Proceedings of the
Third American Conference on Human Vibration

June 1-4, 2010

Edited by
David Wilder, Ph.D.
Salam Rahmatalla, Ph.D.
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College of Engineering Department of Biomedical Engineering
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College of Public Health Department of Occupational and Environmental Health
Heartland Center for Occupational Health and Safety

The University of Iowa
Iowa City, Iowa 52242, USA

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Program

of the

Third American Conference on Human Vibration

June 1-4, 2010

Iowa Memorial Union
The University of Iowa
Iowa City, Iowa 52242
U.S.A.

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Conference Synopsis:

When people interact with physical environments that produce vibration and mechanical shock, they can experience responses to the environment ranging from mild to life-changing depending on the characteristics of the exposure. The Third American Conference on Human Vibration, the third in a biennial series starting at NIOSH in 2006 and continuing in Chicago in 2008, provides a forum for scientists, engineers, ergonomists, medical doctors, industrial hygienists, educators, epidemiologists, health and safety specialists, physiologists, psychologists, students and others from government, industry, and academic institutions to discuss and advance research and education in the area of human response to vibration.

Understanding human responses to vibration allows interested stakeholders to improve vibration environments to reduce risks to their users. Conference topics will cover human responses to hand-transmitted and whole-body vibration in general and include measured human responses, modeling, experimental design, sensors, new technologies, and epidemiology studies. Contemporary issues related to prevention measures, occupational health, and data collection used to study the complex, dynamic human response to vibration will be addressed.

David G. Wilder, PhD
Conference Chair

Local Organizers:

David G. Wilder, PhD
Biomedical Engineering Department
College of Engineering

Salam Rahmatalla, PhD
Center for Computer-Aided Design
Civil and Environmental Engineering Department
College of Engineering

Nathan Fethke, PhD
Department of Occupational and Environmental Health
Heartland Center for Occupational Health and Safety
College of Public Health

Jo Ellen Dickens
Director
University of Iowa Center for Conferences

Gareth Smith
Webmaster
Radiation Oncology

American Conference on Human Vibration Scientific Committee

Farid Amirouche, PhD
Biomechanics Laboratory
University of Illinois
Chicago, Illinois, USA

Thomas Armstrong, PhD
Center for Ergonomics
University of Michigan
Ann Arbor, Michigan, USA

Paul Emile Boileau, PhD
Institut de Recherche Robert-Sauve en
Sante et en Securite du Travail
Montreal, Quebec, Canada

Anthony Brammer, PhD
Biodynamics Laboratory of the
Ergonomic Technology Center
University of Connecticut Health Center,
Farmington, Connecticut, USA

Martin Cherniak, MD
Biodynamics Laboratory of the
Ergonomic Technology Center
University of Connecticut Health Center,
Farmington, Connecticut, USA

Ren G Dong, PhD
Health Effects Laboratory,
National Institute for Occupational
Safety and Health
Morgantown, West Virginia, USA

Tom Jetzer, MD
President
Occupational Medicine Consultants, Ltd,
Minneapolis, Minnesota, USA

Kristine Krajnak, PhD
Health Effects Laboratory,
National Institute for Occupational
Safety and Health
Morgantown, West Virginia, USA

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Center for Ergonomics
University of Michigan
Ann Arbor, Michigan, USA

Robert G. Radwin, PhD
University of Wisconsin
Madison, Wisconsin, USA

Subhash Rakheja, PhD
Centre for Advanced Vehicle Technology
Concordia University
Montreal, Quebec, Canada

Douglas Reynolds, PhD
Center for Mechanical & Environmental
Systems Technology
University of Nevada
Las Vegas, Nevada, USA

Danny Riley, PhD
Department of Cell Biology
Neurobiology & Anatomy
Medical College of Wisconsin
Milwaukee, Wisconsin, USA

Suzanne D. Smith, PhD
Air Force Research Laboratory
Wright-Patterson Air Force Base, Ohio, USA

David G. Wilder, PhD
Biomedical Engineering Department
Jolt, Vibration, Seating Lab
Iowa Spine Research Center
University of Iowa
Iowa City, Iowa, USA

Donald Wasserman
Human Vibration Consultant
Frederick, Maryland, USA

Jack Wasserman, PhD
University of Tennessee
Knoxville, Tennessee, USA

Overall Conference Schedule:

Tuesday, 1 June 2010

7:30 AM - 5/6:00 PM	Field trip to Caterpillar, Inc., Depart from Iowa Memorial Union, Madison Street
6:00 - 8:00 PM	Welcome Reception and Registration, 2nd floor ballroom, Iowa Memorial Union

Presentations will occur in the Bijou Theatre, Iowa Memorial Union (IMU) unless indicated otherwise

Wednesday, 2 June 2010

7:30-8:00 AM	Registration and Continental Breakfast, IMU Bijou Theatre Lobby
8:00-8:30 AM	Welcoming Remarks
8:30-9:00 AM	Keynote Address, Ren Dong, PhD
9:00-10:15 AM	Tissue Response to Vibration
10:15-10:45 AM	**Break (**IMU Main Lounge)
10:45-11:30 AM	Tissue Response to Vibration (Continued)
11:30-11:45 AM	HAV (Hand-Arm Vibration) Exposure Risk Reduction
11:45 AM-1:15 PM	**Lunch** (Box lunch, visit vendors) IMU Main Lounge
1:15-1:45 PM	Keynote Address, Tom Jetzer, MD, MPH
1:45-3:15 PM	Characterizing HAV Effects and Environments
3:15-3:45 PM	**Break (**IMU Main Lounge)
3:45-4:45 PM	HAV Modeling
4:45-5:15 PM	Group Picture, location to be announced
	Dinner on one's own

Thursday, 3 June 2010

7:30-8:00 AM	Executive/Scientific Committee meeting (Lucas-Dodge room, IMU, 2nd floor)
7:30-8:00 AM	Registration and Continental Breakfast, IMU Bijou Theatre Lobby
8:00-8:30 AM	Keynote Address, David Wilder, PhD
8:30-9:00 AM	Knowledge Gaps and Diagnosis Related to WBV (Whole-Body Vibration)
9:00-10:00 AM	Characterizing WBV Environments and Effects
10:00-10:30 AM	**Break** (Bijou Theatre Lobby)
10:30-11:15 AM	Characterizing WBV Environments and Effects (Continued)
11:15-11:45 AM	Comfort, Perception and Performance in WBV Environments
11:45-1:15 PM	**Lunch** (Box lunch-2nd floor ballroom, Tour of Center for Computer-Aided Design)
1:15-1:45 PM	Keynote Address, Suzanne Smith, PhD
1:45-3:15 PM	Comfort, Perception and Performance in WBV Environments (Continued)
3:15-3:45 PM	**Break** (Bijou Lobby)
3:45-4:15 PM	Comfort, Perception and Performance in WBV Environments (Continued)
6:30-9:30 PM	**BANQUET (Keynote: A Conversation with Don Wasserman)** 2nd floor ballroom

Friday, 4 June 2010

8:30-9:15 AM	Analysis and Modeling of WBV Responses
9:15-9:30 AM	WBV Exposure Risk Reduction
9:30-10:00 AM	Foot Response to WBV Exposure
10:00-10:30 AM	**Break** (Bijou Theatre Lobby)
10:30-10:45 AM	Instrumentation
10:45-11:00 AM	Pelvis Orientation Control
11:00-11:15 AM	**Closing Remarks**

Welcoming Remarks Speakers' Biosketches:

David Wilder, PhD, Conference Chair: See Keynote Speakers' biosketches

Fred Gerr, MD, is Professor of Occupational and Environmental Health and Epidemiology in the College of Public Health and Professor of Pulmonary, Critical Care, and Occupational Medicine in the College of Medicine at the University of Iowa. Dr. Gerr is trained in Internal Medicine and Occupational Medicine and is Director of the NIOSH-funded Great Plains Center for Agricultural Health and the Occupational Medicine Residency Training program in the Department of Occupational and Environmental Health. For nearly two decades he has been active in the study of work-related musculoskeletal disorders and has recently completed a prospective epidemiological study of musculoskeletal outcomes among manufacturing workers. In addition to an active research program, Dr. Gerr is also a staff physician at the University of Iowa Hospitals and Clinics where he evaluates and treats workers with upper limb disorders. Dr. Gerr has served as consultant to OSHA and NIOSH as well as to both labor and management groups interested in controlling musculoskeletal disorders among working people.

Barry Butler, PhD, (Professor of Mechanical and Industrial Engineering and Dean of the College of Engineering) will speak on his personal experience as an academic leader at the University of Iowa. In addition, he will provide a brief summary of the national engineering agenda and how it relates to Iowa. Butler has experience working as a visiting research fellow for the U.S. Navy and Sandia National Laboratories and as a visiting faculty member at Universite de Provence in Marseille, France. He has periodically engaged in professional consulting with Combustion Sciences Incorporated, Princeton Combustion Research Laboratories, Iowa Public Defenders Office, TRW Vehicle Safety Systems, Automotive Systems Laboratory, Battelle Memorial Institute, and Praxair Surface Technologies. He currently serves on the Boards of several state and national technology-based organizations committed to economic growth and advancing science, technology, engineering and math education. Butler also serves as Governor Culver's Delegate to the Aerospace States Association. Dr. Butler was recently elected to the Board of Directors of the American Wind Energy Association.

Richard Hichwa, PhD, (Associate Vice President for Research Development for Biological, Mathematical and Physical Science) has a background in Nuclear and Medical Physics and has held research and faculty positions at University of Notre Dame, Oak Ridge National Laboratory, University of Wisconsin-Madison, University of Michigan and the University of Iowa. His research interests involve: development of technology and methodology for biochemical and physiological investigation of human cellular function using Positron Emission Tomography (P.E.T.), fostering new areas of biotechnology, computer integration and high speed networking, and development of scientific visualization methodologies for analyzing medical and physical image data. His current projects involve: development of nuclear targets to produce positron nuclides, biochemical modeling of blood flow and oncology radiopharmaceuticals for P.E.T., design of new PET detector systems, design and implementation of distributed image processing systems, investigations of brain blood flow in cognitive stimulation for neurological and psychiatric research, and reduction and containment of radioactive waste products. He has received honors and funding for his extensive work in these areas.

Keynote Speaker and Caterpillar Host Biosketches:

Ren G. Dong, Ph.D. is the Leader of the Physical Effects Research Team in Engineering and Control Technology Branch in the Health Effects Laboratory Division, National Institute for Occupational Safety and Health (NIOSH). He holds an adjunct professorship at West Virginia University. He earned a B.Sc. (1982) and M.Eng. (1984) in Southwest Jiaotong University in China and a Ph.D (1994) in Mechanical Engineering from Concordia University in Canada. He has conducted railway vehicle research and provided consultation services in Centre for Surface Transportation Technology of the National Research Council in Canada. Since joining NIOSH in 1999, he has led the research on hand-arm vibration that has generated more than 70 peer-reviewed journal articles. Dr. Dong has received a Liberty Mutual Award and four of NIOSH's Alice Hamilton Awards in the last five years.

Tom Jetzer, M.D., M.P.H. is an occupational physician in private practice and has been providing medical care to many companies including injury care, consultation, ergonomic consulting, drug testing review and loss prevention for 35 years. He has been the Medical Director of a number of Fortune 500 companies and provides services to many U.S. government agencies including the FBI, US Army, US Post Office, NRC, DOT and the FAA. He has been involved in the medical aspect of vibration trauma including research, treatment and prevention since 1986 and has been a member of ANSI and ISO committees concerning vibration standards.

David G. Wilder, Ph.D. has worked in biomechanics since 1973 and earned his BSME (1974), MS (1978) and PhD (1985) degrees in Mechanical Engineering at the University of Vermont. He is a Professional Engineer (in Iowa and Vermont) and a Certified Professional Ergonomist. His research related to biomechanics of the trunk and lumbar spine began at the University of Vermont College of Medicine Department of Orthopaedics and Rehabilitation as an undergraduate and continued as a graduate student and then as a faculty member. For many years he has conducted in-vitro, in-vivo, field, and clinical studies of the effect of posture, vibration and sudden load on the trunk and lumbar spine. He was the first to report experimental evidence of short-column buckling in the lumbar motion segment due to exposure to a combination of vibration, sitting, and sudden load. Since his arrival at the University of Iowa in 1994 he has earned teaching and service awards. He has been appointed to the University of Iowa Honors Faculty, has received national and international research awards for his work in vibration and back problems, has served with national (ACGIH, ANSI) and international (ISO) standards-setting bodies related to human exposure to vibration, and has been elected Fellow of the American Institute for Medical and Biological Engineering. He holds faculty appointments in the University of Iowa College of Engineering Department of Biomedical Engineering as well as in the College of Public Health Department of Occupational and Environmental Health. He is an Associate Faculty member at the Palmer Center for Chiropractic Research (in Davenport, IA) collaborating on NIH- and HRSA-funded research. More importantly, every month for thirteen years he has tried to calm the concerns (and reduce the muscle tension) of University of Iowa Back Care patients by explaining how their backs work by means of simple mechanical metaphors.

Suzanne D. Smith, Ph.D. is a Senior Biomedical Engineer at the US Air Force Research Laboratory, 711 Human Performance Wing, Human Effectiveness Directorate, Bioscience and Performance Division, Vulnerability Analysis Branch, Wright-Patterson AFB OH. She received the BA degree in 1976 from the Dept of Biology at West Virginia University and the MSE degree in 1980 from the Dept of Mechanical Engineering at West Virginia University. She was hired as a civilian Biomedical Engineer by the USAF Aeromedical Research Laboratory in 1980, conducting biodynamics and injury biomechanics research. Dr. Smith received her PhD in Mechanical Engineering in 1988 from the Dept of Mechanical Engineering, University of Vermont. Dr. Smith is the lead AF expert on human vibration; she has conducted several studies and authored numerous papers on the effects of multi-axis vibration environments, including operational exposures, on human biodynamics, health, comfort, and performance, emphasizing mitigation strategies via the design of aircrew equipment and improved exposure standards. She is the USAF member to the ANSI Accredited Standards Committee on Mechanical Vibration and Shock and the ISO Technical Advisory Group on Human Exposure to Mechanical Vibration and Shock. Her current research is focused on characterizing operational stressor effects on psychophysical/physiological attributes and exploring mechanisms that influence warfighter cognitive performance.

Donald E. Wasserman, MSEE, MBA.: Donald E. Wasserman is an internationally known Biomedical Engineer and a recognized expert in the area of occupational vibration where he has been working for some four decades. In 1971-84, he served as the first Chief of the National Institute of Occupational Safety & Health [NIOSH] Occupational Vibration Group where he was responsible for both developing and implementing this nation's first program in occupational vibration. His NIOSH vibration studies were deemed "ground breaking" and very comprehensive containing medical, epidemiological, industrial hygiene, and engineering measurements/control aspects for both Hand-Arm Vibration and Whole-Body Vibration. These studies formed the basis for much of the vibration research and control implementation in use today throughout the United States. For four decades he has been actively involved in the formulation of virtually all occupational vibration standards, used today both in the U.S. and internationally as promulgated by ISO, ANSI, ACGIH, and NIOSH. He has authored/coauthored more than 100 professional papers, book chapters and books *[Human Aspects of Occupational Vibration; Hand-Arm Vibration: A Comprehensive Guide for Occupational Health Professional]*. Since 1984 to the present he has been a private human vibration and biomedical engineering consultant, lecturer, and consulting scientist; having performed numerous and varied additional studies in this area. He is the holder of two medical instrumentation patents related to occupational vibration. In 1988, he solely developed and has taught nationwide the accredited NIOSH # 596 course on occupational vibration. He is a scientific reviewer for numerous occupational medicine, industrial hygiene, and engineering journals. Mr. Wasserman is an adjunct professor of Industrial Engineering at the University of Tennessee and also serves as a principal senior staff scientist at UT's institute for the Study of Human Vibration. He was the 1999 recipient of the prestigious Baier Award for Technical Achievement awarded by the American Industrial Hygiene Association.

Michael S. Contratto is a technical specialist within Caterpillar's Electronics and Controls research group. Over his 21+ years at Caterpillar, Mr. Contratto has focused on machine and human vibration. He has dealt extensively with seat suspensions, cab mounts and track induced vibration. His objective at Caterpillar has been to provide Caterpillars customer/operators with a comfortable and productive operating environment. Mr. Contratto is currently focusing on means and methods of using a human rated motion platform/ride simulator to improve the development of machines for operator ride comfort.

Meeting Schedule:

Tuesday, 1 June 2010

7:30 AM - 5/6:00 PM	Field trip to Caterpillar, Inc., Depart from Iowa Memorial Union, Madison Street
6:00 - 8:00 PM	Welcome Reception and Registration, 2nd floor ballroom, Iowa Memorial Union

Wednesday, 2 June 2010

7:30-8:00 AM **Registration and Continental Breakfast, IMU Bijou Theatre Lobby**

8:00-8:30 AM **Welcoming remarks, IMU Bijou Theatre**
David Wilder, PhD, Conference Chair
Frederick Gerr, MD, Professor, College of Public Health and College of Medicine
Barry Butler, PhD, Dean, UI College of Engineering
Richard Hichwa, PhD, Associate VP for Research Development for Biological, Mathematical and Physical Science

8:30-9:00 AM **Keynote**: **The Future of Hand-Arm Vibration Research**
Ren Dong, PhD
Team Leader, Physical Effects Research Team
National Institute for Occupational Safety and Health (NIOSH)
Morgantown, West Virginia

9:00-10:15 AM **TISSUE RESPONSE TO VIBRATION**
Session Chair: Tammy Eger, PhD

9:00-9:15 Sandya Govindaraju*, Mwaba Chisela, Danny Riley: VIBRATION DISRUPTS THE ENDOTHELIAL BARRIER OF RAT-TAIL ARTERIES

9:15-9:30 X. Xu*, D.A. Riley, M. Persson, D. E. Welcome, K. Krajnak, S. Govindaraju, R. G. Dong: CHARACTERIZING IMPACT VIBRATION FOR RAT TAIL VIBRATION EXPOSURE EXPERIMENTS

9:30-9:45 Sandya Govindaraju, Olaf Rogness, Magnus Persson, James Bain Danny Riley*: SHOCK WAVE VIBRATION FROM A RIVETING HAMMER CAUSES ALTERED SENSORY PERCEPTION AND CUTANEOUS NERVE DAMAGE IN THE RAT-TAIL

9:45-10:00 Ji-Geng Yan*, David J. Rowe, Lin Ling Zhang, Kirkwood A. Pritchard Jr, Hani S. Matloub, Danny A. Riley: APOLIPROTEIN MIMETIC D-4F PRECODITION EFFECTS TO PREVENT VIBRATION INJURY ---- EXPERIMENT IN RATS

10:00-10:15 Kristine Krajnak, G. Roger Miller, Stacey Waugh, Claud Johnson, Shengqiao Li, and Michael Kashon: VASCULAR RESPONSES TO VIBRATION ARE FREQUENCY DEPENDENT

10:15-10:45 AM **Break (**IMU Main Lounge)

Wednesday, 2 June 2010

10:45-11:30 AM **TISSUE RESPONSE TO VIBRATION** (Continued)
Session Chair: Tony Brammer, PhD

10:45-11:00 Ron House*, Aaron Thompson, Tammy Eger, Kristine Krajnak, Depeng Jiang : VASCULAR SYMPTOMS AND DIGITAL PLETHYSMOGRAPHY ABNORMALITIES IN THE FEET OF WORKERS WITH HAVS

11:00-11:15 Juliana Gonçalves Dornela and Maria Lúcia Machado Duarte*: WHY CAN WHOLE BODY VIBRATION (WBV) CAUSE REDNESS ON VOLUNTEERS? THE EFFECT OF MECHANICAL VIBRATION AND ANXIETY ON PERIPHERAL BLOOD FLOW

11:15-11:30 Sarah A. Klemuk*, Ingo R. Titze: FUNCTIONALITY OF A RHEOMETER-BIOREACTOR TO STRESS AND ENGINEER TISSUE AT SONIC FREQUENCIES

11:30-11:45 AM **HAV (Hand-Arm Vibration) EXPOSURE RISK REDUCTION**
Session Chair: Tony Brammer, PhD

11:30-11:45 Mark B. Geiger*, Richard Borcicky, Gavin Burdge, James Chaney, Steven G. Chervak, Ren G. Dong, Craig M. Henderson, Roy Jardin, Donald Wasserman: PROCESS MANAGEMENT AND TOOL SELECTION TO MINIMIZE RISK OF HAND-ARM VIBRATION SYNDROME

11:45-1:15 PM **Lunch** (Box lunch, visit vendors) IMU Main Lounge

1:15-1:45 PM **Keynote**: **Hand-Arm Vibration: A Physician's Approach**
Tom Jetzer, MD, MPH
Occupational Medicine Consultants
Minneapolis, Minnesota

1:45-3:15 PM **CHARACTERIZING HAV EFFECTS AND ENVIRONMENTS**
Session Chair: Ren Dong, PhD

1:45-2:00 A.J. Brammer*, M.G. Cherniack, E. Toppila, P. Sutinen, R. Lundström, T. Nilsson, G. Neely, T. Morse, A. Sinha, M.J. Eaman, D. Peterson, and N. Warren: TOWARDS A QUANTITATIVE SENSORY TEST FOR HAND NUMBNESS

2:00-2:15 Neil J Mansfield*, Nobuyuki Shibata, Kazuma Ishimatsu, Setsuo Maeda: EFFECT OF GRIPPING IN A TRIGGER POSTURE ON APPARENT MASS OF THE HAND-ARM SYSTEM

2:15-2:30 Bryan Wimer, Thomas W. McDowell, Xueyan S. Xu, Daniel E. Welcome, Christopher Warren, and Ren G. Dong: EFFECTS OF GLOVES ON THE GRIP STRENGTH APPLIED TO CYLINDRICAL HANDLES

Wednesday, 2 June 2010

2:30-2:45 TW McDowell, C Warren, DE Welcome, RG Dong: LABORATORY MEASUREMENT OF RIVETING HAMMER VIBRATION

2:45-3:00 Donald R. Peterson*, Takafumi Asaki, Anthony J. Brammer, Martin G. Cherniack: NOISE AND VIBRATION EXPOSURES TO DENTAL HYGIENISTS

3:00-3:15 Ren G. Dong*, Daniel E. Welcome, Thomas W. McDowell, Xueyan S. Xu, John Z. Wu, and Subhash Rakheja: MECHANICAL IMPEDANCES DISTRIBUTED AT THE FINGERS AND PALM OF THE HUMAN HAND SUBJECTED TO 3-D VIBRATIONS

3:15-3:45 PM **Break (**IMU Main Lounge)

3:45-4:45 PM **HAV MODELING**
Session Chair: Kristine Krajnak, PhD

3:45-4:00 J.Z. Wu, R.G. Dong, D.E. Welcome, X.S. Xu: A THEORETICAL ANALYSIS OF VIBRATION POWER ABSORPTION DENSITY IN HUMAN FINGERTIP

4:00-4:15 S. Adewusi, S. Rakheja, P. Marcotte: BIOMECHANICAL MODEL OF THE HAND-ARM SYSTEM TO SIMULATE DISTRIBUTED BIODYNAMIC RESPONSES

4:15-4:30 Robin DeJager-Kennedy* and Jay Kim: SEMI-ANALYTIC ESTIMATION OF THE RESPONSE OF HAND-HELD TOOLS AND ITS APPLICATIONS

4:30-4:45 S. Pattnaik*, J. Kim: TWO-STEP APPROACH USING LUMPED PARAMETER AND FEM MODELS FOR HAND AND ARM VIBRATION ANALYSIS

4:45-5:15 PM **Group Picture,** location to be announced

Dinner on one's own

Thursday, 3 June 2010

7:30-8:00 AM **Executive/Scientific Committee meeting (Lucas-Dodge room, 2nd floor IMU)**
7:30-8:00 AM **Registration and Continental Breakfast, IMU Bijou Theatre Lobby**

8:00-8:30 AM **Keynote**: **Explaining What We Do**
David G. Wilder, PhD, PE, CPE, FAIMBE
Director, Jolt/Vibration/Seating Lab, Iowa Spine Research Center
University of Iowa, Iowa City, Iowa

8:30-9:00 AM **KNOWLEDGE GAPS AND DIAGNOSIS RELATED TO WBV**
Session Chair: Don Wasserman, MSEE, MBA

8:30-8:45 Helmut W. Paschold: WHOLE-BODY VIBRATION KNOWLEDGE GAPS IN THE US

8:45-9:00 Eckardt Johanning: DIFFERENTIAL DIAGNOSIS OF WHOLE-BODY VIBRATION RELATED DISORDERS

9:00-10:00 AM **CHARACTERIZING WBV ENVIRONMENTS AND EFFECTS**
Session Chair: Don Wasserman, MSEE, MBA

9:00-9:15 Peter W. Johnson*, Patrik Rynell and Ryan Blood: DIFFERENCES IN WHOLE BODY VIBRATION EXPOSURES BETWEEN A CAB-OVER AND CONVENTIONAL FLATBED TRUCK

9:15-9:30 Igor M. Dudnyk, Olena A. Kossenkova-Dudnyk: EVALUATION OF WHOLE-BODY VIBRATION AT WORKPLACES OF TROLLEYBUS DRIVERS AND PROPHYLACTIC MEASURES

9:30-9:45 Dennis A. Mitchell, Luis Morales*: A COMPARISON OF 1980'S AND CURRENT GENERATION LOCOMOTIVE SEATS RELATIVE TO WHOLE BODY VIBRATION HEALTH EFFECTS

9:45-10:00 Yi Qiu and Michael J. Griffin: EFFECT OF BACKREST CONTACT ON THE APPARENT MASS OF THE SEATED HUMAN BODY EXPOSED TO SINGLE-AXIS AND DUAL-AXIS EXCITATION

10:00-10:30 AM **Break** (Bijou Theatre Lobby)

Thursday, 3 June 2010

10:30-11:15 AM **CHARACTERIZING WBV ENVIRONMENTS AND EFFECTS** (Continued)
Session Chair: Suzanne Smith, PhD

10:30-10:45 Lauren Gant*, David Wilder, Donald Wasserman: HUMAN RESPONSE TO SINGLE AND COMBINED SINUSOIDAL VERTICAL VIBRATION

10:45-11:00 Heon-Jeong Kim* and Bernard J. Martin: WHOLE-BODY VIBRATION RESPONSE THROUGH THE UPPER LIMBS ASSOCIATED WITH REACHING MOVEMENTS AND POSTURE

11:00-11:15 Robert Caryn BA*, J.P. Dickey, Alan Salmoni, Peter Lemon, Tom J. Hazell: TRANSMISSION OF ACCELERATION FROM VIBRATING EXERCISE PLATFORMS TO THE LUMBAR SPINE AND HEAD

11:15-11:45 AM **COMFORT, PERCEPTION AND PERFORMANCE IN WBV ENVIRONMENTS**
Session Chair: Suzanne Smith, PhD

11:15-11:30 Nobuyuki Shibata*, Kazuma Ishimatsu and Setsuo Maeda: GENDER DIFFERENCE OF SUBJECTIVE RESPONSES TO WHOLE-BODY VIBRATION UNDER STANDING POSTURE

11:30-11:45 Kazuma Ishimatsu*, Nobuyuki Shibata, Setsuo Maeda: EFFECTS OF WHOLE-BODY VIBRATION ON THE PERCEIVED DURATION OF A VISUAL STIMULUS PRESENTATION

11:45-1:15 PM **Lunch** (Box lunch, Center for Computer-Aided Design Lab Tour)

1:15-1:45 PM **Keynote**: **The Characteristics and Challenges of Higher Frequency, Aircraft Vibration Exposure**
Suzanne D. Smith, PhD
Senior Biomedical Engineer
Air Force Research Lab – Human Effectiveness Directorate
Wright Patterson Air Force Base, Ohio

Thursday, 3 June 2010

1:45-3:15 PM **COMFORT, PERCEPTION AND PERFORMANCE IN WBV ENVIRONMENTS**
Session Chair: Neil Mansfield, PhD

1:45-2:00 Priscila A. de Araújo, Maria Lúcia M. Duarte*, Frederico C. Horta, Lucas A. Penna de Carvalho, Guilherme G. Roca Arenales: THE EFFECT OF EXPOSURE DURATION ON WHOLE-BODY VIBRATION COMFORT

2:00-2:15 Miyuki Morioka and Michael J. Griffin: MASKED THRESHOLDS FOR FORE-AND-AFT VIBRATION OF THE BACK

2:15-2:30 Michele Oliver*, Leanne Conrad, Robert J. Jack, James P. Dickey, Tammy Eger: COMFORT BASED SEAT SELECTION TO MINIMIZE 6 DOF WHOLEBODY VIBRATION IN INTEGRATED STEEL MANUFACTURING MOBILE MACHINERY

2:30-2:45 Pankoke S*, Siefert A: RATING METHODS FOR DYNAMIC SEATING COMFORT TO BE APPLIED WITH NUMERICAL SEAT MODELS, VIBRATION DUMMY TESTS AND PASSENGER RIDE TESTS

2:45-3:00 Katherine Plewa, James P. Dickey*, Tammy Eger, Michele Oliver: ARE COMFORT PREDICTIONS FROM ISO 2631-1 AND SELF-REPORTED COMFORT VALUES DURING OCCUPATIONAL EXPOSURE TO WHOLE-BODY VEHICULAR VIBRATION RELATED?

3:00-3:15 Jonathan DeShaw*, Salam Rahmatalla: EFFECT OF HEAD-NECK POSTURE ON HUMAN DISCOMFORT DURING WBV

3:15-3:45 PM **Break** (Bijou Theatre Lobby)

3:45-4:15 PM **COMFORT, PERCEPTION AND PERFORMANCE IN WBV ENVIRONMENTS**
Session Chair: Neil Mansfield, PhD

3:45-4:00 Suzanne D. Smith, Jennifer G. Jurcsisn, Cecelia J. Harrison: PERFORMANCE ASSESSMENT DURING MILITARY AIRCRAFT OPERATIONAL VIBRATION EXPOSURE

4:00-4:15 Tammy Eger, Michael Contratto, Jim Dickey: INFLUENCE OF DRIVING SPEED, TERRAIN, SEAT PERFORMANCE AND VEHICLE VIBRATION CONTROL FEATURES ON VIBRATION EXPOSURE

6:30-9:30 PM **BANQUET** (IMU 2nd floor ballroom)

Keynote: **The Long View: A Conversation with Don Wasserman**
Donald E. Wasserman, MSEE, MBA
First chief of the NIOSH Occupational Vibration Section

Friday, 4 June 2010

8:30-9:15 AM **ANALYSIS AND MODELING OF WBV RESPONSES**
Session Chair: Salam Rahmatalla, PhD

8:30-8:45 Vinay A.H. Reddy*, Raghu R. Channamallu, Sara E. Wilson NEUROMOTOR TRANSMISSIBILITY OF HORIZONTAL SEATPAN VIBRATION AND A MATHEMATICAL MODEL

8:45-9:00 Guangtai Zheng, Yi Qiu and Michael J Griffin: MULTIBODY MODELLING OF THE VERTICAL APPARENT MASS AND FORE-AND-AFT CROSS-AXIS APPARENT MASS OF THE SEATED HUMAN BODY WITH A BACKREST

9:00-9:15 S. Mandapuram, S. Rakheja, P-E. Boileau: ANALYSIS OF COUPLING EFFECTS IN SEATED BODY BIODYNAMIC RESPONSES TO MULTI-AXIS VIBRATION

9:15-9:30 AM **WBV EXPOSURE RISK REDUCTION**
Session Chair: Salam Rahmatalla, PhD

9:15-9:30 Douglas Reynolds*: SEAT AIR BLADDER SYSTEM FOR PROTECTING VEHICLE OCCUPANTS FROM SHOCK AND VIBRATION

9:30-10:00 AM **FOOT RESPONSE TO WBV EXPOSURE**
Session Chair: Salam Rahmatalla, PhD

9:30-9:45 Aaron Thompson*, Ron House, Tammy Eger, Kristine Krajnak: VIBRATION-WHITE FOOT: A CASE REPORT

9:45-10:00 Mallorie Leduc, Tammy Eger, Alison Godwin, Jim Dickey, Ron House: EXAMINATION OF VIBRATION CHARACTERISTICS FOR WORKERS EXPOSED TO VIBRATION VIA THE FEET

10:00-10:30 AM **Break** (Bijou Theatre Lobby)

10:30-10:45 AM **INSTRUMENTATION**
Session Chair: Salam Rahmatalla, PhD

10:30-10 :45 Pierre Marcotte*, Sylvain Ouellette, Jérôme Boutin, Gilles LeBlanc: DESIGN OF A LOW COST WIRELESS ACQUISITION SYSTEM FOR HUMAN VIBRATION MEASUREMENT IN HARSH ENVIRONMENTS

10:45-11:00 AM **PELVIS ORIENTATION CONTROL**
Session Chair: Salam Rahmatalla, PhD

10:45-11:00 DG Wilder*, E Owens, MR Gudavalli, RD Macken, T Xia, R Vining, K Pohlman, L Corber, W Meeker, C Goertz, J G. Pickar: PELVIC REPOSITIONING IN LOW BACK PAIN PATIENTS

11:00-11:15 AM **Closing Remarks**

Abstracts

Wednesday, 2 June 2010

7:30-8:00 AM **Registration and Continental Breakfast, IMU Bijou Theatre Lobby**

8:00-8:30 AM **Welcoming remarks**

8:30-9:00 AM **Keynote**: **The Future of Hand-Arm Vibration Research**
Ren Dong, PhD
Team Leader, Physical Effects Research Team
National Institute for Occupational Safety and Health (NIOSH)
Morgantown, West Virginia

9:00-10:15 AM **TISSUE RESPONSE TO VIBRATION**

9:00-9:15 Sandya Govindaraju*, Mwaba Chisela, Danny Riley: VIBRATION DISRUPTS THE ENDOTHELIAL BARRIER OF RAT-TAIL ARTERIES

9:15-9:30 X. Xu*, D.A. Riley, M. Persson, D. E. Welcome, K. Krajnak, S. Govindaraju, R. G. Dong: CHARACTERIZING IMPACT VIBRATION FOR RAT TAIL VIBRATION EXPOSURE EXPERIMENTS

9:30-9:45 Sandya Govindaraju, Olaf Rogness, Magnus Persson, James Bain Danny Riley*: SHOCK WAVE VIBRATION FROM A RIVETING HAMMER CAUSES ALTERED SENSORY PERCEPTION AND CUTANEOUS NERVE DAMAGE IN THE RAT-TAIL

9:45-10:00 Ji-Geng Yan*, David J. Rowe, Lin Ling Zhang, Kirkwood A. Pritchard Jr, Hani S. Matloub, Danny A. Riley: APOLIPROTEIN MIMETIC D-4F PRECODITION EFFECTS TO PREVENT VIBRATION INJURY ---- EXPERIMENT IN RATS

10:00-10:15 Kristine Krajnak, G. Roger Miller, Stacey Waugh, Claud Johnson, Shengqiao Li, and Michael Kashon: VASCULAR RESPONSES TO VIBRATION ARE FREQUENCY DEPENDENT

10:15-10:45 AM **Break (**IMU Main Lounge)

VIBRATION DISRUPTS THE ENDOTHELIAL BARRIER OF RAT-TAIL ARTERIES

Sandya Govindaraju[*1], Mwaba Chisela[2], Danny Riley[1]
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[2]University of Wisconsin, Milwaukee, WI 53201

Introduction

We have utilized the rat-tail vibration model to study the acute effects of vibration and explore mechanisms for vascular pathology in HAVS. We reported previously that 4-hr continuous vibration produces vasoconstriction in rat-tail arteries, tight folding and breaks in the internal elastic membrane, and endothelial cell vacuolization injury.[1,2] The present study investigated whether the vasoconstriction and cell damage caused by a single 4-hr vibration exposure disrupts the integrity of the endothelial barrier.

Methods

Morphometric evaluation: Male Sprague-Dawley rats, weighing 275-300 gm had their tails vibrated at 60 Hz, 49 m/s^2 acceleration for 4 hr and were allowed to recover for 0, 1 or 7 days (Immediate, 1d and 7d survival groups), using our rat-tail model.[3] Control sham rats were treated similar to the vibration immediate group except not exposed to vibration. Tail arteries were aldehyde fixed, embedded in epoxy resin and semithin cross sectioned (0.5 µm) and stained for morphometric analysis. Vasoconstriction was determined by lumen size measurement using version 1.28v Image J software (NIH). The total numbers of endothelial vacuoles were counted to assess cell injury.

Evan's Blue (EB) functional assay: To test if vibration disrupts the barrier function of the endothelial layer in the tail arteries, 32 rats were randomly assigned to EB-sham, EB-immediate, EB-1d survival and EB-7d survival groups and treated as described above. Following vibration, rats were anaesthetized, and EB (20 mg/kg body wt) was injected into the systemic circulation via the liver blood supply. After 15 min, a systemic arterial blood sample was collected via cardiac puncture for measurement of the circulating EB concentration. The serum was separated and stored for spectrophotometric assay of EB content using an EB albumin standard curve. Rats were euthanized and perfused with phosphate buffer to clear all EB from the vascular network, and the tail arteries were removed and quick frozen for microscopic and biochemical analysis. A weighed segment of artery was incubated in 100 µl of formamide for 24 hr at 4° C to extract EB. The dye content in the formamide was measured spectrophotometrically at the wavelength of 595 nm and normalized to the EB serum content for the same animal.

Results

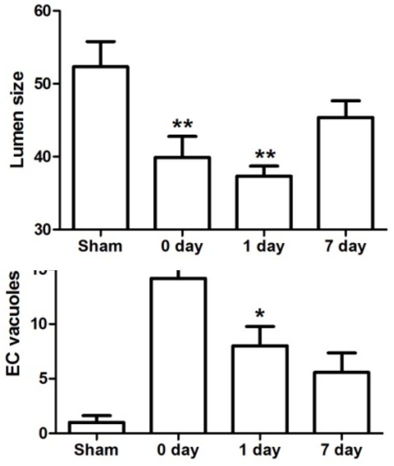

Figure 1: Compared to sham exposure, vibration caused a significant decrease in lumen size immediately following exposure (** $p<0.01$). Vasoconstriction persisted 1 day post-exposure but was not different from sham at 7 days. Vibration increased endothelial cell (EC) vacuoles, a injury index, immediately following exposure compared to sham (***$p<0.001$). Vacuoles persisted in significant numbers in the 1 day survival group (* $p<0.05$ compared to sham and 0 day). At day 7, vacuole numbers were not different from sham.

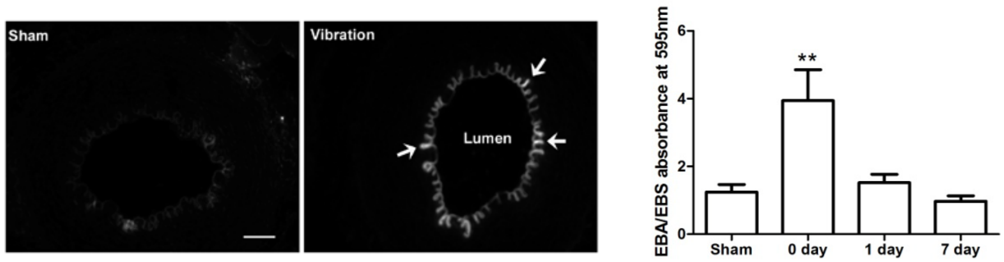

Figure 2: Extravasation of EB into the artery (arrows) was detected on day 0 by immunofluorescence imaging of artery cross sections and confirmed quantitatively by spectrophotometric measurement of EB content in artery extracts (**$p<0.01$). EB levels were not different from sham by day 1 recovery, even though EC vacuoles persisted.

Conclusions

1. A 4 hr exposure to vibration causes persistent vasoconstriction and endothelial cell injury which are reversed by 7 days.
2. Immediately post vibration, the endothelial barrier was breached because circulating EB dye entered the artery wall. The barrier was restored within 24 hr.
3. A single bout of vibration induces arterial pathologies of reduced lumen size and break down of the endothelial barrier. If daily repeated vibration exposure were to sustain these pathologies, the long term consequence would be reduced blood flow and vascular fibrosis predicted for vibration white finger.

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3. Curry, B.D., et al., Vibration injury damages arterial endothelial cells. Muscle Nerve, 2002. **25**(4): p. 527-34.

Characterizing Impact Vibration for Rat Tail Vibration Exposure Experiments

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[**]Medical College of Wisconsin, Milwaukee, WI, USA
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INTRODUCTION

Vibration-induced finger disorders are major components of hand-arm vibration syndrome. The frequency weighting specified in the current standard for the risk assessment of the hand-transmitted vibration exposure emphasizes the risk of injury associated with exposures to vibration frequencies at less than 50 Hz, with the highest weighting value occurring at 12.5 Hz[1]. The validity of this weighting for assessing vibration-induced finger disorders is questionable. Whether and how high-frequency vibrations affect development of the disorders remains an important issue for further studies. It is also unclear whether the rms acceleration adopted in the current standard is a good vibration measure for assessing the risk of shock or impact vibration exposure, and if the biodynamic response of the fingers is closely associated with finger disorders. A new testing platform that uses a riveting hammer to produce impact vibration has been recently developed so that the rat-tail model of vibration-induced injury can be used to investigate the above issues. The objectives of this study are to characterize the impact vibration input to the platform and that transmitted to the tail.

METHODS

As shown in Fig. 1, the rat tail impact testing platform is a riveting hammer vertically fixed on a stand with the rivet set replaced with a bell-shaped steel plate on which the rat tail is positioned during the experiment. Two bungee cords are used as fasteners to provide a load on the platform. The riveting hammer is driven using compressed air, and a pressure regulator controls the input pressure. A scanning laser vibrometer was used to scan five measurement points spread across the platform, glove materials or rat tails. The measurement at each location lasted 10 seconds, and the vibration up to 21.75 kHz was measured. The study variables included applied load, air pressure, measurement location, and platform conditions (air or gel gloved and ungloved). As a random factor, four rats were used in this study. Three trials were performed for each treatment. The time history of the velocity signal from the laser vibrometer in each trial was recoded using a data acquisition system. From the recorded data, three typical vibration measures (peak accelerations, weighted and unweighted rms accelerations) were quantified for characterizing the impact vibration.

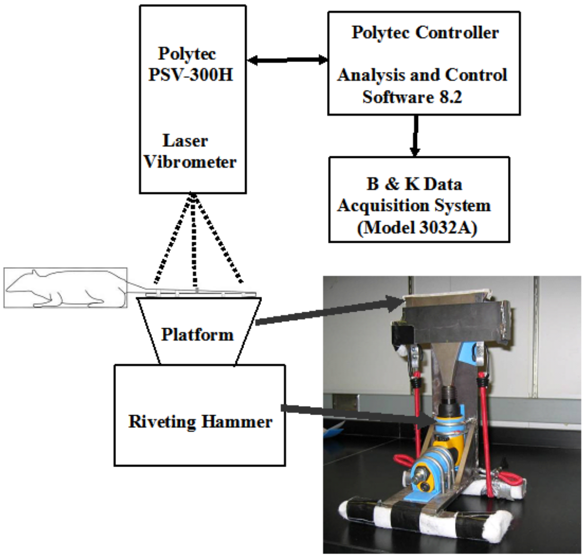

Fig.1 Rat tail impact testing platform

RESULTS AND DISCUSSIONS

Fig. 2 shows typical examples of the acceleration time histories measured at the middle location of the platform in three of the six platform treatments, which were filtered at a cut-off frequency of 1,500 Hz. Peak accelerations on the bare platform (P) were much higher than the rest. Both air glove materials (AG) and gel glove materials (GG) reduced the peaks significantly. The rat tails on the platform (RTP) also absorbed high frequency vibrations and reduced the peaks. Peaks measured from the rat tail on the air glove material (RTAG) were around 500 m/s^2 and were around 300 m/s^2 on the gel glove material (RTGG). Judging purely by the peak accelerations, one would conclude that the impact vibration from the bare platform should cause more severe health effects than that from the glove materials-cushioned platform, especially with the gel glove material.

However, the effects of the glove materials and rat tail on the rms acceleration (integrated from 6.3 to 1,250 Hz in the one-third octave bands) are the opposite: the unweighted and weighted rms accelerations under these conditions were either similar to or greater than those on the bare platform, as shown in Table 1. This is because the glove materials and/or rat tail amplified a portion of the vibration components below 1,250 Hz, although they effectively attenuated high frequency peaks. Based on the ISO risk assessment, results from this study indicate that anti-vibration gloves do not help isolate impact vibration and may make it worse.

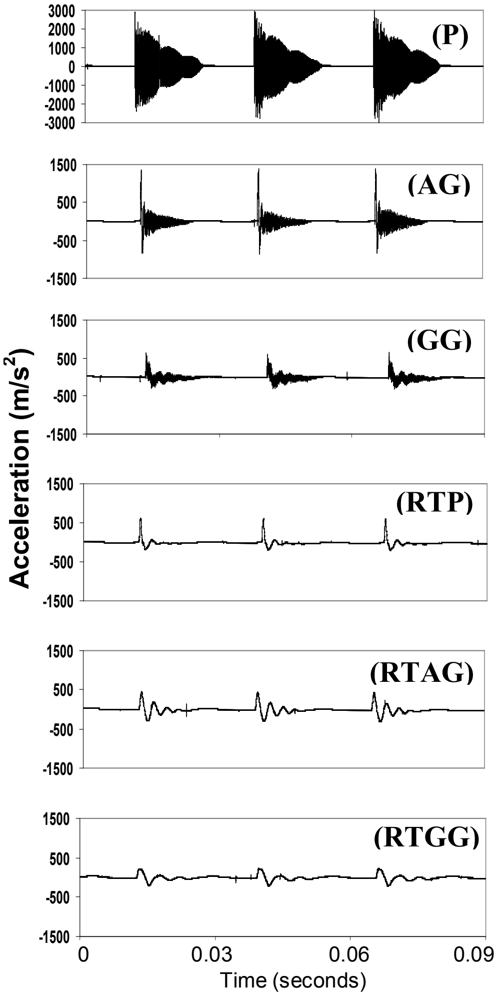

Fig.2 Typical examples of the accelerations

This rat tail impact test platform, together with the glove materials, can be used to study the mechanisms of the impact vibration-induced disorders, to examine the validity of the frequency weighting, and to explore alternative vibration measures.

Table 1 Peaks, Unweighted and Weighted rms Accelerations (m/s^2) with Coefficients of Variation (CV)

	Peaks		Unweighted rms		Weighted rms	
Treatments	Average	CV	Average	CV	Average	CV
P	3010	0.10	82.46	0.03	6.99	0.01
AG	1168	0.14	97.41	0.07	6.9	0.02
GG	492	0.31	81.37	0.08	7.51	0.05
RTP	548	0.25	88.35	0.14	8.52	0.05
RTAG	462	0.14	104.03	0.09	9.1	0.04
RTGG	271	0.13	82.4	0.07	9.84	0.05

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SHOCK WAVE VIBRATION FROM A RIVETING HAMMER CAUSES ALTERED SENSORY PERCEPTION AND CUTANEOUS NERVE DAMAGE IN THE RAT-TAIL

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Introduction

Peripheral neuropathy is a major component of Hand-arm vibration syndrome (HAVS), an occupational disease affecting workers exposed to vibration from hand held powered-tools. Patients with HAVS complain of persistent tingling, numbness, and sensory dysfunction. Several neurophysiological studies of vibration-exposed patients have reported reduced sensory nerve conduction velocity and amplitude in the median and radial nerves. Altered vibrotactile and temperature thresholds also suggest that vibration may injure peripheral nerve endings and mechanoreceptors[1] . Patients with HAVS show a significant reduction in the number of nerve fibers in skin biopsies[2]. Using the rat-tail vibration model, we investigated the effects on tail skin innervation of shock wave vibration from a riveting hammer activated for 12 min.

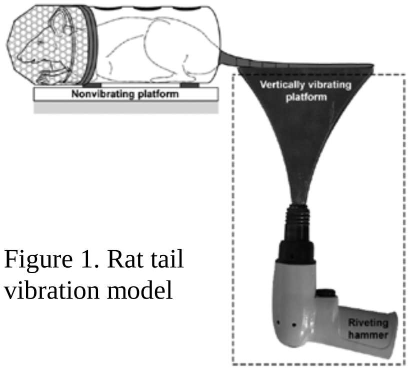


Figure 1. Rat tail vibration model

Methods

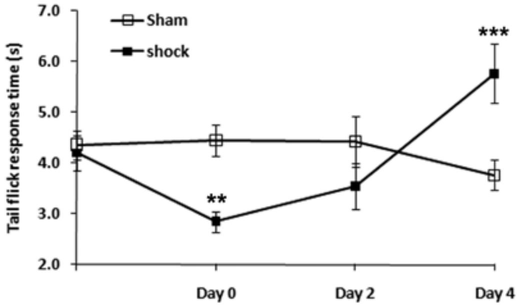
Vibration protocol: Sprague-Dawley male rats weighing 275-300 gm were randomly assigned to one of four groups: shock wave day 0, shock wave 4-day survival, sham day 0 and sham 4-day survival, with an n of 7 or 8 rats/group. The rat was restrained in a tubular cage mounted to a non-vibrating platform. The Atlas Copco riveting gun (RRH04P) was stabilized in a custom-built steel rig. A fan-shaped steel impactor was fabricated as the tool piece to deliver the impulse vibration from the gun and serve as the test platform for the tail (figure 1). The test rat-tails were taped to the platform and vibrated 12 min. The sham animals were restrained with their tails taped to non-vibrating metal platforms within two feet of the riveting hammer.

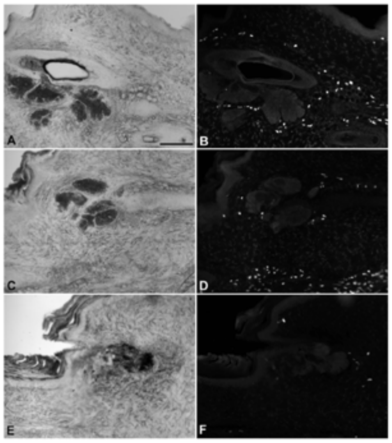
Tail-flick response: The proximal, middle and distal tail segments were stimulated by a noxious heat test apparatus, and the elapsed time at which the rat flicked the tail from the heat was recorded before and immediately after vibration or sham-vibration exposure. The tail-flick test was repeated on day 2 and day 4 for the rats in the survival groups.

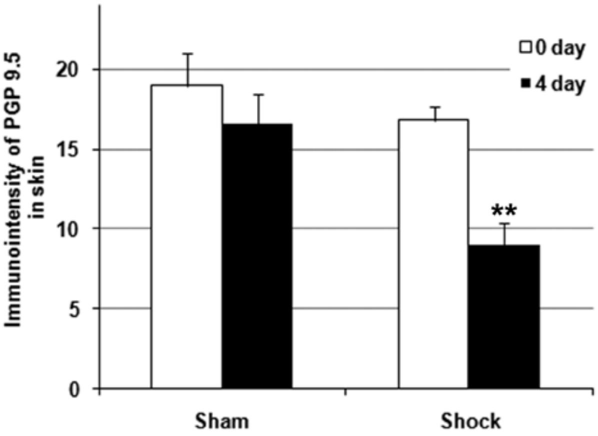
Immunohistochemistry: Cryostat cross sections (30 µm) of tail skin were immunostained with pan-neuronal primary rabbit polyclonal antibodies PGP 9.5 (1:4000 in 0.5% Triton X100, phosphate buffered, Axell, Westbury, NY), goat anti-rabbit biotinylated secondary (1:1000 in 0.5% Triton phosphate buffer, Invitrogen) and avidin linked Alexa-fluor 488 tertiary (1:1000 in 0.5% Triton phosphate buffer, Invitrogen). Immunofluorescence photomicrographs were taken using a fixed time exposure for all sections. The intensity of the immunohistochemical signal pixel brightness was measured using MetaMorph 5.2 imaging software (West Chester, PA).

Results

Figure 2: The tail flick response times were unchanged through the 4 days in the sham vibration group. The shock vibration group demonstrated a significant 34% decrease in mean response time immediately following vibration. Two days post-vibration, the response time was not different from the pre-exposure value. By day 4, the response time was significantly prolonged to 141% of the pre-exposure value.







Figures 3 and 4: Tail skin sections from sham day 0 (A brightfield, B immunofluorescence), shock day 0 (C, D) demonstrated normal immunofluorescence staining of nerve fibers with PGP 9.5 antibody. The shock day 4 group (E,F) exhibited decreased immunoreactivity. ** significantly different from all other groups, p<0.01.

Summary and Conclusions

1. Shock wave vibration causes a hypersensitization to thermal stimuli on day 0 and hyposensitivity by day 4.
2. The hyposensitivity is correlated with loss of nerve fibers innervating the tail skin.
3. The striking functional and structural deficits induced by a single, 12-min exposure to shock wave vibration reveal that impulse vibration is highly neuropathological.

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APOLIPROTEIN MIMETIC D-4F PRECODITION EFFECTS TO PREVENT VIBRATION INJURY

---- experiment in rats

***[1]Ji-Geng Yan, [1]David J. Rowe, [1]Lin Ling Zhang, [2]Kirkwood A. Pritchard Jr,**
[2]Hani S. Matloub,
[3]Danny A. Riley
[1]Department of Plastic Surgery; [2] Department of Pediatric Surgery; [3]Department of Cell Biology, Neurobiology & Anatomy. Medical College of Wisconsin, Milwaukee, Wisconsin, USA

INTRODUCTION

Our previous studies demonstrated that the ventral artery in the rat-tail exposed to short-term vibration shows vasoconstriction and endothelial-cell damage. The present study investigated whether pretreatment with D-4F, an apolipoprotein A-1 mimetic with known antioxidant and vasodilatory properties[1-3], prevents vibration-induced vasoconstriction, endothelial-cell injury and protein nitration

MATERIALS AND METHODS

Male adult SD rats weighing between 250g-300g were used, randomly assigned to 9 groups (n=8 per group, detail, See Table 1) Vibration treatment for rats' tails were 4 hours per day continuously at 60 Hz, 49 m/s^2 r.m.s. acceleration for either 1 or 3 consecutive days. The vibration platform was vertically accelerated by a Brüel and Kjær motor. Vibration parameters were set and rechecked with a Brüel and Kjær Integrating Vibration Meter. D-4F, the ApoA-I mimetic peptide, was synthesized by the Protein and Nucleic Acid Shared Facility of the Medical College of Wisconsin and the BloodCenter of Wisconsin. All rats received intraperitoneal injections one hour prior to the initiation of the vibration experiment protocol. The rats in Groups 3, 5, 7, and 9 received an intraperitoneal injection of D-4F (3mg/kg). All other rats received intraperitoneal injection of sterile saline. One-day groups received a single injection, and the 3-day groups received three injections. The rats were then anesthetized with intraperitoneal sodium pentobarbital. The arteries in tail segments C5 and C6 were dissected under the microscope for paraffin embedding. Arteries from the C7 and C8 segments were dissected under the microscope and postfixed and embedded in epoxy resin as performed previously. Paraffin sections were cut at 6 µm for immunohistochemistry. Staining for nitrated tyrosines by incubating with rabbit anti-nitrotyrosine (1:250, Upstate Biotechnology, Lake Placid, NY) followed by goat anti-rabbit IgG. To quantify immunoperoxidase staining, sections from all group arteries were incubated together and photographed digitally at the same exposure and light intensity setting and X20 magnification. Optical density of staining was analyzed using MegVue 5.0r7 software (Universal imaging Corporation, Downingtown, PA), with four regions positioned at 3, 6 and 9 and 12 o'clock sampled per artery. The values from the four regions were averaged to derive the mean optical density for the artery.

Semithin, epoxy cross sections stained with toluidine blue and digitally imaged for computer-assisted measurement of the artery lumen circumference and length of the internal elastic membrane. The degree of vasoconstriction was defined as the lumen circumference divided by the length of the internal elastic membrane times 100.

RESULTS

Lumen size

The decrease in lumen size was prevented by 1 and 3 days of D-4F treatment D-4F treatment of the sham vibration groups (Groups 2 and 6) produced no detected difference in lumen size when compared with the control group (Group 1). Vibration-induced cellular damage was similar to that described previously in constricted arteries; endothelial cells were severely compressed and protruding into the lumen.

Nitrotyrosine immunoperoxidase staining Intense immunostaining for nitrotyrosine was present in the walls of the arteries of the 1- and 3-day vibration groups. D-4F treatment prevented vibration induction of nitrotyrosine (Fig. 2). Sham vibration groups (Groups 2 and 6) and sham vibration with D-4F injection groups (Groups 3 and 5) exhibited little or no immunostaining.

Optical density quantitation revealed that vibration for 1-day produced darker staining of the tunica media compared to that in the sham vibration groups. D-4F treatment blocked nitration in the vibration groups. Staining of the 1-day Vibration+D-4F group was not different from that of the Shams or Vibration. The 3-day vibration group exhibited greater staining than the 3-day sham vibration group. The 3-day vibration group also exhibited greater staining than the 1-day vibration group. The 3-day vibration with D-4F group showed significantly lighter staining than 3-day vibration group.

DISCUSSION

What attributes of D-4F are postulated to counter vasoconstriction, cell damage and nitration? D-4F has been shown to improve acetylcholine mediated eNOS dependent vasodilation and restores a safe balance of nitric oxide and superoxide anion generation in endothelial cells[2]. With preservation of eNOS function and without superoxide excess, peroxynitrite is not generated to exacerbate endothelial cell damage. Our research indicates that vibration can trigger an intense vasoconstriction, which is a major early contributor for the development of vascular dysfunction in HAVS. The present study shows that D-4F prevents vasoconstriction, which appears to work by preserving NO mediated vasorelaxation. The ability of D-4F to minimize oxidative stress and endothelial cell injury makes it a superb antidote for vibration induced endothelial cell injury[1,3]. Further studies are needed to determine which of the manifold protective actions of D-4F are actively protecting arteries from vibration injury in the rat-tail model.

The knowledge gained from these studies may prove to be useful in the prevention of HAVS

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VASCULAR RESPONSES TO VIBRATION ARE FREQUENCY DEPENDENT

Kristine Krajnak[1], G. Roger Miller[1], Stacey Waugh[1], Claud Johnson[1], Shengqiao Li[2], and Michael Kashon[2]. [1]Engineering and Controls Technology Branch, [2]Biostatistics and Epidemiology Branch, National Institute for Occupational Safety and Health, Health Effects Laboratory Division, Morgantown, WV 26505

Introduction

The current frequency weighting used in the ISO-5349 standard assigns greater weight to lower frequency vibration (i.e., less than 16 Hz), and significantly less weight to exposure frequencies greater than 100 Hz. However, recent experimental and epidemiological studies suggest that this weighting may underestimate the risk of injury associated with exposure to higher frequency vibration (1, 2). The goal of this study was to use a rat-tail model to determine how exposure to higher frequency vibration (i.e., 62.5 – 250 Hz) affects peripheral nerves and arteries. We chose to use this model because previous work from our lab has demonstrated that the biodynamic response of the rat tail and human finger are similar within this frequency range (3), and thus, we expect that the frequency dependent changes we see in this study will be representative of the changes seen in human fingers.

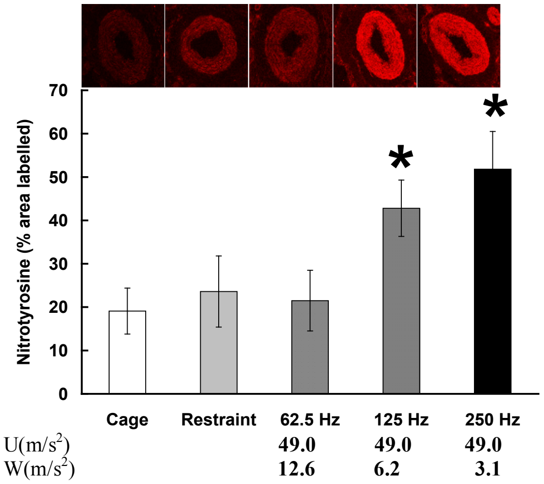
Methods

Animals. Male Sprague-Dawley [Hla:(SD) CVF rats; 6 weeks of age at arrival; Hilltop Lab Animals, Inc, Scottdale, PA)] were used in this study. Rats were maintained in a colony room with a 12:12 reversed light:dark cycle (lights off 0700 h) with food and tap water available *ad libitum,* at the NIOSH facility, which is accredited by the Association for Assessment and Accreditation of Laboratory Animal Care International (AAALAC). All procedures were approved by the NIOSH Animal Care and Use Committee and were in compliance with the Public Health Service Policy on Humane Care and Use of Laboratory Animals and the NIH Guide for the Care and Use of Laboratory Animals.

Exposure. Rats were restrained in Broome style restrainers, and their tails were secured to a platform attached to a shaker. Groups of rats (n = 5 – 8/group) were exposed to vibration at 62.5, 125 or 250 Hz at a constant unweighted acceleration of 49 m/s^2 rms for 4 h/day for 10 days. Restraint control rats were restrained and had their tails secured to stationary platforms. Cage control rats were maintained in their home cages throughout the study.

Procedures. All rats were euthanized 60 min following the last exposure. Ventral tail arteries from the C9-10 region of the tails were dissected and frozen. Gene transcription in these tissues was assessed using total rat genome arrays and/or quantitative RT-PCR. Arteries from the C15-18 section of the tail were frozen or fixed and used for immunohistochemical or morphological analyses.

Results



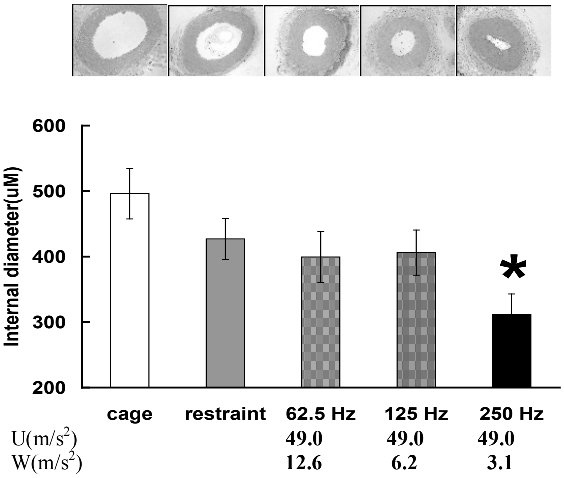


Figure 1. Nitrotyrosine staining, a marker of oxidative stress and damage, was assessed in response to vibration using unweighted (U) and ISO-weighted frequencies (W). Staining was significantly greater in arteries from rats exposed to vibration at 125 and 250 Hz than in arteries from rats in other conditions (* greater than other groups, $p < 0.05$)

Figure 2. Luminal diameter was assessed in response to vibration using unweighted (U) and ISO-weighted frequencies (W).Exposure to vibration resulted in a reduction in the luminal diameter of the tail artery. However, this reduction was only significant in rats exposed to vibration at 250 Hz (* less than cage or restraint controls, $p < 0.05$).

Discussion

- Exposure to higher frequency vibration (i.e.,≥ 62.5 Hz) results in changes in vascular biology and morphology that are indicative of dysfunction.
- Vascular responses to vibration were frequency dependent. Vibration-induced increases in markers of oxidative stress and inflammation (data not shown) were greatest in rats exposed to vibration at 250 Hz. This is the frequency with the lowest ISO-weighted acceleration.
- Vibration transmissibility to the tail is greatest at 250 Hz (3). The fact that markers of injury and dysfunction were also greatest with exposure to vibration at 250 Hz suggests that the additional stress and strain on the soft tissue generated by exposure to this frequency may pose the greatest risk of injury.
- These findings are consistent with the results of other studies suggesting that IS0-5349 underestimates the risk associated with exposure to higher frequency vibration.

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10:45-11:30 AM **TISSUE RESPONSE TO VIBRATION** (Continued)

10:45-11:00 Ron House*, Aaron Thompson, Tammy Eger, Kristine Krajnak, Depeng Jiang : VASCULAR SYMPTOMS AND DIGITAL PLETHYSMOGRAPHY ABNORMALITIES IN THE FEET OF WORKERS WITH HAVS

11:00-11:15 Juliana Gonçalves Dornela and Maria Lúcia Machado Duarte*: WHY CAN WHOLE BODY VIBRATION (WBV) CAUSE REDNESS ON VOLUNTEERS? THE EFFECT OF MECHANICAL VIBRATION AND ANXIETY ON PERIPHERAL BLOOD FLOW

11:15-11:30 Sarah A. Klemuk*, Ingo R. Titze: FUNCTIONALITY OF A RHEOMETER-BIOREACTOR TO STRESS AND ENGINEER TISSUE AT SONIC FREQUENCIES

11:30-11:45 AM **HAV (Hand-Arm Vibration) EXPOSURE RISK REDUCTION**

11:30-11:45 Mark B. Geiger*, Richard Borcicky, Gavin Burdge, James Chaney, Steven G. Chervak, Ren G. Dong, Craig M. Henderson, Roy Jardin, Donald Wasserman: PROCESS MANAGEMENT AND TOOL SELECTION TO MINIMIZE RISK OF HAND-ARM VIBRATION SYNDROME

11:45-1:15 PM **Lunch** (Box lunch, visit vendors) IMU Main Lounge

VASCULAR SYMPTOMS AND DIGITAL PLETHYSMOGRAPHY ABNORMALITIES IN THE FEET OF WORKERS WITH HAVS

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Introduction

The vascular component of Hand-Arm Vibration Syndrome (HAVS), often referred to as vibration white finger (VWF) has been known for many years. There is also evidence to suggest that HAVS may be associated with cold-induced vasospastic abnormalities in the feet.[2] This is an important issue in terms of prevention and compensation, especially in light of the large size of the exposed population. This study was carried out to determine the prevalence and risk factors of cold-induced vasospastic changes in the feet in a group of construction workers who were assessed for HAVS at the Occupational Health Clinic, St. Michael's Hospital, Toronto.

Methods

The subjects in this study were 191 male construction workers. Their occupational histories indicated that they were exposed to hand-arm vibration without significant vibration exposure directly to the feet. Digital photocell plethysmography was carried out in the hands and feet of all subjects and consisted of baseline measurement of blood flow in the fingers and toes followed by measurement after cold water immersion (10 º C for 2 minutes). The scoring was based on the amplitude of the waveforms and the change in amplitude after cold water immersion as follows: 0: all waveforms normal; 1: mild changes; 2: mixture of mild and moderate changes; 3: moderate changes; 4: mixture of moderate and severe changes; 5: severe changes. Binary logistic regression was carried out to examine the relationship between the digital plethysmography findings in the feet and various predictor variables. In this analysis, the digital plethysmography scores in the feet were dichotomized into severe cold induced changes in waveforms (stages 4 or 5) in both feet versus not having any severe waveform changes in both feet. The predictor variables examined included a history of cold intolerance in the feet, years worked in construction, type of construction trade, the average Stockholm vascular scores in both hands combined and the average digital plethysmography scores in both hands combined. Interaction terms were also examined. In all of the models an initial saturated model was fitted followed by backwards stepwise elimination to produce the final model.

Results

The subjects had a median age of 57 years (range: 28-75) and a median number of years worked in construction of 36 (range: 4-52). One hundred and sixty- nine (88.5%) of the workers reported cold intolerance in their feet. The digital plethysmography results indicated that most workers had some degree of objective cold-induced vasospasm in the hands and feet. Only10 workers had normal (stage 0) results in the right and left hands and only one worker had normal results in the right and left feet. Severe cold-induced changes in waveforms in at least one digit (i.e. stages 4 or 5) were found in the right foot in 59 (30.9 %) subjects, in the left foot in 62 (32.5 %) subjects, and in both feet in 49 (25.7%) subjects. The results of the binary logistic regression indicated that in the saturated model the only statistically significant predictor of severe (stage 4 or 5) vascular abnormalities in both feet was the average digital plethysmography score in the hands (odds ratio: 1.69; 95% CI: 1.18 – 2.42). No interaction terms were found to be statistically significant. After backwards stepwise elimination the average digital plethysmography score in the hands continued to be the only statistically significant predictor of objective vascular abnormalities in the feet and the odds ratio (95% CI) increased to 1.87 (1.35-2.59).

Discussion

This study has shown a high prevalence of vascular abnormalities in the feet of workers with HAVS. A total of 88.5% of study participants reported cold intolerance in their feet. The digital plethysmography indicated that 99.5 % of subjects had objective evidence of at least mild cold induced vasospastic changes in each foot and the percentage with at least one digit showing severe changes was 30.9% in the right foot and 32.5% in the left foot. The logistic regression analysis indicated that the key predictor of severe vascular changes in the feet was the extent of digital plethysmography changes in the hands.

In a recent literature review Schweigert [2] indicated that there was evidence to suggest that vascular effects in the lower extremities may be associated with VWF from hand-arm vibration exposure. This is consistent with the results of our study. Hand-arm vibration exposure and HAVS may be associated with both local and central sympathetic stimulation.[3] As well Bovenzi et al.[1] have recently shown that salivary concentrations of the potent vasoconstrictor endothelin ET (1-21) are increased in forestry workers with VWF in comparison to controls which suggests another mechanism for vasospasm in the feet in workers with HAVS.

Our study findings are relevant to understanding the spectrum of health effects associated with hand-arm vibration. Future work could focus on the functional significance of these vascular findings in the feet and their prevention.

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WHY CAN WHOLE BODY VIBRATION (WBV) CAUSE REDNESS ON VOLUNTEERS? THE EFFECT OF MECHANICAL VIBRATION AND ANXIETY ON PERIPHERAL BLOOD FLOW

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Introduction

Mechanical vibrations are physical stimuli that are present in various occupational or even leisure environments, as well as in the daily lives of the population in general. Although the majority of the studies investigate the damaging effects associated to vibration, nothing much is found on the effects of vibration on the peripheral circulation, being that the main objective of this article.

The peripheral circulation can be considered as one whose flow is directed to the muscular system (muscles) and the integumentary system (epidermis and dermis)[1]. The substance responsible to promote the vasodilatation in blood flow is nitric oxide (NO). The NO plays a role in modeling the diameter and vascular resistance of the blood vessels by its ability to relax their sleek muscles[5].

In an experiment conducted by the Group of Acoustics and Vibration in Human Beings - GRAVI$_{HB}$/UFMG, to investigate the effects of whole body vibration (WBV) on human hearing, it was observed that one of the volunteers apparently anxious by the stimulation, presented in the neck and upper limbs redness in some points. However, soon after the stimulus (at 5 Hz, 2.45 m/s^2 in the Z-axis vibration, during approximately 8 minutes), these signs disappeared. Faced with this fact, this article aims at discussing about an updated review on the subject in order to understand what would be the effect of mechanical vibration and anxiety/stress in the peripheral blood flow so to justify the results found in the GRAVI$_{HB}$/UFMG research.

Methods

Papers were reviewed[2], without limitation of initial time until 2010, which related anxiety and/or mechanical vibration (both local and whole body) with their effects on the peripheral blood flow, in order to justify the results found during the GRAVI$_{HB}$/UFMG research. The survey was conducted in libraries and databases such as Medline, Lilacs, BIREME, Pubmed, Wiley Interscience and Science Direct.

Results and Discussions

In total, only 10 studies were found on the effects of mechanical vibration on peripheral blood flow[2]. All these studies found that vibration leads to increased shear stress on the walls of blood vessels. This increase in the mechanical forces has an effect on the DNA. That is because the nitric oxide (NO) is synthesized from the information originating in the DNA of the cells which transcribes this information to the mRNA for the production of nitric oxide (NO), sending it to the tissues of blood vessels (endothelium) where the enzymes nitric oxides (NOs) are present and receive it for the synthesis of NO. Consequently, there is vasodilatation, causing increase in the blood flow, making the skin redness turns visible.

Only seven studies used humans as sample[2]. Moreover, it was observed a great variation between the studies regarding both the types of vibrations used (3 used local vibration and 7 whole body vibration), as well as in relation to both the frequency ranged (0.23 to 2000 Hz) and vibration amplitudes (displacement from 2 to 6 mm and/or acceleration from 2.22 to 46m/s^2) employed. There was no standard on how the vibration information was presented, making the interpretation and comparison of the findings more difficult, as in some cases, not all the necessary information was even reported.

One study[3] in dogs and 2 studies[4,6] in humans used similar amplitude and frequency to that used in the experimental study by GRAVI$_{HB}$/UFMG, arriving to the same conclusions, corroborating to the hypothesis of the study. Therefore, although the region investigated was different, similar conclusion may be drawn.

About the influence of anxiety on peripheral blood flow, 7 studies were found[2] and all these studies corroborate to the occurrence of increased blood flow in the forearm of humans when they are subjected to situations of anxiety / mental or emotional stress.

It was not found any study about the combined factors (vibration/anxiety).

Conclusions

There are few studies in the literature reporting about the effects of the vibrations on peripheral blood flow. Nevertheless, from the studies found, it may be concluded that in the study by GRAVI$_{HB}$/UFMG an increase in the shear forces on the blood vessels walls had caused peripheral vasodilatation and redness in certain parts of the upper limbs and cervical region of the volunteer. Furthermore, the anxiety, as seen in the literature, also causes peripheral vasodilatation and contributed to the appearance of such signals in the volunteer. However, no study was found about the combined effect, vibration/anxiety, being that a suggestion for future work. Moreover, one important point is the urgent need to standardize the information relative to the vibration parameters, with all the relevant information reported, in order to easier the comparison and interpretation of the findings.

Acknowledgment

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FUNCTIONALITY OF A RHEOMETER-BIOREACTOR TO STRESS AND ENGINEER TISSUE AT SONIC FREQUENCIES

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Introduction

Millions of Americans suffer from hearing loss, voice problems or repetitive motion injuries. When tissues are set into vibration at sonic frequencies, the (complex) shear modulus largely governs their macroscopic vibrational properties. Conditioning engineered tissues at sonic physiologic vibrations is believed to improve their functionality when transplanted into patients. Instruments called bioreactors, uniquely designed for the purpose of growing tissues, exposing the tissue to vibration, and quanitfyint their mechanical response, are needed to investigate the potential public health benefits of such treatment. Primary functionalities of a bioreactor include (1) establishing uniform cell distributions in 3D constructs, (2) maintaining gas and nutrient concentrations, (3) providing fluid circulation, and (4) exposing developing tissue to physical stimuli.(Freed and Vunjak-Novakovic, 2000) A stress-controlled rheometer was adapted to function as a bioreactor. The degree to which the rheometer-bioreactor could satisfy the four criteria and simulate vocalization forces were evaluated.

Methods

The Gemini rotational shear rheometer (Malvern Instruments, UK) was used. Appliance adaptations were used to accommodate a 3D matrix and a monolayer of cells. For both adaptations, a custom cup, capable of being sterilized and holding cell culture medium, was fitted to the rheometer base. For the 3D configurations, a polyurethane substrate, used in other bioreactor experiments,(Titze and others, 2004) was seeded with fibroblast cells. The cells were incubated in static conditions for two weeks, and then exposed to vibrations in the rheometer bioreactor. Cell viability was quantified and compared to control conditions, applied torque and resulting strains were recorded, along with linear viscoelastic measurements of the 3D construct for three different vibration conditions. A similar experiment was performed using a dermal equivalent 3D matrix cell culture medium. For the monolayer configuration, cells were seeded onto a coverslip. The coverslip was then attached to either the stationary base or the top rotating plate. Vibration was exerted in the bioreactor by immersing the coverslip in cell culture medium augmented with methyl cellulose to increase fluid viscosity.Stresses up to 4000 Pa at 100 Hz were turned on and off every 10 s for 2 h.

Results

Fibroblast-seeded discs maintained comparable cell viability to controls, whether in static or vibrational conditions. Resulting strains was quantified throughout testing, and rheologic data were obtained.(Klemuk, Jaiswal, and Titze, 2008) Highly cellularized 100 μm thick dermal membranes were unaffected by 10 Hz vibration but were morphologically changed after 1 hour exposure to 100 Hz, 60% strain vibration. A monolayer of laryngeal fibroblast cells, subjected to 2 hours of vibraton, remained unchanged for stress exposures up to 3000 Pa and 100 Hz, but with higher forces, the cells were stripped or adversely deformed.

Discussion

These results demonstrate observable tissue response to phonation-like forces in the rheometer-bioreactor at the cellular level and at the macroscopic properties level, even when exposure time is limited. By modifying cup and plate attachments, tissue constructs of varying architectures can be studied. Modifications to the rheometer-bioreactor are ongoing to increase testing duration and extend vibration conditions.

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PROCESS MANAGEMENT AND TOOL SELECTION TO MINIMIZE RISK OF HAND-ARM VIBRATION SYNDROME

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Introduction

The Department of Defense (DOD) is among the world's largest maintenance organizations. Many of the processes create high hand-arm vibration exposures and related injury risks during maintenance of defense systems and equipment as well as related activities conducted by DOD contractors, both domestically and abroad. Prolonged exposure can permanently injure the worker resulting in medical treatment costs, retraining costs, and disability payments for the life of the injured party.

As an effort to control the exposure and its related hand-arm vibration syndrome (HAVS),[1-4] this project was originally resulted from outreach by Craig Henderson, CIH, an industrial hygienist at the Puget Sound Naval Shipyard, who approached the General Services Administration (GSA) for assistance in obtaining low-vibration power hand tools. A representative of the tools section of GSA communicated this issue to the DOD Ergonomics Working Group.[5] This presentation provided the basis for a project sponsored by the Defense Safety Oversight Council and its Acquisition and Technology Task Force (working group).[6] DOD also requested GSA collaboration in procurement of low-vibration power hand tools.[7] Prior to this project, low-vibration characteristics had not been routinely applied to selection criteria for tool procurement. Also, the Federal supply system included no gloves certified by independent parties as meeting the ANSI 2.70/ISO 10819 standards for anti-vibration gloves.

This project is also part of a larger DOD/Navy effort to better integrate safety and health requirements and technology into management of defense acquisition, sustainment and procurement processes. Technical outreach includes education of safety and health professionals in operation of the Defense acquisition and logistics system; application of the system safety process to management of hand arm vibration and influencing process requirements for maintenance and support operations. Initial efforts included publication of a website describing common safety and health hazards associated with operation and maintenance of navy ships, [8] which included a section on hand arm vibration. [9] (See www.safetycenter.navy.mil/acquisition). The issue of hand arm vibration as a system safety consideration requiring attention in design and support was communicated as a system safety risk requiring recognition and management at an organization level appropriate to the risk. [10] Requirements for risk management through a defense systems life cycle, using the standard practice for system safety,[11] are outlined in DOD acquisition regulations.[12] This project focuses on application of existing management processes, related education of both safety and health professionals and managers of maintenance and logistics processes, coupled with selective update of available products, low vibration power hand-tools and certified anti-vibration gloves, to minimize the risk of hand arm vibration. The approach is also consistent with the National Occupational Research Agenda (NORA) of the National

Institute for Occupational Safety and Health (NIOSH) to provide guidance to the entire occupational safety and health community for moving research to practice in workplaces.[13]

Methods

The Defense Safety Oversight Council in 2007 initiated a project and collaborated with the General Services Administration (GSA) to identify and to incorporate low-vibration power hand tools and gloves certified as meeting the requirements of the ANSI/ISO standards for anti-vibration gloves into the federal procurement process.[6, 7] The project was derived from a collaborative effort between Puget Sound Naval Shipyard and GSA to influence procurement criteria for power hand tools. A working group with DOD/GSA/NIOSH and Coast Guard members was formed. Procurement criteria for anti-vibration gloves, low vibration tools and third party certification guidelines were developed in a meeting hosted by NIOSH in Morgantown, West Virginia in February 2008. The group has continued collaborative efforts and refined the above criteria. An overview of the project was presented to the DOD Industrial Hygiene Forum at the June 2008 American Industrial Hygiene Association Conference.[14]

This project has focused upon identification of processes which create significant exposure risk to hand arm vibration; work with GSA to incorporate vibration (and noise) in procurement criteria for power hand tools and to improve the availability of certified anti-vibration gloves within the Federal supply system. Project contractors included both a logistics management consultant, Robbins Gioia, and an engineer who is one of the world's experts in hand-arm vibration, Don Wasserman. The project differed significantly from other ergonomics and safety evaluations in its initial focus upon integration of process management and coordination with technical process owners.

The project focus was sharing of information among participants, publication of technical information to the safety and health community and outreach to forums not typically linked to the safety and health process.

Education of participants, who were primarily occupational safety and health professionals, focused both upon understanding of the DOD/Federal logistics and acquisition processes and review of information related to hand arm vibration. The agenda of the organizational meeting hosted by NIOSH in Morgantown, West Virginia reflects this balance, Annex 1.

A concurrent effort was made to evaluate available anti-vibration gloves. The two products available in the Federal supply system, both marketed by GSA and described as anti-vibration gloves, were evaluated as unsuitable. Neither conformed to guidelines of the relevant ANSI/ISO Standard.[15] Product was a “half finger” glove; the other item is classified as a motorcycle glove. The GSA product manager refused to have that item evaluated. Evaluation of product management responsibilities via the Headquarters of the Defense Logistics Agency (DLA) determined that technical responsibility for this category of industrial protective equipment rested with DLA. Coordination with the Defense Supply Center Philadelphia, item manager for this stock class, was also a lengthy and frustrating process. Issues included the complexity for the logistics system which complicated engagement by personnel lacking primary training in logistics, tendency for product managers to rely on existing suppliers with less focus upon alternative sources; regulatory requirements favoring or even requiring American manufactured products; and an organization procurement approach that required customer pre-payment of classification and cataloging costs in the range of $25,000 per product. This hindered execution because the contract structure was executed by coordination of a private contractor, Concurrent Technologies Corporation. Acquisition regulations preclude use of Federal funding to pay a private contractor to fund the activities of another Federal entity. Intervention of DLA Headquarters and eventually, OSD Manpower Readiness and Personnel were required to expedite availability of alternative products through the Defense Logistics Information Services.

A concurrent project to support information outreach included;

- Periodic (approximately monthly) teleconferences with key participants, followed by email distribution of information to all contacts on a growing DOD-wide list. Non-government contacts were included as awareness of the project increased. The current list includes approximately 140 main contacts.
- Development of educational materials for laymen (workers and acquisition/logistics professionals), including a one page brochure (Hand Arm Vibration-just the facts) posted on the Naval Safety Center's website and update of the Safety Center's website.
- Presentations at professional conferences including the American Industrial Hygiene Conference[12] and National Defense Industries Association.[16] A half-day workshop was conducted at the Navy Marine Corps Public Health Conference, in March 2009.
- Publications in safety and health forums including the Naval Safety Center's Sea-Shore magazine,[17] the American Society of Safety Engineers on-line journal[18] and the DOD Ergonomics Working Group and Defense Readiness Website.

Results

GSA has incorporated low-vibration and other ergonomic characteristics into their procurement criteria for power hand tools. Three products were available when this abstract was submitted, Table 1. It is anticipated that additional low-vibration tools will be introduced in the immediate future. *Continued availability of these products will depend on demand, which must be stimulated through* ***education of management and process owners****, as well as development* ***and enforcement of requirements for control of occupational exposures.***

Table 1: Currently Available Low Vibration Power Hand Tools

- Pneumatic riveting hammer, described as HAMMER, PNEUMATIC, PORTABLE 5130-01-5716908. Its vibration (<2.5 m/s2) is less than half the level created by many legacy tools.
- Pneumatic reciprocating saw, listed as SAW, RECIPROCATING, PNEUMATIC 5130-01-572-5529. Its vibration (<4 m/s2) is less than half the level created by many legacy tools.
- Needle scaler (needle gun), listed as SCALER, PNEUMATIC, PORTABLE 5130-01-317-2453. To date, GSA has been unable to specify a maximum vibration level for this tool. However, one vendor's product, which served as a guide for the item specification, reportedly had vibration levels in the range of 3.5 m/s, also considerably lower than many legacy products.

Contacts with varied glove manufactures identified four vendors capable of supplying certified anti-vibration gloves meeting ANSI/ISO 10918 criteria.[15] Lack of allocated resources (circa $30,000), procedural delays and apparent intransigence among certain DLA/GSA product managers prevented rapid availability of products with an assigned National Stock Number (NSN). Complex and demanding requirements for "buy American" defense products also complicated rapid product availability. Alternative approaches to providing information to customers requiring these products included

- Development of a list of commercial products distributed as a handout at the DOD Industrial Hygiene Forum at the 2008 American Industrial Hygiene Association Conference and subsequently posted on relevant websites.
- Collaboration with vendors to describe the possibility of listing non-NSN products on the GSA website through the GSA Advantage program (www.GSAadvantage.gov) which permits vendors to list and describe their products via approved distributors. One manufacture of certified anti-vibration gloves took advantage of this alternative.

Eventually, two manufactures, Chase Ergonomics® and Impacto®, were able to develop US made products meeting ANSI/ISO 10819 criteria.[15] Intervention of the Office of the Secretary of Defense (OSD) (Manpower, Personnel and Readiness) was needed support rapid introduction of suitable (certified) anti-vibration gloves into the Federal supply system. An OSD memo was developed and distributed to support DLA and service procurement of certified anti-vibration gloves.[19] Notice of their product's availability was accompanied by a model justification supporting use of the more expensive products.

A brochure and a one-page guide for users of anti-vibration gloves was been developed describing available certified products while listing their national stock numbers.

Several collateral project outcomes and products were developed or implemented as made apparent by the effort. These include;

- NIOSH/Air Force collaboration in evaluation of air frames maintenance/riveting operations at Tinker Air Force Base, to be initiated in approximately April 2010
- Improved tri-service, Coast Guard and private sector collaboration in exchange of information.
- Identification of outdated information in one of the main DOD ergonomics guidance criteria document[20] and submittal of guidelines for its improvement.[21]
- Liaison with product managers and efforts to integrate improved, low vibration tools into certain processes.
- Initiation of a product deficient report related to anti-vibration gloves which resulted in a funded project to be initiated by the Navy Clothing and Textile Research Facility to evaluate available alternative anti-vibration gloves, identify research/development needs and possibly fund development of product improvements. Collaboration with NIOSH is anticipated in this area. Project initiation is anticipated in March or April 2010.

A limited proposal for project extension was submitted from the Acquisition and Technology Task Force to the Defense Safety Oversight Council in January 2010. The proposal focus is upon integrating available low-vibration power hand tools into critical DOD maintenance processes. Collateral tasks include providing relevant program guidance, updating policy as necessary and further educational outreach both in hand-arm vibration and process management.

Discussion

The continued existence of hand-arm vibration syndrome is largely because there is lack of its awareness and the effective implementation of the current standards and available controlling methods[22-25]. Implementation of European standards for evaluation and control of hand arm vibration exposure [23] have increased the availability of low-vibration power hand tools. Customers in the US market will need to take informed advantage of these products or get “stuck” with the products which will become increasingly difficult to sell in Europe- outdated and more hazardous equipment.

Concurrently, better but obviously, more expensive anti-vibration gloves are now available through the Federal supply system. Demand and continued availability will depend upon effective marketing and enforced requirements for use of suitable products.

Many DOD health and safety professionals are not fully conversant with DOD acquisition, logistics and process management systems. Successful execution of the project required education of industrial hygienists in this complex system. Safety and medical support professionals cannot be successful by simply providing technically appropriate advice; they must be effectively engaged in process management and execution. A contractor knowledgeable in the DOD acquisition system was engaged to support the project. A concurrent process of education for safety and health as well as logistics personnel has made the project successful.

The project’s success will ultimately depend on the ability of safety and health professionals to engage the engineering, maintenance, and acquisition authorities responsible for management of specific work-control and maintenance processes, such as riveting and airframes maintenance, tool crib issue, Inspector General evaluation/ inspection criteria, schoolhouse curriculum, etc., and influence the design and support requirements for specific processes and related technical guidance. Efforts also have been made to expand the scope beyond US government boundaries by publicizing the ability of contractors executing government contracts to use the Federal supply system. It is hoped that the very size of the Federal supply system and technical leadership exerted by the associated safety and health professionals may influence product availability and demands for control of a preventable disease.

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Wednesday, 2 June 2010

1:15-1:45 PM **Keynote**: **Hand-Arm Vibration: A Physician's Approach**
Tom Jetzer, MD, MPH
Occupational Medicine Consultants
Minneapolis, Minnesota

1:45-3:15 PM **CHARACTERIZING HAV EFFECTS AND ENVIRONMENTS**

1:45-2:00 A.J. Brammer*, M.G. Cherniack, E. Toppila, P. Sutinen, R. Lundström, T. Nilsson, G. Neely, T. Morse, A. Sinha, M.J. Eaman, D. Peterson, and N. Warren: TOWARDS A QUANTITATIVE SENSORY TEST FOR HAND NUMBNESS

2:00-2:15 Neil J Mansfield*, Nobuyuki Shibata, Kazuma Ishimatsu, Setsuo Maeda: EFFECT OF GRIPPING IN A TRIGGER POSTURE ON APPARENT MASS OF THE HAND-ARM SYSTEM

2:15-2:30 Bryan Wimer, Thomas W. McDowell, Xueyan S. Xu, Daniel E. Welcome, Christopher Warren, and Ren G. Dong: EFFECTS OF GLOVES ON THE GRIP STRENGTH APPLIED TO CYLINDRICAL HANDLES

2:30-2:45 TW McDowell, C Warren, DE Welcome, RG Dong: LABORATORY MEASUREMENT OF RIVETING HAMMER VIBRATION

2:45-3:00 Donald R. Peterson*, Takafumi Asaki, Anthony J. Brammer, Martin G. Cherniack: NOISE AND VIBRATION EXPOSURES TO DENTAL HYGIENISTS

3:00-3:15 Ren G. Dong*, Daniel E. Welcome, Thomas W. McDowell, Xueyan S. Xu, John Z. Wu, and Subhash Rakheja: MECHANICAL IMPEDANCES DISTRIBUTED AT THE FINGERS AND PALM OF THE HUMAN HAND SUBJECTED TO 3-D VIBRATIONS

3:15-3:45 PM **Break (**IMU Main Lounge)

TOWARDS A QUANTITATIVE SENSORY TEST FOR HAND NUMBNESS

***A.J. Brammer[1,2], M.G. Cherniack[1], E. Toppila[3,4], P. Sutinen[5], R. Lundström[6], T. Nilsson[7], G. Neely[8], T. Morse[1], A. Sinha[1], M.J. Eaman[2], D. Peterson[1], & N. Warren[1]**
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Introduction

Sensory tests have long been used in clinical medicine for investigating peripheral neuropathies. The tests were originally primitive – pin prick (for pain), hot/cold objects (for temperature sense), and a cotton wool swab (for fine touch) applied to the skin. In this paper, a recently developed quantitative sensory test (QST) designed to confirm the presence or absence of numbness in the hands has been applied to a population of male forest workers (N=59, mean age 48.7 years, range 37-59), in which the prevalence of numbness reported by the workers was 29%. The test is based on measuring vibrotactile perception thresholds at the fingertips according to the provisions of ISO 13091-1. Under these measurement conditions, responses at specified stimulus frequencies are mediated by the slowly adapting, type I (*SAI*), and fast adapting type I (*FAI*), mechanoreceptors.[2] The metric is constructed from the differences between the thresholds recorded at the fingertip of an individual and the mean values of the thresholds for healthy persons obtained in other studies. In this paper, the performance of the QST is evaluated by adjusting a "fence" value for the metric to detect the onset of numbness.[2]

Methods

When all thresholds are expressed as accelerations in units of dB (re 10^{-6} m.s^{-2}), the summed normalized threshold shift can be written, for each digit,[2] as:

$$TS_{Sum(SD)} = (TS_4/SD_4) + (TS_{32}/SD_{32}) \qquad (1)$$

The shift in threshold at a stimulus frequency of 4 or 32 Hz, i.e., TS_4 or TS_{32}, represents the response of the SAI or FAI receptors, respectively, and is given by the difference between the observed threshold and the mean threshold recorded from the hands of healthy persons at that frequency. As the thresholds of healthy persons appear to approximate Gaussian distributions at each stimulus frequency, the ranges are expressed by standard deviations, SD_4 and SD_{32}, which are used to normalize the threshold shifts. In order to compare values of $TS_{Sum(SD)}$ with symptoms, the metric is taken to be the largest of the threshold shifts recorded from digit 3 or 5, in either hand.

Tests for the statistical significance of an association between the symptoms reported by individuals and values of $TS_{Sum(SD)}$ recorded from their hands have been conducted (Chi-squared test, and Fisher's exact test).[1] For this purpose, 2x2 contingency tables are formed to segregate the reported presence or absence of numbness, and a fence value, *t*, is selected for $TS_{Sum(SD)}$ to correspond to the boundary between the presence and absence of the symptom. The corresponding sensitivity and specificity is also evaluated.[1]

Results and Discussion

The sensitivity and specificity of, and association between, the metric constructed from values of $TS_{Sum(SD)}$ recorded from each subject and their reports of numbness in the hands are shown in Table 1. The statistical significance of the association (p-value) is shown for different fence values, t. While the statistical tests differ somewhat in the fence values associated with numbness, values of $4.5 < t < 4.75$ are most significant, with probability values reaching $p < 0.005$. For these fence values, the sensitivity ranges from 50 to 43.75%, and the specificity from 87.5 to 92.5%.

Table 1: Sensitivity, Specificity and Tests of Association for Reports of Hand Numbness

Fence t	Sensitivity (%)	Specificity (%)	Yates p-value	Fisher p-value
2.00	87.50	12.50	0.65	1.00
2.25	87.50	32.50	0.23	0.19
2.50	81.25	35.00	0.38	0.34
2.75	81.25	40.00	0.23	0.21
3.00	81.25	45.00	0.13	0.08
3.25	75.00	50.00	0.16	0.14
3.50	75.00	57.50	0.06	0.04
3.75	68.75	57.50	0.14	0.14
4.00	56.25	67.50	0.18	0.13
4.25	50.00	75.00	0.14	0.11
4.50	50.00	87.50	0.008	0.005
4.75	43.75	92.50	0.005	0.003
5.00	37.50	92.50	0.02	0.01
5.25	25.00	95.00	0.09	0.05
5.50	25.00	97.50	0.03	0.02
5.75	18.75	97.50	0.12	0.07
6.00	12.50	97.50	0.40	0.19
6.25	6.25	97.50	0.91	0.49

In a previous pilot study involving fifteen vibration-exposed workers, in which the prevalence of numbness was 39%, the statistically significant fence values for reports of numbness ranged from $3.3 < t < 4.4$, but the significance of the association never exceeded $p < 0.02$.[2] The sensitivity was, however, higher (~90%) and the specificity lower (~75%). The pilot study employed the same procedure for measuring vibrotactile thresholds as in this study, but combined values at two stimulation frequencies for each receptor type. Only one threshold per receptor type was obtained in the present study. This, combined with the lower prevalence of symptoms, may explain the differences in the results, but the potential for improving the metric remains to be explored. This would seem possible, as the correlation between threshold shifts in different receptor types within the same finger was much lower in this study (0.49-0.71 versus 0.87-0.97). Nevertheless, the low false positive rate (~10%) and a ~50% rate of confirmation of reported symptoms confirm the potential of mechanoreceptor-specific vibrotactile perception thresholds as a QST for numbness in the hands.

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EFFECT OF GRIPPING IN A TRIGGER POSTURE ON APPARENT MASS OF THE HAND-ARM SYSTEM

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Introduction

Exposure to hand-arm vibration can induce hand-arm vibration syndrome (HAVS), one aspect of which is vibration white finger (VWF). The risk of developing HAVS is related to exposure duration, and the frequency and magnitude of the vibration. As the hand-arm system is not rigid, the extent to which forces are transmitted to the hand is a function of frequency and can be measured using the apparent mass, where a high apparent mass corresponds to higher forces being transmitted when compared to frequencies with a lower apparent mass. The apparent mass is affected by the direction of the vibration and the gripping conditions[1, 2].

When workers are exposed to hand-arm vibration from power tools, they often need to control a trigger. On most construction tools triggers are operated with the first and second finger whilst the thumb, third and fourth finger provide the primary grip for the tool in that hand. This paper reports an experiment to compare the biomechanical response of the hand-arm system when gripping with a 'full' grip and with a 'trigger' grip.

Methods

8 male subjects were exposed to tri-axial random (10 – 1000 Hz) vibration. The vibration had a magnitude of 18 m/s^2 r.m.s. in each direction and was presented through a 40 mm handle containing accelerometers and force cells. Subjects gripped the handle at 30N and pushed at 50N. Tests were conducted with a straight (elbow 180°) and bent arm (elbow 90°). In the 'full' grip condition all fingers were used; in the 'trigger' grip there was no contact of the first two fingers with the handle (Figure 1). Apparent mass was measured separately for finger and palm sides of the hand.

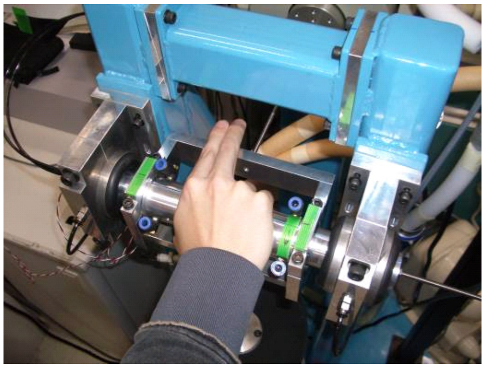

Figure 1. 'Trigger' grip posture.

Results and Discussion

Results for the 'full' grip showed similar trends to those in the literature[1,2] (Figure 2). In the x- and y-axes, the apparent mass in the 'trigger' grip posture was increased for the palm side at low frequencies. On the finger side apparent mass reduced, as expected,

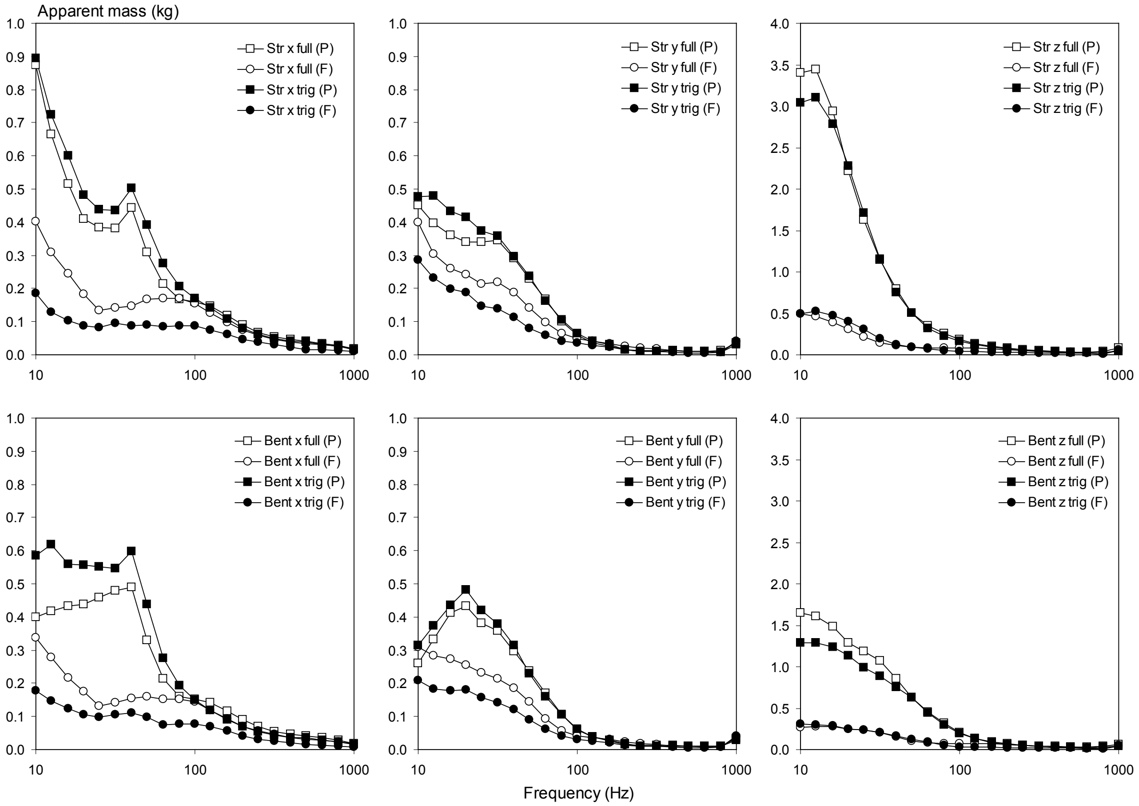

Figure 2. Mean apparent mass of the hand-arm system with straight ('str') and bent arm, with full and trigger ('trig') grip, for the finger (F) and palm (P) side of the hand. Note change of scale for z-axis vibration data.

as there was less finger loading. For z-axis vibration the apparent mass was about 400g lower for the trigger posture (palm side) at low frequencies. For the palm side with bent arm, differences were significant at 12.5 Hz ($p < 0.05$, Wilcoxon) but not for the straight arm. For the finger side, differences at 12.5 Hz were significant in the x- and y-axes for both arm postures.

These results show that although slight differences occur in the apparent mass of the hand-arm system when gripping with a full and trigger posture, changes are relatively small in comparison with inter-subject variability.

Acknowledgement

This study was supported by the Great Britain Sasakawa Foundation.

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Effects of Gloves on the Grip Strength Applied to Cylindrical Handles

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Daniel E. Welcome, Christopher Warren, and Ren G. Dong,

Engineering and Control Technology Branch, Health Effects Laboratory Division, National Institute for Occupational Safety & Health, Morgantown, WV, USA

INTRODUCTION

Anti-vibration (AV) gloves have been used to reduce hand-transmitted vibration exposure. However, some workers have complained of increased hand and arm fatigue when they use these gloves. This is likely because some of the AV gloves could greatly reduce the grip strength or require workers to exert more grip effort in the operation of a vibrating tool. Although this has been generally understood, it is unknown exactly how much the AV gloves could reduce the grip strength applied to cylindrical handles used on many powered hand tools. It is also unclear whether the AV gloves could reduce grip strength more than regular work gloves. To answer these questions, this study measured the total grip strength applied on two cylindrical handles with, and without, wearing different gloves.

METHOD

The grip strength on a cylindrical handle was computed by quantifying the total contact force normal to the handle surface[1]. Two instrumented cylindrical handles (30 mm and 40 mm diam.) were used to measure the contact force. The 30 mm handle was comprised of an aluminum cylinder equipped with a Tekscan pressure mat[1]. The 40 mm handle was a six-piece handle developed in an earlier study[2], which measured the contact force by means of shear strain gauges installed on each of the six arms. As shown in Fig. 1, four types of AV gloves and two types of standard work gloves were used in the experiment. Ten healthy male adult subjects participated in the experiment. The test setup and subject posture are shown in Fig.2. Each subject was asked to apply his maximum grip for 5 seconds. The sampling rate was 5 Hz. The middle 3 seconds of data were used to calculate the grip strength. Two test segments were carried out; one set of trials used the 40 mm handle and the other utilized the 30 mm handle. During each segment, the subject completed three maximum grip efforts on the handle with each of the six gloves as well as in the bare-handed condition for a total of 21 trials (7 hand conditions × 3 trials). The test sequence in each segment was randomized among the subjects. The thickness of each glove was also measured.

Fig. 1. The six gloves used in the study: (1) Mechanix Wear automotive (2) leather/cotton construction (3) Decade gel padded, anti-vibration (4) Impacto leather, air pocket, anti-vibration (5) Impacto mesh, air pocket, anti-vibration (6) ErgoAir pump, air pocket, anti-vibration

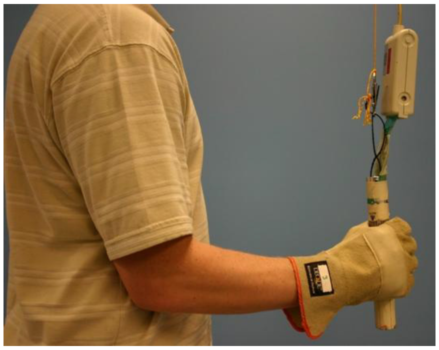

Fig.2. Test setup and subject posture used in the measurement.

RESULTS AND DISCUSSION

As shown in Fig. 3, Glove 1 reduced the grip strength on both handles by less than 10% when compared with the bare hand grip strength. Each of the four anti-vibration gloves (Gloves 3-6) reduced the grip strength by more than 29%, regardless of handle size. One of the standard work gloves (Glove 2) also largely reduced the grip strength (≥25%).

The major underlying cause of the observed strength reduction is likely associated with the mechanics of the glove in the gripping action. A glove is usually bowed and compressed at the palm side, and stretched at the back side. The forces required to generate these deformations must be the result of the hand grip effort. Therefore, part of the hand energy or grip effort must be absorbed by the glove. This mechanism suggests that the stiffness of a glove is likely to play an essential role in the reduction of the measured grip strength. The glove stiffness generally increases with the thickness in the glove material. This explains why the grip strength was reliably correlated with the measured glove thickness.

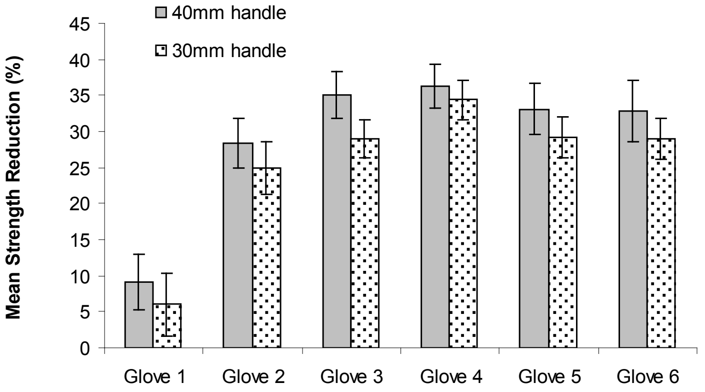

Figure 3. Mean grip strength percent reduction for the six gloves used in testing. (Y-error bars indicate the 95% confidence intervals for each mean).

Glove use also increases the effective handle diameter, as confirmed from the glove influence on the grip force distribution around the circumference of the cylindrical handle. The changed handle size could also positively or negatively affect grip strength, depending on the original handle size. The increase of the handle size from 30 mm using gloves should theoretically increase the grip strength, but instead it was reduced. It is likely that the increased grip effort required to generate more deformation of the glove on a smaller handle counteracts the positive effect of the increased handle diameter.

These observations suggest that it is not the type of glove but the actual stiffness of the glove that primarily determines the reduction in grip strength. Because some AV gloves are thicker or stiffer than most standard working gloves, their reduction effect could be greater than that of the regular gloves. How to lessen the stiffness of AV gloves or to have less influence on the grip strength remains an interesting and useful research topic.

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LABORATORY MEASUREMENT OF RIVETING HAMMER VIBRATION

TW McDowell, C Warren, DE Welcome, RG Dong

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Introduction

As part of a collaboration with the United States Air Force (USAF) 72nd Aerospace Medicine Squadron (72 AMDS), Bioenvironmental Engineering Flight at Tinker Air Force Base (AFB) in Oklahoma, the Physical Effects Research Team (PERT) of the National Institute for Occupational Safety & Health (NIOSH) is studying vibration emissions of riveting hammers used in aircraft assembly and maintenance. The PERT team is involved with the ongoing systematic development of new methodologies for evaluating hand-transmitted vibration exposures and effects. Among those efforts, PERT has completed studies on chipping hammers,[1] impact wrenches,[2] and other powered hand tools. Therefore, an examination of riveting hammer vibrations fits in well with PERT's mission. In this initial study, ten riveting hammers were evaluated in the NIOSH laboratory. Weighted and unweighted vibration data were collected at the tool handles and at the tool operators' ring fingers. The tools were rank-ordered by vibration magnitude for each measurement method. The rank orders generated by the different vibration measurement criteria were then compared.

Methods

The percussive tool test setup used in this study was that specified in the ISO standard for the measurement of vibrations at the handles of chipping hammers and riveting hammers (ISO 8662-2, 1992).[3] The test apparatus features an energy absorber that comprises a steel tube filled with hardened steel balls. (See Fig. 1.) When the percussive tool operates, the energy absorber provides a dynamic reaction force which enables stable and reproducible tool action.

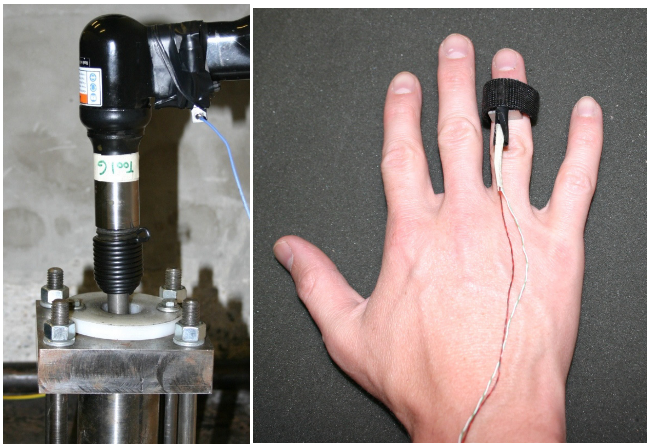

Fig. 1. Tools were operated against the energy absorber specified in ISO 8662-2. Vibration data were collected at the tool handle and at the operator's ring finger.

Ten brand-new riveting hammers were evaluated in this study. Piezoelectric triaxial accelerometers were used to measure the vibrations. Accelerometers were installed on mounting blocks and secured to the tool handles with hose clamps. An adapter-mounted accelerometer was also secured to the operator's ring finger with a Velcro strap. The accelerometer mounts are depicted in Fig. 1.

Six healthy males served as tool operators. Each operator stood on a force measurement plate/platform and applied a downward push force on the tool handle. The tool operators were instructed to apply a feed force of 100 ± 20 N. A computer monitor displayed a full-screen force strip chart so that the tool operator could monitor and control the feed force during tool operation. The tool operators completed five consecutive 10-second trials with each tool. Tool order was randomized among the operators. Tool handle and finger vibration data were collected simultaneously. The vibration data were expressed as the root-mean-square (r.m.s.) values of the accelerations in the 1/3-octave frequency bands, with center frequencies from 10 to 1,250 Hz. The 'total' values of the r.m.s. accelerations were computed with and without frequency weighting per the ISO 5349-1 standard.[4]

Results, Discussion, and Conclusions

The rank-orders of the ten tools for each of the four vibration measurement criteria are presented in Table 1. The rankings are based on the averages of the six tool operators. Tools E and A were consistently ranked with the lowest vibration regardless of tool operator, measurement location (tool or finger), or acceleration weighting (ISO-weighted or unweighted), and Tools H and D were among the highest vibration. The rankings of the other tools were somewhat inconsistent among the ranking criteria. However, it appears that any of the four ranking criteria would be acceptable for initial tool screening. Particularly, the rankings based on weighted accelerations measured on the tool and finger were fairly consistent.

Tool selection should not be based solely on laboratory vibration measurements. Field studies should be conducted to verify or refine tool selection. Other criteria such as productivity, tool versatility, worker acceptance, initial cost, and maintenance costs should also be considered during tool selection.

It is emphasized that ISO 8662 laboratory tool tests are designed for screening tools; these standards are not designed to measure the acceleration values for risk assessment. Therefore, acceleration values obtained via such laboratory testing should not be used for assessing workplace vibration exposures.

Table 1. The rank orders of the ten tools from 1 (lowest) to 10 (highest) vibration by each of the four ranking criteria.

	Ranking Criteria			
Rank	ISO-Weighted Tool Vib.	Unweighted Tool Vib.	ISO-Weighted Finger Vib.	Unweighted Finger Vib.
1	E	E	E	A
2	A	A	A	E
3	F	B	F	B
4	J	F	J	F
5	C	J	C	J
6	B	I	G	G
7	I	C	B	C
8	D	G	I	H
9	G	D	D	D
10	H	H	H	I

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NOISE AND VIBRATION EXPOSURES TO DENTAL HYGIENISTS

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Introduction

The association of hand paresthesias and auditory damage to exposures of high-frequency sound and vibration from dental instrumentation remains unclear. Auditory threshold studies have shown dental practitioners to have significant hearing loss at 3 kHz, 4 kHz, and 6 kHz [1,2]. Experienced hygienists were observed to have elevated Vibration Perception Thresholds (VPTs) at the FAII mechanoreceptors[3] even though daily vibration exposures are below the limit value of the ISO 5349-based European Union Directive[4]. These studies suggest that years of high-frequency exposures may lead to symptoms of Hand-Arm Vibration Syndrome (HAVS) and hearing loss. This paper explores these exposure-response relationships using data from questionnaires, vibrotactile testing, and laboratory measurements of high-frequency dental instruments.

Methods

Two populations of dental hygienists (hygiene students (n=66), and experienced hygienists (n=94) with at least five years of experience) were recruited to investigate the relationships between multiple exposures and symptoms, as well as the early onset of symptoms in previously unexposed students[3]. Job information was obtained by questionnaire and vibrotactile perception thresholds were measured for the FAII (125 Hz), FAI (32 Hz), and SAI (4 Hz) mechanoreceptors on both hands using a tactometer. (Auditory thresholds were not collected.) The most commonly used vibratory dental instruments were identified from the questionnaire data and the weighted and un-weighted 1/3 octave band frequency spectra of sound and vibration up to 63 kHz were measured using a 1/4-inch free-field microphone (4939, B&K, Denmark) coupled with an ultra high-frequency Scanning Laser Vibrometer (PSV-300, Polytec GmbH, Germany). Instruments were operated without load (i.e., no tip contact) at recommended operating pressures and were evaluated using two mounting positions (tool base and typical grip position) using a simulated pinch grip with a similar biodynamic response to a human three-finger grip for grip forces between 30 and 45 N [3].

Results and Discussion

Table 1: Questionnaire Results[3]

	STUDENTS (n=66, 98.5% Female)	**EXPERIENCED (n=94, 97.9% Female)**
Age (SD)	26.1 (6.4)	45.5 (8.8)
Years in Practice (SD)	3.0 (4.3)	21.8 (8.3)
Vibration Exposure (years (SD))	1.0 (1.9)	17.1 (8.7)
Manual Tool Use (hours/week (SD))	5.2 (5.5)	12.0 (7.3)
Vibratory Tool Use (hours/week (SD))	3.0 (3.9)	5.1 (5.4)
Est. Lifetime Ave. Weekly Vib. Exp. (hrs*1000 (SD))	0.3 (0.6)	10.8 (11.5)
Presence of Musculoskeletal Pain (number (%))	27 (40.9)	81 (86.7)
Presence of Carpal Tunnel Syndrome (number (%))	3 (4.6)	17 (18.1)
Use of Hearing Protection (number (%))	2 (3.0)	2 (2.1)

Questionnaire results (Table 1) showed significant differences between mean age, years in practice, and self-reported vibration exposures. Experienced hygienists were shown to be four times more likely to suffer from musculoskeletal pain and carpal tunnel syndrome and only four hygienists (two students and two experienced) reported the use of hearing protection. Average VPTs (Table 2) for the FAII mechanoreceptors of the third and fifth digits of both hands were observed to be slightly higher for the experienced hygienists, while FAI and SAI results showed no differences and there was no association with age for any of the threshold measurements. The sound and vibration levels of the dental instruments varied and the spectra indicated small differences in frequency components between mounting conditions. Table 3 shows the measured unweighted and weighed total band powers for the SPL and the VL. While the weighted results suggest minimal effects on health, the unweighted results, self-reported exposures, and VPTs suggest that accumulated exposures over time may cause musculoskeletal discomfort, HAVS, and possibly hearing loss.

Table 2: Average Vibration Perception Threshold Results[3] in dB (re 1×10^{-6} m/s^2)

HAND AND DIGIT	MECHNORECEPTOR	STUDENTS	EXPERIENCED
Dominant Hand, 3rd Digit	FAII – 125 Hz	103.0 (7.5)	107.0 (8.8)
(Median Nerve)	FAI – 32 Hz	102.7 (6.8)	104.4 (6.3)
	SAI – 4 Hz	83.4 (4.5)	83.6 (5.1)
Dominant Hand, 5th Digit	FAII – 125 Hz	100.6 (6.2)	104.3 (8.8)
(Ulnar Nerve)	FAI – 32 Hz	104.0 (5.7)	104.5 (11.8)
	SAI – 4 Hz	83.8 (3.6)	84.2 (4.5)
Non-Dominant Hand, 3rd Digit	FAII – 125 Hz	101.3 (7.8)	105.2 (9.0)
(Median Nerve)	FAI – 32 Hz	102.5 (6.0)	103.8 (6.5)
	SAI – 4 Hz	83.3 (4.3)	83.2 (4.8)
Non-Dominant Hand, 5th Digit	FAII – 125 Hz	98.9 (5.5)	103.2 (9.3)
(Ulnar Nerve)	FAI – 32 Hz	102.9 (7.2)	104.2 (7.2)
	SAI – 4 Hz	83.4 (4.0)	84.6 (5.1)

Table 3: Sound Pressure Level (SPL) and Vibration Level (VL) Measurements

TYPE	MODEL	MOUNT	OP. FREQ. (kHz)	SPL (re 2×10^{-5} Pa)		VL (re 1×10^{-6} m/s^2)	
				dB	dB(A)	dB	dB(Weighted)
Rotary Polisher	5k	GRIP	4.4	69.2	65.9	169.2	97.6
	RDH	GRIP	4.4	77.4	72.5	168.7	98.1
	Hygiene	GRIP	5.0	72.7	68.9	171.8	101.0
	Titan	GRIP	4.6	70.2	67.7	165.9	94.9
Sonic Scaler	Quixonic	BASE	6.5	73.8	73.0	199.0	46.4
		GRIP	6.5	77.6	77.2	198.7	46.1
	Pirouette	BASE	6.3	80.2	75.4	176.4	51.9
		GRIP	6.3	81.8	79.7	171.4	54.2
Ultrasonic Scaler	Cavitron	BASE	29.0	102.0	75.6	192.3	78.3
		GRIP	29.0	99.6	75.2	198.0	76.6
	Advantage	BASE	27.8	99.3	48.5	201.4	83.0
		GRIP	27.8	94.7	46.9	197.2	65.1

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MECHANICAL IMPEDANCES DISTRIBUTED AT THE FINGERS AND PALM OF THE HUMAN HAND SUBJECTED TO 3-D VIBRATIONS

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INTRODUCTION

Vibration biodynamic response of the hand-arm system is useful for designing tools and anti-vibration devices, for understanding the vibration-induced disorders, and for helping to develop the location-specific frequency weightings for assessing the risk of the hand-transmitted vibration exposure. One of the practical approaches to study the response is to measure the mechanical impedance of the system at the driving-point. Although a considerable number of studies on the impedance along the forearm direction (z_h-axis) have been reported, the studies of the impedances in x_h- and y_h-axes have been very limited, partially because it is difficult to apply a push force orthogonal to the vibration direction on a single axis vibration testing system. Although the recent developments in 3-D vibration test systems have made it possible to measure impedance responses to multi-axis vibration under controlled grip and push actions[1,2], a single study has reported the 3-D impedance only in the preliminary stage[3]. Furthermore, no study has investigated the impedances distributed at the fingers and the palm of the hand in the x_h-axis and y_h-axis, which are required for further modeling studies. Therefore, the objectives of this study are to measure the 3-D impedances distributed at the fingers and the palm of the hand and to examine their basic characteristics.

METHOD

Six male and six female subjects participated in the impedance measurement. As shown in Fig. 1, the hand and arm postures used in the measurement were within the ranges specified in ISO 10068 (1998)[4]. Also consistent with this standard, each subject applied 30 N grip and 50 N push on a 3-D instrumented handle equipped with two tri-axial forces sensors (Kistler 9017B/9018B) and a tri-axial accelerometer (Endevco 65-100), which was used to monitor the grip force and to measure the impedances distributed at the fingers and the palm of the hand in the three orthogonal directions. The push force was measured using a force plate (Kistler 9286AA) on which the subject was standing on during the measurements. In each axis, an identical broad band random vibration spectrum in the 16 to 500 Hz range was applied as the excitation. To examine the impedance differences between the single and the three-axis excitations, the 1-D impedance for each axis was also measured in a separate test. Three trials were performed for each test treatment, each lasting 30 seconds.

Fig. 1 Test setup and subject posture

RESULTS AND DISCUSSION

Fig. 2 shows the impedances distributed at the fingers and the palm the hand, together with their sum that represents the total impedance of the entire hand-arm system[5]. In all three directions, the impedance distributed at the fingers is much less than that at the palm at frequencies below 100 Hz, which suggests that the effective mass of the fingers at such frequencies is much less than that of the palm. Whereas the magnitudes of the impedance at the fingers in the three directions are fairly comparable, the peak impedance at the palm along the forearm direction is obviously greater than those in the other two directions. The fundamental resonant frequency of the impedance at the palm is lower than that observed from the fingers' responses. The resonant frequency also generally varies with the direction of the vibration exposure but those at the palm are fairly consistent in all three directions (about 40 Hz).

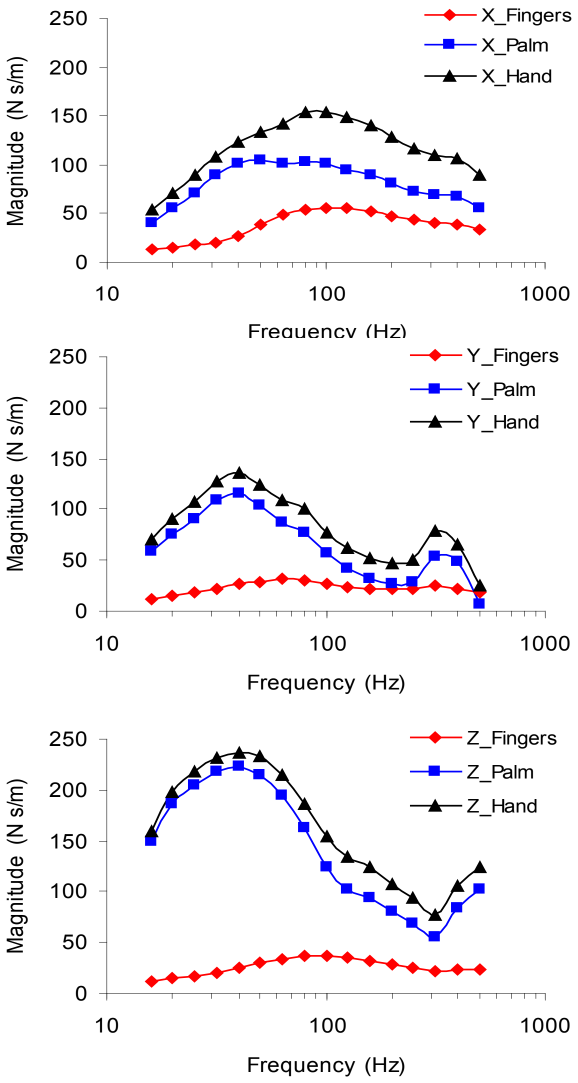

Fig. 2: Impedances in three orthogonal directions

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Wednesday, 2 June 2010

3:45-4:45 PM **HAV MODELING**

3:45-4:00 J.Z. Wu, R.G. Dong, D.E. Welcome, X.S. Xu: A THEORETICAL ANALYSIS OF VIBRATION POWER ABSORPTION DENSITY IN HUMAN FINGERTIP

4:00-4:15 S. Adewusi, S. Rakheja, P. Marcotte: BIOMECHANICAL MODEL OF THE HAND-ARM SYSTEM TO SIMULATE DISTRIBUTED BIODYNAMIC RESPONSES

4:15-4:30 Robin DeJager-Kennedy* and Jay Kim: SEMI-ANALYTIC ESTIMATION OF THE RESPONSE OF HAND-HELD TOOLS AND ITS APPLICATIONS

4:30-4:45 S. Pattnaik*, J. Kim: TWO-STEP APPROACH USING LUMPED PARAMETER AND FEM MODELS FOR HAND AND ARM VIBRATION ANALYSIS

4:45-5:15 PM **Group Picture,** location to be announced

Dinner on one's own

A Theoretical Analysis of Vibration Power Absorption Density in Human Fingertip

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Introduction

The effect of vibration exposure is generally frequency-dependent. However, a reasonable frequency weighting that accounts for any component of the vibration-induced finger disorders, such as the most studied vibration-induced white finger, has not been well established [1]. The current frequency weighting was formulated based on the subjective sensation of the entire hand-arm system measured under some specific testing conditions [2]. We hypothesize that vibration power absorption density (VPAD) is a good measure of the finger vibration exposure, and it may be used to help develop a better frequency weighting for assessing the risk of the finger disorders. We propose a hybrid modeling method for analyzing the VPAD of the finger soft tissues.

Method

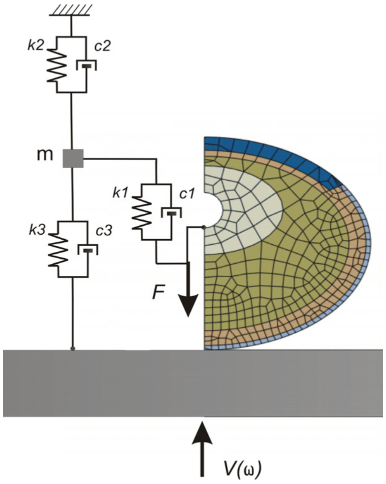

Figure 1: Hybrid model of a fingertip.

The hand-finger system is simulated by using a hybrid model, which combines a lumped parameter model with a two-dimensional finite element (2D FE) model, as illustrated in Fig. 1. The fingertip is simulated using a 2D FE model, while the effective mass of the hand-finger is represented by the mass element *m*. The coupling between the fingertip and hand-finger is represented by the spring and damping element (*k1* and *c1*). The contact between the fingertip and the vibrating plate is simulated in the FE modeling, while the coupling between the hand and the vibrating plate is represented by another spring/damping unit *(k3* and *c3*). The coupling between hand, forearm, and ground is represented using a spring/damping unit (*k2* and *c2*). The fingertip model was assumed to be composed of skin layers, subcutaneous tissue, bone, and nail. The biquadral, plain-strain elements were used in the FE models and the commercial FE software package, ABAQUS (version 6.8), was utilized for the analyses. The skin is assumed to be composed of two layers: the outer skin (0.10 mm thick) and inner skin (1.26 mm thick). The outer skin layer contains stratum corneum and a part of the viable epidermis, and is considered as linearly elastic; while the inner skin layer is composed of dermis and a part of the viable epidermis, and is characterized as nonlinearly elastic. The bone and nail are assumed to be linearly elastic [3]. Two-term Mooney-Rivlin models are applied to characterize the nonlinearly elastic behaviors, and the Rayleigh formula is applied for the frequency-dependent viscous damping characteristics of the soft tissues, as described in our previous studies [4,5].

The lumped element parameters were determined by fitting the model to experimental measurements. The vibration transmissibility of the fingertip was measured using a laser vibrometer (Polytec PSV-300-H). The basic measurement method and testing setup were similar to those reported in a previous study [6]. Briefly, a flat, rectangular aluminum platform (21.6 x 12.7 cm, 1.09 kg) connected to a single-axis vibration testing system (Unholtz-Dickie, TA250-S032-PB) was used to deliver the vibration. The plate was pushed on with an open hand at a given static force (from 15 N to 30 N) during the measurement.

Results

The representative results for the frequency-dependent distributions of the vibration speed magnitude and VPAD across the central line of the fingertip model are shown in Fig. 2. At the tissue/plate contact surface, the vibration velocity is constant at 8 *mm/s*, while the distributions of the vibration within the soft tissue depend on the frequency. When the frequency is equal to or greater than 125 Hz, the distribution patterns of the vibration in the soft tissue varied suddenly:

the gradients of vibration displacement and velocity across the tissue become substantially greater. The VPAD-based frequency weighting curves are calculated and shown in Fig. 3. The curves of the ISO frequency weighting and the normalized vibration transmissibility at the nail are also shown in the figure for comparison.

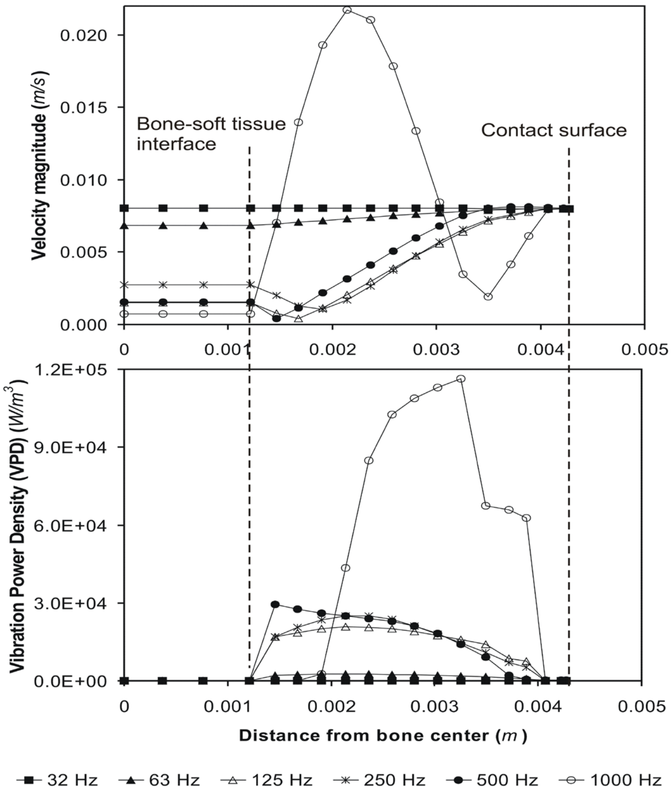

Figure 2: The distributions of vibration velocity and VPAD along the central line of the fingertip model.

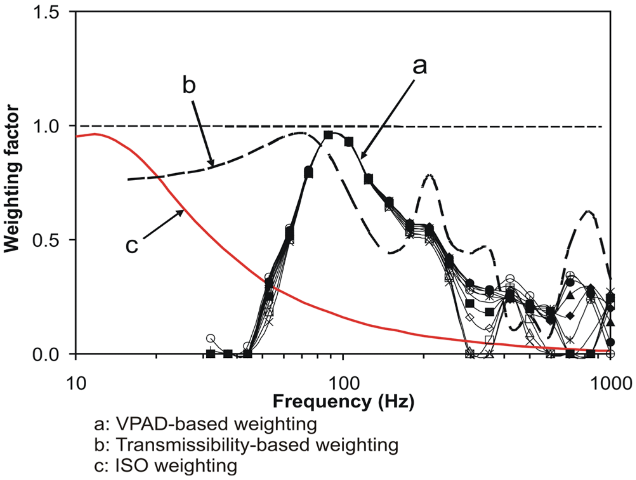

Figure 3: Comparison of the frequency weighting derived using VPAD with ISO-weighting and the weighting derived using the finger surface vibration transmissibility. The VPAD-based weightings were calculated using data at different locations within the soft tissues and shown in different symbols.

Discussion and Conclusions

As shown in Fig. 3, the VPAD frequency weighting of the finger soft tissue is largely different from the current ISO frequency weighting. If the VPAD is more closely associated with the finger disorders than the ISO weighted acceleration, the observed weighting differences suggest that the ISO weighting could overestimate the vibration effect at the low frequency but underestimate the high frequency vibration, which is consistent with the observations reported from some physiological, pathological, and epidemiological studies. It is also interesting to note that the basic trends of the finger surface vibration transmissibility at frequencies higher than 80 Hz are fairly consistent with the VPAD weighting, which suggest that the transmissibility could be utilized to approximately represent the weighting of the VPAD in this frequency range.

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BIOMECHANICAL MODEL OF THE HAND-ARM SYSTEM TO SIMULATE DISTRIBUTED BIODYNAMIC RESPONSES

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Introduction

A number of mechanical-equivalent biodynamic models of the human hand-arm have been developed for potential applications in design of tools and vibration control mechanisms. The vast majority of the reported models have been derived using measured driving-point impedance (DPMI) and do not relate to anatomical structure of the hand-arm system.[1] The models assume hand-arm structure with a fixed support suggesting negligible transmission of vibration beyond the shoulder, although a few studies have reported considerable vibration at the shoulder[2] and the head[3] under exposure to hand-transmitted vibration (HTV). Moreover, the validity of the models in predicting vibration transmission properties of the human hand-arm has not been established, which raises concerns related to their applicability for characterizing vibration-induced loadings and responses of the different hand-arm substructures. This study presents a hand-arm model with a representative biomechanical structure derived on the basis of simultaneously measured DPMI and localized vibration transmissibility responses.

Methods

Fig. 1 shows the hand-arm model structure in the bent-arm posture, where m_i are segment masses, and (c_i,k_i) and (C_i,K_i) represent the linear and rotational visco-elastic parameters, respectively. The shoulder constraint, employed in all of the reported models, is relaxed by considering a lumped mass due to the trunk to account for the reported considerable vibration of the head.[3]

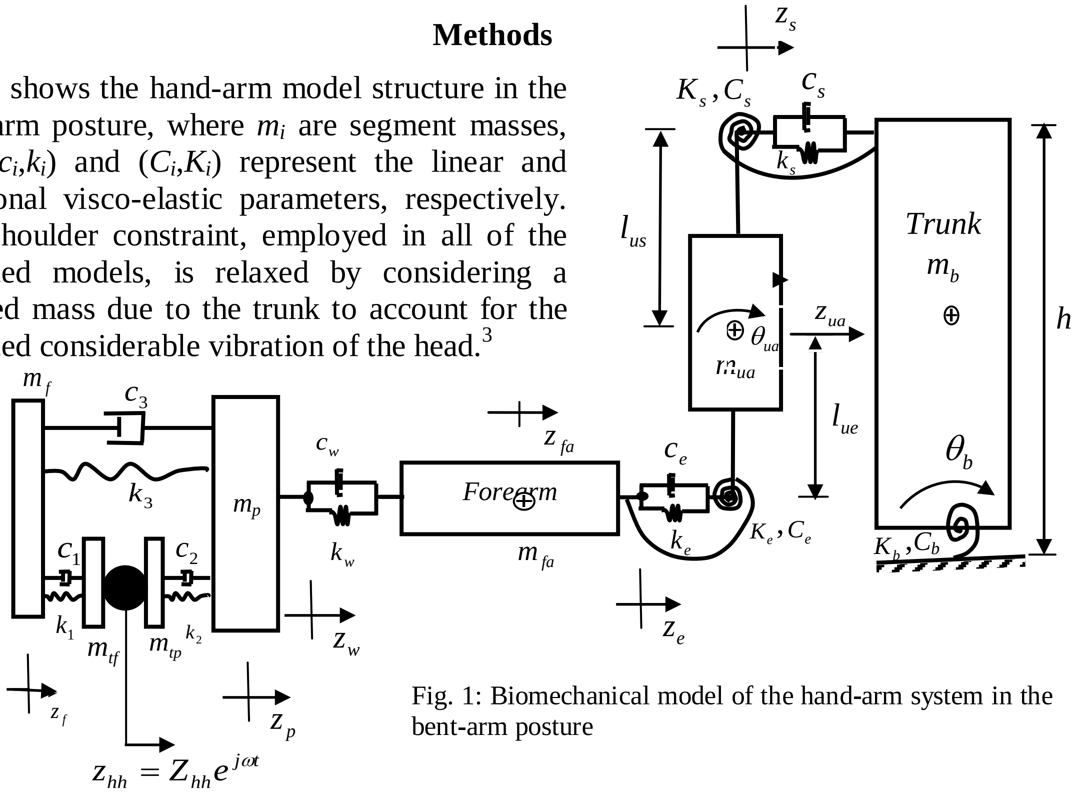

Fig. 1: Biomechanical model of the hand-arm system in the bent-arm posture

Three different target functions were considered for model parameters identification based on: (i) DPMI data alone; (ii) segment vibration; and (iii) combined DPMI and segment vibration data, while hand-arm anthropometry was used to define the inertial and geometry data. Experiments were performed to simultaneously measure DPMI and segment (wrist, elbow and shoulder) vibration responses of six subjects grasping a 40 mm diameter handle subject to z_h-axis broadband random excitation (a_{hw}= 5.25 m/s^2). The subjects applied different levels of controlled grip and push forces during experiments.

Results and discussions

Fig. 2 illustrates comparisons of the measured data with responses of the model derived from the different target biodynamic responses. The model derived on the basis of DPMI alone resulted in very good agreement between the model response and measured data in DPMI alone, with considerable errors in vibration transmissibility responses. The model based on the vibration transmissibility target functions alone resulted in reasonably good agreements between the mean measured and the model transmissibility responses, with poor agreement between the measured and model DPMI responses. The minimization of error in DPMI alone, which has been invariably applied for deriving hand-arm vibration models, provided the most rapid convergence of the solutions, while the resulting model could not be applied for predicting segment vibration responses, and the relative motions across the hand-arm segments for estimating distributed absorbed power. Consideration of both the segment vibration and DPMI as target functions resulted in an acceptable agreements in both the biodynamic responses, which would be better suited for study of distributed responses. The model parameters and responses further suggested strong coupling between the HTV and the trunk vibration.

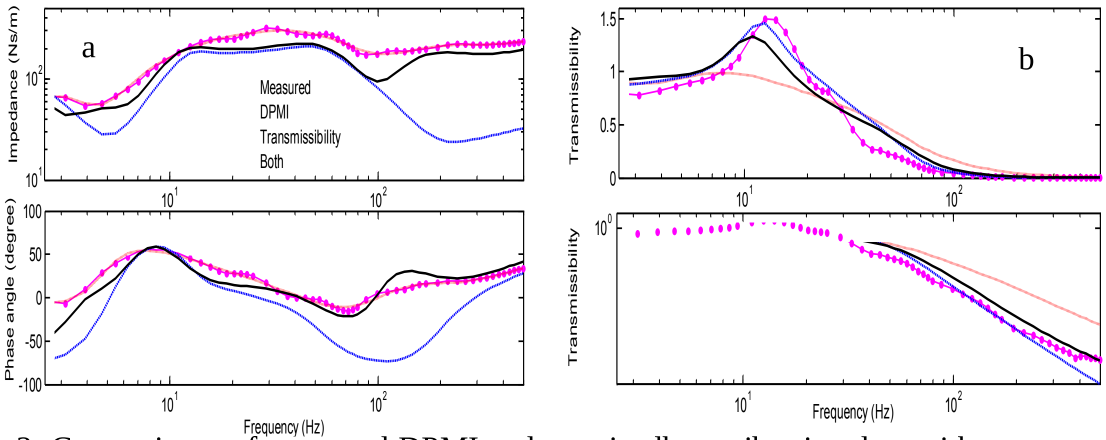

Fig. 2: Comparisons of measured DPMI and z_h-axis elbow vibration data with responses of the model derived using three different target functions.

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SEMI-ANALYTIC ESTIMATION OF THE RESPONSE OF HAND-HELD TOOLS AND ITS APPLICATIONS

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Introduction

Many hand-arm models have been proposed by researchers for various purposes, which include lumped parameter or continuous models[1]. In this paper it is shown that a semi-analytic response solution of a hand-held tool can be obtained by using a given hand-arm model and the tool vibration force estimated from measurement. This semi-analytic solution can be compared with the measured response of the hand-held tool. The approach can be used to compare performance of hand-arm models, and also to estimate the force transmitted to the hand.

Methods

Fig. 1 (a) shows a tool running free and suspended by a very soft bungee cord. Because the spring constant k is small, the response of the tool is:

$$\boldsymbol{X}(\omega) = \frac{\boldsymbol{F}(\omega)}{k-\omega^2 M_{tool}} \cong -\frac{\boldsymbol{F}(\omega)}{\omega^2 M_{tool}} = -\frac{\boldsymbol{A}(\omega)}{\omega^2} \tag{1}$$

From Eq. (1), $\boldsymbol{F}(\omega) = M_{tool}\boldsymbol{A}(\omega)$; therefore the tool vibration force can be estimated from the measured acceleration. It is noted that the tool vibration force is largely a result of unbalanced mass as illustrated in Fig. 1 (a).

Fig. 1 (b) describes the motion of a free-running tool held by a hand-arm modeled as a three D.O.F system. The equation of motion is described as follows;

$$[M]\{\ddot{x}(t)\} + [C]\{\dot{x}(t)\} + [K]\{x(t)\} = \{f(t)\} \tag{2}$$

where, the mass corresponding to x_1 should be taken as M_1+M_{tool}. In the frequency domain, Eq. (2) becomes

$$[K - \omega^2 M + j\omega C]\{\boldsymbol{X}(\omega)\} = \{\boldsymbol{F}(\omega)\} \tag{3}$$

As mentioned above, $\{\boldsymbol{F}(\omega)\} = [M_{tool}\boldsymbol{A}(\omega), 0,0]^T$ is obtained from measurement. Therefore,

$$\{\boldsymbol{X}(\omega)\} = [K - \omega^2 M + j\omega C]^{-1}\{\boldsymbol{F}(\omega)\} = [\boldsymbol{H}(\omega)]\{\boldsymbol{F}(\omega)\} \tag{4}$$

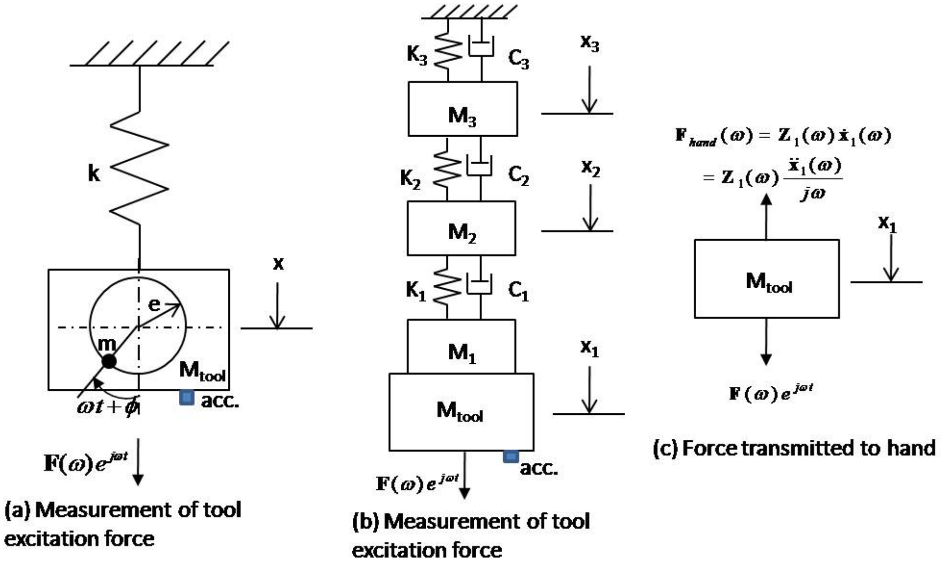
$\{\boldsymbol{X}(\omega)\}$ obtained as such can be considered as a semi-analytic solution because it is the response calculated from the theoretical model using the force estimated experimentally.

Discussions

This semi-analytically estimated response obtained by the above-explained procedure can be used to evaluate performance of a given hand-arm model. Fig.2(a) compares semi-analytically estimated accelerations in the x-direction obtained from 5 different lumped parameter models with the directly measured acceleration of an angle grinder operating hand-held. Figure 2(b) compares measured and simulated acceleration time histories of the tool. The approach can also be used to estimate the tool force transmitted to the hand-arm system. As illustrated in Fig. 1 (c), the force can be calculated by:

$$\boldsymbol{F}_{hand}(\omega) = \boldsymbol{Z}_1(\omega)\frac{\boldsymbol{A}(\omega)}{j\omega} \tag{5}$$

where, $\boldsymbol{Z}_1(\omega)$ is the impedance calculated from the hand-arm model and $\boldsymbol{A}(\omega)$ is the measured acceleration of the tool.

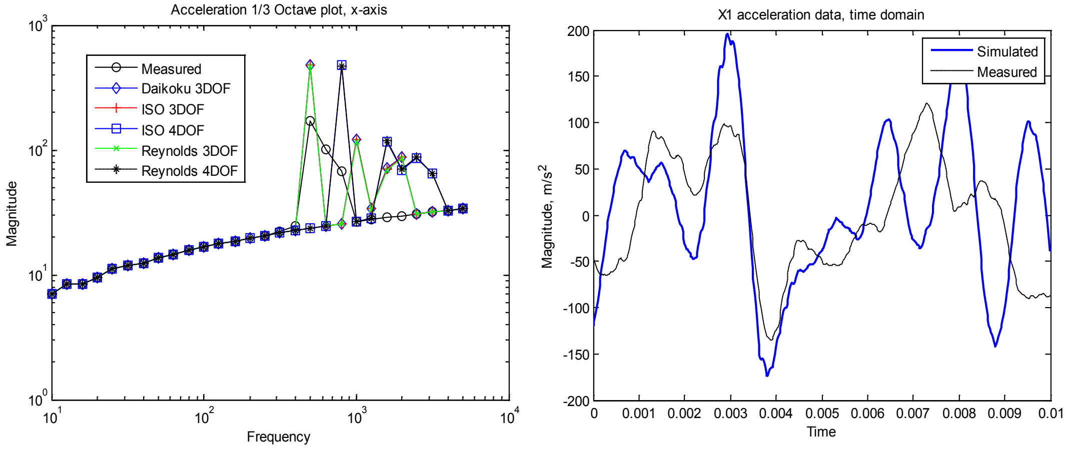


(a) Measurement of tool excitation force

(b) Measurement of tool excitation force

(c) Force transmitted to hand

Fig.1 Concept of semi-analytic estimation of the operating response of the tool and hand-transmitted force



(a) Comparison of accelerations calculated from 5 models with measurement in 1/3 octave spectra

(b) Measured and simulated acceleration time histories from the 3 DOF model proposed by Reynolds

Fig. 2 Comparison of measured and semi-analytically estimated x-direction accelerations of an angle grinder.

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TWO-STEP APPROACH USING LUMPED PARAMETER AND FEM MODELS FOR HAND AND ARM VIBRATION ANALYSIS

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Introduction

Exposure to excessive vibration causes hand and arm vibration syndrome (HAVS) whose precise pathogenesis of HAVS remains unclear[2]. Population study and empirical tests provide useful but limited information; therefore numerical analysis is an attractive option if conducted properly. A lumped parameter based model appears to be more appropriate for analysis of low frequency vibration, while a finite element model is more appropriate for analysis of high frequency vibration. Therefore, a two-step approach that employs both models is proposed in this work. The lumped parameter model is used to estimate forces transmitted through joints tendons and supply basic data for the FEM model. The FEM model is used for further analysis of disorders in the vascular system and interphalangeal joints.

Method & Model

Figure 1 shows a lumped parameter model of one of the fingers gripping a tool bar. Gripping forces have to be estimated from measurements or a separate kinematic analysis. The small spring-mass-damper system attached to each phalange represents the part of the finger in contact with the tool bar. M_i and I_i represent the mass and mass moment of inertia of the i^{th} phalange. Circles specified as θ_1, θ_2, θ_3 are interphalangeal joints modeled as small torsional spring and damped. Solid lines are flexor tendons and lumbrical muscles, and dash lines are inactive extensors. Due to redundancies built in the hand motion, exact analysis of individual tendons and muscles is impossible. As the static gripping is performed muscle recruiting begins with flexor profundus, followed by superficialis, finally with interossei and lumbricales as demand of force increases. Static analysis is conducted to identify active muscles, DC component of the joint force, and then followed by dynamic analysis.

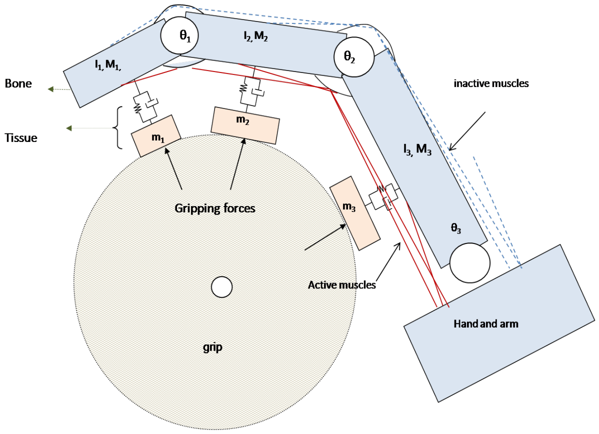

Fig. 1: Lumped parameter based power-grip

Results / Discussion

Figure 2 (left) shows the ADAMS model of the distal phalange, reduced from the model in Fig.1. The element shown as a long linear spring represents the flexor digitorum profundus, a long tendon attached to the upper arm. Effects of local muscles and synovial joints are lumped into a coil spring. Figure 2(right) shows undamped frequency responses calculated from the model. Solid line and dash-dot line represent the response at the tip of the bone with and without tendon, and dotted line is the response of the small muscle mass. Response shows three resonances between 10-100Hz.

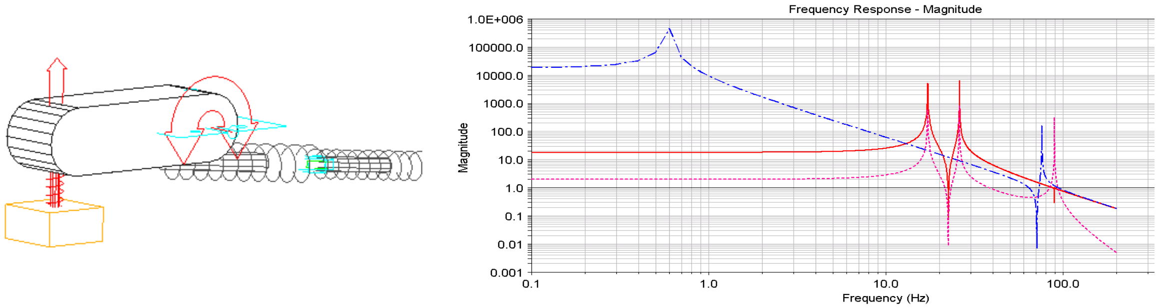

Fig. 2: (Left) ADAMS model (Right) Frequency responses

Figure 3 (left) shows a finite element model consists of distal and proximal segments of an index finger. Figure 3 (right) is the result of ABAQUS analysis that shows contours of the area deformed by 80% of the maximum deformation at various frequencies. It shows that the effect of vibration becomes more localized as the input frequency becomes higher.

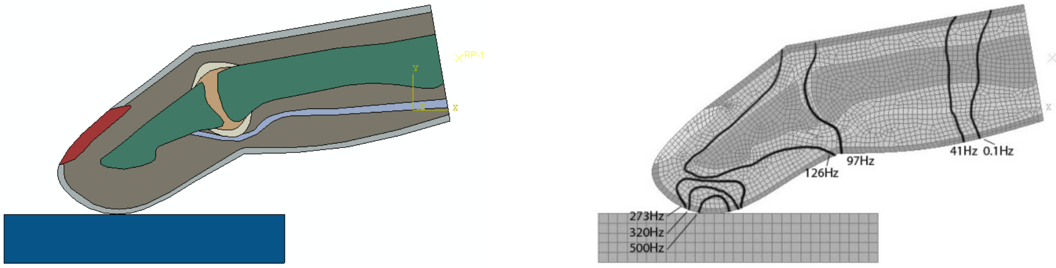

Fig. 3: (Left) Finite element model, (Right) Static deformation contour

Future Work

Estimating proper values of properties and developing a best procedure for the two-step analysis are necessary. Application of the results to understand effects of vibration on joints and vascular disorder is also planned.

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Thursday, 3 June 2010

7:30-8:00 AM **Executive/Scientific Committee meeting (Lucas-Dodge room, IMU, 2nd floor)**
7:30-8:00 AM **Registration and Continental Breakfast, IMU Bijou Theatre Lobby**

8:00-8:30 AM **Keynote**: **Explaining What We Do**
David G. Wilder, PhD, PE, CPE, FAIMBE
Director, Jolt/Vibration/Seating Lab, Iowa Spine Research Center
University of Iowa, Iowa City, Iowa

8:30-9:00 AM **KNOWLEDGE GAPS AND DIAGNOSIS RELATED TO WBV**

8:30-8:45 Helmut W. Paschold: WHOLE-BODY VIBRATION KNOWLEDGE GAPS IN THE US

8:45-9:00 Eckardt Johanning: DIFFERENTIAL DIAGNOSIS OF WHOLE-BODY VIBRATION RELATED DISORDERS

9:00-10:00 AM **CHARACTERIZING WBV ENVIRONMENTS AND EFFECTS**

9:00-9:15 Peter W. Johnson*, Patrik Rynell and Ryan Blood: DIFFERENCES IN WHOLE BODY VIBRATION EXPOSURES BETWEEN A CAB-OVER AND CONVENTIONAL FLATBED TRUCK

9:15-9:30 Igor M. Dudnyk, Olena A. Kossenkova-Dudnyk: EVALUATION OF WHOLE-BODY VIBRATION AT WORKPLACES OF TROLLEYBUS DRIVERS AND PROPHYLACTIC MEASURES

9:30-9:45 Dennis A. Mitchell, Luis Morales*: A COMPARISON OF 1980'S AND CURRENT GENERATION LOCOMOTIVE SEATS RELATIVE TO WHOLE BODY VIBRATION HEALTH EFFECTS

9:45-10:00 Yi Qiu and Michael J. Griffin: EFFECT OF BACKREST CONTACT ON THE APPARENT MASS OF THE SEATED HUMAN BODY EXPOSED TO SINGLE-AXIS AND DUAL-AXIS EXCITATION

10:00-10:30 AM **Break** (Bijou Theatre Lobby)

WHOLE-BODY VIBRATION KNOWLEDGE GAPS IN THE US

Helmut W. Paschold, Ph.D., P.E., C.I.H., C.S.P.
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Introduction

WBV knowledge gaps include assessment of total workers exposed, US specific standards, OSHA standards, comprehensive listing of WBV magnitudes, and safety and health practitioner expertise. The knowledge gaps were identified by an extensive literature review and a prior knowledge survey by the author.

Results

Three major studies address US occupational exposure to WBV. The ACGIH® reported about 7 million US workers.[1] The Occupational Environment: Its Evaluation, Control, and Environment, reported 6.8 million workers.[2] Both of these figures are directly based on a 1974 study providing one of the first estimates of the extent of US WBV exposure, but with significant limitations.[3] Walk-through inspections were conducted in 45 plants during 1971 and 1972 with observational data, not physical WBV measurements, obtained and used to arrive at a conservative total estimate of 7 million.

The National Occupational Exposure Survey (NOES) of 1981 to 1983 included WBV, Agent Code P0651.[4] Researchers in this study visited 4,490 establishments representing 522 industry types with 1,800,000 workers for observations of a great variety of occupational health exposures. Based on WBV observations extrapolated to employment data, NOES reported 1,082,217 US workers as potentially exposed to WBV.

A recent US construction trade survey estimated 540,000 operating engineers (operators of dozers, excavators, loaders, cranes, etc.) had occupational WBV exposure.[5] This high number of WBV-exposed workers in part of one industrial sector of the US workforce suggests that the NOES results greatly underestimated US WBV exposures.

Within the US, the three voluntary WBV standards most commonly referenced are ANSI, ACGIH®, and ISO. The first of the ISO WBV standards was released in 1972 and has been updated several times.[1] The American National Standards Institute (ANSI) originally published American National Standard S3.18 in 1979 that was almost identical to the ISO2631 and later released ANSI S3.18-2002 ISO 2631-1-1997, an adaptation of the most recent ISO standard.[6] WBV exposure limits published by the ACGIH® are based upon the ISO standard.[7] Neither NIOSH nor OSHA has issued WBV standards.[1,8]

WBV magnitude data has been published in a comprehensive listing for various types of equipment such as in a 2000 Great Britain WBV prevalence study.[9] This article reported a number of typical a_{wz} values for numerous machines or vehicles, all based on European findings. Most published WBV a_{wz} values are non-US, only a limited number of US values had been found for mining, agriculture, and railways.

A 2007 survey revealed 38.6% of the US safety and health professionals had *never* heard of WBV.[10] Over two-thirds (69.5%) self-rated their WBV knowledge as little or none.

Discussion

The Wassermann et al. study, with its limitations, may still be the most accurate assessment to date. However, it was emphasized that no measurements were made during the plant tours owing to the lack of techniques to quantify WBV, and that they did not "know the relationship between the different parameters of vibration and the possible health and/or safety effect in long-term occupational vibration exposure".[3, p.39] An updated assessment of exposure in the US workplace is needed.

The absence of a US data driven voluntary standard presents an obstacle to the widespread implementation of WBV remediation through governmental (OSHA) compliance activities. It can be argued that the differences between the US and European trades considering equipment and work methods may be significant with regard to WBV exposures. More monitoring and publication of WBV magnitudes is needed in the many of the US work sectors.

The safety and health community surveyed is comprised of the professionals charged with anticipation, recognition, monitoring and control of workplace health hazards. Despite the apparent prevalence and adverse health effects of WBV, the US safety and health professional community is poorly informed about this topic. Without a reasonable capacity to anticipate the hazards of WBV, the subsequent stages of evaluation and control of the hazard cannot occur, allowing the WBV hazard to continue unabated in many workplaces. Greater efforts are needed in the Research-to-Practice (R2P) aspects of WBV in the US.

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DIFFERENTIAL DIAGNOSIS OF WHOLE-BODY VIBRATION RELATED DISORDERS

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Introduction

Occupational whole-body vibration (WBV) exposure can lead to multiple, often non-specific health complaints and to physical disorders in vehicle operators. Primarily musculoskeletal or neurological disorders of the spine are generally recognized adverse health outcomes of intense and prolonged exposures due to strong epidemiological evidence. In some countries these types of "mechanical" repetitive back injuries are compensable if certain criteria are met.[1] [2] Less frequently organ damage has been reported including the prostate, the intestinal organs (stomach, bladder and kidneys), female reproductive organs, peripheral veins, hemorrhoids, or the cochlear vestibular system.[3] [4] The medical diagnosis, treatment and prevention of occupational low back disorders has been reviewed in a clinical consensus protocol. [5] A prototype health surveillance scheme for WBV has been proposed.[6] However, many physicians and occupational safety and health experts seem not to be familiar with the wide spectrum of health complaints and the proper diagnostic evaluation of WBV-exposed patients.[7] The aim of this study is to review the current medical knowledge and differential diagnostic evaluation methodology.

Methods

Review of peer-reviewed clinical reports and scientific journal publications of whole-body vibration related health effects and the medical differential diagnostic evaluation protocols and recommendations. Review of the evidence and differential diagnosis.

Results

There is general recognition that the diagnostic approach for the medical evaluation of cases with suspected vibration-induced disorders should include a comprehensive work history, a list of hobbies that may include vibration exposure, a complete medical -, family- and social history, review of systems (smoking habits), medications, prior injury and trauma, followed by a complete physical examination. In addition, some special diagnostic laboratory and imaging studies may be indicated to rule out "red flag" conditions. WBV is frequently associated with symptoms such as acute or chronic low back pain, peripheral neuropathy and progressive degenerative changes of the spine, including lumbar inter-vertebral disc disorders. Typically, significant symptoms and signs are severe and chronic pain, paresthesia and neurological dysfunction. To a lesser degree WBV exposure may also lead to neck-shoulder problems, digestive disorders, circulatory disorders, auditory effects, and reproductive problems. The health complaints are typically discomfort, pain or organ related dysfunction. The differential diagnosis includes pathologies principally related to acute trauma (fractures), infections (i.e., tuberculosis), cancer, systemic and chronic diseases (i.e., osteoporosis, auto-immune diseases, inflammatory rheumatologic problems, metabolic diseases (diabetes, thyroid), bone, prostate, renal or psychiatric disorders. Diagnostic tests include blood and urine laboratory studies, radiological imaging and electrophysiological studies. Symptoms, pathology, and radiologic appearances may be only weakly correlated. The prevalence of a prolapsed intervertebral disk among persons with low back pain in primary care is estimated to be 1 to 3 percent. About 4 percent of patients with low back pain in primary care settings have a compression fracture, and about 1 percent have a tumor. Inflammatory rheumatologic conditions (ankylosing spondylitis) and spinal infections are typically less common. The causal diagnosis is based on the medical findings, the differential diagnostic methodology and supportive work exposure data (WBV vibration measurements according to national or international (i.e., ISO 2631-1, ACGIH) guidelines and supportive literature.

Discussion

A proper WBV-related injury diagnosis includes a critical review of the work history, exposure data assessment and the clinical differential diagnostic evaluation. Many health care providers receive little or no training in occupational medicine and recognition of WBV related injuries. The aims of improved WBV *health surveillance* are to assess health status and improve the diagnosis of vibration-induced disorders at an early stage, to inform the workers on the potential risk associated with vibration exposure, to give preventive advice to employers and employees. Customized occupational and clinical health questionnaires and examination protocols may be useful in the systematic medical monitoring of WBV exposed workers and should me more utilized in the medical evaluation.

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DIFFERENCES IN WHOLE BODY VIBRATION EXPOSURES BETWEEN A CAB-OVER AND CONVENTIONAL FLATBED TRUCK

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Introduction

Epidemiological studies have shown a relatively strong association between occupational back pain and the exposure to Whole Body Vibration (WBV) with the risks for injury increasing as the duration and dose of WBV increases. Recent research on self-reported musculoskeletal problems amongst professional truck drivers has shown that approximately 60% of drivers report low back pain. Contributing further the difficulty of quantifying the risk of low back pain from driving occupations is that fact that WBV exposures may vary greatly between vehicle types. Vehicle and seat design have a significant effect on the ability of vibration to travel through the vehicle and reach the operator. Prior research has compared the performance of seat suspensions and their ability to attenuate continuous low frequency and impulsive high frequency WBV exposures. Generally, the major classes of seats which can be installed in vehicles consist of an air suspension, a mechanical suspension, or a solid frame seat with foam and springs as the shock absorbing mechanism. Using a group of experienced truck drivers and calculating time-weight average (TWA) and impulsive WBV exposure parameters, the purpose of this study was to characterize and determine whether there were differences in WBV exposures between a conventional and cab over design flatbed truck.

Methods

Using a repeated measures design and a standardized test route, WBV exposures were compared when thirteen experienced flatbed truck drivers drove two vehicles, 1) a European-style flatbed truck where the drivers were situated directly over the front wheels (cab-over design) and 2) and a North American-style flatbed truck where the cab was situated behind, rather than over, the front wheels. Both vehicles were analyzed with the stock seats that came with the vehicles, which were solid suspension seats with foam and springs as the only shock absorbing material. The 15 minute standardized test route consisted of a section of freeway and two sections of city streets. A tri-axial seat pad ICP accelerometer (model 356B40; PCB Piezotronics; Depew, NY) was mounted on the driver's seat and the same model accelerometer was securely mounted on the floor of the vehicle. A WBV data acquisition system (model DA-20; RION Co., Ltd.; Tokyo, Japan) was used to collect raw (S_{ed}) and time weighted average vibration exposures (A_w, Crest Factor, VDV). The A_w, VDV, and S_{ed} values were all normalized to an eight hour day to reflect the drivers' normal work shift. Vehicle speed was collected using a GPS device. Differences in WBV exposures between the trucks were evaluated using paired-t tests and considered significant when p-values were less than 0.05.

Results

Table 1 shows a significant difference in A_w, VDV, and S_{ed} between the cab-over and conventional flatbed truck designs with the cab-over having substantially higher exposures. With respect to exposure limits outlined in ISO 2631-1[1] and 2635-5[2] both the cab-over and conventional truck designs were above the 0.5 m/s^2 action limit for A_w in the dominant z-axis. The VDV measurements were above the 9.1 $m/s^{1.75}$ action level but below the exposure limit (21 $m/s^{1.75}$). Finally, the cab-over design S_{ed} measurements were above the 0.5 MPa action level but below the 0.8 MPa exposure limit while the conventional design truck was below the action limit.

TABLE 1: Mean (±SE) Z axis WBV measures over the whole route by vehicle type [n=13].

	Vehicle Type			
Parameter	**Cab-Over**	**Conventional**	**Difference**	**p-value**
A_w (8) (m/s^2)	0.75 (± 0.02)	0.56 (± 0.02)	0.19	<0.0001
Crest Factor	8.9 (± 0.44)	11.5 (± 0.43)	-2.62	0.0011
VDV (8) ($m/s^{1.75}$)	16.3 (± 0.38)	13.4 (± 0.4)	2.94	<0.0001
S_{ed} (MPa)	0.72 (± 0.06)	0.48 (± 0.02)	0.24	0.002
Speed (km/hr)	54.9 (± 0.14)	55.4 (± 0.16)	-0.45	0.63

Discussion

The WBV exposure differences between the conventional and cab-over design flatbed trucks showed that the conventional design performed better in attenuating TWA and impulsive exposures. These finding indicate, when selecting vehicles configurations for professional drivers, it may be important that employers consider the differences in WBV exposures between different vehicle options. The results of this study indicated that, relative to vehicles where the cab was situated over the front wheels, vehicles with a cab situated behind the front wheels may decrease occupational WBV exposures. Although the study was conducted in North America, the results may be of interest to the European community which fall under the current European Directive 2002/44/EC [3]. In the future, it would be interesting to evaluate the performance of commercially available seat interventions including semi-active and active vibration dampening seats.

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EVALUATION OF WHOLE-BODY VIBRATION AT WORKPLACES OF TROLLEYBUS DRIVERS AND PROPHYLACTIC MEASURES

Igor M. Dudnyk, Olena A. Kossenkova-Dudnyk

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Introduction

The trolleybus is an ecological, clean mode of transportation used in urban areas. It does not pollute the air, and acoustic pollution within the seliteb zone is also minimal. Therefore these vehicles serve as excellent modes of transportation within populated areas with industrial development. However, there is little information about whether drivers of these vehicles are exposed to whole-body vibration (WBV). One monograph was published 30 years ago[5], but our knowledge of whole-body vibration (WBV) and ability to measure it has improved since that time. The goal of this study was to evaluate WBV exposure in trolleybus cabins and determine if there is a potential health risk to drivers working long hours.[1,2,4,7] We found that pathological states in drivers were associated with long hours of operation and intensive exposure to WBV that was above occupational exposure limits (OELs).

This study measured WBV in trolleybus drivers' (at the cabin' floor and seat) to characterize the source of vibration and determine the best ways to protect drivers from WBV exposure during working hours.

Methods

The vibration acceleration on the trolleybus' floor and driver's seat in cabin was measured simultaneously along three mutually perpendicular directions (x-, y- and z-axes). The root-mean-square (rms) value of the vibration was analyzed in one octave bands from 1 to 63 Hz. The measurements were done with Vibropribor Instrument VShV-003M2 (Taganrog, Russian Federation). Data were collected, using a self-administered questionnaire and actual field measurements according to national and international standards.[3,6]

Results

WBV was transmitted to the driver during operation and was classified by source of rise for transport vibration (category). Mechanical fluctuations were the result of movement of the vehicle frame and its separate assemblies and elements of design. Spectral analysis of the vibratory magnitudes enabled us to estimate it as a wide belted vibration. The results of the present study demonstrate that trolleybus drivers are exposed to considerable levels of WBV in the cabin. The levels of vibration, acceleration (rms) in the cabins of these vehicles (floor and seat), exceed the OELs of current standards under certain conditions. These conditions are, inconstant driving with accelerations (speeding up and braking), driving at speeds of more than 30 km/h, the condition of the road surface, different maneuvers, the condition of the trolleybus as result of operating period. There were positive relationships between the levels of acceleration and the speed of driving of all trolleybuses, the condition of the road surface, and period since the vehicle underwent maintenance. Trolleybuses driving interurban routes differed from those servicing urban routes in the speed of driving and the number of stops. Maximum levels of WBV were measured on routes where the surface was uneven and the bus was moving at the considerable speed. The exposures exceeded OELs of acceleration, primarily in the z-axis at low and average frequencies (1 to 16 Hz). Long working hours and long durations of WVB exposure (up to 80 % of working time) could also serve as a risk factor for inducing injury among drivers; trolleybus drivers can drive for 7.5 to 9 hours in a work day. However, the average time of driving is 5 (urban cycle) to 6.5 hours (interurban cycle) each the day. Thus, the intensity and duration of WBV exposure in drivers are both occupational factors that may affect the risk or drivers developing an injury or disorder. Therefore reducing exposure to these factors may protect drivers from the effects of WBV incurred while driving trolleybuses.

Discussion

Three approaches can be used to protect trolleybus drivers from WBV. Vibration isolation systems to reduce oscillations generated by the vehicle can be added, driving surfaces can be repaired and maintained, and anti-vibration seats can be installed to reduce driver's exposure to WBV. From our point of view, pneumatic seats with compressors and air chambers should be installed in all trolleybus cabins. Other interventions include adding "floating" floors to the cabins, and reducing the transmission of vibration to drivers through vehicle maintenance.

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A COMPARISON OF 1980'S AND CURRENT GENERATION LOCOMOTIVE SEATS RELATIVE TO WHOLE BODY VIBRATION HEALTH EFFECTS

Dennis A. Mitchell, Luis Morales*

Introduction

A group of 1980's style locomotive seats were instrumented and tested under controlled conditions and the data was analyzed with respect to International Standards Organization's methods[1] concerning whole body vibration (WBV) and potential health effects. In order to select the two worst performing seats the root-mean-square (RMS), vibration dose value (VDV) were derived for comparative purposes.

The three worst performing seats were then installed in a locomotive so that data relative to WBV could be collected and compared under actual operating conditions to current style locomotive seat data. The data was analyzed relative to WBV ISO and European guidelines concerning health. [1-2]

Methods

All of the 1980 style seats were initially tested per ISO[1] under controlled conditions by installing them on the same locomotive operated by the same engineer and having the WBV data collected over the same portion of track. The engineer was instructed to take the train up to 10 miles per hour and then at 2 minute increments he was to increase the velocity another 10 miles per hour until it reached 50 miles per hour for two minutes and then he was instructed to stop. Each seat test took just under 12 minutes to complete. The three worst performing seats were installed and instrumented and tested under actual operating conditions and the results from these seats were compared to current style seat data.

Figure 1
1980's style "Toadstool" seat and current generation seating

Results

The three worst performing seats were selected based on their VDV vertical axis result. The vertical z-axis was chosen as it has been reported[3-4] to have the highest vibration levels in locomotives when measured under actual operating conditions and the VDV value was chosen as it is a more accurate measure compared to RMS of the true vibration dose. Two of the 1980's style seats are commonly referred to as "toadstool" type seats and one had armrests and the other did not. The third 1980's style seat tested was in use for less than 5 years. The three 1980's style seats were installed and tested in actual operating conditions (through freight) and their average results were compared to an average from twenty five previously collected WBV runs from current style seats. All data were derived from seats installed on Burlington Northern Santa Fe (BNSF) locomotives in revenue service.

Table 1
Average WBV results from 1980's and current style seating on locomotives

Seat Generation	Hours of exposure	RMS (ms^{-2})			A(8) (ms^{-2})			VDV $(ms^{-1.75})$		
		x	y	z	x	y	z	x	y	z
1980's (n=3)	5.92	0.17	0.22	0.28	0.15	0.19	0.24	4.45	5.21	7.39
2000's (n=25)	7.20	0.14	0.21	0.25	0.13	0.17	0.21	3.42	4.47	5.69

Discussion

The average WBV results summarized in Table 1 fall below the health guidance caution zone as outlined in the ISO[1] document and are below the daily exposure action value of 0.5 ms^{-2} for A(8) and 9.2 $ms^{-1.75}$ for VDV as outlined in the European Directive. It is clear that the 1980 style seats have higher WBV data values compared to the current generation of seats, however the 1980 style seats were still below current WBV health guidelines. The current generation of locomotive seating also offers more comfort and ergonomic features than their 1980's counterparts. Locomotive seats that have active vibration dampening devices are currently under development and these seats may offer further WBV performance improvements over the current generation.

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EFFECT OF BACKREST CONTACT ON THE APPARENT MASS OF THE SEATED HUMAN BODY EXPOSED TO SINGLE-AXIS AND DUAL-AXIS EXCITATION

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Introduction

Contact with a backrest affects the apparent mass of the seated human body exposed to single-axis vibration excitation.[1-2] With vertical excitation, a backrest tends to reduce the vertical apparent mass measured on the seat at frequencies less than the resonance frequency but increase the apparent mass at frequencies greater than the resonance frequency. A similar effect is observed with fore-and-aft excitation, with the first resonance in the fore-and-aft apparent mass measured on a seat increasing from 0.7 Hz without a backrest to 4 Hz with a backrest.[3]

This study was undertaken to compare the apparent masses of subjects seated with and without a backrest while exposed to single-axis and dual-axis vertical and fore-and-aft excitation. It was hypothesised that during both single-axis and dual-axis excitation, the fore-and-aft and vertical apparent masses measured on a seat without a backrest would differ from those measured with a backrest.

Methods

Twelve male subjects sat in a normal relaxed upright posture with their hands on their laps and with average thigh contact on a rigid flat horizontal seat with and without a rigid flat vertical backrest secured to the ISVR 6-axis motion simulator. Subjects were exposed to random vibration (0.2 to 20 Hz) with all 15 possible combinations of four vibration magnitudes (0, 0.25, 0.5, or 1.0 $\mathrm{ms^{-2}}$ r.m.s.) in the fore-and-aft and vertical directions. When exciting the body in both axes simultaneously, the two motions were uncorrelated. After mass-cancellation in the time domain, the forces on the seat were used to calculate the fore-and-aft and vertical apparent masses at the seat surface using single-input single-output models.

Results

The medians of the moduli of the fore-and-aft driving point apparent masses of the 12 subjects with and without the backrest during single-axis fore-and-aft excitation (a_x=0.5 $\mathrm{ms^{-2}}$ r.m.s.) and during dual-axis excitation (a_x=0.5 $\mathrm{ms^{-2}}$ r.m.s., a_z=0.25, 0.5 or 1.0 $\mathrm{ms^{-2}}$ r.m.s.) are shown in Figure 1.

The medians of the moduli of the vertical apparent masses of the 12 subjects with and without the backrest during single-axis vertical excitation (a_z=0.5 $\mathrm{ms^{-2}}$ r.m.s.) and during dual-axis excitation (a_z=0.5 $\mathrm{ms^{-2}}$ r.m.s., a_x=0.25, 0.5 or 1.0 $\mathrm{ms^{-2}}$ r.m.s.) are shown in Figure 2.

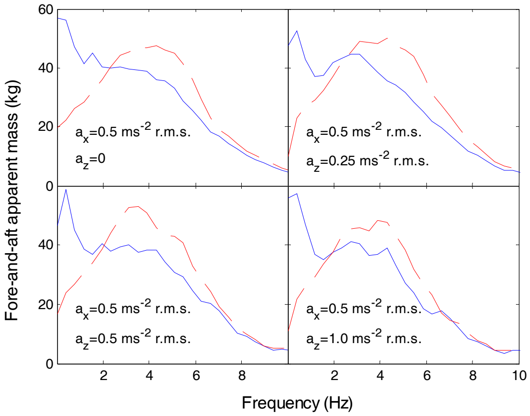

Figure 1 Fore-and-aft apparent mass: —— without backrest; – – – with backrest.

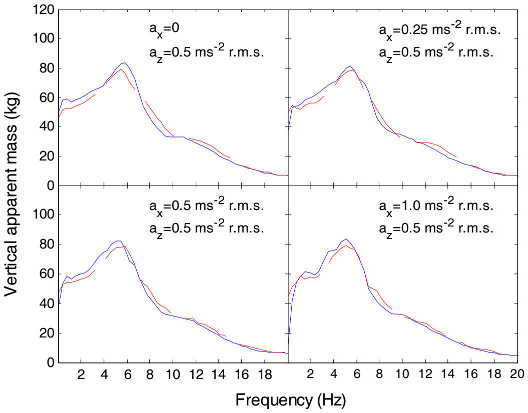

Figure 2 Vertical apparent mass: —— without backrest; – – – with backrest.

Discussion

With single-axis fore-and-aft excitation, the fore-and-aft apparent mass on the seat was greater without the backrest at the lower frequencies but greater with the backrest at the higher frequencies, consistent with previous studies. At two example frequencies in these ranges (0.78 and 3.91 Hz) the differences were highly significant (p=0.002 and 0.002; Wilcoxon). With dual-axis fore-and-aft and vertical excitation, there was a similar effect of the backrest on the fore-and-aft apparent mass with significant differences at the same frequencies for all three magnitudes of vertical excitation shown in Figure 1 (p<0.006).

With single-axis vertical excitation, the backrest tended to affect the vertical apparent mass on the seat as previously reported. Although the simple rigid flat vertical backrest used here produced only small differences, the vertical apparent mass measured on the seat tended to decrease at the lower frequencies and increase at frequencies greater than the resonance frequency. With dual-axis fore-and-aft and vertical excitation, the effect of the backrest on the vertical apparent mass at the seat was similar to that with single-axis vertical excitation. At an example frequency less than the resonance frequency (i.e. 2.73 Hz), the reduction in the vertical apparent mass on the seat was statistically significant with all four magnitudes of fore-and-aft excitation (p<0.012; Figure 2), but at an example frequency greater than the resonance frequency (i.e. 8.2 Hz), there was no statistically significant difference.

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Thursday, 3 June 2010

10:30-11:15 AM **CHARACTERIZING WBV ENVIRONMENTS AND EFFECTS** (Continued)

10:30-10:45 Lauren Gant*, David Wilder, Donald Wasserman: HUMAN RESPONSE TO SINGLE AND COMBINED SINUSOIDAL VERTICAL VIBRATION

10:45-11:00 Heon-Jeong Kim* and Bernard J. Martin: WHOLE-BODY VIBRATION RESPONSE THROUGH THE UPPER LIMBS ASSOCIATED WITH REACHING MOVEMENTS AND POSTURE

11:00-11:15 Robert Caryn BA*, J.P. Dickey, Alan Salmoni, Peter Lemon, Tom J. Hazell: TRANSMISSION OF ACCELERATION FROM VIBRATING EXERCISE PLATFORMS TO THE LUMBAR SPINE AND HEAD

11:15-11:45 AM **COMFORT, PERCEPTION AND PERFORMANCE IN WBV ENVIRONMENTS**

11:15-11:30 Nobuyuki Shibata*, Kazuma Ishimatsu and Setsuo Maeda: GENDER DIFFERENCE OF SUBJECTIVE RESPONSES TO WHOLE-BODY VIBRATION UNDER STANDING POSTURE

11:30-11:45 Kazuma Ishimatsu*, Nobuyuki Shibata, Setsuo Maeda: EFFECTS OF WHOLE-BODY VIBRATION ON THE PERCEIVED DURATION OF A VISUAL STIMULUS PRESENTATION

11:45-1:15 PM **Lunch** (Box lunch-2nd floor ballroom, Center for Computer-Aided Design Lab Tour)

HUMAN RESPONSE TO SINGLE AND COMBINED SINUSOIDAL VERTICAL VIBRATION

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Introduction

Task performance decrement has been reported with exposure to combined vibration by Cohen et al, 1977.[1] In that study subjects were exposed to 3 different sinusoidal vertical vibration conditions: 2.5 Hz, 5 Hz, and a combination of 2.5 and 5 Hz, and asked to complete a task using all four limbs. It was shown that performance was the worst in the combination of 2.5 and 5 Hz. Although the study provides insight into human performance response to complex vibration, it does not provide any physiological or biomechanical measurements. The current study uses Cohen et al.'s methodology as a foundation, but includes collection of electromyography (EMG) to capture muscle activity. This study may explain the substantial decrease in performance during exposure to the combined vibration.

Methods

Fourteen, right-handed males volunteered for the study. The participants were exposed to three trials of four vertical vibration conditions: non-vibration control, vibration at 2.5 Hz, vibration at 5 Hz, and vibration combining 2.5 Hz and 5 Hz. Each vibration condition had an acceleration of 0.69 ms^{-2} rms, and lasted for 30 seconds per exposure. The vibrations were produced with a six-degree-of-freedom Hydraudyne motion platform (Bosch-Rexroth, Netherlands). During exposure, the participants sat upright in a steel tractor seat with no back support or physical postural reminders. The seat and posture assumed by the participants was identical to those in the Cohen et al. study. The subjects were asked to complete a simple four-limb task during the testing in order to resemble the previous study.[1] Surface electromyography (EMG) was used to capture the muscle activity of the left and right lumbar erector spinae (ES) muscles because the erector spinae muscles are primarily responsible for support during forward flexed tasks.[2] Two Ag-AgCl bipolar electrodes (Model D-100, Therapeutics Unlimited, Iowa City, IA, USA) with built in pre-amplification were placed on the left and right lumbar ES. Back muscle (EMG) activity was calibrated, recorded and ensemble-averaged. In order to compare information between subjects, a normalization taking body weight into account was performed. Two-way analysis of variance (ANOVA) was performed for main effects and interactions. The factors were "vibration condition," with four levels, and "participant," with 14 levels. The mean EMG voltages, the peak-to-peak EMG voltages, and the reaction times were examined.

Results

The mean rectified and smoothed EMG activity differed significantly between participants for the right ES (p=0.000), but not for the left ES (p=0.524). In terms of peak-to-peak rectified and smoothed EMG activity in the left ES, the interaction between participants and environment was significant (p=0.000). Differences detected via paired t-test between peak-to-peak left and right ES activity was significant (p=0.041). Analysis of the right ES activity showed that the response delay differed significantly with environment (p=0.03).

Vertical Vibration Condition						
	2.5 Hz		5 Hz		2.5 Hz and 5 Hz	
Response						
Erector Spinae	Left	Right	Left	Right	Left	Right
Frequency	2.5 Hz	2.5 Hz	5 Hz	5 Hz	2.5 Hz	2.5 Hz
No. Participants	6	2	8	3	5	3

Table 1. Frequency responses and number of participants (out of 14) who responded cyclically to each vibration condition

Not all subjects responded to the vibration frequency (Table 1). The left (L) erector spinae responded more often than the right (R) erector spinae. Both sides only responded at 2.5 Hz to the combined vibration. Chronic involuntary exercise of the muscles opposite the dominant hand could explain why the left erector spinae responded more often than the right.[3] A balanced posture with respect to the vertical acceleration could explain the lack of response in many subjects. Responding only at 2.5 Hz to a combined signal would allow an acceleration component at 5.0 Hz, the seated human's natural frequency, to apply forces to the spine. This could explain both the performance decrement noted above. Cohen, Wasserman and Hornung's 1977 study, the basis for the current study, demonstrated that exposure to the combination of 2.5 Hz and 5 Hz resulted in decreased performance. The lack of response to the 5 Hz component of the input signal is likely correlated with the performance degradation they found.

Discussion

Handedness has a significant effect on erector spinae response and poses the possibility of asymmetric mechanical trunk control. This study has also revealed a significant musculoskeletal control system limitation, raising questions about the ability of the human to cope with complex vibration environments.

References

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WHOLE-BODY VIBRATION RESPONSE THROUGH THE UPPER LIMBS ASSOCIATED WITH REACHING MOVEMENTS AND POSTURE

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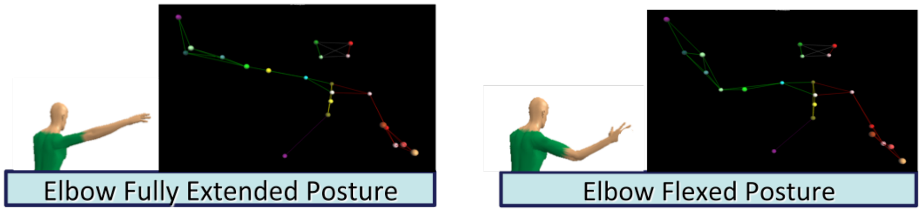
2) Department of Industrial and Operations Engineering, University of Michigan

Introduction

Exposure of human operators to whole-body vibration may induce health risks, interfere with manual operation, and compromise tasks performed in a vehicle [Griffin 1990], [Okunribido et al 2007]. For operator's safety and performance enhancement, numerous investigations have attempted to identify the characteristics of WBV responses of seated individuals. WBV responses are functions of vibration variables [Griffin 1990] and postures [Lim et al 2004], [Kim and Bernard 2008]. As opposed to earlier studies involving limited static postures, the present work analyzes human responses for a large range of arm postures including two elbow flexion constraints in reaching movements.

Methods

Twenty-one participants performed a reaching task on the ride motion simulator of the U.S Army TARDEC, and maintained pointing posture at the end of the reaches for the estimation of WBV transmission. The task consisted of reaching with the right hand seven targets distributed in the right hemisphere of the workspace: upward [TG1], forward-upward [TG2], forward [TG3], forward-lateral [TG4], diagonal-upward [TG5], lateral near [TG6], and lateral far [TG7]. To investigate effects of movement direction and posture on vibration responses of the seated human, all reaches were performed with two postures such as elbow fully extended or flexed (Figure 1). Three vertical vibration conditions with a frequency of 2, 4, and 6 Hz were selected. Reaching movements and cab perturbations were measured by a VICON motion tracking system and tri-axial accelerometers, respectively.

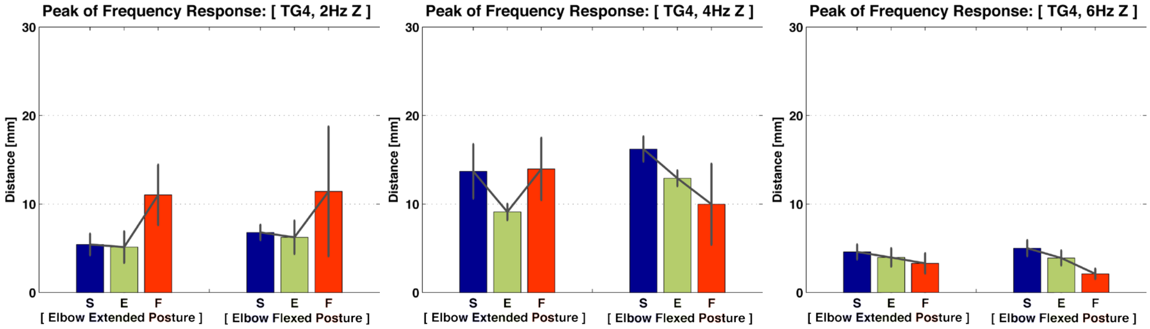

Elbow Fully Extended Posture

Elbow Flexed Posture

Figure 1: Elbow fully extended and flexed postures used during reaching tasks

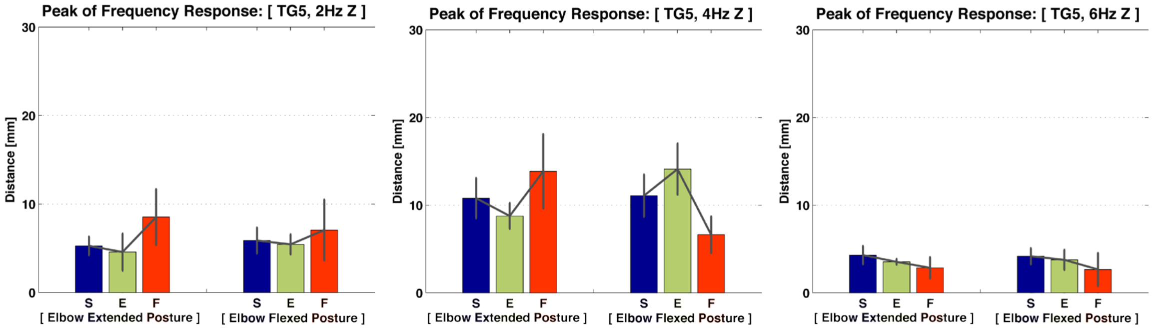
Results and Discussion

WBV responses through the human multi-segment system vary as functions of vibration condition ($p \approx 0$), target direction/location ($p < 0.01$), and elbow joint constraint ($p < 0.01$). Vibration frequency is the dominant factor affecting WBV responses. The interaction between the movement direction and the vibration direction influences WBV responses for specific vibration frequencies. Furthermore, the full extension of the elbow produces small elbow oscillations but contributes an amplification of the finger displacement relative to the elbow, while the elbow flexed posture produces large elbow perturbations but contributes to an attenuation of finger perturbation. In this study, transmission propagated through the upper limb was investigated for vertical sinusoidal vibrations with the selected frequencies only as they correspond to the largest effects. For realistic human motion simulation in vibratory environments, biodynamic characteristics of the seated human under multi-directional vibration inputs may be required to provide a more complete description of whole-body vibration transmissibility and facilitate the implementation of a 3-dimensional biomechanical model development.



(a) 2 Hz vertical vibration (b) 4 Hz vertical vibration (c) 6 Hz vertical vibration

Figure 2: Vibration responses through the upper limb with elbow extended and flexed postures during forward-lateral reach [TG 4]: superscripts S: shoulder, E: elbow, F: fingertip



(a) 2 Hz vertical vibration (b) 4 Hz vertical vibration (c) 6 Hz vertical vibration

Figure 3: Vibration responses through the upper limb with elbow extended and flexed postures during diagonal-upward reach [TG 5]: superscripts S: shoulder, E: elbow, F: fingertip

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Transmission of Acceleration from Vibrating Exercise Platforms to the Lumbar Spine and Head

Robert Caryn BA*[1,2], J.P. Dickey PhD[1,2], Alan Salmoni PhD[2], Peter Lemon PhD[2], Tom J. Hazell MSc[2]
[1]Joint Biomechanics Laboratory, [2]School of Kinesiology, the University of Western Ontario, London, ON

Introduction

Whole Body Vibration platforms have become a popular modality in the fitness and rehabilitation industries. Consequently, whole body vibration has also been identified as a cause of injury in occupational settings[2]. The goal of this study was to quantify the accelerations experienced by the axial skeleton during standing vibration. This study investigated which knee angles effectively dampened vibration to the upper body.

Methods

Healthy male and female subjects completed whole body vibration trials on a vibrating platform (WAVE) that generated vertical vibrations of 2 or 4 mm amplitudes between frequency ranges of 20 and 50Hz. An electrogoniometer (Biometrics SG 150) was used to monitor knee flexion during static squat and dynamic squat trials. Triaxial accelerometers (Biometrics ACL 300/ PCB Piezotronics) were placed on the platform surface, lumbar spine (L5) and forehead. A published transfer function was used to calculate bone accelerations from skin accelerations[1]. The magnitude of the accelerations was calculated using root-mean-square (RMS). Transfer functions describing the magnitude and phase frequency response of the skeleton were calculated for the platform-to-spine and platform-to-head accelerations.

Results

Peak vertical accelerations of the platform ranged from 1 to 6.50 g. RMS accelerations experienced at the spine (0.445 g) and head (1.01 g) were greatest when the knees were close to full extension, resulting in the greatest transmission of mechanical energy (Fig. 1).

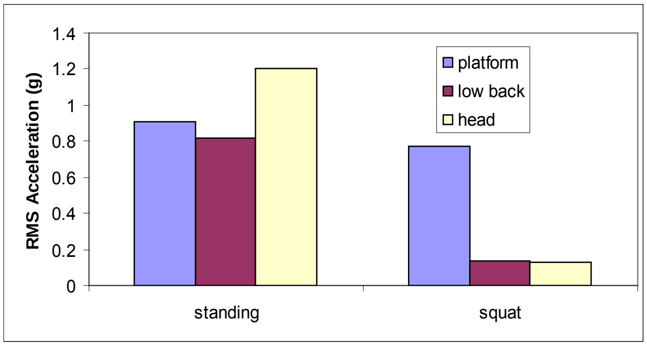

Figure 1. RMS acceleration transmissibility data measured at the head and spine during standing and static squat

Discussion

The transfer functions illustrated that the body is a nonlinear system (data not presented here). The skeletal acceleration amplitudes showed that the axial skeleton is exposed to large amounts of mechanical energy; full knee extension should be avoided. More research is needed to develop guidelines for safe use of vibrating platforms and to explore the long term health effects that may be caused by whole body vibration through the feet.

References

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GENDER DIFFERENCE OF SUBJECTIVE RESPONSES TO WHOLE-BODY VIBRATION UNDER STANDING POSTURE

***Nobuyuki Shibata, Kazuma Ishimatsu and Setsuo Maeda**
National Institute of Occupational Safety and Health, Kawasaki, Japan

Introduction

Passengers in public transportation such as bus and railway are often exposed to whole-body vibration under standing posture. Also regardless of the gender difference, people use the public transportation in their daily life. Although a method of measurement and evaluation of whole-body vibration (WBV) in relation to human health and comfort has been specified in the international standard ISO2631-1 [1], the subjective scale for ride comfort shown in this standard has been based on poor data on female subjects under standing posture.

The main aim of this study was to examine gender difference in subjective response to WBV with different vibration axes under standing posture.

Methods

The experiments were performed with totally twenty four healthy subjects in twenties, twelve males and twelve females with mean ages of 22.3 and 21.6 years old, respectively. None of the subjects have been exposed to high levels or long periods of WBV occupationally or in their leisure time activities. The experiments were approved by the Research Ethics Committee of Japan NIOSH. All the subjects underwent an explanation of the test procedure and gave their written informed consent to participate in this study.

Signals prepared for WBV stimuli were three ISO frequency-weighted r.m.s. acceleration magnitudes of 0.2, 0.4, and 0.8 m/s^2, each of which had a frequency range of 1-100 Hz with a constant power spectrum density. A series of 27 vibration stimuli (three times for three acceleration magnitudes for each direction), each of which was ordered randomly, were applied to the subject standing upright on the platform of a multi-axis vibration system installed in the Japan NIOSH. All the vibration stimuli had a duration time of seven seconds with a two-second pause between adjacent stimuli.

The subjects were asked to respond orally to each vibration stimulus by selecting a certain category number, corresponding to a degree of discomfort they felt, from the five comfort evaluation categories. Subjective scale was obtained from the questionnaire data by using the category judgment method [2].

Results and Discussion

Regardless of vibration axis, the male subjects responded severely to vibration stimuli below a level of category 4 (Uncomfortable) compared to the female subjects. Under standing posture the subjects, regardless of the gender difference, responded more severely to vertical vibration than to fore-and-aft and lateral vibration. Our results suggest that the gender difference between subjective responses to WBV is highly affected by vibration axis and by vibration acceleration magnitude. The data obtained in this study can be contributed as fundamental data to update the present standard, ISO 2631-1.

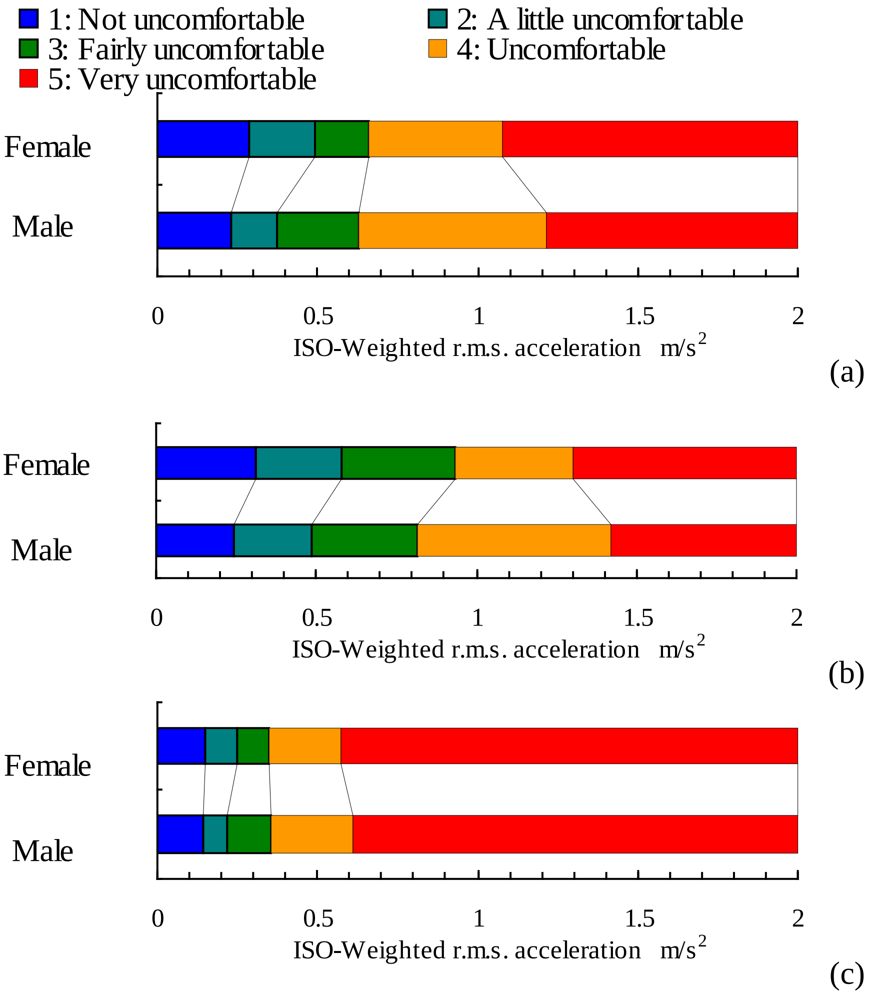

Figure 1 Subjective scales for female and male in (a) fore-and-aft (b) lateral and (c) vertical axis vibration.

References

[1] *Mechanical vibration and shock –Evaluation of human exposure to whole-body vibration- Part 1: General requirements*, International Standard ISO 2631-1: 1997 (International Organization for Standardization, Geneva, Switzerland, 1997).

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EFFECTS OF WHOLE-BODY VIBRATION ON THE PERCEIVED DURATION OF A VISUAL STIMULUS PRESENTATION

Kazuma Ishimatsu*, Nobuyuki Shibata, Setsuo Maeda
National Institute of Occupational Safety and Health, Japan (JNIOSH)

Introduction

Timing of intervals in the seconds-to-minutes range, which is involved in foraging and decision making, is essential for representing the immediate external environment[1]. This is evident in many daily activities such as safely crossing a busy street, driving a vehicle, preparing a meal, and so on. For example, while driving down or crossing a busy street, speed and time estimates are continuously required. There is much evidence to show that subjective judgment of duration (i.e., time estimation) can be lengthened or shortened by non-temporal factors. Whole-body vibration (WBV) could be one of those factors affecting subjective judgment of duration[2]. The current study investigated whether time estimation abilities (i.e., verbal estimations) could be affected by exposure to WBV.

Methods

Participants. Eleven university students (9 females, 2 males) were paid participants. All participants gave written informed consent before taking part in this study, which was approved by the research ethics committee of the JNIOSH.

Apparatus and stimuli. A color AV-tachistoscope (IS-703, IWATSU ISEC Co. Ltd.) controlled timing of the events and generated the stimuli. The stimuli were presented on a 22-inch color monitor. A vibrator (ATS-II V, Akashi Corporation) was used to generate sinusoidal vertical vibration at a magnitude of 1.0 ms^{-2} r.m.s. (unweighted acceleration). The frequency of the vibration used in this experiment was 5 Hz and 16 Hz.

Procedure. Participants were tested individually. The participant sat on a seat of the vibrator, and was given instructions. As this was a prospective verbal estimation paradigm, participants were instructed in advance that their task would be to estimate in seconds how long a visual stimulus was presented in each trial. Four 10-s time estimation trials were administered, as well as four 25-s trials, four 45-s trials, and four 60-s trials. These intervals were presented in a random sequence of 16 trials. Followed by a practice block, each participant performed the task during each of the following three conditions: a baseline block of trials without vibration (0 Hz); a block with 5 Hz vibration; and a block with 16 Hz vibration. The order of performing the experimental blocks was counterbalanced across participants. Within each experimental block, the order of the presentation duration of target was randomly determined for each participant separately. No feedback was given regarding the accuracy of verbal estimates in all experimental blocks. At the end of each experimental block, each participant reported a rating of discomfort from the WBV (from 1, not uncomfortable to 5, very uncomfortable) as well as a rating of distraction by the WBV (from 1, not distracted to 5, very distracted).

Results

Four scores were derived from the verbal time estimation task[3]: Mean time estimates, absolute error values (ABS), a coefficient of variance (CV), and a duration judgment ratio. Mean time estimates represented the raw scores calculated for each time duration interval. The ABS provided an overall measure of accuracy so that if a particular participant tended to error in the direction of both over- and underestimation, the average error would not tend toward zero. The CV allowed us to evaluate how consistent participants were in their verbal estimates of the same target interval. Duration judgment ratios provided an index of accuracy regardless of the size of the standard interval.

Mean score. Analyses of the raw scores revealed a significant main effect for time interval, $F(3, 30) = 116.30$, $MSE = 82.33$, $p < .01$. The main effect of block and the Block x Time interval interaction did not reach statistical significance, *p*s > .20. Consistent with the time perception literature, which indicates that individuals typically underestimate time, the verbal estimates represented an underestimation of time relative to the actual intervals.

ABS score. The ANOVA of the ABS scores revealed a significant main effect for time interval, $F(3, 30) = 12.90$, $MSE = 72.48$, $p < .01$. The main effect of block and the Block x Time interval interaction did not reach statistical significance, *p*s > .15. These indicate that participants' estimates tended to increasingly deviate from true clock time as the interval to be estimated lengthened.

CV score. The ANOVA of the CV scores revealed no significant main effects of time interval and block, or Block x Time interval interaction, *p*s > .20.

Duration judgment ratio score. The ANOVA on the ratio score revealed no significant main effects of time interval and block, or Block x Time interval interaction, *p*s > .20. These findings indicate that the ratio of estimated time to clock time remained stable across time intervals for all three conditions.

Discomfort and Distraction. The discomfort was worst in the 5 Hz block ($M = 3.2$), the second worst in the 16 Hz block ($M = 2.4$), and least in the 0 Hz block ($M = 1.0$), $x^2(2) = 17.15$, $p < .01$. Ratings of the distraction in the vibration blocks [i.e., 5 Hz ($M = 3.5$) or 16 Hz ($M = 2.9$)] were significantly worse than that of the 0 Hz block ($M = 1.1$), $x^2(2) = 17.68$, $p < .01$.

Discussion

The purpose of this study was to investigate whether time estimation abilities (i.e., verbal estimations) could be deteriorated during exposure to WBV. The present study revealed that the WBV used in this experiment could not interfere with verbal estimation performances although participants reported that verbal estimations were distracted by the WBV. This indicated the discrepancy between the verbal estimations and subjective ratings. The distraction in the vibration blocks was worse than that of the baseline block without vibration. Additionally, effects of WBV on discomfort ratings were found. The discomfort in the 5 Hz block was worse than that of the 16 Hz block, suggesting that the effect of WBV could be frequency-dependent. Taken together, in conclusion, time estimation abilities could not be deteriorated during exposure to whole-body vibration.

References

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Thursday, 3 June 2010

1:15-1:45 PM **Keynote**: **The Characteristics and Challenges of Higher Frequency, Aircraft Vibration Exposure**
Suzanne D. Smith, PhD
Senior Biomedical Engineer
Air Force Research Lab – Human Effectiveness Directorate
Wright Patterson Air Force Base, Ohio

1:45-3:15 PM **COMFORT, PERCEPTION AND PERFORMANCE IN WBV ENVIRONMENTS**

1:45-2:00 Priscila A. de Araújo, Maria Lúcia M. Duarte*, Frederico C. Horta, Lucas A. Penna de Carvalho, Guilherme G. Roca Arenales: THE EFFECT OF EXPOSURE DURATION ON WHOLE-BODY VIBRATION COMFORT

2:00-2:15 Miyuki Morioka and Michael J. Griffin: MASKED THRESHOLDS FOR FORE-AND-AFT VIBRATION OF THE BACK

2:15-2:30 Michele Oliver*, Leanne Conrad, Robert J. Jack, James P. Dickey, Tammy Eger: COMFORT BASED SEAT SELECTION TO MINIMIZE 6 DOF WHOLEBODY VIBRATION IN INTEGRATED STEEL MANUFACTURING MOBILE MACHINERY

2:30-2:45 Pankoke S*, Siefert A: RATING METHODS FOR DYNAMIC SEATING COMFORT TO BE APPLIED WITH NUMERICAL SEAT MODELS, VIBRATION DUMMY TESTS AND PASSENGER RIDE TESTS

2:45-3:00 Katherine Plewa, James P. Dickey*, Tammy Eger, Michele Oliver: ARE COMFORT PREDICTIONS FROM ISO 2631-1 AND SELF-REPORTED COMFORT VALUES DURING OCCUPATIONAL EXPOSURE TO WHOLE-BODY VEHICULAR VIBRATION RELATED?

3:00-3:15 Jonathan DeShaw*, Salam Rahmatalla: EFFECT OF HEAD-NECK POSTURE ON HUMAN DISCOMFORT DURING WBV

3:15-3:45 PM **Break** (Bijou Theatre Lobby)

THE EFFECT OF EXPOSURE DURATION ON WHOLE-BODY VIBRATION COMFORT

Priscila A. de Araújo, Maria Lúcia M. Duarte*, Frederico C. Horta, Lucas A. Penna de Carvalho, Guilherme G. Roca Arenales

PPGMEC/UFMG: Post-Graduation Program in Mech. Engineering, Universidade Federal de Minas Gerais; GRAVI$_{HB}$: Group of Acoustics and Vibration in Human Beings, BRAZIL

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Introduction

The effects of whole-body vibration (WBV) are related to both objective factors, such as amplitude, frequency and duration of excitation, as well as subjective factors, such as the kind of function performed by the individual, expectation, vibration perception and sense of discomfort.[1]

The ISO 2631-1 (1997) standard states that two exposures become equivalent when they have the same vibration energy[2]. Therefore, it is expected that the level of comfort should be the same in both situations. The aim of this work is to investigate such hypothesis, that is, if the exposure duration is an important factor in WBV discomfort levels evaluation. The analysis of such parameter (as all as the previous knowledge of the vibration stimulus) is essential for interpreting comfort evaluations due to WBV in human being studies[3]. Several evaluations have been performed by the GRAVI$_{HB}$ researchers in order to understand such interaction[4, 5].

Methods

Fifty male volunteers took part in this experiment. The volunteers sat on a wooden chair with backrest, without cushioning, coupled to a vibrating platform. Each volunteer was exposed to a 5 Hz sinusoidal whole-body vibration in the z-axis (vertical). Weighted RMS acceleration (m/s^2) was measured by a tri-axial accelerometer aimed to measure human responses. This acceleration amplitude sent by the signal generator to the shaker was then maintained for a certain period of time until the desired estimated vibration dose value (eVDV) for each test performed is achieved. Two RMS values (1.56 and 2.34 m/s^2) were established[4,5].

Five groups of 10 individuals were randomly formed, varying exposure duration (t), weigthed accelation (a_w) and eVDV (Table 1). Immediately after vibration exposure, the individuals rated their sense of discomfort during the vibratory stimulus.

The Mann-Whitney test was used to verify the differences between groups, which were analyzed in pairs. Box plot graphics were built for visual analysis of data dispersion around the medians of the groups. The confidence level used was $\alpha = 0.05$.

Results

The A, B, C, D and E groups medians were respectively 5.0, 7.0, 7.0, 6.5, and 7.0 (Figure 1). Comparisons were made between the groups, two by two. Of the ten comparisons performed, only three showed statistically significant differences when using the Mann-Whitney test (Table 2), that is, pairs 2, 3 and 4.

Figure 1 - Box plot

Table 1 - Groups (n=10 each group)

Group	Parameters eVDV $m/s^{1.75}$	 RMS m/s^2	 Time min
A	9,1	2,34	1
B	9,1	1,56	5
C	12	1,56	15
D	13,6	2,34	5
E	13,6	1,56	26

Table 2 - Comparison between groups by Mann Whitney test (n=50)

Pairs of groups		p	Pairs of groups		p
1	AxB	0,09	6	BxD	0,32
2	**AxC**	**0,01***	7	BxE	0,49
3	**AxD**	**0,03***	8	CxD	0,24
4	**AxE**	**0,03***	9	CxE	0,48
5	BxC	0,48	10	DxE	0,31

* Tests that showed statistical significance.

Discussion

Five comparisons are accordingly to the hypothesis that two exposures become equivalent when they have the same VDV, and that the discomfort sensation increases when the vibration energy increases. However, other five comparisons do not confirm these hypotheses. The claim that exposure duration, or the VDV, are influential factors by themselves could not be confirmed by this work. The most probable cause is that these factors overlap each other, exerting different influences accordingly to the other concurrent parameters, such as the weighted acceleration amplitude. In order to verify this hypothesis, new experiments should be developed, with different groups formations, so to provide a better variable control.

This work showed how complex the vibration response research is and that there is a high interaction among the factors exposure duration, acceleration amplitude and VDV for discomfort level perceived by individuals subjected to WBV.

Acknowledgment

The authors would like to thanks the financial support given to this work by FAPEMIG and CNPq.

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MASKED THRESHOLDS FOR FORE-AND-AFT VIBRATION OF THE BACK

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Introduction

The optimization of vehicle ride comfort requires understanding of vibration perception. The detection of one type of vehicle oscillation may be influenced by the presence of other vibrations (e.g. background vibration): a phenomenon known as 'masking' (i.e. the detection of one stimulus is 'masked' by another stimulus). With vibrotactile stimuli applied to an area of skin, masking only occurs when the masker and the test stimulus stimulate the same tactile channel (e.g., Gescheider *et al.*, 1982). Masking influences the perception of hand-transmitted vibration (Morioka and Griffin, 2005), and may influence the perception of low magnitude disturbances to vehicle ride.

This laboratory study was designed to determine masked thresholds of seated persons exposed to fore-and-aft vibration of a backrest and how the detection of one frequency of vibration is influenced by the presence of another frequency of vibration.

Methods

Nine male subjects were exposed to fore-and-aft vibration at the back via a rigid flat vertical backrest (640 x 680 mm) mounted on a Derritron VP 85 vibrator. Unmasked thresholds (Study A) and masked thresholds (Study B) were determined using a two-interval two-alternative forced-choice (2IFC) tracking method (Zwislocki *et al.*, 1958) with the up-down transformed response procedure and a three-down one-up rule. The sinusoidal test motions had frequencies of 4, 8, 16 and 31.5 Hz. The masking stimuli were $^{1}/_{3}$-octave bandwidth random vibrations centered on 4 Hz and presented at five intensities (0 to 24 dBSL). Unmasked thresholds of each test vibration, and the absolute threshold of the masker, were determined in Study A: subjects judged whether the first or the second observation period contained a vibration stimulus (see Figure 1). Masked thresholds were determined in Study B: subjects judged which observation period contained the test stimulus presented at the beginning of each trial. In both Studies, subjects responded by saying, 'first' or 'second'. The masked threshold was defined as:

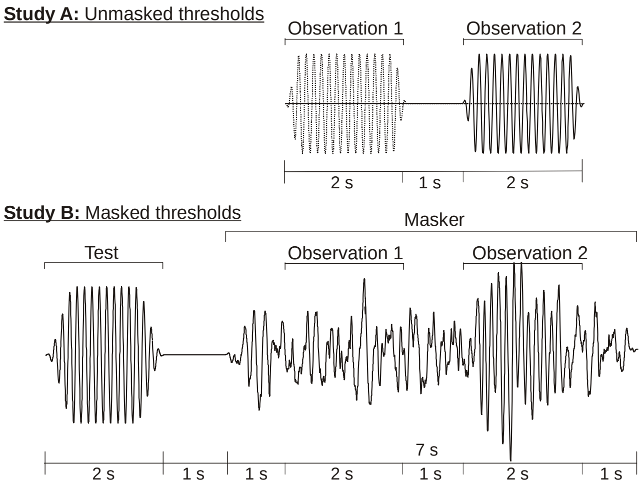

Figure 1 Stimulus timing of a trial for Study A and Study B. Study B example illustrates a $^{1}/_{3}$-octave bandwidth masker centred on 4 Hz with a test stimulus of 8 Hz occurring during the second observation period.

$$\text{Masked threshold (dB)} = 20 \cdot \log_{10}\left(\frac{A_{N\text{dB}}(f)}{A_{0\text{dB}}(f)}\right) \qquad (1)$$

where, at frequency f, $A_{N\text{dB}}(f)$ is the threshold (r.m.s. acceleration) with the masker at N dBSL, and $A_{0\text{dB}}(f)$ is the threshold (r.m.s. acceleration) with the masker at 0 dBSL.

Results

The lowest median unmasked thresholds (about 0.01 ms^{-2} r.m.s.) were obtained at 4 and 8 Hz, with no significant differences between these frequencies (p=0.26, Wilcoxon). From 8 to 31.5 Hz, thresholds increased with increasing frequency (p<0.01) (Figure 2: left). At each test frequency, linear regression of individual masking functions (thresholds with the masker) provided the slopes in Figure 2 (right), showing a significant decrease in masking with increasing frequency of the test stimulus (p<0.015).

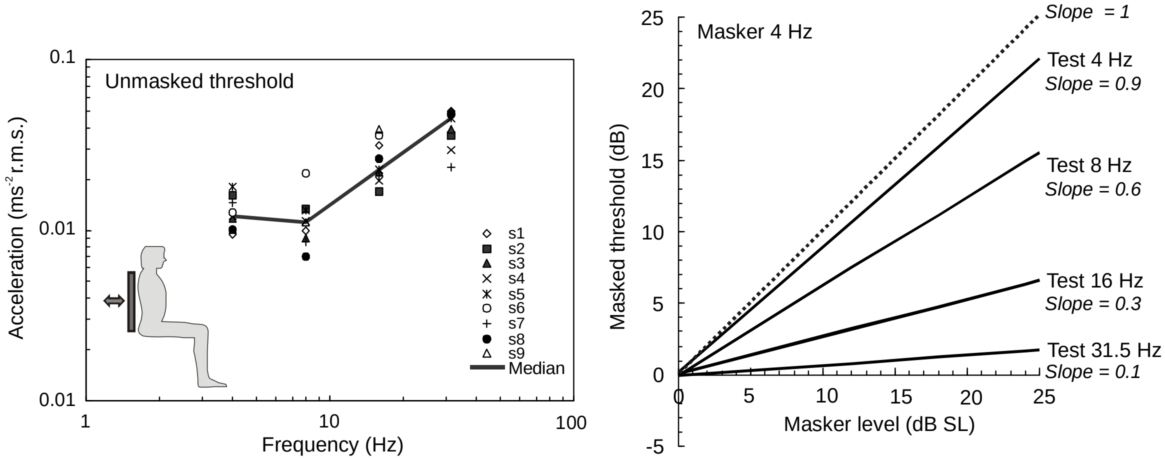

Figure 2 Left: Unmasked thresholds of 9 subjects with median data. Right: Masking functions for test frequencies of 4, 8, 16 and 31.5 Hz with 4-Hz masker vibration.

Discussion

The threshold contour is consistent with the W_c frequency weighting advocated for evaluating the discomfort of fore-and-aft back vibration in ISO 2631-1 (1997). The reduction in the threshold shift as the difference in frequency between the test stimulus and the masker increases can be explained by the involvement of different sensory systems and different body locations in the detection of the test and masker stimuli.

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COMFORT BASED SEAT SELECTION TO MINIMIZE 6 DOF WHOLE-BODY VIBRATION IN INTEGRATED STEEL MANUFACTURING MOBILE MACHINERY

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Introduction

Operators of heavy machinery are often exposed to complex whole-body vibration (WBV) involving simultaneous motion along three translational and three rotational axes (6-DOF). When companies retrofit machines, seats are usually selected and implemented without testing using machine and/or terrain specific vibration inputs to assess seat efficacy. The purpose of this project was to provide the steel industry and others with information which would allow them to more efficiently retrofit existing machines.

Methods

Six-DOF chassis acceleration data were recorded for various mobile machines from the steel making industry.[1] Six, 20 second representative profiles (Table 1) were assembled from the 'worst' WBV machine for use in this seat selection study. Profiles were implemented while subjects sat on one of three heavy equipment seats (BeGe7150, Grammar MSG 95G1721, and a 6801 Isringhausen in which the seat pan cushion was retrofitted with Skydex™ seating material) mounted on a 6 DOF Parallel Robotics System Corporation (PRSCO) robot. Three randomized trials of each combination of seat and profile were conducted using 8 male (22.3±2.0 yrs) and 8 female (23.5±1.8 yrs) inexperienced operators as well as 4 male (47.3±12.3 yrs) experienced operators from a participating steel making company. All subjects provided informed consent and all laboratory procedures were approved by the Research Ethics Board at the University of Guelph. Assessment variables included operator reported normalized (to the operator's mean response) comfort (ORC) which was verbally reported by subjects following each vibration exposure according to methods reported in Dickey et al.[2] The other assessment variable was 6 DOF VTV Weighted Comfort (VTVC) which was assessed using a 6-DOF seat pad transducer according to ISO 2631-1 standards.[3]

Results

For inexperienced operators, factorial ANOVA procedures revealed no significant ($p \leq 0.01$) differences between seats, sex or trials for ORC; however, Bonferroni post-hoc procedures showed that all of the profiles were different from one another ($p \leq 0.01$). For the VTVC, a significant difference was observed between seats with the

BeGe7150 resulting in the lowest VTVC value followed by the Grammar MSG 95G1721 and finally the 6801 Isringhausen. Unlike results for ORC, the VTVC for profile 1 was not significantly different than profile 3. A significant interaction between profile and seat was obtained, indicating that VTVC values were different for various combinations of profile and seat.

For experienced subjects, results were the same as inexperienced subjects for ORC with the exception that profiles 5 and 6 were not different from one another. Unlike the inexperienced subjects, for VTVC, there were no significant differences between seats, but all profiles were found to be different from one another with the exception of profiles 4 and 6.

Profile	ProfileTask/Condition	6-DOF Unweighted Chassis Vibration Total Value (m/s^2)
1	Driving Loaded	2.122
2	Driving Loaded	1.247
3	Driving Unloaded	2.168
4	Driving Unloaded	1.442
5	Slag Pot Pickup	1.028
6	Pot Banging	1.816

Table 1. 6-DOF Vibration total value (VTV) and corresponding field tasks for each of the six vibration profiles. Profiles were developed from a Pot Hauler[1].

Discussion

In the inexperienced operators, the best seat was found to be the BeGe7150 (from VTVC); however, in the small number of experienced subjects, neither ORC nor VTVC resulted in a 'clear cut' seat selection. One of the potential reasons for this is that all three tested seats were considered to be higher end seats and were much better than the seats currently used by the operators in their jobs. The significant interaction effect found between profile and seat in both the inexperienced and experienced operators shows clearly that from a comfort perspective, there may not be one best seat for all of the different vibration profiles encountered in an operator's daily routine.

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RATING METHODS FOR DYNAMIC SEATING COMFORT TO BE APPLIED WITH NUMERICAL SEAT MODELS, VIBRATION DUMMY TESTS AND PASSENGER RIDE TESTS

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Introduction

Seating comfort is accepted to be one of the most important properties of a passenger car in terms of customer acceptance. It can be divided into two sections: Static and dynamic seating comfort. Both static and dynamic comfort is defined by the interaction between the car seat and the occupant itself. While static comfort is mostly assessed by deriving parameters from the static pressure map between seat and occupant [4], dynamic comfort evaluation is based on vibrations that act on the occupant in various ways. It is commonly accepted that vertical accelerations on top of the seat cushion, i.e. between seat and occupant, have the most influence on the occupant's comfort impressions.

However, even though these vertical accelerations can easily be determined by either using simulations with dynamic CAE models of the occupied seat or by performing ride tests with test subjects or vibration dummies, it continues to be difficult to derive objective measures from those accelerations, that relate to the occupant's comfort impression. Nevertheless, car developers need such objective scalar criteria to determine the overall comfort rating of a car or a seat. This paper presents existing and new methods of how to quantify comfort parameters of cars and seats, and shows how these methods can be used either in early phase development with CAE technologies or in hardware phases / for benchmarking with a vibration dummy.

Methods for scalar / multi-scalar Comfort Rating

	Method	*applied to*	*Definition*	*Type*
1	ISO 2631-1	Vehicle	$rms(a_{wz})$	scalar
2	SEAT (ISO 10326-1)	Seat	$SEAT = {rms(a_{wz})}/{rms(a_{wz,0})}$	
3	Dimensions of Perception [3] (see Fig. 1)	Vehicle	Occupant-on-seat: $\hat{A}_1 = rms\left(a_z\big\|_{3Hz}^{10\,Hz}\right)$ Impulse: $\hat{A}_2 = rmq\left(a_{kz}\big\|_{1Hz}^{30\,Hz}\right)$ High-frequency shake: $\hat{A}_3 = rms\left(a_{xz,0}\big\|_{11Hz}^{30\,Hz}\right)$ Body vibration: $\hat{A}_4 = rms\left(a_z\big\|_{1Hz}^{3Hz}\right)$	multi-scalar
4	STF-Parameters (STF = Seat Transfer Function, see Fig. 1)	Seat	Resonance frequency: $f_{res} = freq\left(\max\left(abs\left(\overline{H_S}\right)\right)\right)$ Resonance magnitude: $A_{res} = \max\left(abs\left(\overline{H_S}\right)\right)$ Isolation frequency: $f_{iso} = freq\left(\left(abs\left(\overline{H_S}\right) = 1\right)\right)$ Isolation performance: $\tilde{A}_{iso} = \int_{f_{iso}}^{30\,Hz} \left[abs\left(\overline{H_S}\right)\right] df$	

Table 1: Overview rating methods (a_z: vert. acceleration on top of seat cushion; $a_{z,0}$: vert. acceleration at seat base; *w*: weighted ISO 2631-1; *k*: weighted VDI 2057-2 (1987); $\overline{H_S}$: STF; $a\big|_{1Hz}^{3Hz}$: band limits)

Methods 1 and 2 in above table are subject of standards [1,2], but are not being used in automotive development processes since they are not able to differ between vibration phenomena: Only one scalar value is available for describing the overall comfort “properties” of a vehicle or seat. Application of the multi-scalar methods “Dimensions of Perception” as proposed in [3] and “STF-Parameters” allows for a structured balancing of conflicting engineering targets (like resonance magnitude and isolation performance) and a summarized optimization of dynamic seating comfort with respect to differentiated occupant perceptions (like occupant-on-seat-behavior and high frequency shake).

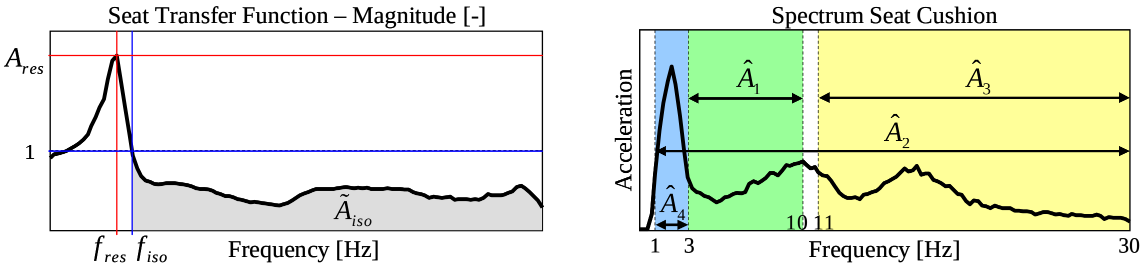

Figure 1: Left: STF-Parameters; Right: Frequency bands for perception dimensions $\hat{A}_1$ to $\hat{A}_4$

Application Scenarios

Application of any of the above mentioned rating methods requires the determination of a_z, the vertical acceleration on top of the seat cushion at the interface between occupant and seat and also the determination of $a_{z,0}$, the vertical acceleration at the seat base. Since a_z significantly depends on the occupant and its interaction with the seat, determination can only be done with an occupied seat. Such determination can be done in the virtual space, using CAE models of the occupied seat, e.g. with CASIMIR [5], or by physical testing using vibrations dummies like MEMOSIK [6] or human occupants. Thus, the rating methods are independent from where the input data (said accelerations a_z and $a_{z,0}$) result from.

Discussion

Two new methods for multi-scalar dynamic comfort rating are presented. Both methods are capable of differentiating between relevant seat and / or vehicle properties that have different effects on the occupant’s comfort perception. Thus, engineering conflicts can be recognized and solved by defining OEM specific weighting (A1 to A4 in “Dimensions of perception”) and targets (in “STF-Parameters”). The methods can be applied with digital and physical testing procedures for the occupied seat and are currently being integrated as post processing options into existing engineering solutions for seating comfort analysis [6,7]. Multi-scalarity enables the methods to be used in conjunction with established target balancing procedures like DoE.

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ARE COMFORT PREDICTIONS FROM ISO 2631-1 AND SELF-REPORTED COMFORT VALUES DURING OCCUPATIONAL EXPOSURE TO WHOLE-BODY VEHICULAR VIBRATION RELATED?

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Introduction

Exposure to whole-body vibration is strongly associated with health and comfort problems. The way in which workplace vibration exposure affects comfort is an important factor in worker activity levels and performance. International standards (ISO 2631-1) predict comfort based on vibration magnitudes, frequencies and durations. The objective of this study was to determine whether the ISO 2631-1 prediction method produces similar results to self-reported field comfort levels during occupational exposure to whole-body vehicular vibration.

Methods

6 degree of freedom seatpan acceleration data were recorded in various industrial machines in forestry[2], mining[4], and construction[1] industries. Following an audio tone at 5-minute intervals, operators reported their comfort level on a ten point scale[3] based on the preceding minute of vibration exposure.

The one minute profiles of raw acceleration data were processed using the appropriate filtering and multiplying factors[5]. Frequency weighted RMS accelerations and point vibration total values were then calculated for each axis and combined as a vector sum. Comfort was predicted from the overall vibration total value for each acceleration profile. Overall vibration total, normalized overall vibration total, and total vibration dose values were compared to self-reported comfort for each of the three industries.

Results

We collected 45 matched sets of comfort and vibration data from 10 mining LHD vehicles, 18 sets of data from 6 forestry skidders and 60 sets of data from 15 construction scrapers. Each industry showed consistent trends for each predicted value; however, there were different relationships between the industries (Figure 1). The data from the construction industry showed weak positive relationships between predicted and self-reported comfort values, whereas the data for the forestry and mining industries showed no relationship or a weak negative relationship between predicted and self-reported comfort.

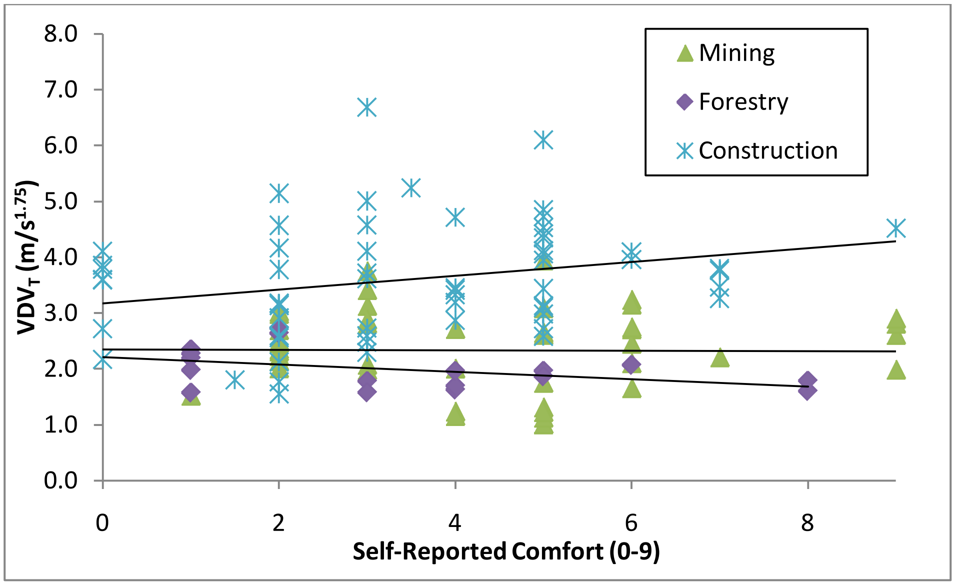

Figure 1. Total Vibration Dose Value (VDV_T) versus Self-Reported Comfort for vehicles in the mining, construction and forestry industries.

Discussion

It is difficult to capture the relationship between comfort and vibration using mathematical equations because comfort is a subjective reflection of many factors. The predicted comfort levels did not accurately represent self-reported comfort. This may be due to limitations of the prediction equations or perhaps that the operators were incorporating additional factors such as temperature, noise and fatigue into their self-reported comfort ratings. In order to improve our understanding of the relationship between multi-axis vibration and comfort, a more controlled study should be done in the laboratory where workplace vibrations are simulated and subjects rate their comfort given a certain acceleration profile.

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EFFECT OF HEAD-NECK POSTURE ON HUMAN DISCOMFORT DURING WBV

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Introduction

It is well known that sitting posture is associated with discomfort and a number of musculoskeletal disorders such as low back pain (Adams et al., 1985). The problem becomes more acute in whole-body vibration (WBV) such as that encountered in farming and construction machinery (Griffin 1988). Seat manufacturers have made significant strides toward developing seats for equipment that help alleviate the vibration transferring to the lower area of the spine. While this is seen as a positive achievement, it is likely that the increased neck-head motion resulting from these seat designs was overlooked. Many cervical spine studies have been developed to estimate the response of the head and neck; however, these studies rarely take head and neck posture into account.

The objective of this work was to study and demonstrate the difference in human biomechanical response to WBV when using different neck postures. Four head-neck postures—up, down, to the side, and normal (straight forward) —were investigated.

Methods

Ten male subjects with ages ranging from 19 to 28 years were used to test each of the four postures using discrete sinusoidal frequencies of 2, 3, 4, 5, 6, 7, 8, and 9 Hz at constant amplitudes of 0.8 m/s^2 RMS and 1.15 m/s^2 RMS. Written informed consent, as approved by the University of Iowa Institutional Review Board, was obtained prior to testing. Subjects were seated in a rigid seat rigidly mounted to a vibration platform as shown in Figure 1. Vibration was generated using a six-degree-of-freedom man-rated shaker table (the Moog-FCS 628-1800 six-degree-of-freedom electrical motion system). In order to isolate the role of the back support and focus on the head-neck motion characteristics, the subjects were strapped to the seat using a neoprene vest and 5 straps. Each discrete frequency was run in the x-direction (fore-and-aft) for 15 sec, with 5 sec stationary breaks. Amplitude and posture combinations were randomized with each discrete frequency so that each subject experienced every combination. Subjects reported their head-neck discomfort using the Borg CR-10 scale with each posture, and then gave a second discomfort rating for the normal posture for each combination. A twelve-camera Vicon motion capture system and crossbow accelerometers were used to acquire the motion of the seat, C7 vertebrae, and center of head.

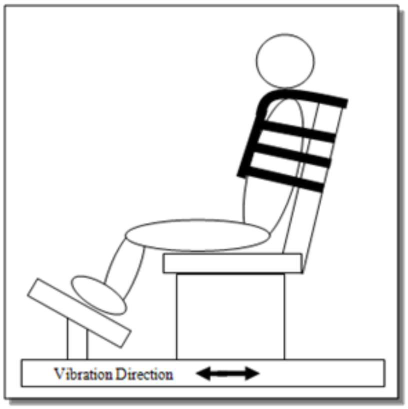

Figure 1 – Experiment Setup

Results

Figure 2 shows the average subjective ratings of 10 subjects based on the Borg CR-10 scale in four different head-neck postures. In general, the normal head-neck posture showed a peak at 4 Hz and another peak around 6 Hz. The up, down, and to-the-side postures showed similar trends with the first peak at 4 Hz, but showed a shift in the second peak to a higher frequency (around 7 Hz). After the first peak (4 Hz), the up and to-the-side postures showed lower discomfort level compared to the normal posture; however, the head-down posture was very sensitive to frequencies higher than 4 Hz and showed a higher discomfort value in that region.

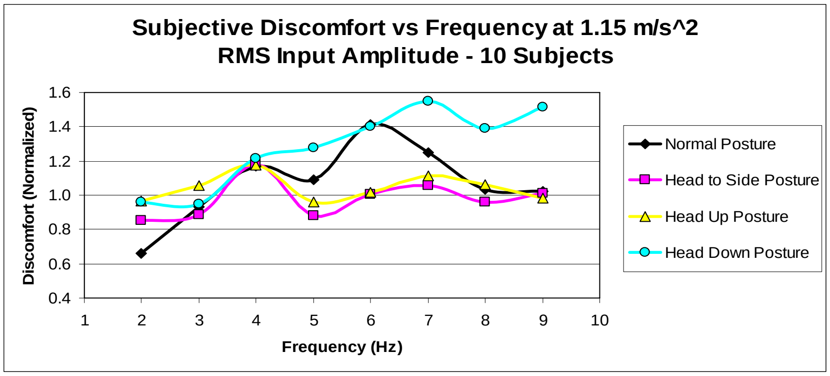

Figure 2: Average Discomfort of 10 Subjects at Discrete Frequencies 2-9 Hz

Discussion

The results have shown that the head-neck posture did not affect the location and the magnitude of the discomfort at the low frequency range, with the first peak at 4 Hz for all postures. However, the head-neck posture has a bigger role on head-neck motion and discomfort at higher frequencies. This is very clear in Figure 2, where the second peak in the discomfort was shifted to a higher peak around 7 Hz. This might be related to stiffer systems or larger motions with more muscle involvement. For the head-down posture, the magnitude of the discomfort function was higher than for the normal posture. This could be associated with the difficulty of generating more muscle activity in that position to support the head-neck region, resulting in more uncontrolled uncomfortable motions. As shown in Figure 2, the discomfort value for the head-down posture increased steadily after 4 Hz. The to-the-side and head-up postures showed less discomfort after the first peak at 4 Hz, but their magnitudes approach the normal posture around 8 Hz. In these postures, the subjects have more flexibility to use the major neck-back muscles to minimize the head-neck motion. This creates a stiffer system and may explain why there is a shift in the second peak in the to-the-side and head-up postures. This work has demonstrated the importance of considering the head-neck posture in future seat-design studies.

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3:45-4:15 PM **COMFORT, PERCEPTION AND PERFORMANCE IN WBV ENVIRONMENTS**

3:45-4:00 Suzanne D. Smith, Jennifer G. Jurcsisn, Cecelia J. Harrison: PERFORMANCE ASSESSMENT DURING MILITARY AIRCRAFT OPERATIONAL VIBRATION EXPOSURE

4:00-4:15 Tammy Eger, Michael Contratto, Jim Dickey: INFLUENCE OF DRIVING SPEED, TERRAIN, SEAT PERFORMANCE AND VEHICLE VIBRATION CONTROL FEATURES ON VIBRATION EXPOSURE

6:30-9:30 PM **BANQUET** (IMU 2nd floor ballroom)

Keynote: **The Long View: A Conversation with Don Wasserman**
Donald E. Wasserman, MSEE, MBA
First chief of the NIOSH Occupational Vibration Section

PERFORMANCE ASSESSMENT DURING MILITARY AIRCRAFT OPERATIONAL VIBRATION EXPOSURE

***Suzanne D. Smith, PhD[1], Jennifer G. Jurcsisn[1], Cecelia J. Harrison[2]**
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Introduction

Military aircrew flying long duration missions aboard rotary-wing and fixed-wing propeller aircraft have repeatedly reported anecdotal symptoms of lower extremity numbing, discomfort, and musculoskeletal pain. Exposure to higher frequency vibration has been cited as a potential contributor. Vibration surveys of these aircraft[1] have shown that the acceleration levels may cause discomfort with the potential for health risk during prolonged and repeated exposures.[2] It is expected that these levels could also affect aircrew performance during long duration missions. Limited studies have focused on the cognitive effects of vibration. Performance studies conducted using lower frequency vibration (<10 Hz) may have introduced errors due to motion disturbances in manual and visual control. One study suggested that monotonous low frequency vibration (<10 Hz) has a tiring effect.[3] Exposure to 16 Hz sinusoidal vibration did show impairments in short term memory. Mean reaction time and attentional lapses were degraded during exposures to 1.0, 1.6, and 2.5 ms^{-2} rms. Interestingly, response errors were significantly higher at 1.0 ms rms^{-2} only, suggesting compensatory activity.[4] This study investigated the feasibility of producing changes in performance during exposure to operational vibration. Task performance, workload perception, and subjective vibration and discomfort assessments were used to evaluate the effects of exposure type and duration.

Methods

Figure 1. Subject Performing MAT-B Tasks.

Eight male and female subjects were exposed to operational vibration associated with the weather officer station in the WC-130J Hercules and the pilot station in the CV-22 Osprey. Four subjects also participated in the No Vibration condition (NO VIBE). The NASA Multi-Attribute Task Battery (MAT-B) equipped with a joystick, toggle switches, and display were used to measure performance (communication response time and error, dials response time and error, lights response time and error, and tracking error) during three consecutive 30-minute exposure intervals (Fig. 1). The NASA Task Load Index (TLX) was used to assess subject workload perception for each interval based on six factors (mental demand, physical demand, temporal demand, own performance, effort, and frustration). The Vibration and Comfort Survey was used to assess subject perception of the vibration and discomfort at the face, head/neck, chest, upper back, lower back, buttocks, upper legs, lower legs, and feet for each interval via a numerical rating system. Vibration sessions were repeated three times; only one NO VIBE session was conducted.

Results

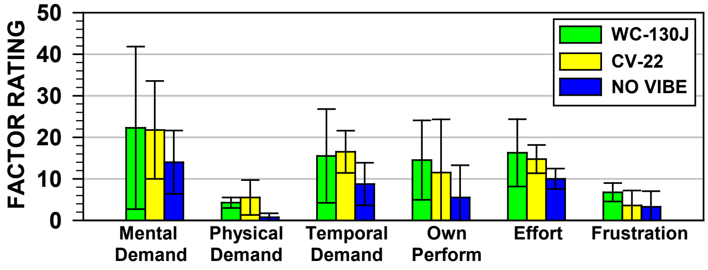

Figure 2. Workload Factor Ratings
(4 Subjects, Vibe Test 3, 90 Min)

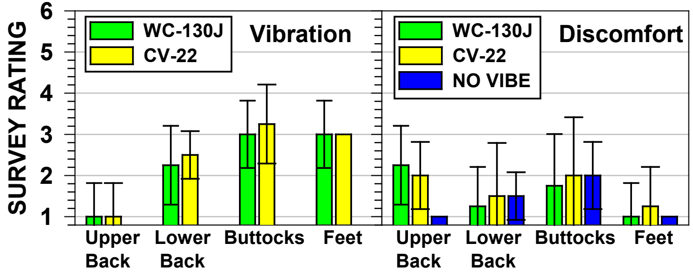

Figure 3. Vibration and Discomfort Survey Ratings
(4 Subjects, Vibe Test 3, 90 Min)

The highest weighted seat pan acceleration occurred for the CV-22 in the vertical direction (~16 Hz) at levels associated with being fairly uncomfortable.[1] In general, there were no significant effects of exposure type and duration on task performance (Repeated Measures ANOVA and Bonferroni Comparison Test). The highest and most variable response time occurred with the dials task. No clear trends were observed in task variability over the 30-minute intervals. In general, there were no significant effects of exposure type and duration on the workload ratings. The lowest workload was associated with physical demand and frustration (Fig. 2). The vibration was felt more in the lower torso (Fig. 3). Higher discomfort was observed for the upper back, lower back, and buttocks (Fig. 3) with most ratings less than 3. The test conductors observed notable subject fatigue (sleepiness) by the end of the exposures. The subjects indicated that the NO VIBE condition made them less sleepy than either vibration condition.

Discussion

The higher frequency operational vibration acceleration levels appeared to have no influence on task performance, workload perception, and vibration/discomfort assessment, although observations do suggest an effect on sleepiness. Discomfort was not necessarily associated with feeling the vibration; prolonged static posture may play a role. The MAT-B tasks did not appear to be sensitive to the fatigue observed during the study. It was not clear whether task performance was affected by compensatory activity. A follow-on investigation will evaluate alternative tasks that specifically challenge vigilance, working and recognition memory, and decision-making. These types of tasks may influence the perception of workload and vibration/discomfort over time.

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INFLUENCE OF DRIVING SPEED, TERRAIN, SEAT PERFORMANCE AND VEHICLE VIBRATION CONTROL FEATURES ON VIBRATION EXPOSURE

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Introduction

Previous studies have shown higher driving speeds, rough terrain and lighter haulage loads can result in higher vibration levels at the operator/seat interface during the operation of underground mining equipment [4]. Furthermore, operators of underground mining equipment are generally exposed to vibration levels above ISO 2631-1 health guidance caution zone levels [2;3]. However, the overall reduction on frequency-weighted r.m.s. acceleration at the operator-seat interface when controlling driving speed, road maintenance, seat amplification and a vehicle design feature believed to help reduce vibration transferred to the operator cab (ride control), have not been collectively examined. Therefore, controlled testing was carried out to determine the estimated A(8) value under different operating conditions that manipulated driving speed, haulage weight, ride control, terrain, and driving task, for two load-haul-dump haulage (LHD) vehicles.

Methods

Whole-body vibration was measured at the floor/seat interface and the operator/seat interface in accordance with ISO 2631-1 guidelines [1]. Two LHD vehicles were driven on a controlled test track by the same operator. Several variables were controlled/manipulated during the testing including driving speed (Gear; G-1, 2, 3, and auto-shift; AS), haulage (loaded bucket; unloaded bucket), ride control (RC on, off), terrain (RT rough terrain typical of a new production zone, MAIN, maintained typical of a graded surface; MT, combination of rough and maintained), driving task (F, forward, B, backward, M, mucking), and seat (NA; no amplification (optimized), A, amplification (not-tuned)). Frequency-weighted R.M.S. acceleration at the operator/seat interface was calculated in order to estimate A(8) values based on vibration exposure under several combinations of the variables above in order to determine predicted risk changes according to the ISO 2631-1 health-guidance caution zone.

Results

Frequency-weighted R.M.S. acceleration values at the floor/seat interface were lowest when the LHD was driven at the lowest speed, forward, over smooth terrain, with ride control on and the bucket loaded (0.20 m/s^2). The highest value occurred when the LHD was driven in the highest gear, backward, over rough terrain, with ride-control off, the bucket unloaded, and seat amplification present (1.29 m/s^2). Predicted changes to A(8) value are illustrated for one of the LHD vehicles for six scenarios including driving with ride control off over rough and smooth terrain using all gears (RC OFF; MT; G1-AS); driving with ride control off over rough and smooth terrain using gears 1-3 (RC OFF; MT; G1-3); driving with ride control on over rough and smooth terrain using all gears (RC ON; MT; G1-AS); driving with ride control on over rough and smooth terrain using gears 1-3 (RC ON; MT; G1-3); driving with ride control on over primarily maintained terrain using gears 1-3 (RC ON; Main; G1-3), and driving with ride control on over mixed terrain using gears 1-AS with no vibration amplification through the seat (RC ON; MT: G1-AS; No seat amp.).

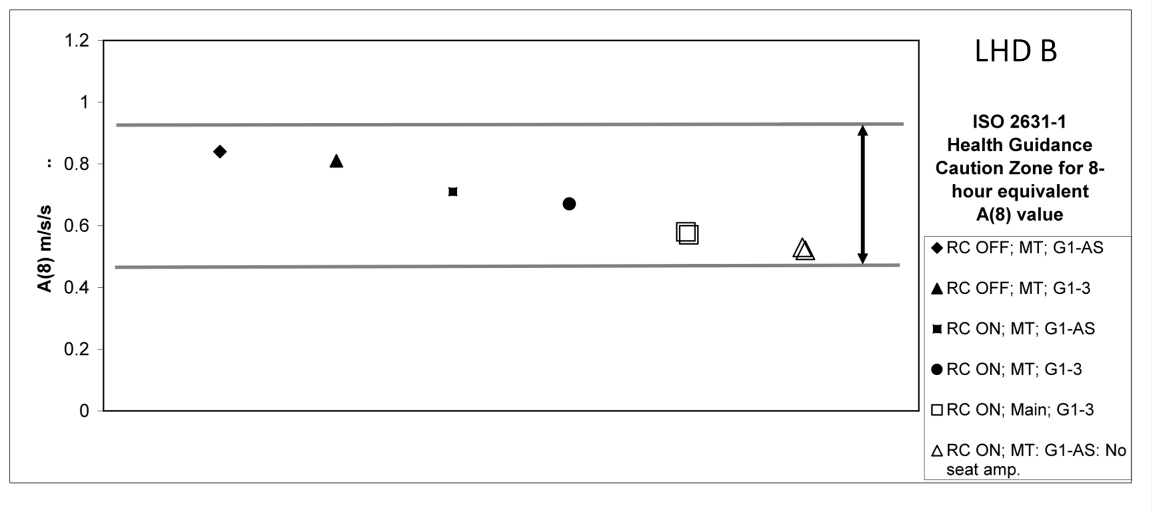

Figure 1 - A(8) values for six scenarios for one vehicles compared to ISO 2631-1 HGCZ.

Discussion

The A(8) decreased from 0.84 m/s^2 when driving with ride control off over mixed terrain using all gears to 0.53 m/s^2 when driving with ride control on over mixed terrain using all gears but with no vibration amplification through the seat (Figure 1). The changes did not result in operator exposure below the ISO 2631-1 HGCZ; however, a significant reduction in exposure is possible with interventions. Therefore, LHD operators need to be aware of the effects of their driving speed. Mining industry leaders need to support reasonable driving speeds for safe production, and they need to mandate comprehensive road maintenance programs to ensure rough roadbeds are repaired in a timely fashion. This study also supports the use of a feature, ride-control, designed to reduce the transmission of vibration to the operator and illustrated the importance of installing a seat in the vehicle that does not amplify vibration at the operator/seat interface.

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Friday, 4 June 2010

8:30-9:15 AM **ANALYSIS AND MODELING OF WBV RESPONSES**

8:30-8:45 Vinay A.H. Reddy*, Raghu R. Channamallu, Sara E. Wilson NEUROMOTOR TRANSMISSIBILITY OF HORIZONTAL SEATPAN VIBRATION AND A MATHEMATICAL MODEL

8:45-9:00 Guangtai Zheng, Yi Qiu and Michael J Griffin: MULTIBODY MODELLING OF THE VERTICAL APPARENT MASS AND FORE-AND-AFT CROSS-AXIS APPARENT MASS OF THE SEATED HUMAN BODY WITH A BACKREST

9:00-9:15 S. Mandapuram, S. Rakheja, P-E. Boileau: ANALYSIS OF COUPLING EFFECTS IN SEATED BODY BIODYNAMIC RESPONSES TO MULTI-AXIS VIBRATION

9:15-9:30 AM **WBV EXPOSURE RISK REDUCTION**

9:15-9:30 Douglas Reynolds*: SEAT AIR BLADDER SYSTEM FOR PROTECTING VEHICLE OCCUPANTS FROM SHOCK AND VIBRATION

9:30-10:00 AM **FOOT RESPONSE TO WBV EXPOSURE**

9:30-9:45 Aaron Thompson*, Ron House, Tammy Eger, Kristine Krajnak: VIBRATION-WHITE FOOT: A CASE REPORT

9:45-10:00 Mallorie Leduc, Tammy Eger, Alison Godwin, Jim Dickey, Ron House: EXAMINATION OF VIBRATION CHARACTERISTICS FOR WORKERS EXPOSED TO VIBRATION VIA THE FEET

10:00-10:30 AM **Break** (Bijou Theatre Lobby)

NEUROMOTOR TRANSMISSIBILITY OF HORIZONTAL SEATPAN VIBRATION AND A MATHEMATICAL MODEL

Vinay A.H. Reddy*, Raghu R. Channamallu, Sara E. Wilson
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Introduction

Recent studies of whole body vibration in seated postures have suggested that the neuromotor system may play a role in the etiology of low back disorders[1-4]. A number of researchers have modeled whole body vibration transmission to the low back, spine and head[5]. However, no model to our knowledge has examined the transmission of mechanical vibration to muscle shortening/lengthening, the neuromotor system and reflex muscle activation. In addition, only a few studies have examined biodynamic vibration transmission in the fore-aft (anterior-posterior) direction. In this work, transmission of fore-aft vibration to the spine rotation and erector spinae muscle activation was assessed and a model of the motion was created.

Methods

Ten healthy young subjects (5 male, 5 female, age 24±3 years, height 1.6 ± 0.04 m, weight 69 ± 4 kg) were assessed. Subjects were screened for low back pain and other neuromuscular disorders. The KU-L Human Subjects Committee approved this study and all subjects gave informed consent. A Ling 1512 electro-dynamic shaker was used to create fore-aft vibration. Data from tri-axial accelerometers on the seatpan and attached to the skin at the T10 spinous process, an electrogoniometer across the lumbar spine, electromyography (EMG) on the erector spinae (ES) muscles at L2/L3 was collected during vibration. EMG data was filtered, rectified, integrated and normalized to a maximum obtained prior to vibration exposure. A running average method was used to analyze and obtain a single ensemble average of the processed data for a vibration period. Responses to fore-aft seatpan vibration (3 Hz to 14 Hz, 1 m/s^2 RMS and 2 m/s^2 RMS) both with and without a backrest were measured. From the ensemble averages, trunk acceleration transmissibility (seatpan acceleration to T10 accelerometer), vibration transmitted to lumbar rotations (seatpan acceleration to electrogoniometer), vibration-induced muscle activity (seatpan acceleration to ES EMG) and muscle activity relative to lumbar rotation (electrogoniometer to ES EMG) were calculated.

A lumped parameter model was created with two lumped masses representing head-arm-trunk (HAT) and the pelvis-legs connected with linear and rotational dampers and springs (Figure 1). The parameters for the model were based on weights of the experimental subjects and anthropometric data from literature[6]. Using Lagrangian dynamics, a linearized state-space model was created. This model was used to compare the model to the experimental data. In addition, using Simulink in MATLAB, the vibration experiment was simulated.

Results

The fore-aft trunk acceleration transmissibility declined with increasing frequency consistent with previous research[5] and increased with the presence of a backrest. Transmissibility was found to be greater at 2 m/s^2 RMS compared to 1 m/s^2 RMS. It was observed that the vibration induced lumbar rotations declined with frequency similar to trunk acceleration transmissibility but with little change in the presence of a backrest. Examining the relationship between muscle activity and lumbar rotation, the magnitude of muscle activity was found to be mostly linearly related to the magnitude of lumbar rotation, suggesting that lumbar rotation is eliciting the muscle response (Figure 2). The peak muscle activity was delayed relative to peak trunk acceleration, with delays of 390ms at 3Hz to 43ms at 14Hz, suggesting a transition from voluntary to reflex muscle activation. The model was found to exhibit a similar pattern of fore-aft vibration transmissibility and lumbar rotation as found experimentally. It was also found to exhibit similar patterns of both fore-aft and vertical vibration transmissibility and lumbar rotation as previously reported in the literature[5,7].

Discussion

In this work, transmissibility of fore-aft vibration to the low back was found to be consistent with previous literature. Muscle activity in fore-aft vibration was found to correspond to lumbar rotation with delays that suggest a transition from voluntary to reflex-modulated erector spinae muscle response. A mechanical model of trunk dynamics has been created and found to have similar transmissibility and lumbar rotations as were observed experimentally. Future work will be to modify this model to incorporate a Hill type model of muscle dynamics and a model of neuromotor response and to assess the model behavior relative to the muscle activity results found in this fore-aft vibration study and previous studies of vertical vibration[7].

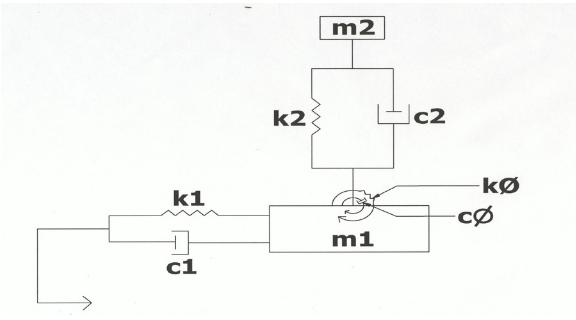

Figure 1 A 2-D model of vibration transmission

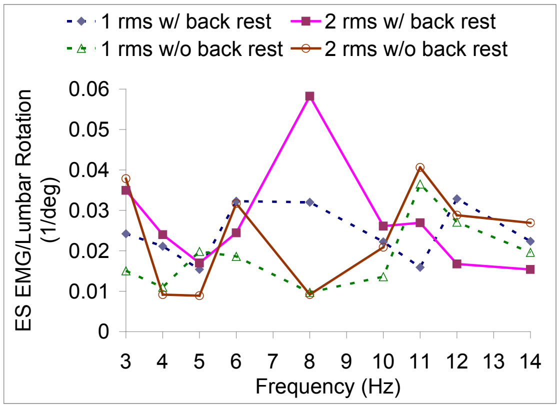

Figure 2 The ratio of muscle activity (fraction of max) to lumbar rotation (deg) was mostly constant with frequency.

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MULTIBODY MODELLING OF THE VERTICAL APPARENT MASS AND FORE-AND-AFT CROSS-AXIS APPARENT MASS OF THE SEATED HUMAN BODY WITH A BACKREST

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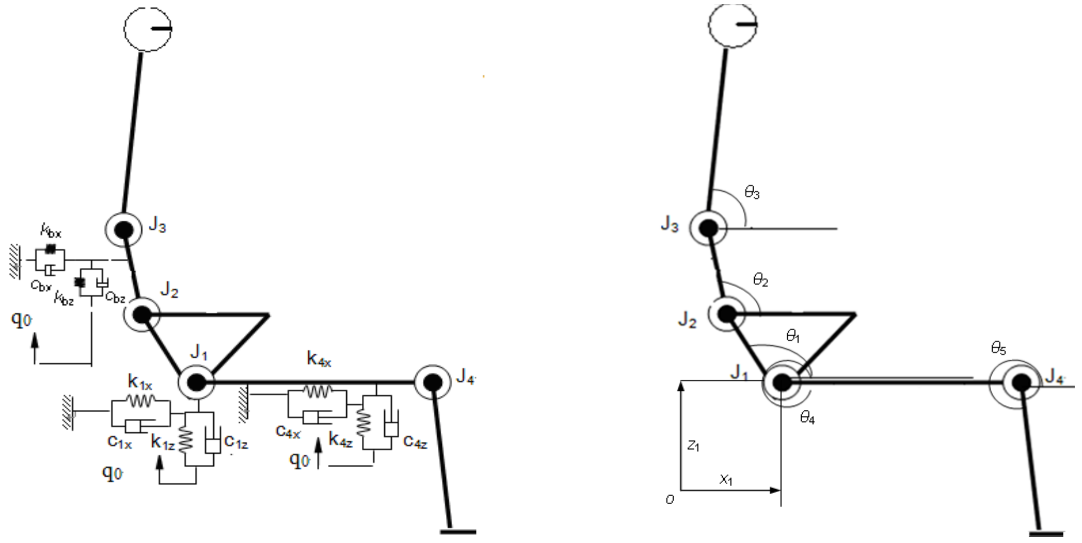
Introduction

Backrests affect the biodynamic responses of the body to whole-body vibration.[1-2] Models of the seated human body exposed to whole-body vibration should therefore take into account the effects of backrests. The purpose of this study was to identify the characteristics of a model needed to reflect both the vertical in-line apparent mass and the fore-and-aft cross-axis apparent mass measured at both the seat and backrest and consider the contribution of each body segment to the dynamic response.

Methods

The human body was represented by five rigid bodies: upper-body, middle-body, pelvis, thighs, and legs (Figure 1). The rigid bodies were inter-connected by pin joints with rotational stiffness and damping. The normal and shear deformation of the pelvis, thigh and back tissues at the seat-occupant interfaces were simulated using linear springs and dampers. The equations of motion of the model were derived using the Lagrange formulation. The geometric and inertial properties were derived from the literature.[3] The mechanical properties were obtained by minimizing the error functions between the computed and measured moduli of the median apparent masses over the frequency range 0.3 to 20 Hz.

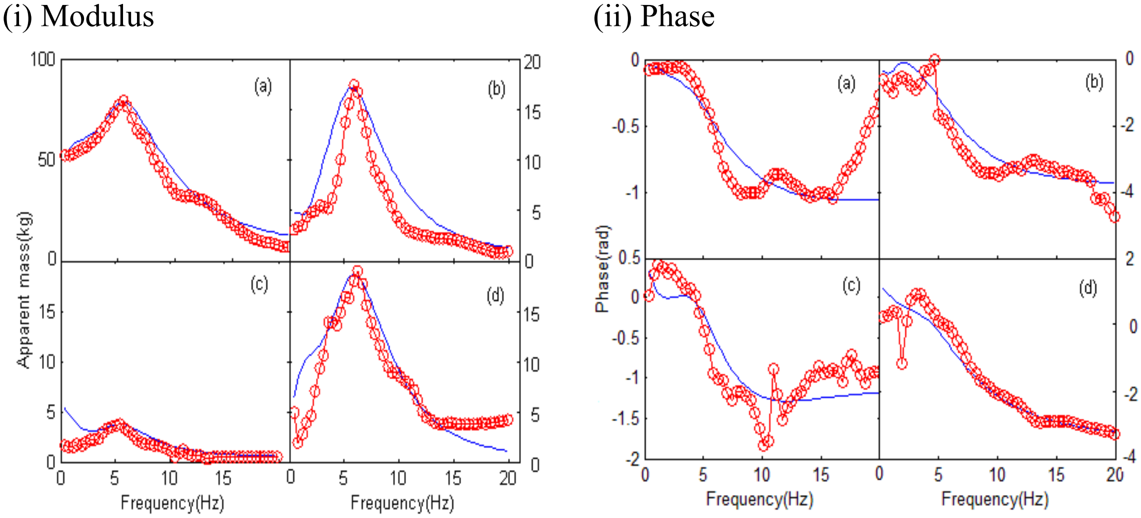


(i) (ii)

Figure 1 A two-dimensional multi-body biomechanical model in the normal upright posture: (i) model structure; (ii) motion description.

Results

The predicted moduli and phases of the vertical apparent mass and fore-and-aft apparent mass at the seat and back are compared with experimental data in Figure 2.[2,4]


(i) Modulus

(ii) Phase

Figure 2 Predicted and measured vertical and fore-and-aft cross-axis apparent mass of the human body with backrest: (i) modulus, (ii) phase. ——— predicted (with backrest contact point at the upper lumbar spine); —○— measured [2,4]; (a) vertical apparent mass on the seat; (b) fore-and-aft cross-axis apparent mass on the seat; (c) vertical apparent mass on the back; (d) fore-and-aft cross-axis apparent mass on the back.

Discussion

The model is capable of predicting apparent masses in reasonable agreement with the measured data. A parameter sensitivity analysis indicated that the apparent masses at the seat and back in the vertical and fore-and-aft directions were mainly influenced by the vertical pelvis stiffness and the rotational motion of the lumbar spine and pelvis.

Contact with a backrest affects the apparent mass and so backrest contact should be taken into account in biodynamic models of human responses to vibration.

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ANALYSIS OF COUPLING EFFECTS IN SEATED BODY BIODYNAMIC RESPONSES TO MULTI-AXIS VIBRATION

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Introduction

The biodynamic responses of seated body exposed to whole-body vibration (WBV) have been mostly studied under single-axis vibration, except for a few very recent studies. The responses to single-axis fore-aft and vertical vibration have shown considerable sagittal plane motions and magnitudes of cross-axis responses. The reported biodynamic responses to multi-axis vibration, however, suggest negligible coupled effects of multi-axis vibration[1,2], although coupled motions of the body are clearly perceived by subjects and observed by experimenters[3]. This raises concerns over suitability of the data analysis method used in deriving multi-axis vibration biodynamic responses. This study examines the current data analysis method, primarily based on H_1 estimator, and an alternate H_3 estimator for analyses of responses to uncorrelated multi-axis vibration. The relative effectiveness of the H_3 estimator in emphasizing the coupling effects of multi-axis vibration is demonstrated through analyses of apparent mass (APMS) and seat-to-head-transmissibility (STHT) data to dual-axis (*xz*) vibration.

Methods

Majority of the studies have reported biodynamic responses derived using the H_1 method based on cross-spectral density (CSD) of the measured signals, such that:

$$H_{kl} = \frac{S_{a_k b_l}}{S_{a_k}} \; ; k=x,\ y,\ z \text{ and } l=x,\ y,\ z \tag{1}$$

Where $H_{kl}(j\omega)$ defines the complex direct ($k=l$) or cross-axis ($k \neq l$) APMS or STHT function, $S_{a_k b_l}$ is CSD of the response (force measured at the driving-point or the head acceleration along direction l, $l=x,y,z$) and the input acceleration a_k ($k=x,y,z$) with auto-spectral density of S_{a_k}. A few studies have also employed power-spectral density (PSD) or root-mean-square (RMS) methods, which yield identical magnitude results under single axis vibration. Using the linear system theory, the total response along each axis under multi-axis vibration can be considered as the sum of both the direct- and cross-axis responses to individual axis, such that:

$$\bar{H}_k = \frac{S_{a_k \bar{b}_k}}{S_{a_k}} = \sum_l \frac{S_{a_k b_{kl}}}{S_{a_k}} \tag{2}$$

Where $\bar{H}_k$ is total biodynamic response along axis k, $S_{a_k \bar{b}_k}$ defines CSD of total response to input along k, $S_{a_k b_{kl}}$ is CSD of either direct ($k=l$) or cross ($k \neq l$) component of response along k to single axis excitation along l and b_{kl} is response along k due to excitation along l. In multi-axis experiments, the vibrations applied along individual axis are uncorrelated ($S_{a_k a_l} = 0$), which would lead to $S_{a_k b_{kl}} = 0$ ($k \neq l$). Consequently, the biodynamic responses derived using H_1 method would not account for the contributions of the cross-axis components observed under single axis vibration. The PSD method considers auto-spectral density of response alone and could thus appropriately account for cross-axis components, while it would not provide the phase data. Alternatively, the H_3 estimator combines the advantages of both the H_1 and PSD methods, by incorporating the cross-axis components and providing the phase information, and is given by:

$$H_k = \sqrt{\frac{S_{a_k \bar{b}_k}}{S_{a_k}} \frac{S_{\bar{b}_k}}{S_{\bar{b}_k a_k}}} \tag{3}$$

The suitability of H_3 estimator is investigated through analyses of STHT and APMS data acquired with 9 seated subjects exposed to individual *x* and *z*-axis and combined *xz* axes.

Results

Fig. 1 compares the mean vertical APMS and STHT responses obtained under single-axis vibration using the H_1 method, and under dual-axis vibration using H_1 and H_3 estimators. The dual-axis responses derived using H_1 are quite comparable to the single-axis responses, particularly in APMS, as reported[1,2]. The H_3 method, on the other hand, shows greater coupling effect of the dual-axis vibration by emphasizing contributions due to cross-axis responses observed under single-axis vibrations, which are evident at lower frequencies. The results obtained using H_3 method also support the response attained through superposition of direct and cross axis responses to single-axis vibration[3]. The H_3 method is thus considered better suited for the analysis of biodynamic response data to uncorrelated multi-axis vibration and the study of coupling effects.

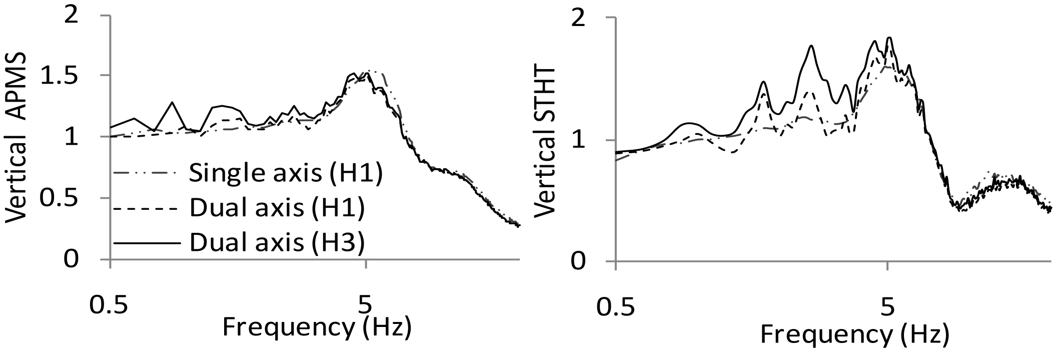

Fig. 1: Comparisons of single- and dual-axis vertical APMS and STHT responses.

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Acknowledgement: Authors acknowledge the support provided by JNIOSH in conducting the experiments.

SEAT AIR BLADDER SYSTEM FOR PROTECTING VEHICLE OCCUPANTS FROM SHOCK AND VIBRATION

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G. Ladkany, University of Nevada, Las Vegas

Introduction

Landmines are a great threat to military vehicles and their occupants. Mine blasts can completely destroy vehicles and kill all the occupants or disable the vehicle and leave the occupants severely injured. Injuries sustained during a landmine blast come from fragmentation that enters the vehicle through a hull breach, hot gasses expanding through the vehicle, or shock created from the extreme pressure of the landmine blast.[2] A specially designed air bladder seat cushion can be used to significantly mitigate the high intensity shock experienced by the occupants during a survivable mine.

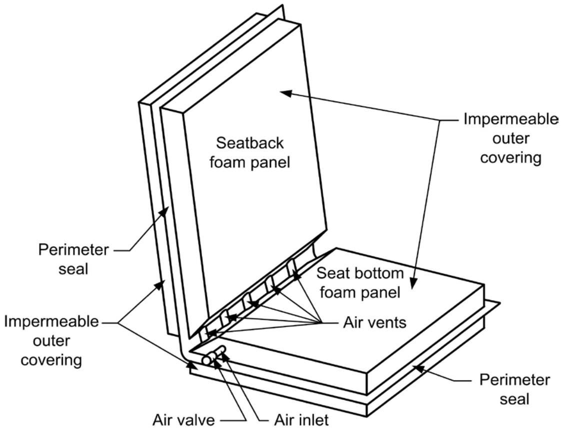

Figure 1

Methods

Figure 1 shows a schematic representation of the lightweight, foam-filled, inflatable mine blast attenuating seat. It consists of specially designed lightweight foam-filed interconnected seat bottom and seat back air bladders that are supported by a rigid frame. The seat system is to be used in conjunction with a five-point restrain system.

The shock attenuation characteristics of the seat were measured using a Lansmont shock test system drop tower at the U.S. Army Applied Research Laboratory. Drop tower tests were conducted using a Gesac Thor NT anthropodynamic dummy. Two sets of tests were conducted: dummy in a seat frame without the air bladder seat cushion and dummy in a seat frame with the air bladder seat cushion. The seat was dropped from heights that ranged from 5 to 35 in. (12.7 to 88.9 cm). The drop tower was set up to create a 5 msec wide shock pulse for each drop height. The parameters that were measured are: acceleration of the seat frame, acceleration between the air bladder seat cushion and the buttock of the dummy, pelvis acceleration of the dummy, and the spine load (force) of the dummy. Parameter measurements were made only in the vertical direction. The dynamic response index (DRI) was calculated from the measured pelvis acceleration.

Results

Figures 2 through 4 show the results of the drop tower tests. Figure 2 shows the peak pelvis acceleration as a function of the seat frame input acceleration. Figure 3 shows the peak spine load (force) as a function of the seat frame input acceleration. Figure 4 shows the DRI as a function of the seat frame input acceleration. The solid curve in each figure shows the results for the seat frame and dummy without the air bladder seat cushion. The dotted curve shows the results for the seat frame and dummy with the air bladder seat cushion.

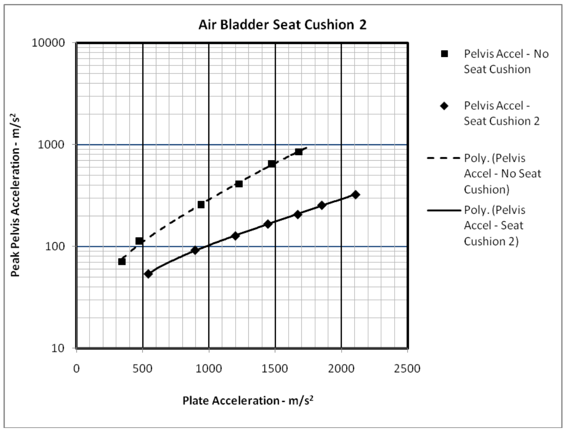

Figure 2

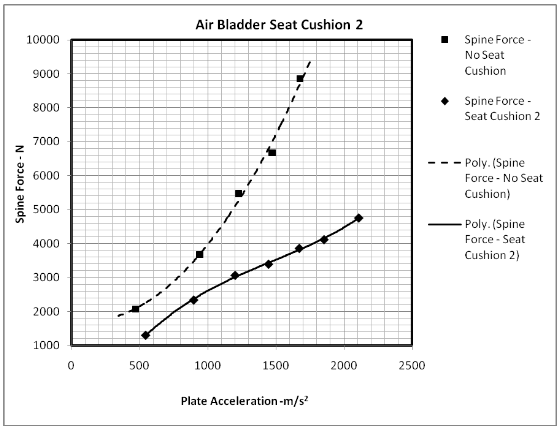

Figure 3

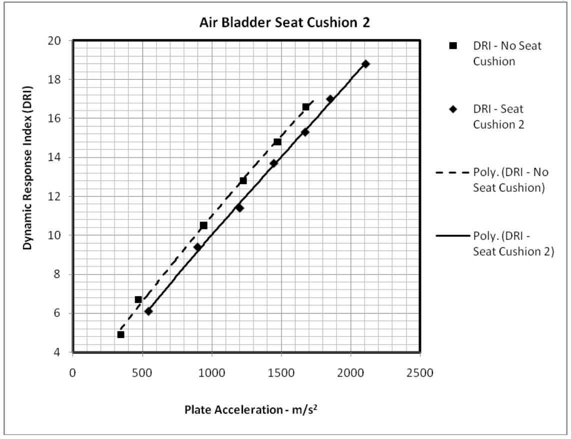

Figure 4

Discussion

The results of the drop tower tests show that the use of the air bladder seat cushion shown in Figure 1 significantly reduced the amplitude of the seat frame shock energy that was transferred to the Thor NT anthropodynamic dummy. At a drop height of 25 in. (63.5 cm), the peak seat frame acceleration was 1,472 m/s^2. Without the air bladder seat cushion, the dummy's pelvis acceleration was 851 m/s^2, peak spine load (force) was 8,852 N, and DRI was 16.6. With the air bladder seat cushion, the dummy's pelvis acceleration was 236 m/s^2, peak spine load (force) was 4,030 N, and DRI was 15.9. To minimize the potential for injury, the dummy's pelvis acceleration should be less than 226 m/s^2, spine load (force) should be less than 6,672 N, and DRI should be less than 17.7.[1]

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VIBRATION-WHITE FOOT: A CASE REPORT

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Introduction

Hand-arm vibration syndrome (HAVS) refers to the neurological, vascular and musculoskeletal problems that may arise in persons with sufficient exposure to segmental upper-extremity vibration. That a condition analogous to HAVS might occur in the feet after prolonged exposure to segmental lower-extremity vibration is biologically plausible though not well studied. To our knowledge, the current evidence for this condition is limited to one case report in the literature.[1]

Methods

A 54-year-old retired miner presented to our occupational disease specialty clinic with a chief complaint of pain, blanching and cold intolerance in his toes. The worker had a significant history of foot-transmitted vibration exposure over his 18-year career as a miner, most specifically from the operation of underground bolting machines in the 4 years prior to assessment. These machines expose workers to foot transmitted vibration because the control console is mounted on the machine and the platform upon which the worker stands vibrates when the machine is in operation. The worker in this case underwent a standardized assessment for HAVS consisting of a complete medical history, physical examination, blood work to rule out systemic causes of vasospastic disease and neurological disorders, nerve conduction studies in the hands, and digital plethysmography of the fingers and toes.

Results

Cold provocation plethysmography, nerve conduction studies and current perception threshold testing were all normal in the hands. Digital plethysmography for the toes showed moderate dampening of all toes waveforms post-cold stress (see Figure 1). These results indicate a vasomotor disturbance associated with cold sensitivity in the toes but not in the hands. There was no personal or family history of primary Raynaud's phenomenon and blood work to rule out systemic causes of vasospastic disease showed no significant results. The worker was diagnosed with "vibration white-foot"; a related though anatomically distinct entity to HAVS. The diagnosis was based on exposure history, compatible symptoms, a negative work-up for other secondary causes of Raynaud's phenomenon, and objective documentation of cold-induced vasospastic disease in the toes by plethysmography.

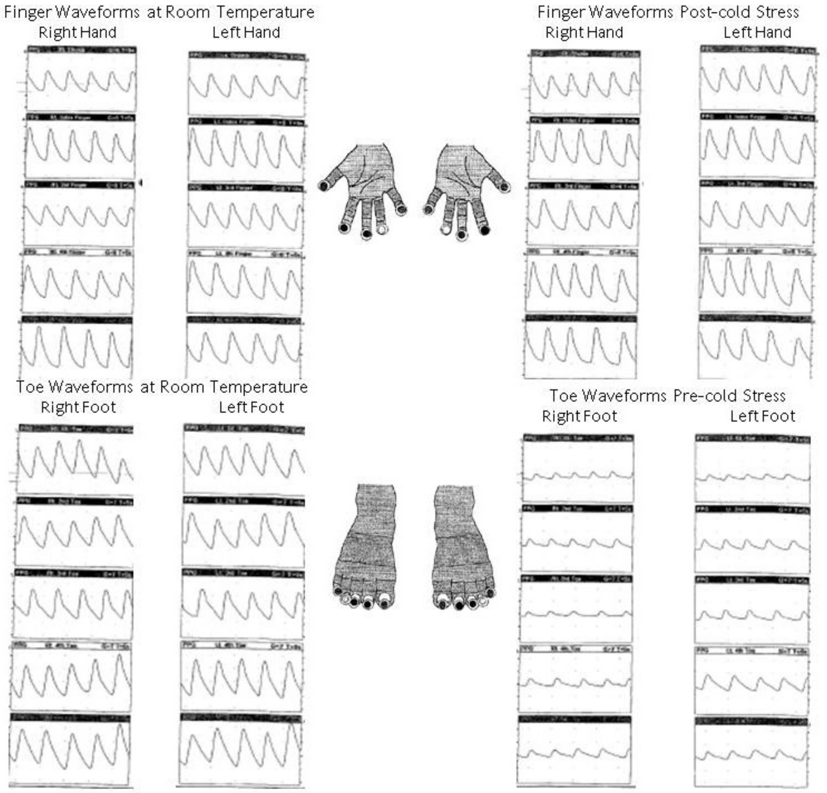

Figure 1: Plethysmography results showing finger and toe waveforms at room temperature and post-cold stress. These results indicate cold-induced vasospastic disease in the feet but not in the hands.

Discussion

This case represents the inverse presentation of most HAVS patients, who typically present with primary symptoms in the hands. There is evidence to suggest that patients with HAVS may have concurrent, albeit usually less severe, vascular and neurologic symptoms in the feet.[2] Most authors have related the vascular symptoms in the feet of HAVS patients to be primarily due to a centrally mediated sympathetic mechanism. This case suggests that while centrally mediated mechanisms may contribute to the vibration syndrome in the hands and feet, local pathology secondary to direct segmental vibration exposure also plays a significant, role in some cases. Recognition that foot-transmitted vibration can result in a HAVS-like syndrome in the feet should help to facilitate appropriate investigation and management of exposed workers, while also increasing awareness of this under-recognized condition.

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EXAMINATION OF VIBRATION CHARACTERISTICS FOR WORKERS EXPOSED TO VIBRATION VIA THE FEET

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Introduction

Prolonged exposure to hand-transmitted vibration has been shown to cause debilitating vascular, neurological, and musculoskeletal problems to the hand-arm[1]. Workers who are exposed to vibration via the feet could also be at risk for similar health problems[2]; however, limited research has examined the characteristics (frequency content, acceleration, amplitude) of vibration (from occupational sources) entering the body via the feet. In mining applications, vibration that enters the body via the feet has often been initiated with vibration from a hand-tool that has caused a working platform (that a worker is standing on) to vibrate. Therefore, the purpose of this study was to document the characteristics of vibration experienced at the feet under typical mining equipment operation.

Methods

Four types of underground mining equipment (locomotive; jumbo drill; raise platform wood; raise platform metal) that expose workers to vibration through the feet were tested. Equipment types were split into two categories, primary and secondary, depending on the origin of vibration. Transmitted vibration from a primary source originated from a motor responsible for moving a vehicle (locomotive). The vibration exposure at the feet was classified as a secondary source exposure if the vibration was originally generated by a "powered-tool" that was attached or supported on the surface the worker stood on (jumbo drill; raise platform wood; raise platform metal). Vibration measurements were collected at the location where the worker stood to complete the required job task. Background information and a musculoskeletal disorder questionnaire were also collected for each equipment operator.

Results

Vibration exposure resulting from a primary source exposure had a dominant frequency below 6.3 Hz. However, the dominant frequency recorded from secondary source exposures were predominantly in the 31.5 and 40 Hz range (Table 1). Two workers indicated they have been diagnosed with white feet and all other workers reported discomfort in their lower limbs. The wooden raise platform and the metal raise platform exposed the workers to vibration levels at the feet that placed them above the ISO 2631-1 health guidance caution zone, when the 8-hour frequency-weighted r.m.s acceleration exposure levels were considered (ISO, 1997).

Table 1: Vibration characteristics recorded at the feet during the operation of underground mining equipment. Musculoskeletal discomfort reported by the workers is also summarized.

Machine	**Source**	**DF_z (Hz)**	**a_{wz} (m/s/s)**	**Reported Musculoskeletal Discomfort 1=mild discomfort; 4 = severe discomfort**
Locomotive-1	Primary	6.3	0.43	Neck:1, Lower Back:2, R.Wrist:1, L.Wrist:1, L.Knee:1, R.Knee:1
Locomotive-2	Primary	3.15	0.36	L.Knee:1, R.Knee:1, L.Ankle:3, R.Ankle:1
Jumbo Drill (1 drill boom)	Secondary	31.5	0.16	R.Shoulder, R.Wrist 2, L.Wrist:2, L.Feet:1, R.Feet:1 **Diagnosed with white hands and feet**
Wooden Raise Platform (1 drill operating)	Secondary	40	1.1	L.Shoulder:2, R.Shoulder:2, L.Elbow:2, R.Elbow:2, Upper Back:2, Lower Back:2, L.Wrist:2, R.Wrist:2, Hips&Thighs:2, L.Knee:2, R.Knee:2, L.Ankle:2, R.Ankle:2 **Diagnosed with white hands and feet**
Metal Raise Platform (1 drill operating)	Secondary	40	1.08	*Worker 1:* L.Ankle:1, R.Ankle:1, L.Knee:3, R.Knee:3, Hips&Thighs:1, L.Wrist/Hand:2, R.Wrist/Hand:3, Lower back:3, L.Elbow:1, R.Elbow:1, Upper back:1, L.Shoulder:2, R.Shoulder:2, Neck:3 *Worker 2:* L.Ankle:2, R.Ankle:2, L.Knee:2, R.Knee:2, L.Wrist:3, R.Wrist:3, Lower back:1, Upper back:1
Metal Raise Platform (1-drill with “anti-vibration” leg)	Secondary	40	0.8	

Discussion

Workers standing on the jumbo drill and raise platforms experienced dominant frequency vibration known to be associated with hand-arm vibration syndrome. The jumbo drill operator and one of the raise workers confirmed they have already been diagnosed with white feet. The dominant frequency recorded at the feet of the locomotive operators was in the range associated with “whole-body” health effects. Interestingly, one of the locomotive workers reported greater discomfort in the neck and lower back. Further investigation is warranted to determine long-term health effects resulting from vibration exposure via the feet.

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Acknowledgements

Funding provided by the Centre for Research Expertise for the Prevention of Musculoskeletal Disorders and the Workplace Safety and Insurance Board of Ontario, Canada.

Friday, 4 June 2010

10:30-10:45 AM **INSTRUMENTATION**

10:30-10 :45 Pierre Marcotte*, Sylvain Ouellette, Jérôme Boutin, Gilles LeBlanc: DESIGN OF A LOW COST WIRELESS ACQUISITION SYSTEM FOR HUMAN VIBRATION MEASUREMENT IN HARSH ENVIRONMENTS

10:45-11:00 AM **PELVIS ORIENTATION CONTROL**

10:45-11:00 DG Wilder*, E Owens, MR Gudavalli, RD Macken, T Xia, R Vining, K Pohlman, L Corber, W Meeker, C Goertz, J G. Pickar: PELVIC REPOSITIONING IN LOW BACK PAIN PATIENTS

11:00-11:15 AM **Closing Remarks**

DESIGN OF A LOW COST WIRELESS ACQUISITION SYSTEM FOR HUMAN VIBRATION MEASUREMENT IN HARSH ENVIRONMENTS

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Introduction

In order to perform multichannel time signal acquisition in harsh environments like underground mines, where there is a high risk of having the equipment damaged or destroyed, it is convenient to use a robust low cost system that allows remote control and monitoring. Such a system has been developed and successfully tested in underground mines for human vibration assessment, and will be presented in this abstract.

Methods

The acquisition system is composed of two National Instrument NI-9234 USB boards (IEPE, 24 bits), giving a total of 8 channels, an external LI-ON battery, one minicomputer with solid-state hard disk for added robustness, and a small waterproof Pelican^{TM} case. Pictures of the acquisition system are shown in Fig. 1. The system had to be very compact in order to be installed on certain equipment where the space was very limited (see Fig. 1, right). The acquisition process was implemented under LabVIEW^{TM}, with two different sampling rates for hand-arm (5120 Hz) and whole-body vibration (512 Hz). Using the "Remote desktop" function of Windows XP$^{®}$, a second laptop computer was used to wirelessly control and monitor (time signals and spectra) the acquisition process. The IEPE mode of the NI-9234 boards was used to supply electrical power to the accelerometers, requiring the use of AC coupling. Since the NI-9234 board has, in AC coupling, a roll-off of 3 dB at 0.5 Hz, a digital FIR filter was added to correct the low

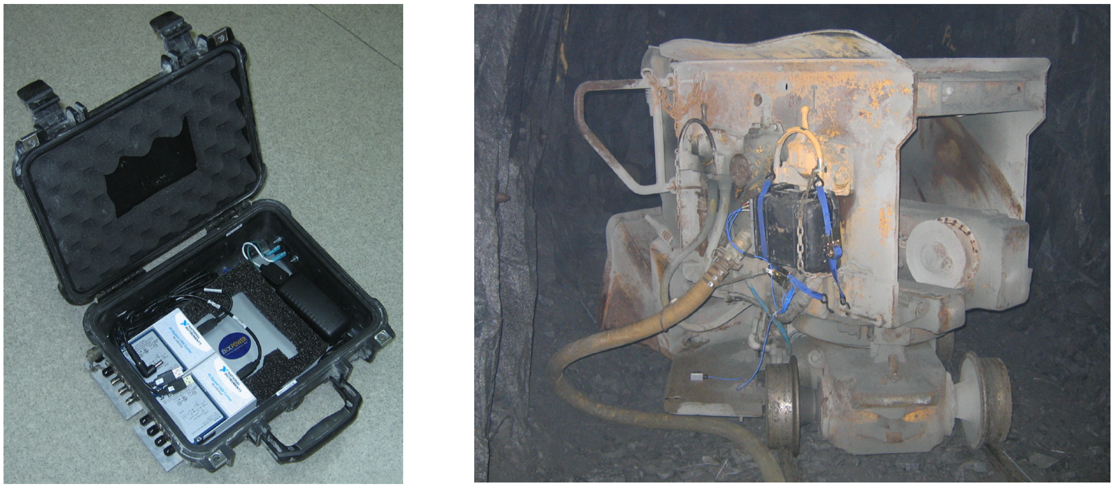

Fig. 1: Acquisition system without the mini Laptop in order to show the components (left), acquisition system and accelerometer installed on muck machine (right).

frequency response in whole-body vibration measurement mode, in order to satisfy the newer standard ISO 8041:2005[1]. In addition, it has been shown that low frequency components can have a significant effect on WBV metrics[2]. The digital FIR filter coefficients for the sampling rate of 512 Hz were calculated using the FIR2 function of MATLAB®. The target frequency response of the filter was the measured compensation needed to achieve a flat response in the entire frequency range. In practice, compensation was only needed between 0 and 6.3 Hz. A total of 2000 coefficients were used for the FIR filter.

Results

Fig. 2 shows the compensation achieved by the FIR filter (filter gain) in the low frequency range, with the lower and upper limits being the target gain ±1 dB. It is further shown that the filter satisfy the ISO 8041:2005[1] ±2 dB tolerance at 0.315 Hz. The digital filter has a linear phase (not show in the figure), which translates to a delay in the time domain. It was possible to implement the filter in real time during the acquisition of the time signal. The system has been validated using electrical signals and different known vibration levels. It also has been successfully used to measure human vibration in 8 underground mines on 24 different mining equipments.

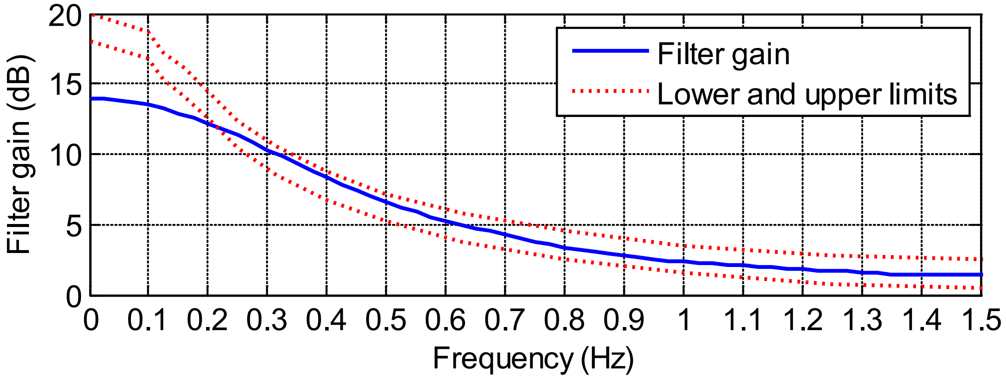

Fig. 2: Filter gain, also showing the ±1 dB tolerance (lower and upper limit).

Discussion

A low cost wireless acquisition system has been built to perform time signal acquisition in harsh environment like underground mines. The system has been validated and successfully used to assess human vibration in different underground mines.

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PELVIC REPOSITIONING IN LOW BACK PAIN PATIENTS

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Introduction

As mechanical shock and vibration environments evolve, it is important to understand their potential effect on human operators with complex biomechanical characteristics comprised of passive and active mechanical components of varying mass, damping, stiffness, and actuation characteristics. Because the lumbar spine can exhibit local, short-column buckling, stability of the seated human depends on postural control of the pelvis and trunk.[1-2] The ability to sense the position of body parts in space depends on higher-order integration of proprioceptive, vestibular and visual information. Mechanoreceptors in the skin, muscles and joints can all contribute to proprioception.[3] Limb repositioning has long been used to study the mechanisms of proprioception.[4] We have been evaluating the ability of seated low back pain patients to reposition their pelvis. The results have implications for isolation design and standards development.

Methods

Using electromagnetic position and orientation sensors attached to the skin over T1, L1, L3, and S1, 66 low back pain patients (41 women, 25 men; 91% low back pain duration > 1 year) were evaluated for their ability to reposition their pelvis while seated, without a backrest, hands crossed on their chest, on a small platform that could rotate about a transverse axis approximately aligned with the centers of rotation of the patient's femoral heads. Each patient was instructed to locate a pelvic target position, tilt their pelvis either forward or backward for 3 cycles, and then return to the target positions.

Test Abbreviation	Target Position	Movement Initiation
NF=	Neutral (self-selected)	Forward
FF =	Forward	Forward
FB =	Forward	Backward
BF =	Backward	Forward
BB =	Backward	Backward
NF =	Neutral	Forward
NB =	Neutral	Backward

Blindfolded, each patient accomplished the repositioning task using the six combinations of target position and direction of movement initiation listed in the Table. Accuracy of repositioning was assessed by changes in the length of the spine from S1 to T1 (mm), horizontal location of the T1, L1 and L3 sensors with respect to the sacrum (mm), and lumbar flexion angle (deg) were calculated.

Results

The mean error (difference between initial and final positions for each test) was normalized by the difference between the mean maximum and mean minimum movements for each outcome. This was averaged across all six pelvic repositioning tests (NF, FF, FB, BF, BB, NF, NB). No tests for significance differences have been conducted. Measurements on 66 individuals indicates that the standard deviation exceeds the mean of the error.

Normalized errors	Error/(Max-Min) Average across movements
Length of Spine error S1 to T1	0.070
T1 horizontal position error with respect to Sacrum	0.076
L1 horizontal position error with respect to Sacrum	-0.006
L3 horizontal position error with respect to Sacrum	-0.047
Lumbar Flexion Angle error	0.046

Discussion

In this pilot study, a method was explored for evaluating the ability of low back pain patients to reposition their pelvis. Sixty-six of a planned sample size of 200 patients have been evaluated before treatment for low back pain. Although not evaluated for statistical significance, the normalized errors of motions were less than 8%, with the position of L1 with respect to the sacrum having the lowest normalized error. Insight developed from work like this will help determine the importance of considering control of posture in static or vibrating, seated conditions. There are several limitations of the described dataset: it represents only individuals with low back pain, data are still being collected, and only descriptive statistics have been evaluated.

Acknowledgements Under the leadership of Dr. Joel Pickar, this project entitled: *Effect of Spinal Manipulation on Sensorimotor Functions in Low Back Pain Patients*, was supported by Grant Number U19 AT004137 from the National Center for Complementary and Alternative Medicine (NCCAM). This investigation was conducted in a facility constructed with support from Research Facilities Improvement Program Grant Number C06 RR15433-01 from the National Center for Research Resources, NIH.

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