and was highest using 34-kg payload. *Conclusions* The results suggested that shoulder fatigue may limit endurance performance, thereby indicating the importance of a well-designed shoulder strap. A fatigue intensity predictive model was proposed to allow prediction of human load carriage limits and fatigue intensity trend for endurance exercise.

Keywords Backpacks · Biomechanical assessment · Load carriage · Fatigue intensity predictive model · Skin contact pressure

Y. Shen · J. Zheng (✉) · C. Li · Y. Guo · P. Ren
The Quartermaster Research Institute of the General Logistic Department,
Beijing 100010, China
e-mail: jaroncheng@126.com

S. Long and B.S. Dhillon (eds.), *Proceedings of the 14th International Conference on Man–Machine–Environment System Engineering*,
Lecture Notes in Electrical Engineering 318, DOI 10.1007/978-3-662-44067-4_2

2.1 Introduction

Backpacks or personal load carriage systems are commonly used by soldiers to carry heavy loads in different terrains and gradients even in long-distance marching or in the fighting [1]. With technological advancements, loads carried by soldiers especially in terms of increased firepower and protection equipments have progressively increased. Unfortunately, carrying heavy loads often caused discomfort, fatigue, and injuries and affecting soldiers' operational performance [2]. In a recent military report, US rifle squads carried fighting load of 28.3 kg (34.9 % body weight (BW)), approach march load of 43.1 kg (52.6 % BW), and emergency approach march load of 58.2 kg (73.6 % BW) [3]. A difficulty for military personnel have to face is to assess the fatigue or injury that various loads will have on foot soldiers. Even though payload and mission are known, there are only a few strategies to assess or predict the impact of loads on the soldiers. It is important to develop a predictive model or equation that encompasses more of the major variables that limit performance of load carriage in the field.

Till date, the studies of fatigue predictive model for human load carriage particularly in military conditions are limited and less reported, especially applying both biomechanical and physiological approaches. This paper will explore the relationships between fatigue and backpacks and give some suggestions for improving the design of backpack and reducing discomfort or fatigue when carrying heavy loads. Finally, a fatigue intensity predictive model was proposed to allow prediction of human load carriage limits and fatigue intensity trend for endurance exercise, which would be used to provide backpackers and military with a simple guideline to assess the load reasonably carried by a soldier or backpacker, the duration with corresponding load, and the dropout rate for a certain task.

2.2 Methods

2.2.1 Subjects

Five male individuals with a mean (±SD) age, body weight, and height of 24.2 ± 3.7 years, 64.5 ± 11.59 kg, and 172.2 ± 2.39 cm, respectively, enrolled in this study. The participants were healthy Chinese men and had no muscular or skeletal illness that would influence load carriage performance. Both written consent and verbal consent were obtained from all participants prior to experiment. They were asked to have a good rest and avoid caffeine, alcohol, smoking, and intense physical activity at least 24 h prior to the experiment.

2.2.2 Apparatus and Measurements

The pressures at shoulder, back, and hip regions were measured by miniature pressure sensor (Model 9801, Tekscan, USA). The 9801 sensor has sensing region dimension of 7.6 × 20.3 cm that is so small that a minimal change to the curvature of the shoulder strap can be measured. Two 9801 sensor pads were put on each region to detect pressure of both sides, as shown in Fig. 2.1. Each 9801 sensor was plugged into a data scanner where pressure data were collected and sent to PC via USB cable where the data can be viewed, analyzed, and stored in real time with I-Scan® application software. Heart rate (HR) was acquired using a chest HR belt and a wristwatch monitor (S610i, Polar, Finland). The HR data stored in wristwatch monitor will be uploaded to PC via infrared port after experiment.

2.2.3 Procedure

The experimental trials began at 08:00. Temperature of the climate chamber was maintained at 25 °C throughout all the trials. Participants visited the climate chamber at our institute for three exercise sessions on non-successive days. The payloads were packed into the modern Chinese army backpack that was adjusted to fit each participant with a balanced and uniform load distribution. Five participants will perform treadmill tests (5 km/h speed, 0 % incline) under three

Fig. 2.1 Location of 9801 pressure sensors

different conditions (29, 31.5, or 34 kg). Every three minutes, numerical fatigue intensity (0 to 10 where “0” indicates “no fatigue” and “10” indicates “fatigue as bad as it can be”) on three regions (shoulder, back, and hip) and whole body were recorded by the researcher, until finishing 50 min of trail or until the participant reported stopping exercising.

2.2.4 Statistics

Descriptive statistics were used to calculate mean values for fatigue intensity. The root mean square (RMS) was used to describe the magnitude of skin contact pressure in three minutes. $P < 0.05$ was considered significant. All statistical analyses were performed in SPSS 11.0 and MATLAB 7.0.

2.3 Results

Figure 2.2 shows the mean HR resulting from 50 min of load carriage on a treadmill for three payloads. In Fig. 2.2, the regression equation for each payload was calculated based on time (independent variable) and mean HR (dependant variable). The slope for regression equation became steeper as the payload increased. Figure 2.2 also shows that mean HRs generally reached a plateau (slopes became gentle) between 25 and 40 min of exercise.

Figure 2.3 shows the RMS of skin contact pressure during 50 min of load carriage exercise for three payloads. It can be seen that the trends of RMS of skin contact pressure in back, shoulder, and hip regions in three-payload conditions are all changing smoothly. But the overall amplitudes of RMS of pressure in shoulder regions are higher comparing with other two regions (back and hip). And the difference is most obvious in 34 kg payload.

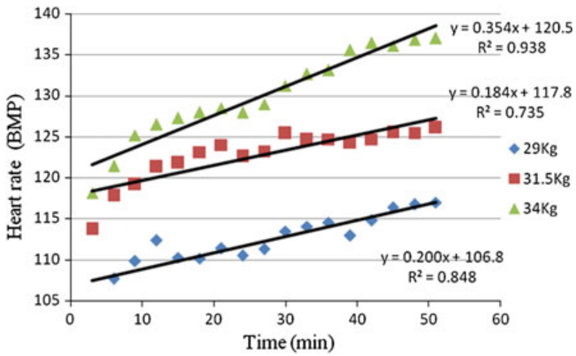


Fig. 2.2 Mean HR during 50 min of load carriage exercise

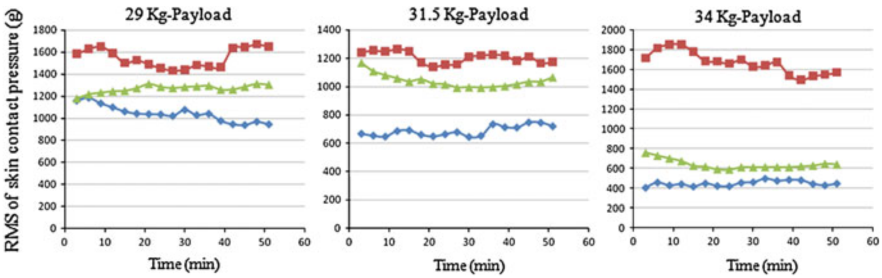


Fig. 2.3 The RMS of skin contact pressure during 50 min of load carriage exercise

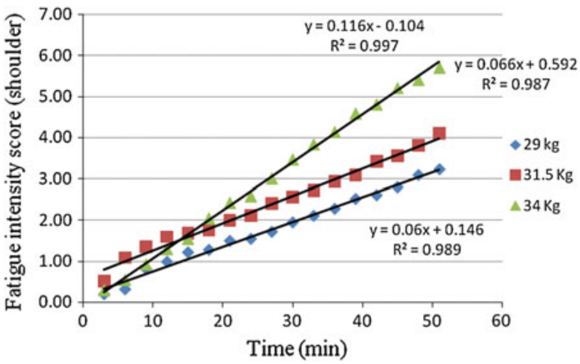
Table 2.1 Perceived fatigue score of shoulder, back, and hip regions and whole body in three-payload conditions

Time	Shoulder			Back			Hip			Whole body		
	29 kg	31.5 kg	34 kg	29 kg	31.5 kg	34 kg	29 kg	31.5 kg	34 kg	29 kg	31.5 kg	34 kg
50 min	3.2	4.1	5.7	3.3	2.1	1.3	3.1	2.3	3.7	3.6	3.3	3.9

Table 2.1 shows perceived fatigue scores of three regions and whole body during 50 min exercises in three-payload conditions. In shoulder and hip regions, the fatigue scores increased as the payloads changing from 29 to 34 kg. But the opposite is in back region. Whereas there is no regular changes of the whole body fatigue score. Table 2.1 also shows that shoulder region was the most discomfortable region on the body and was highest using 34-kg payload.

To develop fatigue predictive model for load carriage, a number of regression equations were calculated. Figure 2.4 shows the regression equations for each payload, calculated based on fatigue scores from the most discomfortable of shoulder region (dependent variable) and time (independent variable). Figure 2.5 shows the regression equations, calculated based on shoulder fatigue (dependent

Fig. 2.4 The relationship between shoulder region fatigue and excising time during load carriage



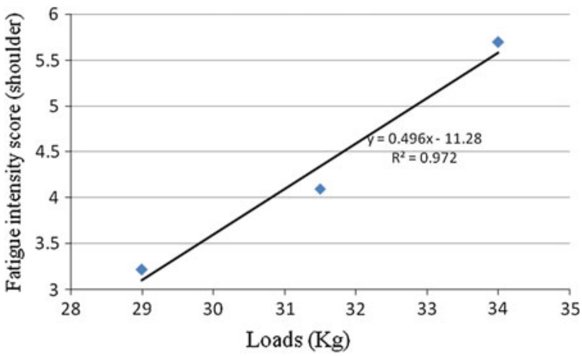


Fig. 2.5 The relationship between shoulder region fatigue and payload during load carriage

Model 1 Prediction of load carriage duration for discrete payloads ≤ 34 kg	Model 2 Prediction of percent of maximal fatigue intensity for a given payload during 50-minute exercise.
If payload is known (e.g. 29, 31.5, 34 kg), then the maximal duration can be predicted. Choose appropriate regression equation from Figure 4; Where, x = time; y = shoulder fatigue score. **For example:** To predict how long backpacker can endure 31.5 kg before fell exhausted. y = 0.066x + 0.592; (31.5 kg), when y = 5.7, x = 77 minutes; Therefore, backpacker can endure 77 minutes exercise when carrying 31.5 kg payload.	If the payload is known, then the percent of maximal fatigue intensity can be predicted. **Step 1:** Use equation from Figure 5: y = 0.496x - 11.28 Where, x = load; y = shoulder fatigue intensity. **Step 2:** Use following equation: % maximal fatigue limit: = y/5.7 × 100%. **For example:** If 33 kg payload is carried for 50 minutes, backpacker will be working at the following percent of his maximal fatigue limit. **Step 1:** y = 0.496× 33 –11.28 y = 5.1 **Step 2:** % maximal fatigue limit: = 5.09/5.7 × 100%= 89.3% Therefore, fatigue is predicted to be 5.1/10 during payload carriage of 33 kg for 50 minutes which is 89.3% of maximal load carriage fatigue limit.

Fig. 2.6 The fatigue intensity predictive model

variable) and payload (independent variable). For this test, all participants could complete 50-min exercises without resting using all three payloads.

Based on above findings, a simple fatigue predictive model will be proposed (Fig. 2.6).

2.4 Discussions

As expected, each participant showed increasing tendency of mean HR in all three-payload conditions and reached a plateau between 25 and 40 min (Fig. 2.2). When starting exercise, the cardiorespiratory system is trying to accommodate body to changed load conditions, so the HR increased rapidly. After about 25 to 40 min, the body tends to balance, so a plateau appeared. But the HR would continue to grow up as the exercising intensity increased, and then, the body would explore potential of the body to adapt to new change [4]. The highest mean HR recorded was 137 beat/min (BPM) (34-kg payload), suggesting that the HR was in the low end of cardiorespiratory limit. Tanaka et al. reported that following equation could be used to predict maximal HR (HRmax): $\mathrm{HRmax} = 208 - (0.7 \times \mathrm{age})$ [5]. Based on mean age of our participants (24.2 year), the expected HRmax would be 191 BPM. From Fig. 2.2, it can be calculated that the participants were excising at 71.1 % of HRmax (34 kg). Kenney et al. reported that about 70 % of HRmax could be accepted for most healthy individuals [6]. Based on above, all participants always took exercises within maximal cardiorespiratory limit, even for the heaviest 34-kg payload, suggesting that HR may be not a major factor for predicting fatigue when carrying under 34-kg payload.

Some studies have suggested that the shoulder region played the most important role in determining load carriage limit and will be most vulnerable region of feeling fatigue or pain [7, 8]. This study gets similar results that both in 31.5- and 34-kg payloads condition, fatigue scores of shoulder region are the biggest. But in 29-kg payload, the most discomfortable region was back. Table 2.1 shows that fatigue scores of the shoulder, back, and hip regions in 29-kg payload were 3.2, 3.3, and 3.1, respectively, suggesting the differences between them had no significances ($P > 0.05$). This maybe can be explained that perceived fatigues in three regions are so small in this low payload condition (29 kg) that it cannot be differentiated. In all payloads conditions, fatigue score of shoulder region in 34 kg was highest, suggesting that shoulder fatigue may limit endurance performance, thereby indicating the importance of a well-designed shoulder strap. The sternum strap and hip belt may also improve fatigue by reducing shoulder pressure through the redistribution forces over a larger surface on the anterior body during endurance exercise. These results are similar to other studies [1, 9, 10].

Figure 2.3 shows the RMS of pressure in shoulder region in all three-payload conditions are higher than other regions, but almost no differences existed among three-payload conditions. By contrast, the RMS of pressure in back and hip regions seemed to present regular trends of increasing as adding payloads. It was possible that the sternum strap and hip belt shared much pressures distributed in shoulder region when payload increased. So that is why the RMS of pressure in shoulder had less change, whereas those of back and hip increased. This also on the other hand proved that well-designed sternum strap and hip belt would improve backpack performance in load carriage and proved the backpack used in this study had good performance. The skin contact pressures could be acquired with film-type sensors, but some indeterminacy due to volatile contact areas between skin and backpacks, bending errors, poor repeatability, and calibration limitations still existed [11]. So modern pressure mapping technology must resolve these problems or explore alternative methods to study biomechanical factors in load carriage. As such, using two 3-axis accelerometers to assess the contact forces and pressures between the backpack and person seems to be a prosperous method [12].

Some limitations of our studies must be pointed out. First, payload or duration should be increased. In this study, the maximum payload was 34 kg, 52.7 % of BW. But Fig. 2.4 shows that the maximal mean fatigue score was only 5.7 in shoulder region. It was obvious that the participants did not reach their physical limits. US army defined the limit of payload in load carriage was 50 kg based on previous statistical data acquired from Afghanistan and the Falkland Islands battles. Second, the number of participants was small (N = 5). It was important to have a dropout rate in order to develop a comprehensive fatigue predictive model through increasing samples, payloads, or duration of exercise. Third, this study tested a limited payloads (29, 31.5, 34 kg), march speed (5 km/h), incline (0 %), and duration (50 min). Only when testing wide conditions, the predictive model could have good performance in actual application.

2.5 Conclusion

A fatigue intensity predictive model was proposed to allow prediction of human load carriage limits and fatigue intensity trend for endurance exercise. The fatigue predictive model only considering limited physiological and biomechanical aspects. But more factors should be introduced, such as demographic factor including body size, gender, and age, fitness and injury factors, and so on. In this paper, the study on fatigue predictive model is only elementary and groping, and a lot of work need to do in the future.

References

1. Knapik JJ, Reynolds KL, Harman E (2004) Soldier load carriage: historical, physiological, biomechanical, and medical aspects. Mil Med 169(1):45–56
2. Roy TC, Knapik JJ, Ritland BM et al (2012) Risk factors for musculoskeletal injuries for soldiers deployed to Afghanistan. Aviat Space Environ Med 83(11):1060–1066
3. Coalition Task Force 82, Coalition Joint Task Force 180 (2010) The modern Warrior's combat load: dismounted operations in Afghanistan. CreateSpace Independent Publishing Platform, Seattle
4. Wenger HA, Bell GJ (1986) The interactions of intensity, frequency and duration of exercise training in altering cardiorespiratory fitness. Sports Med 3(5):346–356
5. Tanaka H, Monahan KD, Seals DR (2001) Age-predicted maximal heart rate revisited. J Am Coll Cardiol 37(1):153–156

6. Kenney WL, Wilmore JH, Costill D (2011) Physiology of sport and exercise, 5th edn. Human Kinetics, Champaign
7. Holewijn M, Meeuwsen T (2001) Physiological strain during load carrying: effects of mass and type of backpack. Technical Report. ADP010987
8. Whiteside RA, Doan JE, Reid SA et al (1999) Integrated patrol pack and rucksack development phase IIIB: performance testing of suspension components. DCIEM-CR-2001-087
9. Holewijn M (1990) Physiological strain due to load carrying. Eur J Appl Physiol Occup Physiol 61(3–4):237–245
10. Knapik J, Harman E, Reynolds K (1996) Load carriage using packs: a review of physiological, biomechanical and medical aspects. Appl Ergon 27(3):207–216
11. Hadcock LJ, Bryant JT, Stevenson JM (2002) Pressure and force distribution measurement for the design of waist belts in personal load carriage systems. Contract#W7711-0-7632-02/A
12. Morin EL, Stevenson JM, Reid SA et al (2005) Development of a dynamic biomechanical model for load carriage: phase V—development of the biomechanical model by means of the portable measurement system. ADA480769

Chapter 3
The Changes of Physiological and Biomechanical Indices and Their Relations to Fatigue During Treadmill Walking with Different Loads

Jiewen Zheng, Yuhong Shen, Chenming Li, Pengfei Ren and Yafei Guo

Abstract *Objectives* To analyze the changes of physiological and biomechanical signals and their relations to fatigue in treadmill walking with backpack load. *Methods* Cardiopulmonary function parameters, shoulder force, trunk pressure, and perceived fatigues are sampled simultaneously with six healthy men during 30-min treadmill walking experiments under five different conditions of backpack loads. *Results* HR, BR, VE, and VO2 gradually increased as the load increased, and the increasing rate became bigger during 37–39 kg tests. Shoulder force and shoulder pressure were strongly correlated with load. Pressures at waist and back regions were influenced by the tension degree of waist and chest belts. The 37-kg load was the turning point of human cardiopulmonary function starting working overload. The perceived fatigues in shoulder and whole body are more intense than those of back and waist. *Conclusions* The coordinate ability of cardiopulmonary system should be considered when studying treadmill walking with loads greater than 37 kg. Shoulder force and pressure are considered as main factors for fatigue evaluation.

Keywords Backpack · Load carriage · Perceived fatigue · Physiological signals · Biomechanical signals

J. Zheng · Y. Shen (✉) · C. Li · P. Ren · Y. Guo
The Quartermaster Research Institute of the General Logistic Department,
Beijing 100010, China
e-mail: yuhong810@aliyun.com

S. Long and B.S. Dhillon (eds.), *Proceedings of the 14th International Conference on Man–Machine–Environment System Engineering*,
Lecture Notes in Electrical Engineering 318, DOI 10.1007/978-3-662-44067-4_3

3.1 Introduction

Carrying heavy loads for long distances is a common requirement to military personnel, various types of workers, and recreational hikers [1]. With technological advancements, loads carried by people especially for soldiers in terms of increased firepower and protection equipments have progressively increased. Physical transport of heavy load over long distances often caused discomfort, fatigue, and injuries and affecting soldiers' operational performance [2–4]. In a recent military report, U.S. rifle squads carried fighting load of 28.3 kg (34.9 % body weight (BW)), approach March load of 43.1 kg (52.6 % BW), and emergency approach March load of 58.2 kg (73.6 % BW) [5]. Even though U.S. Army has been attempting to reduce loads carried by soldiers, little effects were obtained for maintaining requirements of combat. According to statistics of U.S. Army, there were 257,000 cases of injuries in lower extremity induced by overload combat equipments in 2007. Thus, it is very significant to study relative factors leading to fatigues and injuries by various load–condition experiments. At present, many researchers have done much works related to load carriage applying with physiological and biomechanical methods, such as to analyze forces distributed in trunk regions using pressure sensors, to study effects of load carriage on kinematics of gait using human motion detecting system [4, 6, 7]. Many load carriage relevant works have been done in China, but most of them only applied heart rate (HR), body temperature, oxygen uptake (VO2), and other physiological variables to study optimal load for single soldiers and to evaluate load carriage systems [8–10]. The characteristics of physiological and biomechanical signals during different-load treadmill walking and their relationships with perceived fatigues have not been studied so far. The purpose of this study was to systematically analyze the characteristics and trends of HR, breathing rate (BR), VO2 and other physiological parameters, forces on shoulder, back and waist regions, and perceived fatigues during different-load conditions, and to explore relative factors leading to body fatigue.

3.2 Methods

3.2.1 Subjects

Six male individuals with a mean (±SD) age, body weight, and height of 24.7 ± 3.5 year, 63.8 ± 8.3 kg, 172.0 ± 2.3 cm, respectively, enrolled in this study. The participants were healthy Chinese men and had no muscular or skeletal illness that would influence load carriage performance. Both written and verbal consent were obtained from all participants prior to experiment. They were asked to have a good rest and avoid caffeine, alcohol, smoking, and intense physical activity at least 24 h prior to the experiment.