Forward - Welcome Address

Welcome to the beautiful city of Seattle, my home and the home of the Continuing Education Program, NIOSH Education and Research Center and the OSHA Education Center of the Department of Environmental and Occupational Health Sciences within the School of Public Health at the University of Washington. It is our pleasure to share our beautiful city with you, the wonderful conference center at Cedarbrook Lodge and the excellent array of speakers on human vibration from all around the world. It is also our great pleasure to welcome our keynote speakers, Tohr Nilsson and Jens Wahlström both in the Department of Occupational and Environmental Medicine at Umeå University in Northern Sweden. Both keynote speakers have done Meta-Analyses on Hand-Arm Vibration and Whole-Body Vibration respectively, demonstrating the associations between work-related vibration exposures and various adverse health outcomes.

Based on the array of excellent presentations you will see from speakers all around the world, Human Vibration is turning a critical corner where new controls to reduce exposures are becoming available and exposures assessment methods are being refined and equipment capabilities are being extended. Perhaps most importantly, our assessment methods are decreasing in size and cost and increasing in capability with respect to the duration, quality and amount of detailed data that can be minimally-or non-invasively collected. These new capabilities will put a focus on “Big Data” and the field of epidemiology to better elucidate associations between work exposures and health.

A final important future area for all of us to focus on is the cost of work-related vibration disorders and the immense potential for improving worker health, saving money and benefiting and profiting all parties involved (workers, their families, unions, companies). Companies should not consider their worker’s compensation premiums as sunk costs, but rather actively work to recognize and reduce their worker’s compensation costs through investing in interventions that reduce vibration exposures in the working environment. Cost-utility and other economic analyses will demonstrate the investment returns will be many-fold and many interventions will turn a profit, some substantial saving millions of dollars over the long run.

Finally, I want to thank the numerous people who helped prepare for this conference, too many to mention here; it really does take a village. I also want to thank the local companies that helped host tours; this includes Boeing Corporation, PACCAR and King County Metro. In addition, I want to thank USSC Group for supporting the social gathering and those companies that had booths showing their equipment: Reactec, Sensodyne, and Svantek. Finally, I would like to thank the Scientific Review Committee for their tireless and timely work reviewing abstracts: Ren Dong, Tom McDowell, Jay Kim, Florin Marcu and myself.

Let’s have a great conference and time together and enjoy all that the conference surroundings and Seattle has to offer.

Peter W. Johnson
7th ACHV Conference Chair
7th American Conference on Human Vibration – 2018

7th ACHV Organizing Committee

Peter Johnson, PhD; Conference Chair
Professor, Department of Environmental and Occupational Health Science
University of Washington, Seattle, WA, USA

Jeong-ho (Jay) Kim, PhD
Assistant Professor, School of Biological and Population Health Sciences
Oregon State University, Corvallis, OR, USA

Florin Marcu, PhD
Human Vibration Engineer, Redmond, WA, USA

Nancy Simcox, MS
Director, Continuing Education Programs
Department of Environmental and Occupational Health Science
University of Washington, Seattle, WA, USA
7th American Conference on Human Vibration – 2018

7th ACHV Scientific Committee

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

Paul-Émile Boileau, PhD
Institut de Recherché Robert-Sauvé en Santé et Sécurité du Travail Montreal, Quebec, Canada

Anthony J. Brammer, PhD
Biodynamics Laboratory
University of Connecticut Health Center
Farmington, Connecticut, USA

Martin G. Cherniack, MD, MPH Biodynamics Laboratory
University of Connecticut Health Center
Farmington, Connecticut, USA

James P. Dickey, PhD School of Kinesiology Western
University London, Ontario, Canada

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

Tammy Eger, PhD
School of Human Kinetics Laurentian
University Sudbury, Ontario, Canada

Thomas Jetzer, MD
President, Occupational Medicine Consultants, Ltd.
Minneapolis, Minnesota, USA

Peter W. Johnson, PhD
Environmental & Occupational Health Sciences
University of Washington, Seattle, Washington, USA

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

Thomas W. McDowell, PhD
Health Effects Laboratory Division
National Institute for Occupational Safety & Health
Morgantown, West Virginia, USA

Michele Oliver, PhD, P.Eng. School of Engineering,
University of Guelph, Guelph, Ontario, Canada

Donald R. Peterson, PhD Biodynamics Laboratory
University of Connecticut Health Center
Farmington, CT, USA

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

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

Danny A. 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
Dayton, Ohio, USA

Aaron Thompson, MD, MPH, FRCPC
Faculty of Medicine & Dalla Lana School of Public Health
University of Toronto
Toronto, Ontario, Canada

Donald E. Wasserman, PhD Human Vibration Consultant
Frederick, Maryland, USA

Jack Wasserman, PhD
Institute for the Study of Human Vibration
University of Tennessee, Knoxville, Tennessee, USA

Daniel E. Welcome, PhD
Health Effects Laboratory Division
National Institute for Occupational Safety & Health
Morgantown, West Virginia, USA

David G. Wilder, PhD Jolt/Vibrations/Seating Laboratory
University of Iowa, Iowa City, Iowa, USA

John Z. Wu, PhD
Health Effects Laboratory Division
National Institute for Occupational Safety & Health
Morgantown, West Virginia, USA

Xueyan S. Xu, PhD
Health Effects Laboratory Division
National Institute for Occupational Safety & Health
Morgantown, West Virginia, USA
Thank you to the following sponsors for the generous support:

![Reactec](image1)

![Svantek](image2)

![Sensidyne](image3)
# Conference Program Table of Contents

**Day 1 Wednesday, June 13, 2018**
- Keynote Address: Review and Meta Analysis of Hand Arm Vibration Disorders .......................... 1
- Session 1: Hand-Arm Vibration Exposures in Occupational Environments .................................. 4
- Session 2: High Frequency Hand-Arm Vibrations ...................................................................... 11
- Session 3: Characterizing and Mitigating Arm Vibration Exposures ......................................... 24
- Session 4: Future Needs of HAV Assessment, Reporting and Standards .................................. 35

**Day 2 - Thursday, June 14, 2018**
- Keynote Address: Review and Meta Analysis of Whole Body Vibration Disorders with Focus on the Low Back ...................................................................................................... 42
- Session 1: Whole Body Vibration Exposures in Occupational Environments .............................. 45
- Session 2: Field Methods to Evaluate Whole Body Vibration ...................................................... 54
- Session 3: Methods to Evaluate and Improve Human Vibration Exposure Assessment .......... 66
- Session 4: Whole Body Vibration Assessment in Special Environments .................................. 75

**Day 3 - Friday, June 15, 2018**
- Session 1: Adverse Health Outcomes Associated with Vibration and Shocks ..................... 82
- Session 2: Sensory and Motor Issues Associated with Hand-Arm Vibration ............................ 86

**Index of Authors** ......................................................................................................................... 100
Review and Meta Analysis of Hand Arm Vibration Disorders

*Tohr Nilsson

Occupational and Environmental Medicine, Department of Public Health and Clinical Medicine, Umeå University, Sweden
REVIEW AND META-ANALYSIS OF HAND-ARM VIBRATION DISORDERS

*Tohr Nilsson

Occupational and Environmental Medicine, Department of Public Health and Clinical Medicine, Umeå University, Sweden

Introduction

Extensive and prolonged exposure to manual work involving the use of vibrating power tools can lead to a number of adverse health effects, primarily in the peripheral neurological, vascular and musculoskeletal systems. Increased occurrence of Raynaud's phenomenon, neurosensory injury and carpal tunnel syndrome has been reported for more than 100 years in association with work with vibrating machines. Vibration induced white fingers (VWF) and sensorineural injuries are the main adverse health effects reported, related to hand intensive manual work with vibrating machines. The current risk prediction modelling (ISO-5349) for "Raynaud's phenomenon" is based on only a few studies published 70 to 40 years ago. There are no corresponding risk prediction models for neurosensory injury or carpal tunnel syndrome, nor any systematic reviews comprising a statistical synthesis (meta-analysis) of the evidence.

The aim of this overview is to provide the experience from a systematic review of the literature on the association between Raynaud's phenomenon, neurosensory injuries and carpal tunnel syndrome and hand-arm vibration (HAV) exposure. Moreover, to present estimates of the magnitudes of such associations based on the outcomes from statistical synthesis (meta-analysis) and to discuss the possibilities and pitfalls in the interpretation of the results.

Methods

Our systematic review covers the scientific literature up to January 2016. The databases used for the literature search were PubMed and Science Direct. Only studies in which a measurement or an estimation of vibration exposure has been reported are included in this review. We found a total of 4,335 abstracts, which were read and whose validity was assessed according to pre-established criteria. 294 articles were examined in their entirety to determine whether each article met the inclusion criteria. The possible risk of bias was assessed for each article. 52 articles finally met the pre-established criteria for inclusion in the systematic review.

Results

The results show that workers who are exposed to hand-arm vibration have an increased risk of vascular and neurological diseases compared to non-vibration exposed groups. The crude estimate of the risk increase is approximately 4-5 fold. The estimated effect size (odds ratio) is 6.9 for the studies of Raynaud's phenomenon when including
only the studies judged to have a low risk of bias. The corresponding risk of neurosensory injury is 7.4 and the equivalent of carpal tunnel syndrome is 2.9.

**Discussion**

Our results demonstrate that workers who are exposed to HAV have an increased risk of vascular and neurological diseases compared to non-vibration exposed groups.

The present risk assessment model in the annex of ISO 5349-1 relates only to the prevalence of Raynaud's phenomenon and is based on the relation to the level of vibration intensity, number of years of exposure. This annex\(^1\) is also often used for risk assessment of neurological injuries. Our results\(^2\) show that the relationships between vibration exposure and Raynaud's phenomenon and neurosensory injury represent different functions. Risk assessment of neuro-sensory impairment based on the data of ISO 5349 may thus be misleading. The validity of this conclusion is to be discussed in terms of possible publication bias, outcome bias, exposure bias, method bias and conceptual and methodological changes during the study base period.

The literature review also reveals that there is a lack of research on the interactions between various diseases (comorbidity) and the various manifestations of HAVS. An issue closely related to comorbidity is the question on how individuals' potential vulnerability to vibration exposure modifies the development of HAVS. Comorbidity, age-related modifying factors and the possible interactions with drugs and other vasoactive or nerve-disturbing exposures have mostly been overlooked in present research.

At equal exposures, neurosensory injury occurs with a 3-time factor shorter latency than Raynaud's phenomenon. Which is why preventive measures should address this vibration health hazard with greater attention.

**References**


SESSION 1 - HAND ARM VIBRATION EXPOSURES IN OCCUPATIONAL ENVIRONMENTS

Electric Rotary Vs Pneumatic Rock Drill: Differences in Handle Vibration and Productivity

- Drilling into Concrete
  *David Rempel, Andrea Antonucci, Alan Barr, Michael R. Cooper, Bernard Martin
  – Department of Bioengineering, University of California, Berkeley CA, USA

Zero Vibration Injuries – Achieved by Machine Redesign

- Eva Troell, Hans Lindell and Snævar Leó Grétarsson
  – Swerea IVF, Möln达尔 Sweden,

Hand Arm Vibration Among Manufacturing Industry Workers in Washington State

- Stephen Bao and Ninica Howard
  – Washington State Department of Labor and Industries, Olympia WA, USA
ELECTRIC ROTARY VS PNEUMATIC ROCK DRILL: DIFFERENCES IN HANDLE VIBRATION AND PRODUCTIVITY DRILLING INTO CONCRETE

*David Rempel, Andrea Antonucci, Alan Barr, Michael R. Cooper, Bernard Martin

Department of Bioengineering, University of California, Berkeley

Introduction

Drilling large holes into concrete is performed in commercial construction for structural upgrades (e.g., dowel and rod) and for inserting anchor bolts. The work is physically demanding with high levels of exposure to hand vibration, noise and respirable silica dust. Pneumatic rock drills are considered to be a robust and productive tool for cutting large holes by structural contractors, stone workers, and rock miners. However, the newer, heavier and more powerful electric rotary hammer drills may be competitive with pneumatic drills. To date, no studies have compared electric and pneumatic drills, of similar mass, on vibration and productivity under the same drilling conditions.

Methods

A test bench system was used to measure productivity and handle vibration for a pneumatic rock drill and an electric rotary hammer drill, of similar mass, drilling into concrete block. The test bench system was programmed to drill 3 holes to a 100 mm depth with a constant force on bit (88 N). The mass of the electric rotary hammer drill (Hilti TE-70 AVR; 8.3 kg; 46 Hz percussion frequency) and pneumatic rock drill used (American Pneumatic Tool, Model APT-115; 8.6 kg; 48 Hz percussion frequency) were similar. New, 19 mm diameter 2-carbide tipped bits of similar mass were used. The handles were held with a 4 fingered rubber lined gripper and at the chuck by a Y fixture. Tool handle acceleration was measured following ISO 28927-10 (2011) with some changes. ISO requires drilling by subjects but with the test bench a machine does the drilling. Vibration was measured with a triaxial accelerometer (Svantek SV105AF) attached to the drill handle and oriented according to ISO 5349-1. A human vibration meter and analyzer (Svantek SV-106 A) sampled at 6000 Hz and unweighted and weighted ($a_{hw}$) rms hand acceleration levels were generated according to ISO 5349-1. The accelerometer was calibrated at the beginning and at the end of each test.

For productivity measurement, 3 holes were drilled to a depth of 200 mm with each drill. A video camera recorded bit location during drilling and the video was analyzed on a frame-by-frame basis to record rate of penetration.

Results

Mean ISO weighted handle vibration for the pneumatic rock drill was 39.14 m/s$^2$ (SD=2.53) and for the electric rotary drill were 7.15 m/s$^2$ (0.11) ($p=0.002$). The unweighted handle vibration for the pneumatic drill was 346.9 m/s$^2$ (14.8) and for the electric drill 78.7 m/s$^2$ (4.0) ($p=0.001$). The highest weighted vibration level was measured along the x-axis for the electric drill, but was along the z-axis for the pneumatic
drill. Across the frequency spectra, the highest unweighted acceleration levels for the electric drill were between 100 to 800 Hz while for the pneumatic drill they were between 800 and 1600 Hz. A peak near 50 Hz associated with the percussion frequency was also observed for both drills.

For productivity measurement, mean rate of penetration (ROP) was slightly greater for the electric drill, 9.1 mm/s (0.1), compared to the pneumatic drill, 8.7 mm/s (0.4), but the difference was not significant (p=0.15).

**Discussion**

The handle vibration levels for the pneumatic drill were much higher than the electric drill. According to the allowable upper limit of daily vibration exposure A(8) (ISO 5349-1, 2004), a worker would be allowed to operate the electric drill for up to 3 h 55 min per day while the pneumatic drill could only be operated for 8 minutes. Drill handle vibration levels for the electric drill are similar to levels reported in other bench studies. In a prior study, drilling with a 19 mm diameter bit and a feed force of 150 N was associated with a weighted vibration level of 7.8 m/s² and an unweighted level of 92.1 m/s² (Antonucci et al., 2017). The higher values reported in the Antonucci paper may be due to the higher feed force used in the study. A study of miners (Phillips et al., 2007) reported total weighted handle vibration levels (a<sub>h</sub>) of 21.9 m/s² for the pneumatic rock drill and 9.2 for the electric drill (mass of drills not reported). A study of stoneworkers using pneumatic rock drills reported a mean weighted handle vibration of 30.7 m/s², but, again, the mass of drill and bit size were not reported (Bovenzi et al., 1994).

The electric hammer drill was competitive with the pneumatic rock drill on productivity but produced substantially less handle vibration. Contractors who do structural upgrades to of bridges, roads, airport runways and buildings tend to use pneumatic rock drills for dowel and rod work. However, electric rotary drills with torque and mass similar to rock drills are now available. Structural contractors should be advised to switch to electric rotary drills for dowel and rod and other similar concrete drilling.

**Acknowledgements**

This research was supported by the Center for Constructions Research and Training (CPWR) through NIOSH Cooperative Agreement Number U60-OH009762. Its contents do not necessarily represent the official views of CPWR or NIOSH.

**References**

ZERO VIBRATION INJURIES – ACHIEVED BY MACHINE REDESIGN

*Eva Troell, Hans Lindell and Snævar Leó Grétarsson,
Swerea IVF, Mölndal Sweden

Introduction

The objective is to address the society challenge to reduce vibration injuries, today the most common cause of occupational disease in Sweden\(^1\). Every day, 400,000 workers are exposed more than two hours per day to vibrating machines. Vibration injuries causes significant costs for society, great personal suffering and often need for relocation of personnel within the company.

The project “Zero Vibration Injuries” is a Swedish initiative with the objective to take a holistic approach on the problem. The vision "Zero vibration injuries" should be achieved by addressing the source of the problem; by reducing vibration levels in handheld machines. Vibration is reduced by design solutions based on balance rings, Auto Tuning Vibration Absorber (ATVA) and traditional vibration isolation\(^2,3\).

In this context also the high frequency content of vibrations, above 1250 Hz that ISO 5349 does not include, is included and is to be reduced since it is a potential risk for causing substantial vibration injuries\(^4,7\). Meanwhile, waiting for a new standard or supplementary standard, the high frequency vibrations should be handled by a precautionary approach.

In the project machines have been redesigned in order to demonstrate the possible reduction of vibrations. Machines included were e.g. impact wrench, drill hammer, chisel machine, dental tool and a rammer plate, which represents the majority of machines that causes vibration injuries, Figure 1.

Figure 1. Machines that have been redesigned for emitting lower vibrations.

To reach the vision it’s necessary to create a demand from the machine users for low vibrating machines in order to motivate the machine manufacturers to construct and market the machines. It is also necessary for all parties to be able to measure the vibration levels to be able to compare different machines and select the one with lowest vibrations.
Methods

The work is based on three main activities:

- To show that the lower vibration machines are good or better alternatives to the machines used today. The redesigned machines are to be implemented in demonstration environments. These are limited industrial production environments of a full-activity enterprise with associated productivity and quality requirements.
- To facilitate selection of low vibrating machines. In order to enable machine users to require, assess and purchase low-vibration machines, equipment for measuring and assessing ISO and high frequency vibration is developed. Additionally, a "Vibration Map" will be developed to assist the user to assess the vibration of a certain machine.
- To establish a cultural change around the companies behavior regarding vibration to achieve a holistic view, also including high frequency vibrations and to a greater extent solve the problem by choosing low vibrating machines.

Discussion

Achieving “Zero vibration injuries” is a high set vision. One great advantage with the project is the partners; the consortium involves all stakeholders in the society, i.e. machine manufacturers, machine users, the Swedish work environment authority, employer and labor organizations as well as occupational medicine and vibration researchers. To get closer to the vision on long term a new standard or supplementary standard to ISO 5349 is needed as well as additional medical research focusing on vibration injuries caused by high frequency vibrations.

Acknowledgements

This project was funded by the Swedish Innovation Agency VINNOVA in the Challenge-Driven Innovation program.

References

Hand-Arm Vibration among Manufacturing Industry Workers in Washington State

Stephen Bao*, Ninica Howard,
Washington State Department of Labor and Industries, Olympia, WA, USA

Introduction

Literature shows strong evidence of a positive association between high level exposure to hand-arm vibration (HAV) and vascular symptoms of HAV syndrome. The high level exposure (5 to 36 m/s²) has been reported among different workforces including forestry workers and stone drillers. Although there is evidence of a positive association between hand/wrist vibration and carpal tunnel syndrome (CTS), a combination of risk factors, such as high hand force, repetition and awkward postures, is reported to have a stronger positive association with CTS. The objective of the present study is to compare HAV related to hand-held power tool use among workers in manufacturing companies with high and low workers’ compensation rates.

Methods

State-funded claims data of work-related musculoskeletal disorders (WMSD) of the hand/wrist region between 2000 and 2008 were extracted from the Washington State industrial insurance database. The distribution of the claims rates was calculated. Companies in the 75th percentile and 25th percentile within the same 4-digit NAICS codes (North American Industry Classification System) were invited to participate in this study. Sixteen companies were recruited for the study. Using NAICS codes, these companies were involved in (1) other wood product manufacturing, (2) sawmill and wood preservation, (3) architectural and structural metals manufacturing, and (4) plastics product manufacturing. Among these companies 8 pairs were matched on their size (small: 20-49 employees, medium: 50-100 and large: >100) and NAICS codes. Each pair included one company in the 75th percentile of hand/wrist WMSD claims (high claim status) and one company in the 25th percentile (low claim status). A representative sample of the workforce within job titles was selected for evaluation of the physical demands.

Risk levels (low, moderate, high, and very high) were assigned to each job risk factor. For hand-held power tool use tool type and brand name (if available) were recorded together with information on duration of use in a typical work shift. Tools’ vibration levels were estimated based on (1) their published declared vibration values, or (2) a combination of the reference values of the types of tools and the condition of the tools, based on observation. The 8-hour equivalence vibration values (Vib₈-hr) were calculated. HAV risk levels were categorized according to guidelines of the European Union (low: Vib₈-hr < 2.5 m/s², moderate: 2.5 ≤ Vib₈-hr < 5 m/s², high: Vib₈-hr ≥ 5 m/s²). Risk related to different forceful hand exertions (pinch and power grip force) and hand repetition were evaluated according to the Washington State Caution Zone and Hazard Zone Checklists. Risk factors in the Hazard and Caution Zone were considered high and moderate risk respectively, and low risk if exposures were below the Caution Zone. Combination risk factors for the hand and wrist were assessed using the Strain Index (SI) method. Risk levels were assigned low: SI < 3; moderate: 3 ≤ SI < 5; high: 5 ≤ SI < 7; very high: SI ≥ 7.
Correlation analyses, using Pearson correlation coefficient, were conducted between the different risk factor levels and risk levels of hand-arm vibration. Logistic regressions, adjusted by 4-digit NAICS codes, were performed between the risk factor levels and the hand/wrist WMSD claims status.

**Results**

Slight correlations were found between power tool use and the following risk factors: the power grip force ($R = 0.19$, $p<0.0001$), pinch grip force ($R = -0.14$, $p=0.0039$), and the SI ($R=0.11$, $p=0.0251$). No correlation was found between repetition and power tool use ($R=0.07$, $p=0.1242$).

The logistic regression analysis results are shown in Table 1. While the higher levels of risk quantified by SI, pinch force and repetition were significantly associated with high hand-wrist claim status, moderate risk level of power tool use actually was associated with low hand-wrist WMSD claim status.

**Table 1. Odds ratios of some major risk factors in the manufacturing industry**

<table>
<thead>
<tr>
<th>Exposure variable</th>
<th>Risk level comparison</th>
<th>Odds ratio (95% confidence interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Strain Index (SI)</td>
<td>Very high vs. low</td>
<td>1.8 (1.0–3.3)</td>
</tr>
<tr>
<td></td>
<td>High vs. low</td>
<td>1.9 (0.9–3.9)</td>
</tr>
<tr>
<td></td>
<td>Moderate vs. low</td>
<td>0.9 (0.5–1.7)</td>
</tr>
<tr>
<td>Power tool use</td>
<td>High vs. low</td>
<td>0.4 (0.1–1.7)</td>
</tr>
<tr>
<td></td>
<td>Moderate vs. low</td>
<td>0.5 (0.2–1.0)</td>
</tr>
<tr>
<td>Hand repetition</td>
<td>High vs. low</td>
<td>1.9 (1.2–3.1)</td>
</tr>
<tr>
<td></td>
<td>Moderate vs. low</td>
<td>0.6 (0.3–1.0)</td>
</tr>
<tr>
<td>Hand pinch force</td>
<td>High vs. low</td>
<td>2.0 (1.0–4.0)</td>
</tr>
<tr>
<td></td>
<td>Moderate vs. low</td>
<td>0.9 (0.3–3.1)</td>
</tr>
<tr>
<td>Hand grip force</td>
<td>High vs. low</td>
<td>1.2 (0.6–2.2)</td>
</tr>
<tr>
<td></td>
<td>Moderate vs. low</td>
<td>0.4 (0.2–1.3)</td>
</tr>
</tbody>
</table>

**Discussion**

It appears that the high hand force and high repetition, which are hand/wrist WMSD risk factors, are associated with high hand/wrist WMSD claims rates. However, moderate levels of vibration, due to hand-held power tool use, may be an indicator that forceful manual tasks are improved with power tool use. These levels are seen to be associated with lower hand/wrist WMDS claims’ rates.

**References**

<table>
<thead>
<tr>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
</table>
Health Effects Laboratory Division, National Institute for Occupational Safety and Health, Morgantown WV, USA |
Department of Mechanical Engineering and the Boeing Advanced Research Center, University of Washington, Seattle WA, USA  
*Riley HansonSmith  
The Boeing Company and the Boeing Advanced Research Center and University of Washington, Seattle |
| Vibration Produced by Percussive Hand Tools is an Underestimated Contributor to the Development of Vibration Injury | Ronnie Lundström  
Department of Public Health and Clinical Medicine, Occupational Medicine, Umeå University, Sweden |
| High Frequency Vibration: Measurement, Effects on Biologic Tissue and Risk Assessment | Hans Lindell and *Eva Troell  
Swerea IVF, Mölndal, Sweden |
| Five Week Riveting Hammer Vibration: Rat Tail Sensory Nerves         | Jordan Zimmerman, James Bain and *Danny Riley  
Medical College of Wisconsin, Department of Cell Biology, Neurobiology & Anatomy, Milwaukee WI, USA  
Chaowen Wu  
Medical College of Wisconsin, Department of Plastic Surgery, Milwaukee WI, USA  
Hans Lindell and Snævar Leó Grétarsson  
Swerea IVF, Mölndal, Sweden |
| Changes in Biomarkers of Cardiovascular Dysfunction in an Animal Model of Hand Arm Vibration Syndrome | Kristine Krajnak, Stacey Waugh and Thomas McDowell  
Health Effects Laboratory Division, National Institute for Occupational Safety and Health, Morgantown WV, USA |
RIVET BUCKING BAR ACCELERATION: FEED FORCE EFFECTS

*T.W. McDowell, X.S. Xu, C. Warren, D.E. Welcome, R.G. Dong

National Institute for Occupational Safety & Health, Morgantown, WV, USA

Introduction

Percussive riveting is the primary process for attaching the outer sheet metal “skins” of an aircraft to its airframe. Workers using manually-operated riveting tools (riveting hammers and rivet bucking bars) are exposed to significant levels of hand-transmitted vibration (HTV) and are at risk of developing components of hand-arm vibration syndrome. To protect workers, employers can assess and select riveting tools that produce reduced HTV exposures. Researchers at the National Institute for Occupational Safety & Health (NIOSH) have developed a laboratory-based apparatus and methodology to evaluate the vibrations of rivet bucking bars. Using this simulated riveting approach, this study investigated the effects of feed force on the vibrations measured on several typical rivet bucking bars and that transmitted to the bucking bar operator’s wrist.

Methods

The experiments were conducted using an updated version of the laboratory-based apparatus and methodology for simulating a riveting task and evaluating rivet bucking bar vibrations developed in a recent NIOSH study. The NIOSH approach (see Figure 1) is similar to the lab evaluations presented in the ISO 28927 series for hand-held non-electric tools where sample tools within a tool group are operated by human test subjects against a specified, consistent load while the vibration emissions are measured near where the vibration enters the tool operator’s hand. Eight healthy volunteer test subjects (seven male, one female) were recruited locally to operate the bucking bars. Five bucking bar models were assessed: Bar A is a traditional cold-rolled steel bar; Bar B is a heavier tungsten alloy bar with the same shape and size as the steel bar; Bars C, D, and E feature spring-damper configurations. Two samples of each bucking bar model were used in the study. Three feed force levels were evaluated: 40±10 N, 65±10 N, and 90±10 N. Each bucking bar operator completed three trials with each bucking bar/force level combination.
Results

Figure 2 shows the frequency-weighted acceleration averages measured at the bucking bar for each bucking bar model for each of the three levels of feed force. As shown in the figure, the traditional cold-rolled steel bar (Bar A) exhibited the highest acceleration averages at all three force levels. The solid-metal bars (Bars A and B) and one of the spring-damper bars (Bar E) tended to have decreased acceleration as the feed force increased. Two of the spring-damper bars (Bars C and D) exhibited their lowest weighted acceleration averages at the middle feed force level (65 N). As can also be seen in the figure, these two bars were more sensitive to the feed force effect as compared to the other bars.

Discussion

The feed forces applied to bucking bars in sheet metal riveting applications varies from task to task depending on the rivet size, rivet composition, sheet metal thickness, and other factors. This study shows that different bucking bar designs will respond differently to variations in feed force. This means that the feed force required for a specific riveting operation should be an important consideration when selecting bucking bar models. To help in the informed selection of bucking bars, candidate bar models should be evaluated at multiple feed force levels. The results of this study suggest that at least three levels of feed force should be considered in bucking bar vibration evaluations. This is especially true for bucking bars featuring spring-damper systems, as this study has shown that these models are particularly sensitive to changes in feed force, and these bars are optimized for certain feed force ranges. In all cases, the feed force levels used in bucking bar evaluations should be representative of the feed forces observed in actual workplace riveting applications. In addition to evaluating the vibration at the bucking bar, the vibration at the wrist should also be measured as additional information for assessing and selecting rivet bucking bars. As observed in this study (not shown in this abstract), some bucking bar designs may offer reduced vibration exposures to the bar operator’s fingers while providing little attenuation of wrist acceleration. Knowledge of such trade-offs can be important for making informed rivet bucking bar selections.

References


Disclaimer: The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.
Comparing Vibration Exposures Across Tungsten and Steel Bucking Bars for Aluminum Riveting

Ryan Mott\textsuperscript{1,2}, Wadih Zaklit\textsuperscript{1,2}, Bryan Ford\textsuperscript{1,2}, Luke Wayrin\textsuperscript{1,2}, Joe Garbini\textsuperscript{1,2}, Per Reinhall\textsuperscript{1,2}, Riley HansonSmith\textsuperscript{2,3}

\textsuperscript{1}Department of Mechanical Engineering, University of Washington, Seattle
\textsuperscript{2}Boeing Advanced Research Center at the University of Washington, Seattle
\textsuperscript{3}The Boeing Company

Introduction

Riveting tasks in aerospace manufacturing have high injury rates from repetitive high impact exposure. Tungsten bucking bars (TBB) have been shown previously to reduce the exposure to vibrations when compared to steel bucking bars (SBB) of similar geometry\textsuperscript{1}. It is not clear from these studies if the tungsten bars are superior due only to their increased mass or due also to tungsten’s material properties.

The objective of the study was to test steel and tungsten bucking bars of the same mass and analyze their ergonomic impact via ISO 5349-1 exposure limits and performance via rivet formation rates. Analysis was also completed of RMS values for the raw data and 1500 Hz cutoff filtered raw data. This testing specifically targeted large diameter (5/16”), deep stack riveting common in aluminum wing fabrication. After gathering experimental data, we analyzed the tool vibrations and rivet formation rates to determine which tools were optimal for mechanics to utilize in production.

Methods

Riveting is a chaotic task that involves manual control of the duration and magnitude via the rivet gun’s trigger. This makes it challenging to perform quantitative studies with consistent inputs. To address this variation, we have constructed an automated riveting test bench, pictured below in Figure 1.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{automated_riveting_bench.jpg}
\caption{Automated riveting test bench in the Boeing Advanced Research Center at the University of Washington, Seattle}
\end{figure}

The test bench positions the gun and bucking bar, applies a constant push force, and fires the rivet gun for a predetermined cycle time. This provides very consistent inputs for each rivet. A uniform duration for each cycle allows us to analyze the
formation rate. Additionally, the bench uses a suite of sensors to measure the tool vibration. This includes shock accelerometers, load cells, and laser displacement sensors.

Results

There are two main criteria for evaluating bucking bar performance, the formation rate and the vibration exposure level. The formation rate indicates how long it takes to form the rivet, and any reduction in the forming time reduces exposure to both the bucking bar operator and the rivet gun operator. The second criterion is the vibration exposure level from the ISO 5349-1 standard, 1500Hz cutoff and raw data. The results showed the TBB and SBB performed roughly equivalently in terms of exposure levels via the ISO 5349-1 weighted standard. For the 1500Hz cutoff, the TBB was 28% less than the SBB (107.7 m/s² TBB vs. 142.7 m/s² SBB) and for the raw data TBB had 3.45 times the acceleration of SBB (1341.8 m/s² TBB vs 388.0 m/s² SBB). The TBB formed rivets about 14.6%+/−7.1% faster on average than the SBB.

![Figure 2. ISO 5349-1 exposure levels and average formation time using a tungsten bucking bar and a steel bucking bar of the same mass.](image)

Discussion

The results of this testing indicate that per the ISO 5349-1 frequency weighting curve the TBB is superior to a SBB of the same mass. This is accomplished by reducing the formation time of the rivet while keeping the same exposure level. The 1500Hz cutoff shows additional benefits for the TBB by reducing the exposure values. Finally, the raw data shows significantly higher exposure for the TBB at high frequencies. This high frequency data brings some uncertainty into the results and indicates that further studies into the appropriate frequency cutoff and frequency weighting would be valuable. It is hypothesized that the reduction in cycle time is because tungsten is stiffer and harder than steel (Young’s Modulus of 331 GPa and 200 GPa, respectively). Another benefit of a tungsten bar is its smaller footprint, so it can fit into tighter access areas of the structure than a steel bar of the same mass could. Based on this testing we recommend using tungsten bucking bars over steel bars where feasible.

References

VIBRATION PRODUCED BY PERCUSSIVE HAND TOOLS IS AN UNDERESTIMATED CONTRIBUTOR TO THE DEVELOPMENT OF VIBRATION INJURY

Ronnie Lundström

Department of Public Health and Clinical Medicine, Occupational Medicine, Umeå University, Sweden

Introduction

During 1979 it came to my attention that some dentists after practicing their profession for many years were forced to resign because of reduced tactile perception in their dominant hand. Their fingers felt stiff and numb, and the ability to perform precision work that was regarded as indispensable could no longer be maintained. These complaints led to the suspicion that exposure to high-frequency vibration produced by dental hand pieces used in their daily work was a possible cause. Hand pieces used in dentistry at that time, as well as nowadays, have high rotational speed (over 200,000 rpm). Vibration measurement indicated vibration levels as high as ~100 m/s² within the frequency range of 1-50 kHz. My suspicion was supported some year later when I found elevated vibrotactile perception thresholds on the "drilling" hand within a group of dentists. Similar results were presented by others some year after. A follow-up study on physiotherapists, exposed in their profession to vibration (around 1 MHz) from the handles of ultrasonic therapy devices, indicated a similar medical results.

Health effects of hand-held percussive tools

These early findings definitely supported the idea that high frequency vibration has a detrimental effect on health and boosted my interest to look into the area in more depth. After a comprehensive review of the scientific literature available at that time (i.e., before 1986), it was apparent that exposure to high frequency and/or shock-type vibration from tools like impact wrenches, scalers, pedestal grinders, jack and riveting hammers have an underestimated risk influence on humans. A follow-up review was also conducted some years later. The reviews showed that several studies were either demonstrating, or otherwise suggesting, that percussive tools may have a more pronounced detrimental effect on humans when compared with non-percussive ones. Relatively high prevalence (~25-100 %) of vascular and neurological disturbances, such as vibration-induced white finger (VWF) and impaired tactile sensibility, was observed. The reason for the high prevalence was not clear, but it seemed likely that vibration that contained repetitive transients with high peak acceleration levels and/or very high frequency components with high vibration levels was an important contributor to the onset of disorders. Since then and up until now several other reviews have been published that reach similar conclusions. For references, see.

Measurement and risk assessment of percussive vibration

The international standard ISO 5349 specifies methods for measurement and risk assessment for vibration in terms of frequency-weighted acceleration. The nominal gain of the frequency-weighted calculation is zero dB from about 6 to 16 Hz, and a gain of -6
dB and at least -12 dB per octave up to and above 1250 Hz. The risk of vibration injury is thus considered to decrease with increasing frequency when assuming humans are less sensitive to high frequency components. Moreover, it is clearly stated that ISO 5349 is only provisionally applicable to percussive tools. The European directive for vibration is more or less based on ISO 5349 but does not state whether it is applicable for percussive vibration or not. Current knowledge suggests that guidelines for risk assessments for human exposure to high frequency and/or percussive vibration should be included in future versions of the ISO-standard.

**Summary and conclusions**

When considering knowledge gained over the past 4 decades regarding human exposure to hand-transmitted vibration from percussive tools it seems justified to draw the following conclusions:

- High frequency and percussive vibration have detrimental effects on health.
- ISO 5349 is not applicable for high frequency and/or percussive vibration and underestimates the risk for developing health effects.
- Revision of ISO 5349, or at least an amendment or appendix to it, is needed to cover high frequency and/or percussive vibration.
- Further research is needed about the relationship between short- and long-term exposure to percussive vibration and related health effects.
- Carefully targeted epidemiological studies on possible health effects caused by specific percussive tools are particularly warranted.

**References**

HIGH FREQUENCY VIBRATION: MEASUREMENT, EFFECTS ON BIOLOGIC TISSUE AND RISK ASSESSMENT

Hans Lindell
Swerea IVF, Sweden

Introduction

Vibrations from tools with high amplitude and high frequency content above 1250 Hz have long been suspected to cause vibration injuries\textsuperscript{1-6,9}. Regrettably, there is no standard assessing the risk associated with these vibrations. ISO 5349\textsuperscript{7}, the current standard that almost all regulations and legislation are based upon such as the EU Vibration Directive\textsuperscript{8}, only covers vibrations up to 1250 Hz. Frequencies above this are not considered at all for risk estimation. This means that several occupational groups are exposed to potentially harmful vibrations not regulated by worker’s protection directives, and even more importantly, it prevents development of preventive measures from the vibration source, the tool itself. Examples of major occupational groups exposed to high frequency vibrations are users of impact wrenches, scalers and high rpm grinders and dental drills.

Methods

Key factors for establishing a basis for assessing high frequency vibrations are, first; the ability to accurately measure high frequency vibrations, second; to understand how the vibrations propagate into the finger tissue via the skin, and third; to achieve knowledge on how the vibration affects biological material. Important progress has been made in several areas, as described in the references\textsuperscript{9}.

Results

The following statements can be made based on the current knowledge from the cited references:

- There are several studies that show that ISO 5349 underestimates the risk for injuries from high frequency transient vibrations.
- Acceleration can be measured accurately up 50 kHz with ultra light MEMS accelerometers on tools.
- Impact machines generate high amplitude, high frequency, transient accelerations.
- High frequency transient accelerations from impact machines are nearly eliminated by the weighting filter in ISO 5349 and, thereby, rejected from risk evaluation.
- Simulation models indicate that high frequency vibrations from machines generate pressure waves that propagate into the finger tissue and cause strain and high strain rates in the finger tissue. The models predict that the epidermis layer of the finger has a relatively small attenuation.
- High frequency transient vibrations can be substantially reduced by redesign of machines.
Discussion

There is a need for a revision of ISO 5349 or an amendment/appendix in order to cover risk from high frequency vibration which also would give an important incentive for machine producers to improve machine design.

In order to improve risk assessment from transient vibrations, the acceleration signal could be studied in the time domain instead of the frequency domain as today. There is a need to reconsider if the current approach in ISO 5349 is the best strategy, i.e., to use the transferred vibration energy to tissue as a measure for health effect assessment. The weighting curve of ISO 5349 in practice performs integration of acceleration to velocity which relates to transferred energy. Alternative approaches to consider are the unweighted accelerations which give the strain of the tissue or the derivative of the acceleration which correspond to the strain rate of the tissue. These approaches would comply with risk estimation in mature adjacent fields such as impulse noise, crash injuries, and material fatigue.

It would also be a substantial improvement for future research if epidemiological studies would also monitor the time signal of the acceleration at higher frequencies and not be satisfied with the ISO 5349 weighted energy average which is the case for the vast majorities of studies.

References

FIVE WEEK RIVETING HAMMER VIBRATION: RAT TAIL SENSORY NERVES

Jordan Zimmerman¹, James Bain¹, Chaowen Wu², Hans Lindell³, Snævar Leó Grétarsson³, and *Danny Riley¹
Medical College of WI ¹Cell Biology, Neurobiology & Anatomy and ³Plastic Surgery, Milwaukee, WI, USA, ³Swerea IVF, Sweden

Introduction

After 10 or more years, 50% of aerospace riveters develop occupational Raynaud’s vasospastic disease¹. Occurrence for bucking bar holders is 4.5 times that of riveting gun operators². During WW II, the mean onset of vasospastic disease for women riveting hours/day was 8 months³. Our riveting hammer rig emits substantial r.m.s accelerations at the operating frequency (35 Hz), but 10-50 fold higher levels at 12 and 16 kHz⁴. These findings implicate shock waves generated by percussive tools as major contributors to vibration disease. The ISO 5349 risk assessment calculation emphasizes low frequency energy because the kHz energy is rejected by frequency weighting. Our rat tail, riveting hammer rig simulates bucking bar exposure. One 12 min exposure to riveting hammer vibration destroys sensory nerve endings and reduces thermosensitivity of the tail⁵. Increasing vibration exposure from 1 to 12 min causes greater nerve damage⁴.

The present study investigated whether 5 weeks of repeated, 12 min-daily vibration exposure produces marked nerve loss in mechanosensory complexes on tail hairs.

Methods

Female rats (5 wks old) were randomly assigned to 5 wk vibration and 5 wk sham nonvibrated groups (n=9/group¹). At completion, rats were euthanized, and tail segments were removed, chemically fixed, decalcified, and frozen for tissue sectioning. Sections (60 µm) were immunostained with PGP9.5 antibodies to visualize lanceolate nerve fiber endings forming mechanosensory complexes encircling hairs. The biological structural integrity of nerves was assessed by qualitative and quantitative light microscopy at the Medical College of Wisconsin.

The frequency power output of the rat tail vibration platform, accelerated by a pneumatic Atlas Copco RRH04P riveting hammer, was measured by Lindell and Grétarsson at Swerea to quantify the vibration magnitude and frequency characteristics. Signals from a piezoresistive accelerometer (PCB 3501A2060KG) were sampled at 1 MHz (National Instruments 9223) and low pass filtered at 50 kHz with a 6th order Bessel filter. Dominant frequencies were identified using a fast Fourier transform of 200 msec time intervals. The r.m.s average of 25 intervals was determined by linear weighting.

Results

On average, 69±2% of the hairs in sham controls were innervated in sections cut through the level containing lanceolate neural complexes. This level was defined by sebaceous oil glands and fat cells abutting the hair follicle (right figure). In vibrated rats, the percentage of hairs innervated (53±4%) was lower than
that (69±2%) in sham, indicating vibration-induced neural destruction. Normal lanceolate complexes had parallel, straight and darkly-stained nerve endings, whereas abnormal complexes exhibited irregular, discontinuous and weakly-stained lanceolate endings. There were 18.8% abnormal complexes in the sham. The 5 week vibrated contained a significantly (p=0.0086, Fisher’s exact test) higher percentage (44.9%) of abnormal complexes than sham, consistent with vibration nerve damage.

At 20 psi, the peak magnitudes at low frequencies were 40.5 Hz plus the 1\textsuperscript{st}, 2\textsuperscript{nd}, and 3\textsuperscript{rd} harmonics. Peak magnitudes of 2000-8000 m/s\(^2\) r.m.s. occurred at the high frequencies of 12.3, 16.4, 21.4, 27.2, 28.9, 37.1, 41.5 and 46.9 kHz (Figure left). The calculated ISO 5349 weighted acceleration was 9 m/s\(^2\).

**Discussion**

The riveting hammer rig has stable vibration peak amplitudes, a spectrum similar to other percussive tools such as impact wrenches and chisels. The ISO 5349 weighted acceleration, averaging 9 m/s\(^2\), primarily reflects energy in the 40.5 Hz operating frequency and the 3 harmonics. The low value for frequency weighted acceleration emphasizes that the 2000 to 8000 m/s\(^2\) r.m.s vibration power in the 10-50 kHz range is a major component factored out and likely the major cause of nerve damage.

Five weeks of vibration caused complete destruction of 16% of the lanceolate mechanosensory innervation complexes indicating total degeneration. Of those complexes remaining, 45% were abnormal which is consistent with repeated die back and regrowth of lanceolate nerves. If the regrowth capacity of nerves is lost due to repeated injury, then persistence of a neural defect would be expected. Regrowth during repeated insults may explain why it takes years for permanent neural deficits to establish in workers. The observed nerve damage from riveting hammer accelerations may have been vibration energy (m/s\(^2\) r.m.s) in the low (Hz) and high (kHz) frequencies. The much larger magnitudes in the kHz range point to shock vibrations as the primary destructive component. From these data, we suggest that the kHz components of percussive tools be included for improved assessment of risk.

**References**

CHANGES IN BIOMARKERS OF CARDIOVASCULAR DYSFUNCTION IN AN ANIMAL MODEL OF HAND-ARM VIBRATION SYNDROME

*Kristine Krajnak, Stacey Waugh, Thomas McDowell

Engineering and Controls Technology Branch, Health Effects Laboratory Division, National Institute for Occupational Safety and Health, Morgantown, WV.

Introduction
Studies using a rat-tail model of hand-arm vibration syndrome (HAVS) have demonstrated that repetitive exposure to vibration at the resonant frequency results in peripheral vascular and sensorineural dysfunction that is similar to that seen in workers with HAVS \(^1,2\). Exposure to vibration at the resonant frequency also results in changes in gene transcription and markers of oxidative stress that are indicative of broader changes in cardiovascular function \(^3\). The goal of this study was to use the rat-tail model of vibration developed at NIOSH to determine if repetitive exposure to vibration at the resonant frequency would result in changes in markers of cardiovascular dysfunction.

Methods
Animals. Male Sprague Dawley rats (n = 8 rats/group, 6 weeks of age at arrival) were obtained from Hilltop Lab Animals, Inc. (Scottsdale, PA), and acclimated to the animal facilities and restraint for 5 days. Rats were then exposed to vibration or control conditions for 10 consecutive days.

Exposure. Rats were placed in Broome Style restrainers, and their tails were strapped onto platforms attached to a shaker or isolation blocks using four, 1 cm wide elastic straps. Rats whose tails were strapped to platforms mounted onto shakers were exposed to 4 hr of tail vibration (250 Hz, 49 m/s\(^2\)), each day for 10 consecutive days. Control rats were housed in the same exposure chamber with vibrated rats, but they were not exposed to vibration.

Sample collection and analyses. Heart and kidney tissues were collected 24 h after the last exposure. Changes in gene expression for inflammatory factors, and factors involved in mediating vascular remodeling and oxidative stress, were measured by quantitative RT-PCR. Reactive oxygen species (ROS) were measured by colorimetric assays, and proteins were measured by Western blot analyses.

Results

![Figure 1](image)

**Figure 1.** Exposure to vibration increased gene expression of factors that mediate vasodilation (neuronal nitric oxide synthase; nNOS), inflammation (nNOS, and tumor necrosis factor-α), and vascular growth (runx-related transcription factor-1; runx-1) in heart tissue (A). In the kidney (B), exposure to vibration resulted in an increase in the inflammatory factor interleukin 1-β (Il1-β), and in the anti-oxidant enzyme, superoxide dismutase-2 (SOD2). *p < 0.05.
Figure 2. Exposure to vibration resulted in increases in nitric oxide ($N_{\text{ox}}$; Fig 2A) and overall ROS concentrations (B) in the heart. In the kidney, ROS levels (C) were not affected by vibration exposure; $N_{\text{ox}}$ concentrations were not detectable (data not shown). *$p < 0.05$.

Discussion

• Exposure to segmental (tail) vibration increased measures of oxidative stress and inflammation in the heart. It has been hypothesized that these changes may be mediated by the responses of the autonomic nervous system to vibration$^{4-6}$.
• Vibration also resulted in an increase in runx-1 expression in the heart. The increase in the expression of this gene may stimulate angiogenesis in the heart.
• The effects of vibration on gene transcription in the kidney were examined because the kidney regulates circulating electrolyte levels. There was a slight increase in inflammation and a reduction in the expression of the anti-oxidant, SOD$_2$, but there was no increase in measures of oxidative stress in the kidney.
• Based on the results of this study, it appears that early changes in vibration-induced cardiovascular function may be the result of a prolonged vasoconstriction of peripheral arteries, which mediate blood pressure$^2$, or changes in autonomic input to the cardiovascular system.

References


Disclaimer: The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.
SESSION 3 - CHARACTERIZING AND MITIGATING ARM VIBRATION EXPOSURES

Finger Vibration on a Handheld Workpiece
*Daniel E. Welcome, Xueyan S. Xu, Chris Warren, Thomas W. McDowell, Ren G. Dong
  – Health Effects Laboratory Division, National Institute for Occupational Safety and Health, Morgantown WV, USA

Nonlinear Tuned Vibration Absorber on Reciprocating Tools
*Snævar Leó Grétarsson and Hans Lindell
  – Swerea IVF, Mölndal, Sweden

Development of a Convenient and Reliable Method for Measuring Vibration Transmissibility of Gloves at Fingers
*Xueyan Sherry Xu, Daniel E. Welcome, Chris Warren, Thomas W. McDowell, Ren G. Dong
  – Health Effects Laboratory Division, National Institute for Occupational Safety and Health, Morgantown WV, USA

Physical Constraints Associated with Current Anti Vibration Gloves and New Glove Design Alternatives
*Markus Berger
  – Y. Berger & co AB / Eureka Safety

Standing Centre of Pressure Alters the Vibration Transmissibility Response of the Foot
Katie Goggins and Brent Lievers
  – Bharti School of Engineering and Centre for Research in Occupational Safety and Health, Laurentian University, Sudbury, ON, Canada
Marco Tarabini
  – Department of Mechanics, Politecnico di Milano, Lecco, Italy
*Tammy Eger
  – Centre for Research in Occupational Safety and Health and School of Human Kinetics, Laurentian University, Sudbury, ON, Canada
FINGER VIBRATION ON A HANDHELD WORKPIECE

Daniel E. Welcome, Xueyan S. Xu, Chris Warren, Thomas W. McDowell, Ren G. Dong

Engineering & Control Technology Branch, Health Effects Laboratory Division
National Institute for Occupational Safety and Health
Morgantown, West Virginia 26505, USA

Introduction

After golf club heads are removed from their castings during fabrication, they require additional grinding. The metal club heads are often held by hand during the grinding process. Significant vibration can be transmitted to the fingers holding the workpieces during such processing. A recent study found a significant prevalence (>12%) of the vibration white finger among workers performing the fine grinding of golf club heads in some sports equipment factories. The objectives of this laboratory investigation were to measure the response of the fingers holding a club head during a simulated exposure and to identify a better vibration-reducing glove for the grinding operation.

Methods

In order to simulate the exposure of the fingers holding the golf club head, eight volunteer subjects (5 female and 3 male) pushed the golf club head against a vibrating instrumented handle attached to a shaker as shown in Figure 1. A 3D laser vibrometer (Polytec, PSV-500) was used to measure the response of the fingers at twelve points – three on the index and middle fingers of the right and left hands – and one point on the club head between the hands and one point on the handle fixture. The handle fixture was oriented at 45° as shown in the Figure to improve the sight lines of the lasers. The subject held the club head with both hands against the cylindrical handle instrumented with two force sensors (Kistler 9212) and two tri-axial accelerometers inside of each side of the handle (Endevco 65-100 and PCB 356A12) on a uniaxial vibration test system (Unholtz-Dickie, TA250-S032-PB). An accelerometer (PCB 356B11) was also attached to the club head. The constant velocity excitation spectrum (10 to 1,600 Hz) defined in the current ISO 10819 (2013) was used. The contact area of the handle was covered with a layer of electrical tape under rubber bands to minimize any metal-to-metal contact between the handle and golf club head. The subjects were asked to maintain a vertical line of contact between the club head and handle surfaces and keep their fingers flat against the top surface of the club head. The subjects pushed against the handle with two feed force levels: 15 and 30N. Along with the bare hand, three glove conditions were tested: a neoprene dipped glove, an air bladder glove, and a cotton-covered glove currently used in the grinding operation at a workplace. Each condition had two trials and each trial lasted under 1.5 minutes.
Results

The average transmissibility for all of the points on the fingers of all of the subjects for the 30N feed force for each glove condition are shown in Figure 2. The resulting spectra were very similar for the 15N feed force (not shown).

Discussion

As shown in Figure 2, the air bladder glove and cotton-covered glove only marginally reduced the vibration on the fingers in the frequency range of 50 to 100 Hz. More surprisingly, they increased the vibration above 100 Hz. This may be partially because the gloved finger vibration is not only affected by the expected cushion function of the gloves but also by other unexpected effects of the gloves. For example, these gloves may have a lower coefficient of friction (CF) than that of the bare hands so that a larger hand force has to be applied on the club head to control it and to provide the required feed force. As a result, the finger resonant frequency (the second peak shown in Figure 2) is obviously higher than that of the bare fingers. This resulted in a higher vibration transmissibility in the high frequency range. Also because of the reduced CF, it was difficult to maintain exactly the same finger postures and positions on the club head as those with bare hands. This may also change the apparent mass and vibration pattern of the fingers. Conversely, the neoprene glove has a higher CF so that the applied control force, finger postures, and positions on the club head may be similar to those with bare hands. As a result, the cushion function of this glove may play a dominant role in determining the glove transmissibility at the fingers. This explains why each of the resonant peak frequencies of the fingers wearing this glove were marginally lower than that of the bare fingers, as shown in Figure 2. The spectra for grinders used in the factories peak at 20-40, 63, 100-125 and above 250 Hz depending on the grinding machine’s condition. These observations suggest that the neoprene glove is a better selection than the other two gloves for the grinding operation.

References


Disclaimer: The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.
NONLINEAR TUNED VIBRATION ABSORBER ON RECIPROCATING TOOLS

Snævar Leó Grétarsson*, Hans Lindell
Swerea IVF, Box 104, 431 22, Mölndal, Sweden

Introduction

Hand held power tools with reciprocating action, such as needle scalers, tampers, rock drills and breakers expose workers to high levels of vibration. These machines usually have a piston that is driven back and forth creating a periodic force on the rest of the machine. This periodic force is the dominating source of vibration on these tools.

Different approaches can be taken to reduce the vibration exposure on the operator. One common approach is to isolate the handles from the rest of the machine. The vibration exposure can be reduced with isolation but in order to maximize the degree of isolation the coupling between the handles and the rest of the tool has to be soft. If the stiffness of the coupling is reduced too much the tool can become uncontrollable. The stiffness is therefore a compromise between controllability and vibration isolation.

Another option is to use a tuned vibration absorber (TVA) to counter the excitation force. The linear tuned vibration absorber is an old invention. It was first patented in 1909 by Frahm¹ and later described by Den Hartog². Linear TVAs are useful for suppressing unwanted resonances in buildings but their effectiveness often is limited in tools with reciprocating action because of the narrow suppression band. If the TVA is tuned to frequency above the excitation frequency the effect of the suppression is very limited and if the TVA is tuned to a frequency slightly below the excitation frequency, the TVA will amplify the vibrations instead. Tuning the absorber is therefore difficult and if the operating frequency of the tool varies the use of a linear TVA is impossible.

The effective frequency range can however be broadened significantly by introducing nonlinear spring characteristics³. This has been implemented on three pneumatic machine types. First on a hand held impact machine⁴ (HHIM) and later on a rock drill and a tamper

Methods

The internal mechanism of all three machines is similar. All three have a piston that is driven back and forth in a cylinder. The key difference is that in the rock drill and the HHIM the piston hits the drill/chisel but in the tamper the piston is connected to the butt with a rod.

The NLTVA consists of a counter mass that slides on the outside of the mechanism and the movement is restricted by linear springs. The nonlinearity is introduced by preloading the springs and by having a small gap between the spring and the counter mass. The vibration of the handles on the HHIM and the rock drill is further reduced by attaching the housing with handles to the internal mechanism via vibration isolators. The engineering model of the HHIM and rock drill can be seen in Figure 1. On the tamper the housing \((m_h)\) and mechanism \((m_m)\) are fixed to each other. The equations of motion are set up based on the engineering model and transformed to a computational Matlab model. The model has been validated in a special test rig, where all parameters can be controlled. The parameters of the NLTA are optimized for each machine to minimize the vibration amplitude of the handles around the operating frequency.
stiffness of the vibration isolation is chosen as soft as possible without compromising the controllability. The simulated displacement of the handles on the HHIM with vibration isolation and NLTVA can be seen in figure 2. The displacement of: a single mass machine, machine with vibration isolation and a machine vibration isolation and LTVA is shown for comparison.

Figure 1: HHIM engineering model.

Figure 2: Vibration level on the HHIM handle

Results

Figure 2 shows how the effective frequency range of the TVA is significantly widened by introducing nonlinearities. The TVA can therefore be used on machines with varying operating frequency. The combined vibration isolation and NLTVA reduces the acceleration of the handles on the HHIM from 20 m/s$^2$$_{haw}$ to 2.7 m/s$^2$$_{haw}$. The same approach lowers the vibration level of a pneumatic drill from 18 m/s$^2$$_{haw}$ to 3 m/s$^2$$_{haw}$. By adding a NLTVA to the tamper the acceleration has been halved, from 32 m/s$^2$$_{haw}$ to 16 m/s$^2$$_{haw}$.

Discussion

The NLTVA has been successfully implemented on three tool types. When the NTVA is combined with vibration isolation, the acceleration of handles can be reduced significantly. A small pre series of the HHIM machines has been built and the machines are being tested in a granite quarry.

The work is part of the project ‘Zero vibration injuries’ which is funded through Vinnova's Challenge-Driven Innovation program. The goal of the project is to reduce vibration injuries by demonstrating how vibration exposure and injuries can be reduced by redesigning the tools.

References

1. Frahm, H. (1911). Device for damping vibrations of bodies. US989958A
DEVELOPMENT OF A CONVENIENT AND RELIABLE METHOD FOR MEASURING VIBRATION TRANSMISSIBILITY OF GLOVES AT FINGERS

Xueyan Sherry Xu, Daniel E. Welcome, Chris Warren, Thomas W. McDowell, Ren G. Dong

Engineering & Control Technology Branch, Health Effects Laboratory Division
National Institute for Occupational Safety and Health
Morgantown, West Virginia 26505, USA

Introduction

The vibration transmissibility of a glove is used to assess its vibration-reducing (VR) effectiveness. It is defined as the vibration transmitted to the glove interior divided by that input to the glove exterior. While the input vibration is usually measured on an instrumented handle or a tool handle, the transmitted vibration at the palm of the hand is measured using a palm adapter equipped with an accelerometer in many studies. This procedure has also been adopted in the current standard for the screening test of anti-vibration gloves. Since an acceptable method has not been developed to directly measure the transmitted vibration at the glove-finger interface, an indirect or on-the-finger method has been usually used to evaluate the effectiveness of the glove at the fingers through the measurement and comparison of the finger vibrations with and without wearing the glove. Although this method is theoretically valid, the increased number of measurements may bring about more uncertainties and reduce the reliability of the evaluation. It is highly desired to develop a more reliable and convenient method for the evaluation. The objective of the current study is to develop such a method.

Methods

The method proposed in this study is based on the direct measurement of the transmitted vibration at the glove-finger interface using a novel finger adapter. The adapter was designed based on a set of requirements specified on the basis of our general knowledge of vibration and the findings of a previous study. The transmissibility of a glove or a resilient material at the fingers can be measured with the finger adapter, simultaneously with the measurement of the transmissibility at the palm using a palm adapter recommended in the standard glove test. The test setup and subject postures are as shown in Figure 1. When the adapter is held at the middle sections of the middle and ring fingers, the accelerometer is aligned with the vibration direction of the shaker. This adapter position was used in the measurement of the glove finger transmissibility in this study.

Six subjects participated in the measurement of the glove transmissibility at the fingers using the new adapter. The test treatments include the following variables: two finger adapters with different base thicknesses, four models of gloves (mechanical, gel, neoprene, air bubble) and one resilient material (air bubble), four hand force combinations.
(15 N grip, 30 N grip, 50 N grip, and combined 30 N grip and 50 N push). Another treatment was the simultaneous measurements of the transmissibility at the fingers and palm of the hand under the combined 30 N grip and 50 N push forces. Two repeated trials were conducted for each treatment.

**Results**

Examples of the simultaneously measured transmissibility spectra of the gloves at the fingers and palm of the hand under 30 N grip force and 50 N push force are shown in Figure 2.

![Graph showing transmissibility spectra for gloves 1 to 5 at fingers and palm](image)

Figure 2. Averaged vibration transmissibility at the fingers and palm for gloves 1: mechanical work glove; 2: gel glove; 3: neoprene glove; 4: air bubble glove; and 5: air bubble sponge resilient material.

**Discussion**

The results demonstrate that the new finger adapter can provide a reasonable measurement of the glove transmissibility at the fingers. The resonant peaks are consistent with those of the finger biodynamic response. The basic trends of the transmissibility spectra of the glove are consistent with those predicted with a model of the glove-hand-arm system. The new finger adapter provides a convenient and reliable tool for the further studies of VR glove effectiveness. It may also help objectively develop more effective VR gloves. If the finger adapter method is added to the standard screening test of anti-vibration gloves, its screening reliability is likely to be substantially increased with minimal increases in cost and test time.

**References**


Disclaimer: The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.
PHYSICAL CONSTRAINTS OF CERTIFIED ANTI VIBRATION GLOVES
AND A SUGGESTED PARADIGM SHIFT

Markus Berger*
Y.Berger & co AB / Eureka Safety

Introduction
Exposure to hand arm vibrations is common in the workforce and prolonged exposure is well known to cause health problems described as Hand Arm Vibration Syndrome (HAVs). The use of Vibration Reducing Gloves is one of many methods to reduce the risk of HAVS. Other methods include reduced exposure time, lower vibrating tools, general working condition and better training of operators. Anti-vibration (AV) gloves are defined by the ISO 10819:2013 standard. Most AV gloves have a soft material made from an elastic polymer with air filled cavities (foams or larger air filled cavities) with a material thickness from 5-7mm. These gloves can be subject to potentially harmful resonance at the palm around 30-40 Hz and at the fingertips from about 100-400 Hz\(^1\,^2\). Protection gradually improves above these frequencies. The thicker and softer materials that are used, the lower the resonance frequency and the better the protection becomes at high frequencies. The challenge with anti-vibration gloves is that they have areas in the frequency spectrum where they may increase finger resonance, which can contribute to injury, and they can reduce manual dexterity and put strain to the hand by increasing the grip effort\(^3\). The ISO 5349 standard is used to calculate the weighted average acceleration. This is done by using acceleration in the spectrum per 1/3 octave ranging from 6.3-1250 Hz. The ISO weighting emphasizes the low frequencies. For instance, at 200Hz the relative weight is only 10% of the weight at 12,5Hz. It is now well proven that the fingers and the smaller physiological sub-structures within the fingers react differently from the ISO weighting curve. There is no exact definition but it is expected that the potentially harmful resonance in the fingers takes place in the range 100-300 Hz and are relatively less sensitive below or above these frequencies\(^4\). The objective of this study is to explore the limits of the different AV glove design options.

Methods
A simple single lump-mass-spring model has been set up with material thickness, modulus and mechanical damping and engaged weight as independent variables. The resonance frequency at different engaged weight and material thicknesses was estimated to illustrate the principle constraints in the glove design.

Lab tests on worn gloves made of 2, 4 and 6mm Neoprene closed cell foam where tested according to the ISO 10819:2013 to illustrate the importance of palm material thickness. There were minor differences in hole structure as well as other materials in the glove.

The finger attenuation was tested using a 1-axis laser vibrometer to scan to the top surface of the ring finger. The ISO 10819:2013 equipment and procedure was used with the exceptions that no push force was used and the subject stood perpendicular to the standard position.
Results

![Graph 1: Simulations of glove padding thickness and engaged mass; its influence on resonance frequency.](image1)

Figure 1, Simulations of glove padding thickness and engaged mass; its influence on resonance frequency.

![Graph 2: Glove tests in an ISO 10819 test rig using gloves with different thickness of neoprene foam.](image2)

Figure 2, Glove tests in an ISO 10819 test rig using gloves with different thickness of neoprene foam.

Discussion

Most gloves with passive soft materials will experience a frequency range of harmful resonance before reaching attenuation at higher frequencies. These ranges will differ for palm and fingers. The traditional AV glove designs might work well for palm and arms at frequencies above 40 Hz but are not as effective below ~400Hz for the fingers. The motor frequency and hence a major contributor to the acceleration for many of the most common tools are found between 20-400Hz. Three different solutions may be considered to overcome this problem:

1) Increasing the glove thickness and softness to lower effective frequency range, Figure 1 (left) illustrates the needed thickness to reach attenuation at the finger tips for example at 200Hz would be too thick to be practical. If the vibration risk is at very high frequencies and there is a requirement for high manual dexterity, the thickness of the padding can also be reduced.

2) Leaving the glove fingers without padding: this solution will deny the glove protection benefits at high frequencies but will avoid the harmful resonance at lower frequencies.

3) Increasing the weight of the finger system either by creating a stiffness between finger/palm or adding weight to the finger system.

This preliminary work is demonstrating that in addition to the current AV gloves, alternative frequency specific gloves may to designed better protect both palm and fingers from their natural resonant frequencies.

References

2. CIOP/Y Berger internal test reports 2016-18
5. Lindell H. Swerea/IVF (2016), personal message .xls based single lump mass-spring model
6. Dong R and Welcome DE 2018, personal message
STANDING CENTRE OF PRESSURE ALTERS THE VIBRATION TRANSMISSIBILITY RESPONSE OF THE FOOT

Katie Goggins\textsuperscript{1,2}, Marco Tarabini\textsuperscript{3}, Brent Lievers\textsuperscript{1,2}, and *Tammy Eger\textsuperscript{2,4}
\textsuperscript{1}Bharti School of Engineering, Laurentian University, Sudbury, ON, CND
\textsuperscript{2}Centre for Research in Occupational Safety and Health, Laurentian University, Sudbury, ON, CND
\textsuperscript{3}Department of Mechanics, Politecnico di Milano, Lecco, Italy
\textsuperscript{4}School of Human Kinetics, Laurentian University, Sudbury, ON, CND

Introduction

Workers who stand on vibrating platforms or equipment—including those in mining, farming, forestry, and construction—are exposed to foot-transmitted vibration (FTV) on a daily basis\textsuperscript{1,4,6}. This chronic exposure puts them at an increased risk of developing vibration-induced white-foot (VIWFt), a condition that can include symptoms such as pain and numbness in the toes and feet, increased sensitivity to cold, blanching in the toes, and joint pain\textsuperscript{3}. A major short-coming of most previous studies is that they have been limited to upright standing and the effects of weight distribution on FTV have not be studied explicitly\textsuperscript{2,5}. Thus, the goal of the current work is to determine how changes in centre of pressure (COP) affect the vibration response of the foot.

Methods

Twenty-one participants (15 males and 6 females, with an average (± standard deviation) age of 24 (±7.8) years, height of 175.6 (± 8.9) cm, mass of 70.1 (± 13.7) kg were asked to assume one of three standing positions (forward-lean, neutral, backward-lean) while exposed to vertical vibration. The axial location (y-coordinate) of the COP (measured using Pedar-Expert insoles) was normalized with regards to participants’ foot length, and the normalized y-coordinate (%) was used for analyses. The vertical vibration stimulus was provided by an electromagnetic shaker (LDS V830), with a maximal displacement of 50 mm. Each measurement encompassed a sine sweep vertical vibration of 30 mm/s, from 10-200 Hz, lasting 51 seconds. The platform acceleration was measured with an accelerometer and a Polytec Laser Doppler Vibrometer (LDV) was used to measure the velocity at 24 anatomical locations on the foot, while the participant assumed each of the three standing positions.

Results

A mixed model analysis at each measurement location revealed significant differences (\(p<.001\)) in the transmissibility response when the COP was shifted toward the forefoot and rearfoot, with the exception of measurements taken at L1 (lateral midfoot proximal to the 3\textsuperscript{rd} and 4\textsuperscript{th} metatarsal) (\(p=.765\)) in the backward lean position. The largest average peak frequency response occurred in the forward lean position and lowest in the backward lean position, at all measurement locations except the five around the ankle (M3, M4, L3, L4, and H1). At these five locations around the ankle, the backward lean
position resulted in a larger average peak frequency than the natural and forward lean positions. Differences based on the COP location are evidenced by the individual transmissibility responses from the three locations shown: the first metatarsal (T1P3), medial midfoot (M2), and lateral ankle (L4) (Figure 1).

![Figure 1: Individual transmissibility responses (21 participants) at three anatomical locations (T1P3, M2, L4) in three positions (forward lean, natural, backward lean).](image)

**Discussion**

Changes in the average peak transmissibility frequency and magnitude suggest concentrating the COP to a particular portion of the foot causes an increase in peak transmissibility frequency and a decrease in peak transmissibility magnitude to that anatomical area. The results of this study have direct implications for creating a foot-specific International Standard for measuring FTV exposure, modelling FTV, and developing control strategies to mitigate FTV exposure in the future.

**References**

Session 4 - Hand Arm Vibration Standards and Exposure Assessment

Can New Technology Address the Practical Limitations Identified Within ISO 5349-1 Annex D?
*Setsuo Maeda
– Department of Applied Sociology, Kindai University, Japan
Jacqueline McLaughlin and Leif Anderson
– Reactec Ltd., Edinburgh, UK

A Macro Data Evaluation of Variance in Perceived Workforce HAV Exposure Risk Across Over 400 Organisations Employing Continuous Monitoring Technology
*Leif Anderson and Jacqueline McLaughlin
– Reactec Ltd., Edinburgh, UK

Evaluation of Automated Measurement of Trigger Time for Vibrating Machine Tools
*Jakob B. Riddar, Karin Fisk and Catarina Nordander
– Occupational & Environmental Medicine, Faculty of Medicine, Lund University, Sweden
Ingrid Liljelind
– Occupational & Environmental Medicine, Faculty of Medicine, Umeå University, Sweden
CAN NEW TECHNOLOGY ADDRESS THE PRACTICAL LIMITATIONS IDENTIFIED WITHIN ISO 5349-1 ANNEX D?

*Setsuo Maeda¹, Jacqueline McLaughlin², Leif Anderson²

¹ Department of Applied Sociology, Kindai University
² Reactec Ltd. UK

Introduction

At present employers seek to follow guidance within the ISO5349-1¹ standard for preventing HAVS. Within clause 4.3 of this standard, it is stated that the characterization of the vibration exposure is assessed from the acceleration of the surface in contact with the hand as the primary quantity. Therefore, ISO 5349-1 is assuming that the hand-transmitted vibration exposure magnitude is the tool handle vibration measurement, although the hand-transmitted vibration is affected by the many factors of Annex D of ISO 5349-1 standard as shown in Figure 1.

For many years, the factors outlined within Annex D of ISO 5349-1 have not been adequately captured when making an assessment of hand-transmitted vibration exposure for the purposes of prevention of HAVS in real world environments. A desire by employers to adhere strictly to the ISO 5349-1 standard may be contributing to inaccurate dose assessments and inferior outcomes for the worker. Although researchers have shown the effects of many of these factors on the vibration magnitude, their results cannot apply directly to evaluate the hand-transmitted vibration in the real work site.

Methods

To illustrate the effects of these factors on the human response to vibration, Maeda and Dong² performed the following experiment. The following conditions were applied:

<table>
<thead>
<tr>
<th>No</th>
<th>Frequency (Hz)</th>
<th>ISO 5349 Weighting RMS Values</th>
<th>Unweighted Peak Accelerations (m/s²)</th>
<th>Hand Coupling Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
<td>20 N grip</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>8.0</td>
<td>12.63</td>
<td>20 N grip</td>
</tr>
<tr>
<td>3</td>
<td>125</td>
<td>8.0</td>
<td>89.07</td>
<td>20 N grip + 40 N push</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
<td>20 N grip + 40 N push</td>
</tr>
<tr>
<td>5</td>
<td>16</td>
<td>8.0</td>
<td>12.63</td>
<td>20 N grip + 40 N push</td>
</tr>
<tr>
<td>6</td>
<td>125</td>
<td>8.0</td>
<td>89.07</td>
<td>20 N grip + 40 N push</td>
</tr>
</tbody>
</table>
Results and Discussion

This Figure 2 illustrates that the Temporary Threshold Shift (TTS) observed in test subjects applying a coupling action of 20 N grip and 40 N push is greater than TTS observed in those applying a coupling action of 20 N grip. Although the vibration magnitude of the handle is the same magnitude, the TTS is affected by the coupling action under vibration exposure. As Maeda\(^3\) has shown before, TTS is proportional to the Tool Handle Vibration magnitude. However, in this experiment, Tool Handle Vibration was the same magnitude. From these results, the real hand-transmitted vibration magnitude might be increasing in consideration of the relationship between TTS and Vibration magnitude as shown by Maeda. Maeda and Dong have shown the coupling action affects the physiological effect even though the Tool Handle Vibration magnitude remains constant. Evaluation of the real Hand-Transmitted Vibration dose was not included in their paper.

![Figure 2. TTS results measured in (a) Japan lab and (b) US lab.](image)

For getting the real Hand-Transmitted vibration for preventing HAVS in the work site, we need the measurement equipment to take many factors of Annex D of ISO 5349-1 standard into the real Hand-Transmitted vibration. The investigators seek to assess the utility of recently developed wearable technology (Reactec, HAVwear HVM-002) in addressing the many factors listed within Annex D of ISO 5349. The effectiveness of continuous monitoring through wearable sensors will be presented at the 7\(^{th}\) ACHV by the authors.

References

A MACRO DATA EVALUATION OF VARIANCE IN PECIEVED WORKFORCE HAV EXPOSURE RISK ACROSS OVER 400 ORGANISATIONS EMPLOYING CONTINUOUS MONITORING TECHNOLOGY

Leif Anderson Jacqui McLaughlin
Reactec Ltd., Vantage Point, 3 Cultins Road, Edinburgh EH11 4DF, UK

Introduction

This study seeks to illustrate the variances which exist between perceived workforce hand arm vibration (HAV) exposure and actual workforce exposure by analysing data from over 400 organisations currently employing wearable continuous monitoring technology. Acquiring large data sets for the study and statistical analysis of differences in real world HAV exposure has not previously been practical due to the availability and usability of traditional measurement equipment and the limitations of manual reporting systems. Recent advances in monitoring technology coupled with the advent of the IOT are changing this however and the data presented within this study provides a previously unseen bird’s eye view of exposure risk across entire organisations and sectors. It illustrates the degree to which organisations still rely on either manufacturer’s data or static data that is generally not representative of the work undertaken. This real time vibration data coupled with assessments of the effectiveness of existing control measures provides an indication as to why new cases of HAVS continue to be reported even within organisations who comply with the requirements of current legislation 2.

Method

The data presented has been acquired from approximately 450 private and government organisations currently employing a wearable monitoring system for the purposes of risk assessing HAV exposure (Reactec, HAVwear) 3. Organisations featured in the data set operate in a broad range of sectors including construction, heavy civil engineering, grounds maintenance, local authorities, automotive, aerospace and manufacturing with the number of workers under surveillance at each ranging from 10 to 1,000. Variance within respective sectors is also analysed within the scope of this study.

Users of the wearable system are required to enter static vibration data for all of their tools which represents the data they would have previously used for performing their exposure risk assessment. In Europe, all tool manufacturers are required to provide static tool vibration levels based on specific test protocols identified within ISO 28927. The wearable device then monitors the actual vibration sensed on the individual utilising a 3-axis accelerometer, thus capturing the effects of different substrates, tool wear and operator technique. The system also tracks the exact time the trigger is pulled removing previously relied upon after the fact estimates.
Results

Table 1 contains static tool vibration data in m/s\(^2\) alongside continuous monitoring data acquired across the subject organisations over a period of 18 months for a subset of commonly used tools. Static vibration levels were provided from tool manufacturers or third party static testing. Field levels were acquired from the wearable monitoring system.

Table 1 – Static vibration levels and field vibration levels and total accumulated trigger times assessed using Reactec HAV wear.

<table>
<thead>
<tr>
<th>Tool</th>
<th>Static Levels (m/s(^2)) Mean</th>
<th>Range</th>
<th>Field Levels (m/s(^2)) Mean</th>
<th>Range</th>
<th>Trigger time (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grinders</td>
<td>5.8</td>
<td>3.5 - 7.5</td>
<td>5.4</td>
<td>3.4 - 6.6</td>
<td>5727</td>
</tr>
<tr>
<td>Chipping Hammers</td>
<td>7.8</td>
<td>6.5 - 9.1</td>
<td>11.6</td>
<td>8.0 - 13.8</td>
<td>1542</td>
</tr>
<tr>
<td>Impact Drills</td>
<td>8.7</td>
<td>7.5 - 8.8</td>
<td>10.6</td>
<td>8.2 - 12.3</td>
<td>1362</td>
</tr>
<tr>
<td>Chainsaws</td>
<td>5.0</td>
<td>3.6 - 5.4</td>
<td>6.5</td>
<td>5.0 - 7.5</td>
<td>810</td>
</tr>
</tbody>
</table>

Discussion

Analysis of the macro data shows there appear to be differences between the static estimates and actual field monitored worker exposures across a broad range of organisations. An underestimation of exposures appeared to be present across all sectors analysed, and the higher field-based exposures may be a result of the lack of effectiveness of the existing task based control measures. These elevated exposure levels occurred for some or all workers within organisations which believe they had adequate controls in place. Field vibration levels differing from static data used during risk assessment should be considered as a potential contributing factor to new cases of HAVS.

References

EVALUATION OF AUTOMATED MEASUREMENT OF TRIGGER TIME FOR VIBRATING MACHINE TOOLS

Jakob B. Riddar¹, Karin Fisk¹, Ingrid Liljelind², Catarina Nordander¹
¹ Occupational & Environmental Medicine, Faculty of Medicine, Lund University
² Occupational & Environmental Medicine, Faculty of Medicine, Umeå University

Introduction

In order to prevent work-related injuries, the Vibration Directive 2002/44/EC states that work with vibrating machine tools shall be risk assessed and remedied if deemed too high. A risk assessment requires knowledge of how much the machine tool vibrates, i.e. the vibration level, as well as the trigger time. The vibration level is relatively easy to measure while it is much more difficult to measure the trigger time.

To date, the trigger time has been determined primarily by subjective timing estimates based on surveys or diaries. The subjective methods have shown that it is harder to estimate time in intermittent work than in continuous. Several studies have shown that workers working with vibrating tools overestimate their daily exposure time¹-³. As objective references, observations have been used with timing of the use of machines. However, this is very time-consuming and costly.

The objective for this study was to evaluate whether trigger time can be measured accurately with a machine activated automated measuring system (AMS) compared to observations and questioners. The study was performed on carpenters at four Swedish building firms.

Methods

Occupational & Environmental Medicine (OEM) accessed data from a retooled AMS originally intended for garden tools that measures usage time of machine tools (MT). Each machine was equipped with a sensor that detects the engine’s speed and thus when the machine was turned on. Each operator carried a personal logger that registered that operator’s machine usage by triangulation of closeness between logger and sensor. The recorded data was then transmitted to a cloud service for online accessibility. That allowed the machine time to be continuously recorded in the field for several weeks. The reliability of the system was evaluated by traditional observations with timing of machines uses (OT), where operators afterwards estimated their time in a survey (ET).

Results

Trigger times for over 60 tools were successfully measured during 12 workdays. As can be seen in Figure 1 the carpenter’s ET always exceeded both OT and MT. The average ET exceeded OT by 390 %. There was a good compliance between MT and OT.

When comparing the specific machine trigger times for each workday a linear regression between MT vs OT of 0.93 (R² = 0.85) can be seen in Figure 2. The linear regression for ET vs OT was 2.1 (R² = 0.29).
Figure 1. The sum of all machine trigger times for each workday: MT and ET respectively as percentage of sum of OT. Zero indicate a 1:1 ratio.

Figure 2. Specific machine trigger times for each workday: MT and ET vs OT.

Discussion

The machine activated AMS proved to correspond well with the observations while the estimations on average was overestimated 2.1 times for machines and 3.9 times on daily bases, as seen previously in literature.

Some minor problems can occur if two operators come in close proximity so the logger cannot tell them apart. Other drawbacks with the machine activated AMS is that it cannot measure air or gunpowder driven tools. Nor does the AMS measure the vibration level but it can be added in the online system.

Several vibration activated measuring systems for trigger time are available that also continuously measure the vibration level. Based on OEM’s experience with those systems it has been problematic to distinguish between real machine vibration and for instance hand motions making it hard to discern when the machine had been turned on. Most solutions for that problem rely on extra work from the machine operator. The machine activated AMS does not have such shortcomings making it easy to use with a minimum of burden to the machine operator.

References

KEYNOTE TALK

Review and Meta Analysis of Whole Body Vibration Disorders with Focus on the Low Back

*Jens Wahlström
– Occupational and Environmental Medicine, Department of Public Health and Clinical Medicine, Umeå University, Sweden
REVIEW AND META-ANALYSIS OF WHOLE-BODY VIBRATION DISORDERS WITH FOCUS ON THE LOW BACK

* Jens Wahlström
Occupational and Environmental Medicine, Department of Public Health and Clinical Medicine, Umeå University, Sweden

Introduction

Occupational exposure to whole-body vibration (WBV) during driving has long been acknowledged as a risk factor for low back pain (LBP) and sciatica. During the last 15 years several reviews have been published but only few paid special attention to the exposure assessment in the original studies\textsuperscript{1,2}. There are also reports on other musculoskeletal symptoms such as neck pain associated to WBV exposure.

The presentation will focus on a systematic review and meta-analysis on the association between exposure to whole-body vibration and low back pain and sciatica\textsuperscript{2} and extend to also report on studies focusing on associations between neck pain and WBV exposure.

Methods

Our systematic review\textsuperscript{2} covers the scientific literature up to December 31\textsuperscript{st} 2013. The article selection process was conducted according to the PRISMA guidelines. Two of the authors independently examined all titles and abstracts. We scrutinized the full text of relevant papers and determined whether they met the inclusion criteria. We included articles with both exposure assessments of WBV estimated via database or measurements and health outcomes in the form of LBP or low back disorder and sciatica.

Results

The literature search for low back pain and sciatica gave a total of 306 references out of which 28 studies were reviewed and 20 were included in the meta-analysis. The meta-analysis was conducted on 20 studies and when comparing exposed to non-exposed groups in the risk of LBP the overall odds ratio was 2.2 (95% CI 1.6-2.9). The results for sciatica showed an overall odds ratio of 1.9 (95 % CI 1.4–2.7). For LBP the funnel plots showed a symmetrically distribution around the estimated effect suggesting little effect of publication bias, but for sciatica there was an asymmetrical tendency suggesting that some medium sized and small studies with negative or null findings were not published. An additional literature search was performed in December 2017 and four additional papers were identified. Three papers showed an association between WBV and LBP and one between WBV and sciatica.

The literature regarding neck pain and WBV are much more sparse than regarding low back pain. However, most studies show an increased risk of neck pain in individuals occupationally exposed to WBV.
Discussion

Our results show that workers who are exposed to WBV have an increased risk of both LBP and sciatica compared to non-exposed groups. The pooled estimates of the risk are approximately doubled. The available literature also indicates that exposure to WBV increase the risk for neck pain.

Workers exposed to WBV always have exposure to other biomechanical factors associated with both low back pain and neck pain. Exposures such as adverse postures, heavy lifting and psychosocial factors have only partially been addressed and controlled for.

The results show that we should strive to have the lowest exposure to WBV as possible. Unfortunately, there are insufficient data to determine what a “safe” level is, i.e. a level at which risk is not increased. There is a need for further research on the relationship between exposure and response that also take into account possible interactions with occupational biomechanical factors.

References

Evaluation of the Impact of Whole Body Vibration Data Collection Strategies on Exposure Estimation

*Luz S. Marín
- Department of Safety Sciences, Indiana University of Pennsylvania, Indiana PA, USA
Jack T. Dennerlein
- Department of Physical Therapy, Movement, and Rehabilitation Sciences, Northeastern University, Boston MA, USA
Lope H. Barrero
- Department of Industrial Engineering, Pontificia Universidad Javeriana, Bogota, Colombia
Peter W. Johnson
- Department of Environmental and Occupational Health Sciences, Department of Industrial and Systems Engineering, University of Washington, Seattle WA, USA

Whole Body Vibration Associated with Dozer Operation at Two Australian Surface Coal Mines

*Danellie Lynas and Robin Burgess Limerick, Holly Whitelaw and Roseanne Baxter
- Minerals Industry Safety and Health Centre, Sustainable Minerals Institute, University of Queensland, Brisbane, Australia

Assessment of Whole Body Vibration Exposures Among Garbage Truck Drivers

*Hyoung Frank Ryou and Peter W. Johnson
- Department of Environmental and Occupational Health Sciences, University of Washington, Seattle WA

Resonant Frequency Identification At 24 Locations on the Foot when standing In a Natural Upright Position

Katie Goggins and Brent Lievers
- Bharti School of Engineering, Laurentian University and Centre for Research in Occupational Safety and Health, Laurentian, Sudbury, ON, CND
Marco Tarabini
- Department of Mechanics, Politecnico di Milano, Lecco, Italy
*Tammy Eger
- Centre for Research in Occupational Safety and Health, Laurentian University and School of Human Kinetics, Laurentian University, Sudbury, ON, CND
EVALUATION OF THE IMPACT OF WHOLE BODY VIBRATION DATA COLLECTION STRATEGIES ON EXPOSURE ESTIMATION

* Luz S. Marín¹, Jack T. Dennerlein², Lope H. Barrero³, Peter W. Johnson⁴,⁵

¹ Department of Safety Sciences, Indiana University of Pennsylvania
² Department of Physical Therapy, Movement, and Rehabilitation Sciences, Northeastern University
³ Department of Industrial Engineering, Pontificia Universidad Javeriana
⁴ Department of Industrial and Systems Engineering, University of Washington
⁵ Department of Environmental and Occupational Health Sciences, University of Washington

Introduction

Heavy equipment operators in the mining industry suffer high rates of musculoskeletal disorders (MSDs), which is believed to be related to their exposure to whole body vibration (WBV)¹. Protecting workers effectively requires monitoring exposure levels in a way that accurately identifies exposures to WBV that are above the recommended 8-hour daily action or exposure limits. For example, in mining, the different tasks completed during the shift combined with operating vehicles over different types of road surfaces can create variability in the operators’ exposure which might not be accurately characterized using short-time measurements. Misclassification of the exposure can lead either underestimation or overestimation in the health risk estimates affecting employers’ ability to successfully protect workers.

Thus, the aim of this research was to compare different data collection strategies (short and long duration measurements) based on their ability to estimate daily exposure to WBV from a fleet of heavy equipment in an open-pit coal mine.

Methods

The whole-body vibration exposure measurements were collected from a fleet of nine heavy equipment vehicles utilized daily in an open-pit surface coal mine in Colombia. Up to 24 hours of continuous whole-body vibration exposure data were collected per day from each vehicle. Vehicles were typically operated over an 8-hour work shift. Therefore, one day of measurements consisted of three shifts of vehicle operation. Raw whole-body vibration exposure data were collected at 1280 Hz with either a 4- or 8-channel data recorder (Model DA-20 or DA-40; Rion Co., LTD.; Tokyo, Japan) according to ISO 2631-1 and 2631–5 standards².

The 1-hr exposures based on the ISO 2631-1:1997 and ISO 2631–5:2004 standards were calculated, normalized to 8-hours of exposure and then compared with WVB exposures based on the whole shift measurements.
Results

A preliminary analysis was conducted to compare the seat-measured 1-hr and whole shift (8-hr) measurements for the daily weighted root mean square (r.m.s.) acceleration A(8) from the x-axis. As Figure 1 shows, the 1-hr measurements appear to approximate the whole shift measurements relatively well. Statistical analysis, the comparison of VDV exposures and comparison of the Y and Z axis is ongoing.

![Figure 1. Comparison of A(8) values on the X-axis based on whole shift hour measurements for mining vehicles operated 8-hour shift.](image)

Discussion

Preliminary results for the A(8) exposures in the X-axis demonstrated that the 1-hr WBV exposures appeared to mirror the full shift measurements. In a subsequent more detailed analysis, the duty cycle (duration of moving and idle periods) for each vehicle will also be characterized as this may further inform the appropriate sampling duration for measurements. Lack of accuracy in quantifying WBV exposure may negatively impact opportunities for protecting workers. Measuring WBV exposure in the most efficient way will help to reduce costs and ensure accuracy in the characterization of equipment operator WBV exposures. Accurate exposure estimates are necessary to assist in understanding the potential adverse health effects that may be associated with exposure to WBV.

References

WHOLE-BODY VIBRATION ASSOCIATED WITH DOZER OPERATION AT TWO AUSTRALIAN SURFACE COAL MINES

*Danelie Lynas, Robin Burgess-Limerick, Holly Whitelaw & Roseanne Baxter
Minerals Industry Safety and Health Centre, Sustainable Minerals Institute
University of Queensland, Brisbane, Australia

Introduction

Bulldozers are used extensively on surface mine sites, and have previously been identified as potential sources of high amplitude whole-body vibration exposure. An iOS application (WBV) has made it possible to use consumer hardware to efficiently estimate whole-body vibration exposures simultaneously across multiple pieces of equipment. A previous survey\(^1\) at an Australian surface coal mine provided 15 long duration measurements and revealed extreme variability. The variability is a likely a consequence of differences in tasks performed, geological conditions and operator behaviour. A larger sample of dozer measurements taken from two different sites is examined here to examine the issue in more detail.

Methods

Two hundred and fifty-four measurements were recorded from 23 different dozers during active operation, across two different mine sites (15 from site A, 8 from site B). The measurements were obtained via the WBV iOS application (v2.2) installed on multiple iPod Touch devices\(^2\). The WBV application was configured to record continuous 20-minute samples of three-dimensional accelerometer data. Wd and Wk frequency weightings specified by ISO2631.1 were applied to horizontal and vertical accelerations respectively, before calculation of r.m.s and VDV amplitudes of the frequency-weighted accelerations. Raw accelerometer data gathered in each 20-minute sample were visually inspected. Periods in which minimal acceleration levels (less than 0.1 m/s\(^2\) peak to peak) corresponding to no equipment movement were recorded were discarded. Resulting measurement durations ranged from 140 to 660 minutes (median = 440 minutes) for site A, and 20 to 360 minutes (median = 154 minutes) for site B. Average r.m.s values were calculated for each measurement, and VDV measures were extrapolated to an eight-hour exposure for each measurement [VDV(8)].

Results

Data gathered from individual dozers (Fig 1) during different shifts demonstrated considerable variability suggesting that variability is a function of some combination of task characteristics rather than individual equipment characteristics (such as maintenance). Similar variability was evident across both mines. In total, 60 of the 254 measurements exceeded the HGCZ for VDV(8) and 31 of the measurements exceeded the eight-hour HGCZ for r.m.s.
Figure 1a: VDV(8) vs RMS values for each of 69 long duration vertical whole-body vibration measurements taken from dozers during normal operations at site A. Data from the same dozer on different shifts indicated by the same symbol. Figure 1b: VDV(8) vs RMS values for each of 185 long duration vertical whole-body vibration measurements taken from dozers during normal operations at site B. Data from the same dozer on different shifts indicated by the same symbol.

Discussion

The findings confirm that dozers deserve close attention by mine operators. It is important that the conditions associated with extreme vibration exposures are identified, and opportunities for preventing such exposures developed and implemented.

Systematic measurements are taken at frequent intervals and correlated with additional information such as a detailed task assessment will better assist with appropriate selection of effective control measures. Until the operator is able to be separated from the equipment via either dozer automation or tele-remote control, a combination of design and administrative controls has the greatest potential to reduce exposure of equipment operators to whole-body vibration. The relatively low cost of the iPod Touch hardware, and the accuracy and simplicity of the WBV application, has the potential to allow routine collection of whole-body vibration exposure data by site-based workplace safety and health staff as part of a systematic whole-body vibration risk management program.

References


ASSESSMENT OF WHOLE-BODY VIBRATION EXPOSURES AMONG GARBAGE TRUCK DRIVERS

*Hyoung Frank Ryou and Peter W. Johnson

Department of Environmental and Occupational Health Science, University of Washington

Introduction

A number of studies have shown an association between whole-body vibration (WBV) exposures and the onset and development of low back pain among occupational vehicle operators. Garbage truck drivers are exposed to a high risk of work-related musculoskeletal diseases due to the WBV exposures during garbage collecting operations, driving on various road conditions and manual material handling activities.

The purpose of this study was to evaluate and compare the WBV exposures of four different types of garbage trucks which are used in both commercial and residential waste collecting operations and determine whether these exposure levels are above currently recommended vibration exposure action limits.

Methods

WBV exposures from four types of garbage trucks (Front loader, Rear loader, Side loader, and Tilt frame) were collected from twelve garbage truck drivers during their regular work shift. Tri-axial seatpad accelerometers were mounted on top of the driver’s seat, and an accelerometer was also mounted on the floor under the driver’s seat. Three to four hours of acceleration data were collected using a data recorder with a 1280 Hz sampling rate for each channel. A GPS unit with a sample rate of 1 Hz was placed in the vehicle to collect concurrent vehicle location and speed.

The collected WBV exposure data from each vehicle were segmented based on routine routes of the waste collection between the city and a remote dumping station where the garbage was incinerated. Per ISO 2631-1 standard, the daily average weighted value (A(8)) and the cumulative-impulsive Vibration Dose Value (VDV(8)) WBV exposures were calculated across the four types of garbage trucks. In addition, time to reach the ISO 2631-1 daily action limits for A(8) and VDV(8) were calculated.

Due to the small sample size, non-parametric Wilcoxon rank-sum tests were used to evaluate the difference in the WBV exposures across the four types of garbage trucks.

Results

A total of 31 route segments between the city and remote site were extracted and analyzed from the 12 sets of vehicle measurements. The results indicated that the vertical (z) axis was the predominant exposure for both A(8) and VDV(8). As shown in Figure 1, the predominant axis WBV exposure on three of the four garbage truck types were above the ISO A(8) daily vibration action limit (0.5 m/s^2), and all trucks exceeded VDV(8) daily vibration action limit (9.1 m/s^1.75). Comparing the seat and floor-measured vibration, the seats in the Front loader and Tilt frame vehicles attenuated the A(8) exposures on average by 27% and 15%, respectively; whereas the seats in the Rear
Loader and Side Loader vehicles amplified the A(8) vibration on average by 15% and 60%, respectively. Based on A(8) exposures, the time to reach ISO daily vibration action limits ranged between 4 and 11 hours. Compared to the A(8) exposures, the VDV(8) exposures reduced garbage truck operating times on average by over 4 hours indicating the impulsive exposures were more predominant.

![Figure 1. Median (±IQR) A(8) and VDV(8) WBV exposures across the four types of garbage seat trucks](image)

**Discussion**

This study characterized and compared the WBV exposures among four different types of garbage trucks. The results demonstrated that these truck drivers were experiencing WBV exposures that were at or above the ISO daily vibration action limits for both A(8) and VDV(8) exposures. In addition, compared to the A(8) exposures, the time to reach ISO daily vibration action limits were on average over four hours shorter for the VDV(8) exposures. These results indicate that the impulsive WBV exposures appeared to be more predominant. The results also showed that two types of garbage truck seats attenuated the vibration whereas two seats amplified the vibration exposures. As a result, further comparison of the different seat types may be merited to determine if the seat vibration properties are seat dependent (e.g., seat model, suspension type, and seat age), vehicle dependent (e.g., type of vehicle, vehicle vibration properties, etc.) or both. Further investigation may contribute to a better understanding how to improve seat vibration attenuation performance.

**References**

RESONANT FREQUENCY IDENTIFICATION AT 24 LOCATIONS ON THE FOOT WHEN STANDING IN A NATURAL UPRIGHT POSITION DURING VERTICAL VIBRATION EXPOSURE

Katie Goggins¹,², Marco Tarabini³, Brent Lievers¹,², and *Tammy Eger²,⁴
¹Bharti School of Engineering, Laurentian University, Sudbury, ON, CND
²Centre for Research in Occupational Safety and Health, Laurentian University, Sudbury, ON, CND
³Department of Mechanics, Politecnico di Milano, Lecco, Italy
⁴School of Human Kinetics, Laurentian University, Sudbury, ON, CND

Introduction

Exposure to vibration entering the body through the feet is associated with whole-body health effects such as low-back pain² and segmental effects that impair circulation to the toes¹,⁴. In order to develop effective control strategies to mitigate injury risk, research is needed to identify the resonant frequencies of different regions of the foot. Therefore, the objective of this study is to identify the resonant frequencies at 24 locations on the foot while maintaining a natural upright standing posture.

Methods

Twenty-one participants (15 males and 6 females), with an average (± standard deviation) age of 24 (±7.8) years, height of 175.6 (± 8.9) cm, mass of 70.1 (± 13.7) kg volunteered for the study. Participants stood on an electromagnetic shaker that produced a 20mm/s² sine sweep from 10-200Hz in 51 seconds. Transmissibility was measured with a Laser Doppler Vibrometer at 24-points on the right foot, while participants stood barefoot in their natural upright standing posture. Transmissibility was calculated according to the H1 frequency response estimator³. The frequency at which the average maximal transmissibility magnitude occurred, for each point, was identified.

Results

Overall, the average transmissibility response was found to vary across anatomical locations on the foot with different average peak transmissibility frequencies for the toes (93-147Hz), midfoot (50-80Hz), and ankle (16-33Hz) (Figure 1a). The corresponding average peak transmissibility magnitudes were found to be: toes (1.35-2.45), midfoot (1.36-1.53), and ankle (1.29-1.91) (Figure 1b). The primary resonant frequency was higher at the toes than at the ankle regions. At the most distal point on the 1st and 5th toe, resonance occurred at 135 Hz with a mean transmissibility magnitude of 1.48, and at 80 Hz with a mean transmissibility magnitude of 1.91. At a medial point on the mid-foot the resonant frequency and associated transmissibility magnitude were 35 Hz and 1.35 respectively. At measurement points on the heel and medial and lateral ankle the resonant frequency occurred at 10Hz with associated transmissibility magnitudes of 1.08, 1.23, and 1.27 respectively.
Figure 1: Average (solid line) and standard deviation (dotted line) peak FTV frequency (a) and amplitude (b) measured at 24 locations on the foot.

**Discussion**

The fundamental resonant frequency at each location on the foot-leg system has some similarity to that at the corresponding location on the hand-arm system\(^5\). The results provide further evidence to suggest impaired circulation to the toes, which is observed with a clinical diagnosis of vibration-induced white foot\(^4\) could be associated with exposure to FTV at higher frequency exposures. However, health implications associated with these higher exposure frequencies are not typically considered in a traditional ISO-2631-1 analysis of standing whole-body vibration exposure. Future research should validate weighting-curves suitable for assessing health effects associated with higher frequency exposures to vibration transmitted through the feet.

**References**

SESSION 2 - LABORATORY AND FIELD METHODS TO EVALUATE WHOLE BODY VIBRATION EXPOSURES

The Effects of Whole Body Vibration on Biomechanical Loading and Non Driving Task Performance in a Self Driving Car Environment  
*Kiana Kia  
School of Mechanical, Industrial, and Manufacturing Engineering, Oregon State University, Corvallis OR, USA  
Peter W. Johnson  
Department of Environmental and Occupational Health Sciences, University of Washington, Seattle, USA  
Jeong Ho Kim  
School of Biological and Population Health Sciences, Oregon State University, Corvallis OR, USA

Performance of Boseride and Air Suspension Seats in a Laboratory Test of Trucking Vibrations  
Ben Dietze and *James P. Dickey  
School of Kinesiology, University of Western Ontario, London, Ontario Canada  
Tammy Eger  
Centre for Research in Occupational Safety and Health and School of Human Kinetics, Laurentian University, Laurentian University, Sudbury, ON, Canada  
Bronson Du and Philip Bigelow  
School of Public Health and Health Systems, University of Waterloo, Ontario, Canada

Simplified Single or Multi Directional Shaker Inputs from Field Data for Suspension Seat Transmissibility Testing  
*James Haylett  
Commercial Vehicle Group, Inc., New Albany, OH

Beyond Back Pain: Acute Cognitive and Motor Effects of Simulated Whole Body Vibration in Lab Based Experiments  
*Catherine Trask  
Canadian Centre for Health and Safety in Agriculture, University of Saskatchewan, Saskatoon, Canada  
Marcus Yung  
Division of General Medical Sciences, Washington University, St Louis MO, USA  
Stephan Milosavljevic  
School of Physical Therapy, University of Saskatchewan, Saskatoon, Canada
Exploring the Association Between Truck Driver Fatigue and Exposure to Whole Body Vibration

*Fangfang Wang
– Department of Industrial and Systems Engineering, University of Washington, Seattle WA, USA
Hugh Davies
– School of Population and Public Health, University of British Columbia, Vancouver, BC
Bronson Du
– School of Public Health and Health Systems, University of Waterloo, Ontario, Canada
Peter W. Johnson
– Department of Environmental and Occupational Health Sciences, Department of Industrial and Systems Engineering, University of Washington, Seattle WA, USA
THE EFFECTS OF WHOLE BODY VIBRATION ON BIOMECHANICAL LOADING AND NON-DRIVING TASK PERFORMANCE IN A SELF-DRIVING CAR ENVIRONMENT

Kiana Kia\textsuperscript{1}, Peter W Johnson\textsuperscript{2}, and Jeong Ho Kim\textsuperscript{3*}

\textsuperscript{1}School of Mechanical, Industrial, and Manufacturing Engineering, Oregon State University, Corvallis, OR
\textsuperscript{2}Department of Environmental and Occupational Health Sciences, University of Washington, Seattle, WA.
\textsuperscript{3}School of Biological and Population Health Sciences, Oregon State University, Corvallis, OR

*E-mail address: jay.kim@oregonstate.edu

Introduction

The new technology of autonomous and self-driving cars allows the drivers to freely use their laptops and tablets while being transported. However, self-driving car passengers are still exposed to unwanted movements in many directions up-and-down, side-to-side, fore-and-aft, and roll, pitch and yaw movements, called Whole Body Vibration (WBV). WBV is associated with various adverse health effects including discomfort, fatigue, motion sickness, and musculoskeletal pain (Burström, Nilsson, & Wahlström, 2015; Kim, Zigman, Dennerlein, & Johnson, 2016). WBV can also adversely affect the performance of non-driving tasks including reading and working on tablet and computer (Goode, Lenné, & Salmon, 2012; Lin, Liu, Chao, & Chen, 2010; Narayanaamoorthy & Huzur Saran, 2012). As it has been shown that different suspension seats can attenuate WBV to varying degrees, we hypothesize that using different suspension seats can also affect the muscular load and non-driving (passenger) task performance. The objectives of this study are: 1) to evaluate the effects of WBV exposure on muscle activity and non-driving task performance in a simulated autonomous vehicle environment; 2) to determine the efficiency of the different suspension seats in reducing WBV and its related muscle activity and improving non-driving task performance.

Methods

In a repeated-measures laboratory experiment, a total of 18 subjects (9 males and 9 females) performed four different computer tasks (keyboard typing, omni-directional pointing with a laptop trackpad, web-browsing, and reading) while sitting on three different suspension seats (vertical electromagnetic active, multi-axial y- and z-axis electromagnetic active, and a no-suspension seat), while being exposed to vibration profiles collected from the floor of a passenger van. These profiles were recreated and simulated on the motion platform. Whole body vibration (WBV), muscle activity (EMG) in shoulder and low back, and non-driving task performance were measured. A mixed model linear regression or analysis of variance with restricted maximum likelihood estimation (REML) was used to determine the differences in WBV, EMG, and non-driving task performance between the three seat suspensions.
Results

The results on the WBV measurement showed that seat measured average weighted vibration \( [A(8)] \) and vibration dose value \( [VDV(8)] \), and static compressive dose \( [\text{Sed}(8)] \) on both the vertical active \( [A(8) = 0.29 \text{ m/s}^2, \text{VDV}(8) = 10.70 \text{ m/s}^{1.75}, \text{and Sed}(8) = 0.29 \text{ MPa}] \) and multi-axial active suspension seats \( [A(8) = 0.29 \text{ m/s}^2 \text{ and VDV}(8) = 10.22 \text{m/s}^{1.75}, \text{and Sed}(8) = 0.28 \text{ MPa}] \) were lower than no-suspension seat vibration \( [A(8) = 0.36 \text{ m/s}^2 \text{ and VDV}(8) = 12.84 \text{m/s}^{1.75}, \text{and Sed}(8) = 0.35 \text{ MPa}] \). Despite the significant differences in WBV between the different suspensions there were no significant differences across three different suspension seats in task typing performance (typing speed and accuracy: \( p' \text{'s} > 0.83 \)), pointing task performance (movement time and accuracy: \( p' \text{'s} > 0.13 \)), web-browsing (number of questions and webpages read: \( p = 0.42 \)), and reading (number of words read: \( p = 0.30 \)). However, the results showed a trend that the trackpad pointing task performance on the multi-axial active suspension seat was improved as compared to no suspension seat (\( p = 0.13 \)). The muscle activity in the low back (erector spinae) and shoulder (trapezius) muscles also showed no significant differences (\( p' \text{'s} > 0.22 \)).

Discussion

The results of this study showed that active suspension systems reduced seat measured WBV up to 50\% in Z-axis \( [A(8)] \) and \( [VDV(8)] \) and 25\% in \( [\text{Sed}(8)] \) in a simulated autonomous vehicle environment. Despite this significant reduction in WBV, there were negligible differences across three different suspension seats in muscle activity and non-driving task performance. However, the active suspension seat may be beneficial in an autonomous vehicle environment, especially for the impending use of professional autonomous bus and truck operators who will engage in longer duration vehicle operation.

References

PERFORMANCE OFBOSERIDE AND AIR SUSPENSION SEATS IN A LABORATORY TEST OF TRUCKING VIBRATIONS

Ben Dietze1, Tammy Eger2, Bronson Du3, Philip Bigelow3, *James P. Dickey1

1School of Kinesiology, University of Western Ontario, London, Ontario Canada
2Centre for Research in Occupational Safety and Health, Laurentian University, Sudbury, Ontario, Canada
3School of Public Health and Health Systems, University of Waterloo, Waterloo, Ontario, Canada

Introduction

Long-haul truck drivers are exposed to high levels of whole-body vibration and often experience low-back pain.1, 2 Seat selection influences vibration exposure, and can either amplify or attenuate vibration depending on how well the seat is tuned to the vibration exposure.3 Field research has evaluated the effectiveness of different seats,4, 5 but it is difficult to control the vibration exposure as it depends heavily upon vehicle speed, which is difficult to control from trial to trial. Laboratory tests can ensure that the vibration exposure is the same between seating conditions, enabling true side-by-side analysis.3, 6 Active seat technology is now available, and it is important to evaluate the performance of this emerging technology. The purpose of this study was to evaluate the performance of the BoseRide active suspension seat compared to an industry standard air suspension seat, on vibration exposures reflecting long-haul trucking in Manitoba.

Methods

Chassis vibrations were measured from long-haul truckers in Manitoba using methods detailed in International Organization for Standardization (ISO) 2631-1 whole body vibration standards. Similarly to other researchers,7 the vibration data were parsed into different segments based on the road type (roadside stop, parking Lot, Urban, Provincial road, Highway, Rural, Jobsite, and Detour). The vibration signals were replicated in the laboratory using man-rated vibration platform (R3000, RPSCO, Hampton, NH, USA). Accelerations were measured at the base of the seat and the seatpan, for a BoseRide active suspension seat, and an industry standard Air suspension seat. Unweighted RMS accelerations were calculated to evaluate the performance of the different seats in three environments: jobsite, urban and highway.

Results

The chassis, and seatpan accelerations for the BoseRide and Air-Suspension seats are presented in Figure 1. Both seats attenuated the vertical vibration for all road segments (BoseRide 35-50%, Air-Suspension 7-15%). The Air-Suspension seats amplified the vibrations in the X and Y directions for the Jobsite and Urban vibration segments. The BoseRide seat had small attenuations in the X direction and small amplifications in the Y direction for all road segments.
Figure 1. Unweighted RMS accelerations for the chassis, BoseRide and Air-suspension seats for segments of Jobsite, Urban and Highway operations.

Discussion

The BoseRide seat attenuated vertical vibrations, but amplified vibrations along the X and Y axes for some operational environments. The Air-suspension seat attenuated along all vibration axes for highway operations, but amplified the vibrations along the X and Y axes in the jobsite and urban operational environments. Our findings for vertical vibrations are consistent with previous research. The BoseRide seat greatly attenuated vertical vibrations, and may be effective for operational environments where the vertical vibrations dominate.

References

SIMPLIFIED SINGLE OR MULTI-DIRECTIONAL SHAKER INPUTS FROM FIELD DATA FOR SUSPENSION SEAT TRANSMISSIBILITY TESTING

*James Haylett*¹

¹Commercial Vehicle Group, Inc., New Albany, OH

Introduction

Field collected vibration data, which is important to measure and understand the inputs into the seat, can be quite complex to process, present, and replicate in a lab especially if measuring all recommended 12 DOFs. ISO 7096 was generated using construction field data and simplified for Z only excitation, while the need to generate and evaluate simplified inputs for X, Y, and rotational excitations remains.

Methods

A construction vehicle was instrumented with 3 cab floor triaxial accelerometers and cushion and backrest seat pad accelerometers recorded the driver WBV exposure. An eDAQ data acquisition system recorded vibration sampled at 1000 Hz while the vehicle was operated through different test track motions and normal vehicle operations.

Results

Operation 1 involved significant X motion with rapid changes from vehicle forward to reverse. Operation 2 involved bumpier ride with noticeable Z and Y motion. Their associated A(8) components are shown in Table 1. While both of these overall exposures are below the ISO daily action limit, they were quite transient, so were above the VDV action limits in multiple directions.

Table 1: A(8) values for each surface, direction with dominant components highlighted.

| Operation | Cushion Aₓ | Cushion Aᵧ | Cushion A₂ | Backrest Aₓ | Backrest Aᵧ | Backrest A₂ | Feet Aₓ | Feet Aᵧ | Feet A₂ | Roll Aₓ | Roll Aᵧ | Roll A₂ | Pitch Aₓ | Pitch Aᵧ | Pitch A₂ | Yaw Aₓ | Yaw Aᵧ | Yaw A₂ | Overall Rotation | OVERALL A(8) | OVERALL time [s] |
|-----------|------------|------------|------------|-------------|-------------|-------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-------------|-------------|-----------------|
| 1         | 0.128      | 0.085      | 0.122      | 0.218       | 0.052       | 0.116       | 0.008  | 0.155  | 0.115  | 0.089  | 0.036  | 0.004  | 0.028  | 0.004  | 0.004  | 0.004  | 0.012  | 0.311       | 728          |
| 2         | 0.053      | 0.133      | 0.179      | 0.221       | 0.109       | 0.156       | 0.190  | 0.055  | 0.069  | 0.225  | 0.091  | 0.294  | 0.190  | 0.069  | 0.069  | 0.201  | 0.366       | 292          |

The X vehicle input was an important contributor for Operation 1 on both the seat surface X and seat-back X directions to the comfort and perception of the operator and accounted for 75% of the overall vibration total value. For reference the seat surface Z is 49%. The Fore-Aft (F-A) isolator was an important component reducing exposure for this application so a custom X transmissibility shaker test was developed.

A shaker (MTS MAST 523.20) iterated Operation 1 from 1 to 80 Hz in 6 DOF to an acceptable level of error using 3 control accelerometers on the shaker table from the vehicle cab floor near the seat base. Then 5 DOF were simply set to zero so that only X was played out. The frequency content was simplified to capture two vehicle resonances (1 and 23 Hz) and a Gaussian random time history was generated. The field amplitude histogram was examined and correlated well with a Gaussian distribution. This time history was 500 sec long to generate smoother FRFs with better coherence.
With a custom X input different seat conditions were examined in more detail. The FRF with respect to the X input is shown in Figure 1, left side, for the seat surface (Black) vs. seat back (Blue). The F-A isolator, which can be closed by the operator, has an FRF in Figure 1, right side, is shown with the isolator closed (Orange) vs. open (Black) for seat surface X with similar frequency trends at the seat back. Closing the F-A isolator leads to much larger exposure at seat surface (see inset table) around 5 Hz.

Figure 1: FRF for seat surface and seat back (Left), F-A isolator open vs. closed (Right).

In Operation 2 Y inputs lead to significant seat surface Y, seat-back Y, and Roll exposures contributing 68% to the overall vibration, whereas seat surface Z is 46%. The Lateral stability or freeplay is an important feature for these seats so a custom Y (and Roll) transmissibility excitation was developed.

As before the vibration data was replicated on a 6 DOF shaker and simplified signals were generated from 1 to 50 Hz and played in Y, Roll, then Y and Roll directions. The 1 DOF Y translational and 1 DOF Roll rotational ordinary coherence was high from 0.5 to 4 Hz, but the in the 2 DOF input these 1 DOF components showed poor coherence at all but 1 Hz (Y translational) and 4 Hz (Roll rotational) frequencies.

Discussion

In Operation 1 it was informative to play sine cycles at 3 Hz which corresponded to a resonance of the F-A isolator with large displacements (max: 66 mm pk-pk). Whereas the resonance at 17.4 Hz corresponded to an armrest joystick local mode.

In Operation 2 both of the 1 DOF inputs excited different motion from the seat, with Roll (peak around 4 Hz) causing more lateral backlash in the suspension components and Y (1 Hz) causing more foam/dummy mass motion. There was an improvement in multiple and partial coherence considering the 2 DOF MISO (Multiple Input – Single Output) system as opposed to the 1 DOF systems. In the future different simplified time-varying inputs, end-stop strikes, seat design modification effects on the FRF / SEAT, and further analysis of simplified multi-DOF inputs will be explored.

References

BEYOND BACK PAIN: ACUTE COGNITIVE AND MOTOR EFFECTS OF SIMULATED WHOLE BODY VIBRATION IN LAB-BASED EXPERIMENTS

*Catherine Trask¹, Marcus Yung², and Stephan Milosavljevic³

¹ Canadian Centre for Health and Safety in Agriculture, University of Saskatchewan ² Division of General Medical Sciences, Washington University in St Louis, ³ School of Physical Therapy, University of Saskatchewan

Introduction

Whole body vibration (WBV) exposure from vehicle and machinery operation has long been acknowledged as a risk factor for low back pain and/or hip pain. WBV has also been shown to have long-term consequences beyond musculoskeletal disorders, including peripheral nervous system dysfunction, visual and vestibular disturbances, prostate disorders, and gastrointestinal problems.

The acute effects of occupational levels of WBV are less understood, but several researchers have speculated that non-musculoskeletal acute effects could contribute to occupational injury events, including machinery-related injuries, falls, and vehicle crashes. According to Transport Canada, the majority of heavy vehicle crashes can be attributed to driver error. It has been hypothesized that these errors may be caused or compounded by the short-term effects of WBV, including observed increases in cognitive impairment, stress and loss of memory, loss of balance, reduced proprioception, or decrements in sensory and motor response. For instance, a perturbed sense of position or an increased error in judgment might lead to a loss of control event such as a vehicle rollover. However, the acute effects of occupational levels of WBV at different vibration intensities remains poorly understood. The aim of this paper is to summarize the results of two lab-based studies investigating acute effects of WBV.

Methods

In order to simulate realistic occupational WBV exposures, field measurements of an agricultural all-terrain vehicle (ATV) were used to program a hexapod robot (Rotopod 3000, Mikrolar Inc) mounted with an ATV frame, seat, and handlebars. Eighteen healthy adult participants experienced 60 mins of exposure in 4 conditions described in table 1. Threshold values were based on a previously-measured average of 2.43 hrs daily WBV exposure in agricultural ATV users. Participants performed a test battery pre- and post-exposure: (1) Rating of Perceived Discomfort using Borg’s CR10 scale, (2) Rating of headache or discomfort using a 10-centimeter Visual Analog Scale (VAS), (3) Postural sway evaluation, (4) Blink frequency, (5) King-Devick (K-D) test, and (6) Psychomotor Vigilance Task (PVT). Pre- and post-differences for each condition were analyzed using either a paired t-test (parametric) or Wilcoxon signed-rank test (non-parametric). To determine differences between conditions, normalized pre/post changes were subjected to a one-way repeated measures ANOVA and Tukey-Kramer post hoc test (parametric), or Friedman’s test and Wilcoxon signed-rank post hoc test (non-parametric).
Results

Percentage differences in pre-post performance are presented in table 1. Despite significant pre-post effects, there were few significant differences between conditions. Differences between conditions were limited to PVT median number of lapses, where pre/post changes were significantly higher during the ELV-level vibration condition compared to Control (F=2.58 p=0.05, Control vs. ELV: p=0.037).

Table 1: Pre-post % performance differences by condition, sig. differences shaded

<table>
<thead>
<tr>
<th>Performance Metrics</th>
<th>Control quiet sitting</th>
<th>Low EAV</th>
<th>Shock EAV + shock</th>
<th>High ELV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Borg RPE</td>
<td>11.5%</td>
<td>7.8%</td>
<td>4.4%</td>
<td>9.6%</td>
</tr>
<tr>
<td>Headache</td>
<td>60%</td>
<td>91%</td>
<td>50%</td>
<td>154%</td>
</tr>
<tr>
<td>Postural sway</td>
<td>9%</td>
<td>53%</td>
<td>65%</td>
<td>61%</td>
</tr>
<tr>
<td>Blink</td>
<td>-11%</td>
<td>15%</td>
<td>17%</td>
<td>15%</td>
</tr>
<tr>
<td>K-D</td>
<td>0</td>
<td>-1%</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>PVT reaction time</td>
<td>9%</td>
<td>5%</td>
<td>3%</td>
<td>6%</td>
</tr>
<tr>
<td>PVT median # lapses</td>
<td>100%</td>
<td>50%</td>
<td>0%</td>
<td>100%</td>
</tr>
</tbody>
</table>

EAV = exposure action value; ELV = exposure limit value; ‘shock’ = transient impacts/bumps

Discussion

There were more significant pre-post differences in performance with increasing vibration intensity, and some pre-post sensorimotor effects even after lower intensity vibration (EAV). Even the highest simulated vibration exposures in the current study were within guidelines (i.e. below ELV), yet some effects were still observed. Given that real-life occupational exposures can occasionally exceed these guidelines, it would seem likely that these acute effects could be present in occupational settings. These phenomena warrant further research to determine the extent of these acute effects and their potential impact on error and injury or collision risk. Prior workplace studies have investigated the effect of occupational driving on driver vigilance,¹ This lab-based study attempted to identify what aspects of WBV exposure (i.e. shock and level) may contribute to these effects. Except for PVT performance, the present study did not find significantly higher acute effects with WBV than quiet sitting without WBV. Thus, WBV may not be fully responsible for the observed acute sensorimotor or cognitive effects. This study was performed on young, healthy university community members who may not represent the machinery operation workforce, and the simulated exposures did not include any of the cognitive demands required during actual driving. Further research on the effects of exposure intensity and duration is required to support these findings.

References

EXPLORING THE ASSOCIATION BETWEEN TRUCK DRIVER FATIGUE AND EXPOSURE TO WHOLE BODY VIBRATION

*Fangfang Wang¹, ², Hugh Davies³, Bronson Du⁴, Peter W. Johnson¹, ²

¹ Department of Industrial and Systems Engineering, University of Washington
² Department of Environmental and Occupational Health Sciences, University of Washington
³ School of Population and Public Health, University of British Columbia
⁴ School of Public Health and Health Systems, University of Waterloo

Introduction

It is believed that exposure to whole-body vibration (WBV) may increase truck driver fatigue, and driver fatigue may contribute to vehicular accidents¹. Previous studies of truck-induced WBV exposures have focused on musculoskeletal disorders, whereas the effects of WBV on truck drivers’ cognitive fatigue have been less rigorously studied.

The aim of this study was to determine whether truck-induced WBV had effects on truck driver fatigue during a regular shift. An industry-standard passive suspension seat and an active suspension were compared to determine if there was a difference in truck drivers’ vigilance and cognitive fatigue as measured by the Psychomotor Vigilance Task (PVT). The active suspension seat has been shown to reduce the truck drivers’ mean vibration exposures by up to 55%². Truck seats which reduce fatigue may decrease the chances of fatigue-related accidents.

Methods

Eleven regional, short-haul truck drivers were recruited (mean age 52.3). Drivers were studied on two separate daytime shifts: day 1, they used the trucks’ original-fitted passive suspension seat and on day 2, an active suspension seat (BoseRide System; Bose Corporation; Framingham, MA, USA). During each shift, the drivers drove on the same 280 km route (11 hours).

Seat and floor WBV exposures were measured according to the ISO 2631-1 standard. With each seat, drivers were asked to perform a 5-minute PVT on a tablet to assess their reaction times immediately before and after each shift. In the PVT, subjects were instructed to press a button as soon as they saw a stimuli (a scrolling number) appear on the screen; stimuli appear randomly every 2-10 seconds for approximately 40 trials³. Three reaction time metrics were compared between the two seats: the mean reaction time, the mean of the fastest 10% reaction times, and the lapse percentage (the percentage of reaction times longer than 0.5 seconds). Repeated measures analysis of variance (RANOVA) methods were used to evaluate the differences in PVT performance between pre-/post-shift for both WBV exposure conditions.
Results

There were significant differences (p < 0.0001) in the z-axis seat-measured WBV exposures between the two seats with the active suspension seat providing a much smoother ride compared to the original-fitted passive seat (50% reduction in the seat-measured A(8), 0.27 m/s² vs 0.54 m/s² respectively).

For mean reaction times there was a trend indicating a potential difference (p=0.054) with slower post-WBV reaction times when the subjects had used the passive seat (Figure 1). In addition, significantly longer fastest 10% reaction times (p = 0.021) and higher lapse percentage (p=0.025) were found post-WBV with the passive seat.

Discussion

The results showed that compared to the original-fitted passive air-suspension seat, the active suspension seat substantially improved the ride quality for the truck drivers and reduced the seat measured WBV exposures by 50%. This improvement in ride quality also appears to affect driver cognitive fatigue. Compared to the passive suspension seats, truck drivers were better able to maintain vigilance when operating the truck with the active suspension seat. The results were also consistent with a previous laboratory-based study, where 8 drivers experienced 2-hour WBV exposures in the passive and active suspension seats, where longer reaction times were observed in the passive suspension seat, post-exposure⁴. Therefore, we contribute to growing evidence that the active-suspension truck seats help reduce driver fatigue and may ultimately contribute to a reduction in fatigue-related accidents, injuries and their associated costs.

References

Day 2 - Thursday June 14, 2018

SESSION 3 - METHODS TO EVALUATE AND IMPROVE HUMAN VIBRATION EXPOSURE ASSESSMENT

Mobile App Offers Low Cost Way to Evaluate Whole Body Vibration
*Alan G. Mayton and Brian Y. Kim
  – National Institute for Occupational Safety and Health, Pittsburgh Mining Research Division, Pittsburgh, PA

Comparison of Vibration Measurement Accuracy Between a Low Cost, Portable IMU System and a Gold Standard Accelerometer System
*Benjamin Pierson
  – Public Health Residency Program, Madigan Army Medical Center and Department of Environmental and Occupational Health Sciences, University of Washington, Seattle WA, USA
  – Dept. of Environmental & Occupational Health Sciences, University of Washington, Seattle WA, USA

The Impact of Contact Force on the Accuracy of Hand Arm Vibration Measurement
*Jacek Kuczyński; Marketing Manager
  – Svantek Sp. z o.o., Warsaw, Poland
  – Central Institute for Labour Protection – National Research Institute; Department of Vibroacoustic Hazards, Warsaw, Poland

Comparisons of Two Calibration Methods of a Hand Force Mapping System
*Yumeng Yao and Subhash Rakheja
  – CONCAVE Research Center, Concordia University, Montreal, Canada
  – Institut de recherche Robert Sauvé en santé et en sécurité du travail (IRSST), Montréal, Canada
MOBILE APP OFFERS LOW-COST WAY TO EVALUATE WHOLE-BODY VIBRATION

Alan G. Mayton* and Brian Y. Kim

National Institute for Occupational Safety and Health (NIOSH)
Pittsburgh Mining Research Division, Pittsburgh, PA 15236 U.S.A.

Introduction

Off-road mining equipment operating on rough surfaces under harsh conditions can produce whole body vibration (WBV) and mechanical shock exposure to equipment operators. Until recently, the only methods to measure WBV were by using costly vibration measurement systems that vary widely and may cost from $4,000 to $50,000 and require technical expertise to analyze the data and arrive at meaningful results. University of Queensland researchers have developed the WBV app for use on an iPod Touch. They have also investigated its use as a simple, low-cost way to estimate WBV exposure in a mining environment.1, 2

National Institute for Occupational Safety and Health (NIOSH) researchers performed a recent study that focused on the measurement accuracy of the WBV app. The field study involved data collection for 13 mobile machines (seven front-end wheel loaders and six haul trucks) operating at one sandstone mine and three limestone mines in central and southwestern Pennsylvania and northern Virginia. A major objective of the NIOSH research study was to assess the accuracy of the WBV app and determine if it can be a useful tool for monitoring WBV exposure on mobile mining equipment that are utilized at surface mines and quarries.

Methods

NIOSH researchers measured WBV (in three directions – X (fore-aft), Y (side-to-side), and Z (vertical)) for operators of mobile mining equipment as they performed their normal work. NIOSH used a Siemens SCADAS–SCR05 16-channel data recorder with 24-bit resolution (Siemens PLM Software, Troy, MI) as the reference, high-quality precision system to which the iPod Touch device (iPod A1509, iOS 9.3.5, 2013, Apple Inc., Cupertino, California) running the WBV app was compared. To measure WBV, NIOSH used a PCB 356B40 seat pad accelerometer with the SCADAS recorder. Collected data were stored in flash memory on a SD card. The WBV app uses the built-in triaxial accelerometer in the iPod to collect acceleration data and calculates frequency-weighted estimates of WBV exposure. The results presented in this paper focus on vibration in the Z direction, since it is typically of greatest interest and can be associated with the greater risk for back injury/pain.

The iPod Touch device was placed under the front-most portion of the circular seat pad according to the WBV app User Manual (downloadable from University of Queensland website at http://ergonomics.uq.edu.au/WBV/WBVpod/Index.html).

Results and Discussion

Figures 1(a) and 1(b) are the graphical displays of frequency-weighted acceleration ($a_w$) and vibration dose value (VDV), respectively in the vertical direction comparing the Siemens/LMS with the iPod measures at the seat and normalized for an 8-hour exposure duration. The figures indicate good agreement between the two systems.
Absolute differences in percent for \( a_w \) (8) measures comparing the Siemens/LMS and iPod measurement systems ranged from 0.1% to 8.5%. Twelve of the 13 instances showed percent differences of 4.2% or less. Absolute differences in percent for VDV (8) measures comparing the Siemens/LMS and iPod measurement systems ranged from 0.3% to 18.8% percent. Eleven of the 13 instances showed percent differences of 4.4% or less. Moreover, the \( a_w \) and VDV levels show strong Pearson correlation coefficients of 0.998 and 0.981, respectively.

Figure 1 (a) and (b). Weighted acceleration 1(a) and VDV 1(b) measured in the vertical direction at the seat and normalized to an 8-hr shift for the Siemens/LMS and iPod app.

This study showed that the iPod Touch using the WBV app can serve as a low-cost tool to estimate operator WBV exposures on mobile mining equipment. Burgess-Limerick et al. have conducted studies with iPod app in surface mining operations.\(^2,3,4\) This NIOSH study demonstrates results similar to those obtained by Burgess-Limerick et al. In their report,\(^4\) Burgess-Limerick and Lynas obtained 96 vertical measurements of acceleration using the iPod app and a commercially available vibration measurement device, the Svantek SV 106. The results showed an average variance between the SV 106 and the iPod app of 0.033 m/s\(^2\) with an average constant error of 0.013 m/s\(^2\). The standard deviation of constant error was 0.039 m/s\(^2\), which they purport indicates a 95% confidence of ± 0.07 m/s\(^2\) for the vertical direction when using the WBV app downloaded to an iPod Touch; moreover, results were noted to be consistent with those previously obtained using the app.

References

COMPARISON OF VIBRATION MEASUREMENT ACCURACY BETWEEN A LOW COST, PORTABLE IMU SYSTEM AND A GOLD-STANDARD ACCELEROMETER SYSTEM

*Benjamin Pierson¹,², Dawn Ryan², and Peter W. Johnson²

¹Public Health Residency Program, Madigan Army Medical Center
²Dept. of Environmental & Occupational Health Sciences, University of Washington

Introduction

Characterization of WBV exposure is important for development of mitigation strategies. Traditionally, gold standard accelerometer systems (high quality accelerometers and loggers) are used which can be bulky, involve managing and protecting the accelerometer cables, and can be expensive. Recently, relatively inexpensive compact Inertial Measurement Units (IMUs) with built in batteries and memory have emerged which may allow them to be used for collecting WBV exposures. While the ease of use of these new devices may allow for much more efficient collection of WBV exposure data, it is important to assess if the data provided from these devices is similar to those collected from traditional gold standard devices. Using single axis sinusoidal inputs in a controlled lab setting, the aim of this study was to compare the acceleration measurement accuracy between a Gold-Standard system and a compact, low cost self-contained IMU. If the lower cost, portable IMU system has reasonable measurement accuracy, it may be suitable for field measurements where the installation and use of the Gold-Standard systems may be more challenging and/or cost prohibitive.

Methods

Using an accelerometer calibrator (Model 9110D, The Modal Shop, Cincinnati, OH), the vibration measurement accuracy of the Gold-Standard accelerometer system (Rion DA-40 logger with a PCB 356B41 triaxial accelerometer) and IMU system (Model AX-3, Axivity, Hoults Yard, UK) were compared. The sampling rates of the two systems were 1280 Hz and 400 Hz respectively. Each device was excited at 5 different frequencies and 5 different amplitudes (see Tables 1 and 2) spanning the frequency range likely to be encountered during the measurement of WBV. Then, the RMS values of the weighted and unweighted accelerations were calculated, and the measurement accuracy was characterized by calculating the mean absolute error in m/s² and the percent mean absolute error.

Results

Tables 1 and 2 show the errors for the Gold-Standard and IMU systems respectively across the different frequencies and amplitudes tested. Across all measurements the mean absolute error for Gold-Standard and IMU systems were 0.01 m/s² and 0.11 m/s² respectively. For the weighted accelerations, the differences between systems were smaller with the mean absolute measurement errors being 0.01 m/s² and 0.04 m/s² respectively (data not shown).
Table 1 – Measurement accuracy of the gold standard system by vibration frequency and amplitude including mean absolute and % mean absolute errors.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Gold Standard System – m/s²</th>
<th>Mean Abs Error (m/s²)</th>
<th>Mean Abs Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.125 0.25 0.50 1.0 5.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Hz</td>
<td>0.117 0.24 0.48</td>
<td>0.01</td>
<td>4.8%</td>
</tr>
<tr>
<td>8 Hz</td>
<td>0.124 0.25 0.50 1.01</td>
<td>0.00</td>
<td>0.6%</td>
</tr>
<tr>
<td>16 Hz</td>
<td>0.125 0.25 0.51 1.01 5.07</td>
<td>0.02</td>
<td>0.8%</td>
</tr>
<tr>
<td>32 Hz</td>
<td>0.125 0.25 0.51 1.01 5.00</td>
<td>0.00</td>
<td>0.4%</td>
</tr>
<tr>
<td>100Hz</td>
<td>0.124 0.25 0.50 1.00 4.98</td>
<td>0.00</td>
<td>0.4%</td>
</tr>
<tr>
<td>Mean Abs Error</td>
<td>0.002 0.01 0.01 0.03</td>
<td><strong>0.01</strong></td>
<td>-</td>
</tr>
<tr>
<td>% Mean Abs Error</td>
<td>1.5% 1.3% 1.3% 0.7% 0.6%</td>
<td>-</td>
<td><strong>1.1%</strong></td>
</tr>
</tbody>
</table>

Table 2 – Measurement accuracy of the IMU system by vibration frequency and amplitude including mean absolute and % mean absolute errors.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>IMU System – m/s²</th>
<th>Mean Abs Error (m/s²)</th>
<th>Mean Abs Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.125 0.25 0.50 1.0 5.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Hz</td>
<td>0.143 0.27 0.50</td>
<td>0.01</td>
<td>7.2%</td>
</tr>
<tr>
<td>8 Hz</td>
<td>0.142 0.27 0.51 1.02</td>
<td>0.02</td>
<td>6.1%</td>
</tr>
<tr>
<td>16 Hz</td>
<td>0.140 0.27 0.50 1.01 5.02</td>
<td>0.01</td>
<td>4.2%</td>
</tr>
<tr>
<td>32 Hz</td>
<td>0.136 0.26 0.49 0.98 4.90</td>
<td>0.03</td>
<td>3.5%</td>
</tr>
<tr>
<td>100Hz</td>
<td>0.112 0.20 0.37 0.72 3.63</td>
<td>0.37</td>
<td>22.5%</td>
</tr>
<tr>
<td>Mean Abs Error</td>
<td>0.015 0.03 0.08 0.50</td>
<td><strong>0.10</strong></td>
<td>-</td>
</tr>
<tr>
<td>% Mean Abs Error</td>
<td>11.7% 6.4% 8.2% 10.0%</td>
<td>-</td>
<td><strong>9.0%</strong></td>
</tr>
</tbody>
</table>

**Discussion**

Based on the results, it appears that the unweighted vibration measurement accuracy between the Gold-Standard and IMU systems were not substantially different at frequencies below 32 Hz. The IMU system underestimated the vibration amplitudes at the 32 Hz and 100 Hz frequencies, but these differences may be due to the lower sampling frequency of the IMU system (400 Hz) relative to the Gold-Standard system (1280 Hz). When the weighted vibrations were calculated, the differences between systems decreased. Areas of future research include evaluating higher IMU sampling frequencies and the comparison of measurement accuracy between the Gold-Standard and IMU-based systems in real world random vibration scenarios.

**References**

THE IMPACT OF CONTACT FORCE ON THE ACCURACY OF HAND-ARM VIBRATION MEASUREMENT

*Jacek Kuczyński¹ and Piotr Kowalski, Ph.D.²

¹Marketing Manager - Svantek Sp. z o.o., Warsaw, Poland
²Department of Vibroacoustic Hazards, Central Institute for Labour Protection – National Research Institute;, Warsaw, Poland

Introduction

Measurement of hand-arm vibration with the use of a hand mounted sensor ensures achieving the most representative measurements, taken at the point of contact of hand with a vibrating tool. When measuring vibration on a hand, simultaneous measurement of contact force verifies whether the force magnitude is sufficiently rigid. The contact force also provides information on the operator’s work schedule and may help to instruct operators if they are using excessive or too little force when working with hand-held tools. Additionally, by knowing both the coupling force value and the vibration acceleration, it is possible to calculate actual vibration energy dose that has been transferred to a hand.

Methods

The accuracy of vibration measurements using hand-arm adapters has been tested in 240 measurements in total, performed at the Polish National Research Institute at the Central Institute for Labour Protection. The impact of coupling force on vibration magnitudes has been assessed with Svantek’s SV106 human vibration meters and SV105AF hand-arm adapters (push force thresholds in tests were: 0 N, 20 N, 50 N, 100 N).

Results

The results proved that measurements taken with hand-arm adapters provide correct vibration results regardless of contact force changes and type of vibration signal. The study has also indicated that it is necessary to define a minimum force threshold in order to mitigate the uncertainty related to the contact between hand and a vibrating tool.

Figure 1. The ratio of vibration values measured with the applied force against to the reference values with no force applied.
Discussion
The conducted study proves that the effect of changes of the force thresholds applied by the operator are irrelevant to the measured vibration acceleration values. This assumption is valid for the forces above a threshold of 20 N, below which it is necessary to ensure the correct coupling between the hand-arm adapter and vibrating surface. Together with the force level drop below 20 N, the uncertainty related to the coupling increases rapidly. However it is necessary to note that in practice, for tools generating high vibration amplitudes, the threshold of 20 N may not guarantee perfect coupling, therefore higher threshold levels should be established.

References
COMPARISIONS OF TWO CALIBRATION METHODS OF A HAND FORCE-MAPPING SYSTEM

*Yumeng Yao¹, Subhash Rakheja¹, Pierre Marcotte²

¹ CONCAVE Research Center, Concordia University, Montreal, Canada
² Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), Montréal

Introduction

Exposure to hand-transmitted vibration (HTV) is generally assessed on the basis of accelerations measured at the hand-handle interface near the palm region¹, while the contribution due to contact force exerted by the hand (palm and fingers) is neglected. The hand force distributed over the palm and fingers has been reported to significantly affect the transmission of vibration to the hand-arm system². Although some efforts have been made to develop hand force measurement systems³, a reliable measurement system does not yet exist, especially for field implementations. In this study, the design of a flexible thin-film hand force-mapping system for reliable measurement of the contact force between the hand (palm and fingers) and the tool handle is briefly described together with its static performance characteristics. Two different calibration methods are used to derive static characteristics of the mapping system, which include: a two-point power law method; and a multiple point calibration method. The static properties obtained from the two methods in terms of drift, linearity, repeatability and hysteresis are subsequently compared, which suggest important significance of the calibration method.

Methods

Fig. 1(a) illustrates the thin-film and flexible hand force-mapping sensor, designed for measurements of the contact force distributed over the surface of the hand with peak pressure up to 2 bars. The sensor consists of 372 sensels, and signal analysis software yields forces imposed by the palm and individual fingers of the hand. The static characteristics of the sensor, however, were found to be sensitive to the method of calibration. Two different calibration methods were thus explored to study the effects on the sensor performance. These included the two-point power law and multiple point calibration methods. The calibrations, equilibration and assessments of the sensor were performed using the air bladder platform, shown in Fig. 1(b). The desired measurement range was initially defined so as to maximize the dynamic range of the hand sensor, while avoiding overloading. The hand force sensor was placed in the air bladder setup and equilibrated by applying three different levels of uniform pressure (0.5, 1, 1.5 bar). The equilibration permitted computations of compensation factors to account for differences in sensitivity of individual sensels using the I-Scan software. The software also permitted scaling of the sensitivity so as to achieve maximum dynamic range, irrespective of the measurement range.

The calibrations were performed using two methods: a two-point power law method; and a multiple-point calibration method. In the power law method, the sensor was subjected to two calibration loads: 20% and 80% of the maximum test load. For the multiple-point method, the sensor was subject to ten different loads in the range of 0 to 2 bars with increments of 0.2 bar. In both the methods, the equilibration and calibration were performed 30 seconds after applying the loads so as to minimize the sensor drift and hysteresis. The static characteristics of the hand sensor were evaluated in terms of its
linearity, repeatability, hysteresis and output drift. The sensor output under the 1-bar input was recorded for two minutes to quantify the output drift. The normalized residual errors, magnitudes of difference between the measured output and applied input, were also evaluated. The sensor was subject to four discrete loads (14.8, 36.4, 85.4 and 140.3 N) on a flat surface in a gradual loading and unloading manner. Measurements were repeated three times and the data analyzed to evaluate sensor’s linearity, repeatability and hysteresis.

Fig. 1: (a) A pictorial view of the hand force mapping system; and (b) sensor calibration setup

**Results and Discussions**

The two-point power law method revealed lower residual error (Table 1) than the multiple point method. Apart from being simple, the two-point method showed higher accuracy compared to the multiple-point method. Both methods revealed strong linearity ($r^2=0.99$) and comparable output drift after 15s (1.7%), while lower drift was observed with the two-point method (2.9% at 30s; and 4.6% at 60s) compared to the multiple-point method (3.5% at 30s and 5.7% at 60s) The two- and multiple-point methods revealed repeatability of measurements, evaluated in terms of coefficient of variation (CoV) of the mean, in the order of 1.5% and 2.5%, respectively (Table 2). The two-point method also showed slightly lower hysteresis compared to the multiple-point method. The results suggest that the power law method best matches the steady state non-linear physical behavior of the sensor, while the multiple-point method is not beneficial in improving the sensor performance and it may cause an additional instability in the calibration process.

<table>
<thead>
<tr>
<th>Applied force (N)</th>
<th>2-point power law</th>
<th>10 point calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measured force (N)</td>
<td>Residual error</td>
</tr>
<tr>
<td>860</td>
<td>852.5</td>
<td>-0.9%</td>
</tr>
<tr>
<td>1720</td>
<td>1740.6</td>
<td>1.2%</td>
</tr>
<tr>
<td>2580</td>
<td>2636.2</td>
<td>2.2%</td>
</tr>
<tr>
<td>3440</td>
<td>3498.8</td>
<td>1.7%</td>
</tr>
<tr>
<td>Mean</td>
<td>1.5%</td>
<td>1.95%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Static properties</th>
<th>2-point power law</th>
<th>10 point calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drift at 15s</td>
<td>1.7%</td>
<td>1.7%</td>
</tr>
<tr>
<td>Repeatability CoV</td>
<td>1.5%</td>
<td>2.5%</td>
</tr>
<tr>
<td>Hysteresis Mean</td>
<td>5.5%</td>
<td>5.8%</td>
</tr>
</tbody>
</table>

**References**

SESSION 4 - WHOLE BODY VIBRATION ASSESSMENT IN SPECIAL ENVIRONMENTS

The Effect of Road Type on Neonate Whole Body Vibration Exposures During Ambulance Transport
*Dawn M. Ryan, June Spector and Peter W. Johnson
– Department of Environmental and Occupational Health Sciences, University of Washington, Seattle, WA
Adam Lokeh and David Hirschman
– Children’s Minnesota Hospital, Minneapolis MN, USA
Rob Parker
– Bose Corporation, Framingham MA, USA

Aircrew Multi-Axis Vibration Exposures During Operation of the Blackhawk Uh-60l Helicopter
*Suzanne D. Smith
– Air Force Research Laboratory, 711 HPW/RHCPT, Wright-Patterson AFB OH, USA
Steven G. Chervak and Jay E. Clasing
– Army Public Health Center, Aberdeen Proving Ground, Bethesda MD, USA

Drop Tower Test Results For Measuring The Shock Attenuation of Marine Craft Seats
*Douglas Reynolds
– Department of Mechanical Engineering, University of Nevada, Las Vegas NV, USA
THE EFFECT OF ROAD TYPE ON NEONATE WHOLE BODY VIBRATION EXPOSURES DURING AMBULANCE TRANSPORT

*Dawn M. Ryan 1, Adam Lokeh2, David Hirschman2, June Spector1, Rob Parker3, Peter W. Johnson1

1 Department of Environmental and Occupational Health Science, University of Washington
2 Minnesota Children’s Hospital, Minneapolis, MN, USA
3 Bose Corporation, Framingham, MA, USA

Introduction

Newborn infants delivered in a compromised health state often require transport between secondary and primary care hospitals. Neonates experience high levels of mechanical vibration and shocks during inter-hospital ground transport, but it is not clear how the transport equipment or road type affects these Whole Body Vibration (WBV) exposures. WBV exposures, when high, may impact the infants’ near and longer-term health outcomes.

The objective of this study was to measure and characterize WBV exposures during simulated newborn infant inter-hospital ground transport and determine how the vehicle-based vibration is transmitted through the chain of equipment used to support newborn infants (the stretcher, transfer sled and isolette). WBV exposures were measured over a typical transport route using a traditional stretcher system which included a mattress and a fluidized pad placed inside an isolette. The isolette rides on top of the stretcher and transfer sled and acts as a protective housing for the infant.

Methods

Measurements were taken from a 1.3 kg simulated, newborn infant that was transported over a 46-minute, 32 km route between two hospitals. The route included three different road types: city streets, freeway, and highway. Seven accelerometers were placed on the stretcher systems starting at the ambulance floor and ending at the interface between the fluidized pad and the simulated, newborn infant. Rion DA-40 data loggers were used to collect the raw vibration data from each accelerometer at 1280 Hz and a GPS logger collected vehicle speed and position every second. Using the GPS data, from representative 30 second segments of each road type, the predominant, z-axis average weighted (Aeq) WBV exposures and weighted power spectral densities (PSDs) were calculated.

Results

The average, z-axis, WBV exposure measured from the ambulance floor was 0.30 m/s², 0.40 m/s², and 0.55 m/s² on city street, freeway, and highway road types, respectively. The average speeds were 20 km/h, 100 km/h and 60 km/h respectively. Amplification occurred throughout the chain of transport equipment from the floor to the interface location where the baby rested. The corresponding exposures measured at the interface were 0.70 m/s² on freeways and 0.95 m/s² on the highways, indicating just over
70% increase in the vibration measured at the interface relative to the floor. The increase over the city streets was 102%, raising the exposure at the interface to 0.60 m/s². As shown in Figure 1, the PSDs indicated there were differences in frequency content across the three road types. All road types created 1-3 Hz low frequency resonance in the system, but each road type had its own unique vibration profile. As shown in Figure 1, travelling over the city streets resulted in a vibration energy concentration at 7 Hz, freeway travel created vibration energy concentration at 12 Hz, and highway travel created a broad spectrum of vibration energy between 5 – 18 Hz.

Figure 1. Weighted Power Spectral Densities and average weighted acceleration (m/s²) measured at floor and interface for each road type.

Discussion

Regardless of road type, all the measurements at the level of the interface exceeded the ISO and EU daily exposure action values. The stretcher system below the interface caused up to a two-fold increase in the infant’s vibration exposure relative to the vibration measured at the floor of the ambulance. The PSDs demonstrated that 1 – 3 Hz low frequency resonance was present when travelling over all road types and that each road type had distinct and different higher frequency energy profile. Due to the high levels of vibration that were measured, the addition of some sort of suspension to the rigid stretcher system may merit further investigation. Based on the unique vibration signatures of each road type, the stretcher suspension system should be designed to attenuate low frequency resonance between 1 – 3 Hz, if possible, and should operate and attenuate road-induced vibration with frequency content between 5 - 18 Hz. This information on vibration frequency content may assist if future stretcher systems are designed to reduce road-induced vibration.

References

AIRCREW MULTI-AXIS VIBRATION EXPOSURES DURING OPERATION OF THE BLACKHAWK UH-60L HELICOPTER

Suzanne D. Smith, PhD\textsuperscript{1}, Steven G. Chervak\textsuperscript{2}, Jay E. Clasing, LTC\textsuperscript{2}

\textsuperscript{1}Air Force Research Laboratory, 711 HPW/RHCPT, Wright-Patterson AFB OH
\textsuperscript{2}Army Public Health Center, Aberdeen Proving Ground, MD

Introduction

Military aircrew continue to report back discomfort, pain, and injury associated with flying rotary-wing aircraft. Posture, vibration, and seating have been targeted as contributing factors. The Army and Air Force are collaborating on a project to expand the limited data on aircrew vibration exposures during military flight operations. Data will be entered into a database for improving equipment design and vibration mitigation strategies. This paper focuses on aircrew exposures during operation of the UH-60L Blackhawk. Comfort and health risk were assessed in accordance with ISO 2631-1\textsuperscript{1}.

Methods

Four portable battery-powered data acquisition units (DAUs) were used to collect accelerations at the pilot station (cockpit), two crew chief stations (mid-cabin), and two aircrew locations (aft cabin). Triaxial accelerometer packs were attached to the floor or base of each seat. Triaxial acceleration pads were placed on top of the seat pan and seat back (except aft aircrew). Twenty-second data records were collected during typical aircraft tasks and the associated flight test conditions. The acceleration spectra were estimated at each station, measurement site, and direction. The overall weighted accelerations were used to calculate the point vibration total value ($pVTV$) in each direction and the overall vibration total value ($oVTV$) for assessing comfort reaction and health risk (ISO 2031-1\textsuperscript{1}). Equipment and data collection/analysis techniques were similar to that used in a previous study aboard the HH-60M\textsuperscript{2}.

Results

Figure 1 illustrates sample seat pan acceleration spectra at the pilot station. At all stations, measurement sites, and for most flight conditions, a substantial peak was observed at \textasciitilde 17-17.5 Hz and was associated with the blade passage frequency (BPF). As shown in the figure, the highest peak did not necessarily occur in the vertical direction.

Figure 2 illustrates the pilot comfort reactions\textsuperscript{1} for all data records ($oVTV$s). Comfort reactions primarily ranged from a little to very uncomfortable.

Figure 3 illustrates the mean unweighted and weighted overall accelerations, $pVTV$s, and $oVTV$s for all level flight data at two stations. The figure shows exposure variations with respect to magnitude and direction among the stations.
The majority of level flight records showed that aircrew were exposed to the potential for health risk in less than eight hours depending on the airspeed (note time durations in Fig. 3). The pilot and aft aircrew were exposed to the potential for health risk in as little as 1-2 hours of flight. Both pilot and aft aircrew showed at risk exposures in less than 8 hours.

**Discussion**

This study further emphasizes that typical mission use of rotary-wing aircraft generates multi-axis, higher frequency vibration above 10 Hz associated with exposing aircrew to the potential for health risk and even likely health risk as defined in ISO 2631-1. The mechanisms by which higher frequency vibration contributes to health symptoms and health risk require further investigation in order to develop or improve effective exposure criteria, ergonomic design requirements, and mitigation strategies.

**References**

DROP TOWER TEST RESULTS FOR MEASURING THE SHOCK ATTENUATION OF MARINE CRAFT SEATS

Douglas D. Reynolds*, Michael A. Schwob, Blake F. Hament,
University of Nevada, Las Vegas, Las Vegas, NV 89154

Introduction

Small marine crafts, typically less than 30 meters (m) in length, travel at high speeds in rough seas. This often results in wave slam events that transmit shocks to marine craft decks with time durations of up to 150 milliseconds and amplitudes that can exceed 16 g’s. These shocks, which are then transmitted to and through deck mounted seat frames, can result in injuries to marine craft operators and crew members. ISO TC 108/SC 4 has established a working group to develop a laboratory method of test to measures the effectiveness of shock mitigating seat systems in reducing the exposure of marine craft operators and crew members to shocks from wave slam events.

Methods

The Center for Mechanical & Environmental Systems Technology constructed a vertical drop tower with a guided seat platform to simulate a shock from a wave slam event. The tower has a vertical drop height of up to 1.5 m. Attached to the bottom of the seat platform were two 51 mm square 610 mm long tubes that terminated into a 510 mm deep sand pit. Vertical acceleration signals were measured with single-axis MEMS accelerometers on the surface of the seat platform near the seat frame and at the interface between the seat top and a 90 kg mannequin placed on the seat. The acceleration signals were filtered with a 20 Hz and an 80 Hz 4-pole Butterworth filter. Two metrics were used to quantify the shocks at the seat platform surface and the interface between the seat top and mannequin: peak acceleration and shock response spectrum (SRS).

The resilient element placed between the mannequin and seat frame was a 102 mm thick seat air bladder. The seat air bladder consisted of an interconnected seat bottom (400 mm x 460mm) bladder and seat back (400 mm x 610 mm) bladder. The resonance frequency of the mannequin sitting on the seat air bladder was around 5 Hz.

Results

Figure 1 shows a comparison of the unfiltered and 80 Hz filtered measured seat platform and seat top acceleration signals. Figure 2 shows a comparison of the 20 and 80 Hz seat platform and seat top acceleration signals. Figures 3 and 4 show the results of the shock response spectrum (SRS) calculations associated with the 20 Hz and 80 Hz filtered acceleration signals. Table 1 presents the peak seat platform and seat top acceleration and related SRS values and the related output/input values and percent increases.

<table>
<thead>
<tr>
<th>Peak Seat Acceleration</th>
<th>Peak Accel. - g</th>
<th>Output/Input</th>
<th>% Increase</th>
<th>Seat SRS Response</th>
<th>SRS Value</th>
<th>Output/Input</th>
<th>% Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seat Base - 80 Hz Filter</td>
<td>7.8</td>
<td>1.64</td>
<td>64</td>
<td>Seat Base - 80 Hz Filter</td>
<td>1.34</td>
<td>1.16</td>
<td>16</td>
</tr>
<tr>
<td>Seat Top - 80 Hz Filter</td>
<td>12.8</td>
<td></td>
<td></td>
<td>Seat Top - 80 Hz Filter</td>
<td>1.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seat Base - 20 Hz Filter</td>
<td>7.6</td>
<td>1.46</td>
<td>46</td>
<td>Seat Base - 20 Hz Filter</td>
<td>1.34</td>
<td>1.15</td>
<td>15</td>
</tr>
<tr>
<td>Seat Top - 20 Hz Filter</td>
<td>11.1</td>
<td></td>
<td></td>
<td>Seat Top - 20 Hz Filter</td>
<td>1.54</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Discussion**

**Effects of Filtering**: Figures 1 and 2 indicate an 80 Hz 4-pole Butterworth filter effectively captured the frequency contents of the seat platform and seat top acceleration signals. Figure 2 indicates a 20 Hz 4-pole Butterworth filter did not capture sufficient frequency content of these signals to accurately replicate them. This did not significantly affect the measured seat platform peak acceleration. However, it resulted in a measured seat top peak acceleration of 11.1 g, a reduction of 1.7 g.

**Output/Input**: The seat system tested can be modeled by:

\[
\text{Output} = \text{Input} \times 3.1415 \times (T / T_n)
\]

where Output is seat top acceleration, input is seat platform acceleration, \(T\) is the time duration of the shock pulse, and \(T_n\) is the period associated with the system resonance frequency. \(T = 100\) ms. For a 5 Hz resonance frequency, \(T_n = 200\) ms. Therefore, for the 80 Hz filter, Output = 12.2 g, as compared to the measured 12.8 g.

The 80 Hz filter yielded a 64 percent increase in the output peak acceleration relative to the input peak acceleration. The 20 Hz filter yielded a 46 percent increase relative to the input peak acceleration. This was a decrease of 18 percent relative to the 80 Hz filter.

**Shock Response Spectrum (SRS)**: Figures 3 and 4 show displacement curves associated with obtaining the SRS values in Table 1. The shock response spectrum value for each curve is the maximum negative displacement value. The output SRS value for the 80 Hz filter was 16 percent higher than the input value. The output SRS value for the 20 Hz filter was 15 percent higher than the input value.

**Conclusion**: Peak acceleration values present a more descriptive and clearly identifiable difference between seat platform and seat top shock acceleration signals.
Session 1 - Adverse Health Outcomes Associated with Vibration and Shocks

**Rotator Cuff Disease in Workers Exposed to Hand Arm Vibration: A Challenge for Prevention**

*Alice Turcot*
- Institut national de santé publique du Québec, Québec, Canada
- Faculty of Medicine, Université Laval, Québec, Canada
- Direction de Santé Publique, Thetford Mines, Canada

**Shock and Vibration Issues in Professional Sports**

*Thomas Jetzer*
- Occupational Medicine Consultants, Minnesota Twins, Minneapolis MN, USA
- Department of Mechanical Engineering, University of Nevada, Las Vegas NV, USA
ROTATOR CUFF DISEASE IN WORKERS EXPOSED TO HAND-ARM VIBRATION: A CHALLENGE FOR PREVENTION

Alice Turcot¹, Louis Morin², Nathalie Cardinal³

¹Institut national de santé publique du Québec, Québec, Canada, G1V 5B3
² Faculty of medicine, Université Laval, Québec, Canada, G1K 7P4
³Direction de santé publique, Thetford-Mines, Canada, G6G 2V2

Introduction

Shoulder disorders are frequent in the working population with a prevalence rate for non-specific shoulder pain of up to 31%¹ and as high as 6% to 11% under the age of 50 years old.² Shoulder pain is among the most common sites of musculoskeletal complaints and represents a frequent cause of medical consultation.³

Shoulder disorders affect the shoulder’s functional status and the quality of life of the individuals who suffer from them. In the case of workers, it can lead to absenteeism and loss of productivity. In 2005-2007, the costs generated annually by shoulder injuries that were covered by the CNESST, including human costs and costs associated with loss of productivity, totaled $393,204,738. Workers who perform tasks with their arms above shoulder height or repetitive tasks are at greater risk of developing shoulder disorders, especially rotator cuff (RC) disorders⁴ such as rotator cuff syndrome (RCS).

In 1981, Bjelle et al. reported that both individual factors such as constitution, age or disease, and external factors such as trauma from occupation or other activities are of etiological importance.² In a previous study, working with hands at or above acromion height was shown to constitute a significant occupational factor. A number of epidemiological studies reporting on potential risk factors for shoulder pain have been done in the past decade. A recent systematic review and meta-analysis has shown moderate evidence that arm-hand elevation and shoulder load double the risk of specific shoulder disorders. Low to very-low-quality evidence was found for an association between hand force exertion, hand-arm vibration, psychosocial job demands and working together with temporary workers and the incidence of specific shoulder disorders.⁵ Conflicting results for the role of hand-arm vibration associated with the onset of shoulder disorders are reported.⁶⁻⁷⁻⁸ In fact, repetitive use of a handheld vibrating tool such as a grinder, is associated with flexion of the shoulder, shoulder load, and hand force exertion among the biomechanical factors described as important risk factors of RCS. The purpose of this study is to examine the risk factors associated with tendinitis, to report the number of tendinitis claims by the CNESST in association with handheld vibrating tools and to isolate the exposition to “vibration” as a risk factor in RCS for a working population.
Methods

A literature review of articles published in French and English on Medline and Embase from 1975 to 2018 relating the association between risk factors and specific shoulder disease will be completed using the following key-words/Mesh descriptors centered around two concepts: rotator cuff disease and work. We then retained articles specific to RCS and covering risk factors associated with aforementioned concepts. Also, an analysis of the CNESST files covering the period between 1997 and 2015 has been conducted to retrace the reports of accepted claims and indemnified workers suffering from shoulder tendinitis. Finally, an ergonomic evaluation of three workplaces has been conducted following a strict evaluation protocol.

Preliminary results

As of the literature review, out of the 325 articles retained, 42 articles were analysed. The exposure to vibrations represents a RCS co-factor in current literature but the specific contribution of vibrations among the other biomechanical factors remains unknown. As of the 27 claims covered by the CNESST for shoulder tendinitis related to vibrations, 13 were associated with the use of handheld vibrating tools. The ergonomic evaluation has documented several major risk factors including working with arms above shoulder level, awkward postures and repetitive movements.

Discussion

Prevention of occupational shoulder diseases is a challenge as many risk factors must be assessed. The relation between vibrations and shoulder disease needs to be properly documented. The ergonomic evaluation allowed to identify upper body musculoskeletal diseases and to focus on exposures to occupational risk factors which can often be avoided by modifying the workplace.

References

SHOCK AND VIBRATION ISSUES IN PROFESSIONAL SPORTS

* Thomas Jetzer MD, MPH, FACOEM ¹, Douglas Reynolds Ph. D ²

¹ Occupational Medicine Consultants, Minnesota Twins
² Department of Mechanical Engineering, University of Nevada, Las Vegas

Introduction

While shock and vibration has long been recognized as a workplace hazard, ergonomic intervention over the years has made significant strides in ameliorating this issues in many jobs. However more recently, the effects of shock and vibration has become to be appreciated as a significant risk factor in various professional sports including soccer, football, baseball as well as other sports activities. This has led to the appreciation of resulting pathology to the head, whole body and extremities depending on the insult. The implication of this has included significant disability, impairment of function and careers, financial cost and post career disease including even death. While the major attention has been focused on professional sports, similar injury and impairment has also been identified in the amateur arena of the same sports. It is recommended, that similar to the endeavors to control whole body and hand-arm vibration in the workplace by the scientific community, that a similar multidisciplinary endeavor be instituted to address and resolve this risk.

Methods

Analysis of injuries in contact sports such as football and hockey indicates a significant incident of head trauma leading to concussions, brain trauma and long-term brain damage. Analysis of hand intensive supports such as baseball and other ball related sports leads to shock damage to the hands and as well as causing other upper extremity pathology. Sports that require prolonged gripping vibration such as mountain biking can lead the same pathological medical conditions seen in industries that have vibration exposure. Exploration of these sports indicates that the incidence and severity of these conditions may be increasing. Attempts to remedy these issues have often been hindered by sport rules, technological limitations and reluctance of players to accept uncomfortable or unfashionable solutions.

Results and Discussion

While there have been considerable investigations to define the level of pathology as result of these shock and vibration hazards in sports, no definitive solution has been found for all or individual supports. Efforts from a combination of engineering, medical and ergonomic resources need to be marshalled to find acceptable solutions. If these solutions are not found, one can only expect an ongoing list of injured athletes, legal and financial challenges and possible threat to the nature of the sport themselves. It is recommended that the expertise that applied to dealing to shock and vibration in the industrial setting now be also directed to the sports venue.
SESSION 2 - METHODS TO FURTHER THE UNDERSTANDING OF SENSORY AND MOTOR ISSUES ASSOCIATED WITH HAND ARM VIBRATION

The Vibration Responses of a Handheld Workpiece and the Hand Arm System

*Xueyan Sherry Xu, Daniel E. Welcome, Chris Warren, Thomas W. McDowell and Ren G. Dong
- National Institute for Occupational Safety and Health, Morgantown, West Virginia, USA
- Hanshen Lin, Bin Xiao and Qingsong Chen
- Guangdong Province Hospital for Occupational Disease Prevention and Treatment, Guangzhou, Guangdong, China

Longitudinal Study of Thermotactile Perception Thresholds When Exposed to Hand Arm Vibration

*Ronnie Lundström and Tohr Nilsson
- Department of Public Health and Clinical Medicine, Occupational Medicine, Umeå University, Sweden.
- Adnan Noor Baloch, Mats Hagberg and Lars Gerhardsson
- Department of Occupational and Environmental Medicine, University of Gothenburg and Sahlgrenska University Hospital, Sweden

White Fingers and Cold Intolerance in Relation to Hand Arm Vibration and Ambient Cold Exposure in Northern Sweden

*Albin Stjernbrandt, Hans Pettersson, Ingrid Liljelind, Tohr Nilsson and Jens Wahlström
- Occupational and Environmental Medicine, Department of Public Health and Clinical Medicine, Umeå University, Sweden

A Multi Scale Approach for Predicting Acute and Chronic Effects of Mechanical Vibration on the Digital Vascular Network

*Christophe Noël
- Electromagnetism, Vibration, Optic laboratory, Institut national de recherche et de sécurité (INRS), Vandœuvre, Nancy, France

A Two Scale Finite Element Model for Vibration Induced Raynaud Syndrome

Yue Hua
- Nanjing University of Science and Technology, China
*Pierre Lemerle
- Institut National de Recherche et de Sécurité, France
- Université de Lorraine, France
Modeling the Vibration Response of a Workpiece Hand Arm System

*Ren G. Dong, Daniel E. Welcome, Xueyan Sherry Xu, Thomas W. McDowell and John Z. Wu
– Health Effects Laboratory Division, National Institute for Occupational Safety and Health, Morgantown WV, USA
Qingsong Chen, Hanshen Lin
– Guangdong Province Hospital for Occupational Disease Prevention and Treatment, Guangzhou, Guangdong, China

Do We Need to Consider Skin Thickness When Conducting Vibrotactile and Thermal Perception Threshold Measurements?

*Ronnie Lundström and Tohr Nilsson
– Department of Public Health and Clinical Medicine, Occupational Medicine, Umeå University, Sweden
Håkan Dahlqvist
– ElMeKon HB, Vindön, Sweden
Mats Hagberg
– Department of Occupational Medicine, Göteborg University, Sweden
THE VIBRATION RESPONSES OF A HANDHELD WORKPIECE AND THE HAND-ARM SYSTEM

Xueyan Sherry Xu¹, Daniel E. Welcome¹, Chris Warren¹, Thomas W. McDowell¹,
Hanshen Lin², Bin Xiao², Qingsong Chen², Ren G. Dong¹

¹Engineering & Control Technology Branch, Health Effects Laboratory Division
National Institute for Occupational Safety and Health
Morgantown, West Virginia 26505, USA

²Guangdong Province Hospital for Occupational Disease Prevention and Treatment
Guangzhou, Guangdong, China

Introduction

Grinding and polishing of handheld workpieces are widely used in the fabrication or repair of some components of sports equipment, tools, furniture, and dentures. Such processes may generate significant vibrations that can be effectively transmitted to the fingers or hands of the workers holding the workpieces. The vibration exposure may cause vibration-induced white finger (VWF). The objective of this study was to characterize the vibration responses of the handheld workpiece and the hand-arm system. Such knowledge is required to enhance the understanding of their vibration response, to develop a model of the system, and to help explore more effective engineering methods for reducing the vibration exposure and health effects.

Methods

The experimental method used in this study is shown in Figure 1. A typical handheld workpiece (a golf club head) was used in the experiment. The two hands held the workpiece with the posture similar to that used in fine grinding.¹ The vibration was provided from a single-axis vibration test system (Unholtz-Dickie, TA250-S032-PB). The excitation spectrum (6.3 to 1,600 Hz) was an extension of that defined in the current ISO 10819 (2013).² It was delivered to the workpiece through an instrumented handle equipped with a tri-axial accelerometer (Endevco, 65-100) and two force sensors (Kistler 9212). Unlike a conventional instrumented handle with a cylindrical shape for the measurement of the biodynamic responses of the hand-arm system, the current handle has a flat interface. It was used to measure the input acceleration, interface feed force, and apparent mass of the workpiece-hand-arm system. The vibration of the workpiece was measured using a tri-axial accelerometer (PCB 356A11) installed on the club head. The vibration at each of the four locations (hand dorsum, wrist, forearm, and upper arm) was measured using adapters equipped with tri-axial accelerometers (Endevco, M35), which was secured in place using a cloth wrap, as also shown in Figure 1. Ten healthy adult subjects (5 males and 5 females) participated in this experimental study. The influencing factors considered in this study include two hand conditions (bare and gloved hands), two feed forces (15 and 30 N), and

Figure 1: A pictorial view of experimental setup and hand-arm postures.
six simulated grinding interfaces represented by six synthetic rubber samples (R1, R2, R3, R45, R55, R65) with different stiffness values.

Results

Examples of the measured impedance and transmissibility spectra for 30 N feed force are shown in Figure 2.

![Figure 2](image)

Figure 2. Examples of mechanical impedance of the entire workpiece-hand-arm system and the vibration transmissibility spectra measured on workpiece, hand dorsum, wrist, and forearm.

Discussion

The results of this study indicate that the vibration of the workpiece was significantly affected by the grinding interface stiffness, applied feed force, and gloves, especially in the major resonance of the workpiece. However, the vibration transmissibility on the hand-arm system was only significantly affected by the feed force and glove. While the use of vibration-reducing gloves marginally increased the resonance of the workpiece, the gloves significantly reduced the vibrations transmitted to the hand dorsum and wrist. This suggests that vibration-reducing gloves can be considered as one of the measures for reducing vibration exposures during the grinding of handheld workpieces.

References


Disclaimer: The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.
LONGITUDINAL STUDY OF THERMOTACTILE PERCEPTION THRESHOLDS WHEN EXPOSED TO HAND-ARM VIBRATION

*Ronnie Lundström¹, Adnan Noor Baloch², Mats Hagberg², Tohr Nilsson¹, Lars Gerhardsson²

¹ Department of Public Health and Clinical Medicine, Occupational Medicine, Umeå University, Sweden.
² Department of Occupational and Environmental Medicine, University of Gothenburg and Sahlgrenska University Hospital, Sweden

Introduction

Exposure to hand-transmitted vibration (HTV) is known to cause neurological symptoms such as reduced sensory perception. The purpose of this study was to compare thermotactile perception thresholds for cold (TPTₐ) and warmth (TPTₜ) among vibration exposed workers and unexposed workers during a follow-up period of 16 years to elucidate if long-term vibration exposure is related to a change in TPT over time¹.

Methods

The study group consisted of male workers at a production workshop at which some of them were exposed to HTV. They were investigated in 1992 and followed-up in 2008. All participants were physically examined and performed TPT bilaterally at the middle and distal phalanges of the second finger. Two different vibration exposure dosages were calculated for each individual, i.e. the individual cumulative lifetime dose (mh/s²) or a lifetime 8-hour equivalent daily exposure (m/s²).

Results

A significant threshold difference was found for all subjects of about 4-5°C and 1-2°C in TPTₐ and TPTₜ, respectively, between follow-up and baseline. No significant mean difference in TPTₐ and TPTₜ (left index finger) between vibration exposed and non-exposed workers at each occasion was found. Corresponding difference for TPTₜ for the right index finger was small but significant. Age was strongly related to TPT. The 8-hour equivalent exposure level (A(8)) dropped from about 1.3 m/s² in 1992 to about 0.7 m/s² in 2008.

Discussion

The main reason for the differences in TPT between the two occasions is explained by the effect of age. The effect of an 8-hour equivalent daily vibration exposure less than 1.3 m/s² seems thus to be negligible. The influence of age has to be considered when using TPT as a tool for health screening

References

WHITE FINGERS AND COLD INTOLERANCE IN RELATION TO HAND-ARM VIBRATION AND AMBIENT COLD EXPOSURE IN NORTHERN SWEDEN

*Albin Stjernbrandt, Hans Pettersson, Ingrid Liljelind, Tohr Nilsson, Jens Wahlström

Department of Public Health and Clinical Medicine, Occupational and Environmental Medicine, Umeå University, Sweden

Introduction

White fingers, or Raynaud’s phenomenon, is a common sequela of hand-arm vibration (HAV) injury. Cold intolerance, without vasospasm, is a related condition that can also occur in vibration-exposed workers. It has been defined as an exaggerated or abnormal reaction to cold exposure, causing discomfort or the avoidance of cold. Both white fingers and cold intolerance can also occur after cold injury. Suspicion has been raised that intolerance to cold can precede the development of white fingers, and the recognition of this early stage could therefore represent an important target for preventive interventions. The objectives of this study was to investigate the occurrence of white fingers and cold intolerance in the general population of northern Sweden, and evaluate the statistical association between these conditions and exposure to HAV and ambient cold exposure.

Methods

Through a postal questionnaire answered by 12,627 subjects (response rate 35.9%) living in northern Sweden, cases with white fingers and cold intolerance were obtained. A sample of cases with white fingers (N=461), cold intolerance (N=374) and matched controls (N=1,386) were invited to participate in two secondary, questionnaire-based nested case-control studies, where they were asked to report their use of different vibrating tools, as well as ambient cold exposure during work and leisure time. HAV exposure was first analyzed as any occupational use, and then subgroups were formed based on the different tools reported. Cumulative (occupational and leisure-time) ambient cold exposure above the 50th percentile was classified as high. Univariate conditional logistic regression was used to analyze the relationships between exposure and symptoms.

Results

White fingers were reported by 12.4%. Our definition of cold intolerance was fulfilled by 4.0%. Among subjects with cold intolerance, 61.5% also stated white fingers. Reporting white fingers was associated with reporting any HAV exposure (OR 1.5; 95% CI 1.1-2.1) as well as high ambient cold exposure (OR 1.3; 95% CI 1.0-1.7). Cold intolerance was more strongly associated with reporting both any HAV exposure (OR 2.1; 95% CI 1.4-3.0) and ambient cold exposure (OR 1.6; 95% CI 1.2-2.1). Looking at
subgroups of vibrating equipment, heavily vibrating tools and impact tools showed the strongest associations with white fingers (OR 2.4; 95% CI 1.6-3.7, and OR 2.0; 95% CI 1.3-2.9, respectively). The same groups of tools also showed the strongest associations with cold sensitivity (OR 2.4; 95% CI 1.5-3.9, and OR 2.4; 95% CI 1.5-3.9, respectively). The use of forestry or gardening tools, or rapidly rotating tools, showed no statistically significant relationship to the outcomes studied.

Discussion

This study shows that both white fingers and cold intolerance are common in the general population of northern Sweden, and that both are statistically related to HAV and cold exposure, on a population level. Vibrating tools with higher A(8) values and transient components showed stronger associations with reporting symptoms, than did tools with less vibrations. Although causal relationships cannot be established with this study design, the results suggest that these heavily overlapping conditions may share some common pathophysiological features. Also, both studied exposures are suitable candidates for primary preventive measures. Additional research is needed to establish the time relationship between exposure and development of symptoms, as well as between the onset of cold sensitivity and white fingers.

References

A MULTI-SCALE APPROACH FOR PREDICTING ACUTE AND CHRONIC EFFECTS OF MECHANICAL VIBRATION ON THE DIGITAL VASCULAR NETWORK

*Christophe Noël
Electromagnetism, Vibration, Optic laboratory
Institut national de recherche et de sécurité (INRS), Vandœuvre-lès-Nancy, France

Introduction

Many physiological, histological, and epidemiological studies\(^1\) have highlighted that risk’s predictions of developing vibration white finger (VWF) symptoms may be overestimated (e.g. breakers) or underestimated (e.g. riveting tools) when this risk is assessed using the procedure described in ISO 5349 standard. Part of these discrepancies was assigned to the ISO 5349 weighting. Thus, a new filter was proposed in ISO/TR 18570\(^1\) based on biomechanical and epidemiological results. In order to get a better inclusion of vascular pathophysiological matters due to vibration, an original strategy based on a time-space multi-scale methodology was set up. This mechanobiological approach combines modeling and measurement of mechanical and physiological quantities in both acute and chronic ways.

Methods

The vibration-induced changes in the thermomechanical quantity fields inside the hand may disturb acute and chronic digital vasoregulation. This imbalance is among the main hypotheses for the onset of vibration-induced white finger. These complex and widely multifactorial mechanisms of the Raynaud’s syndrome pathophysiology may be simplified and split into three sub-models (figure 1) in a double space-time scale. At a macroscopic scale, a three-dimensional finite element model of a vibrated phalanx\(^2\) or a whole hand is firstly defined. It allows the assessment of biomechanical quantities around the Pacinian corpuscles (model A). This mechanoreceptor response may impact the arterial hemodynamics factors of both exposed and non-exposed fingers, by involving a sympathetic nervous system pathway. Then, the mechano-physiological model B links this Pacinian response and the so triggered decrease of the wall shear stress (WSS) exerted by the blood on the endothelium. Eventually, the model C consists in simulating the intimal hyperplasia induced by a chronic fall of the WSS. It leads to an arterial stenosis in the finger which is often related to patient suffering from VWF.

Fig. 1: Synoptic diagram of the time-space multi-scale approach.
Results

The model A evolved using increasing complexity steps, adding more and more accurate and representative anatomical details: starting from an experimental device to identify the more suitable constitutive material laws, through a 3D finger model, up to a whole actual scanned hand with a huge number of anatomical elements (figure 2).

Fig. 2: scanned hand used in the model A; (a) example of anatomical elements; (b) skin acceleration amplitude (m/s²) for the hand gripping a vibrated handle at 104 Hz and 20 m/s² in the y direction.

Regarding the model B, the wall shear stress (WSS) was assessed by combining the Womersley blood flow fluid’s model and hemodynamics measurements carried out with a high spatial resolution ultrasound system (figure 3).

Fig. 3: Measurement of the WSS; (a) experimental setup; (b) WSS in the non-exposed finger without vibration and for an acceleration of 4 g at 100 Hz and 9 g at 200 Hz.

Discussion

The validation of model A is ongoing using comparison with experimental data. The computation of the dynamic strain around the Pacinian corpuscle is on progress by taking into account the effect of a high level of anatomical heterogeneity in the model. Then, the coupling between the hand macro scale finite element model and the Pacinian’s one will be studied using homogenization methods. Finally, Agent Based Model will be used so as to simulate the chronic intimal hyperplasia.

References

A TWO SCALE FINITE ELEMENT MODEL FOR VIBRATION-INDUCED RAYNAUD SYNDROME

Yue Hua\textsuperscript{1}, Pierre Lemerle\textsuperscript{2}, Jean-François Ganghoffer\textsuperscript{3}

\textsuperscript{1}Nanjing University of Science and Technology, China
\textsuperscript{2}Institut National de Recherche et de Sécurité, France
\textsuperscript{3}Université de Lorraine, France

Introduction

Hand-Arm Vibration Syndrome (HAVS), usually caused by long-term use of hand-held power tools, can in some manifestations alter the peripheral blood circulation and cause abnormal vasospasms. The reduction of the lumen of the blood vessels in VWF (Vibration White Finger) subjects, due to hypertrophy or thickening of the vessel wall, may be at the origin of the disease. Direct (structure response) and indirect (involving the nervous system) effects on the structure of blood vessels are suggested\textsuperscript{1}. This study aims to model the vibration transmission from the excitation forces to the small distal finger arteries taking account of cell-growth in the capillary wall. The primary outcomes of the study are the modeling approach itself based on structural zooming which may be enriched in the future by more realistic constitutive laws.

Methods

Considering the propagation of vibration in the hand, two significant length scales clearly emerge: the macroscopic scale as a feature of the finger deformed shapes and the microscopic scale for the description of the capillary growth. It is practically impossible to combine both scales in one model. High mesh refinements on large scales imply cost-prohibitive calculations.

The same consideration should be brought to time integration as coping with short period vibration versus high physiological constant of growth phenomenon.

For these reasons, the model was split into one global FE model of the finger pulp cross-section for the calculation of dynamic mechanical fields induced by the vibration inside the soft tissues and one local FE model of the capillary cross-section with surrounding tissues to compute the long-term capillary evolution defined as a representative volume element (RVE).

Figure 1. Mesh representation of the global (left) and the local (right) FE model.
Both FE models were linked by the reconstruction of the loading conditions of the RVE expressed in terms of constant displacements and integrated from the strain field obtained with the global model at the corresponding observation spot. Averaging techniques were used to ensure significant matching between the two time scales.

The 2D model was largely inspired by J Wu’s approach with a quasi-static preload followed by a steady-state analysis under harmonic conditions. A visco-hyperelastic constitutive law was used for the soft tissues whose properties were tuned in static and dynamic conditions thanks to experimental data extracted from the literature. They were assumed uniform and isotropic.

The local model was defined as a RVE of $45\mu m \times 45\mu m$ conforming with the capillary density in fingers. E. Kuhl’s model was used to drive the isotropic growing process of the capillary wall through one single scalar factor. The blood pressure was kept constant (2 kPa) at the capillary’s inner boundary.

**Results**

Figure 2 shows the evolution of the growth factor and the local thickness in two spots (A,B) of a capillary wall which is located in the maximum compression area of the finger pulp and subject to one cycle of loading (mean vibration strain value) then unloading.

![Figure 2](image)

**Discussion**

The time unit of Figure 2 is arbitrary. Because of static conditions, the deviation from the homeostatic state as well as the recovery is only governed by the growth constants of Kuhl’s model, the latter being driven by stress quantities (trace of Mandel’s tensor) with no frequency dependency. Then the frequency effects may occur in structure resonances only. This can be improved in the future, testing and validating other growth laws through the lens of inverse methods.

**References**

MODELING THE VIBRATION RESPONSE OF A WORKPIECE-HAND-ARM SYSTEM

Ren G. Dong¹, Daniel E. Welcome¹, Qingsong Chen², Hanshen Lin², Xueyan Sherry Xu¹, Thomas W. McDowell¹, and John Z. Wu¹

¹Engineering & Control Technology Branch, Health Effects Laboratory Division
National Institute for Occupational Safety and Health
Morgantown, West Virginia 26505, USA
²Guangdong Province Hospital for Occupational Disease Prevention and Treatment
Guangzhou, Guangdong, China

Introduction

How to control the hand-transmitted vibration exposure and health effects among the workers performing the grinding of handheld workpieces remains an issue.¹ To help explore and identify effective engineering control methods, the objective of this study is to develop a model of a grinding machine-workpiece-hand-arm system for simulating the vibration responses of the system. As the vibration on the workpiece is of major concern in the risk assessment of the vibration exposure, the major purposes of the model were to predict the vibration transmissibility of the workpiece and to help understand its influencing factors.

Methods

As an initial modeling study of the entire machine-workpiece-hand-arm system, only the responses of the system in the horizontal direction vertical to the grinding interface was considered. The workpiece considered in this study was a typical golf club head made by a sports equipment manufacturer.¹ The proposed model of the entire system is shown in Figure 1. For the purposes of the model, the hand-arm system was represented using a mechanical-equivalent structure. A lumped mass of the grinding wheel supported on a spring-damper system was used to represent the grinding machine. No obvious structural resonance of the club head was found from the measured vibration spectra of the club head in the frequency range of concern (6.3-1,250 Hz) in an experimental study;² hence, it was simulated as a lumped mass in the system model. The grinding interface was modeled as a spring-damper system.

This study assumed that the entire system exhibited approximately linear behaviors in its vibration responses for given test conditions. The parameters of the model were calibrated using the mechanical impedance of the workpiece-hand-arm system and the vibration transmissibility of the wrist and upper arm, which were measured in an experimental study.² The vibration transmissibility of the workpiece for each test treatment was also measured in the experimental study, but it was not used in the model calibration. Instead, it was used to examine the model validation by comparing it with the modeling prediction. After the model was developed, another experiment was

Fig.1: A model of grinding machine-workpiece-hand-arm system.
conducted for the further evaluation of the model, in which each grinding interface was simulated by using a section of rubber cut from a real grinding wheel. Three types of wheel rubbers (R45, R55, and R65) were considered in the experiments.

Results

The linear model generally underestimated the vibration of the handheld workpiece when a high interface stiffness ($\geq$ 1,261 kN/m) was considered. However, when the interface stiffness was $\leq$ 1,089 kN/m, the model provided reasonable predictions of the responses on the workpiece and at the wrists, as shown in Figure 2.

![Figure 2. Comparisons of predicted and measured vibration transmissibility spectra](image)

Discussion

When the interface stiffness is within a certain range, its non-linear behavior can be approximately locally linearized. Therefore, the model can provide reasonable predictions of the responses, as shown in Figure 2. As found in this study, the interface stiffness of the belt grinding wheel is in the range from 85 kN/m (new soft rubber tread) to 191 kN/m (worn hard rubber tread), which is well below the acceptable value (1,089 kN/m). The model should be acceptable for helping to understand the system responses and for exploring some engineering methods for reducing the vibration of handheld workpieces in the grinding process.

References


Disclaimer: The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.
DO WE NEED TO CONSIDER SKIN THICKNESS WHEN CONDUCTING VIBROTACTILE AND THERMAL PERCEPTION THRESHOLD MEASUREMENTS?

*Ronnie Lundström¹, Håkan Dahlqvist², Mats Hagberg³, Tohr Nilsson¹

¹ Department of Public Health and Clinical Medicine, Occupational Medicine, Umeå University, Sweden
² ElMeKon HB, Vindön, Sweden
³ Department of Occupational Medicine, Göteborg University, Sweden.

Introduction

Quantitative measurements of vibrotactile and thermotactile perception thresholds (VPT and TPT, respectively) rely on responses from sensory receptors in the skin when mechanical or thermal stimuli are applied to the skin. The objective was to explore if skin thickness (epidermis and dermis) is a factor that needs to be considered when evaluating results from VPT or TPT measurements.

Methods

VPT and TPT were measured on the volar side of the fingertip on 148 male subjects, out of which 116 were manual workers exposed to hand-transmitted vibration and 32 were white-collar (office) workers. Skin thickness was measured using a high-frequency ultrasonic derma scanner system.

Results

The difference in age, perception thresholds and skin thickness between manual and office workers was small and non-significant except for the perception of cold, which was decreased by vibration exposure. The mean skin thickness for both subgroups was 0.57 mm (range 0.25-0.93 mm). Increased age was associated with decreased perception of warmth and vibration. Lifetime cumulative exposure to vibration, but not age, was associated with decreased perception of cold. No association ($P>0.05$) was found between finger skin thickness in the range of about 0.1-1 mm and VPT for test frequencies from 8 to 500 Hz and TPT for warmth and cold. Increased age was associated with reduced VPT and TPT. Vibration exposure was associated with decreased TPT for cold.

Discussion

Skin thickness is a factor that may affect the response from sensory receptors, e.g., due to mechanical attenuation and thermal insulation. No previous studies have measured skin thickness and its relation to VPT and TPT. This study showed no association between skin thickness and vibrotactile perception or thermotactile perception.

Reference

<table>
<thead>
<tr>
<th>Last Name</th>
<th>First Name</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anderson</td>
<td>Leif</td>
<td>36, 38</td>
</tr>
<tr>
<td>Antonucci</td>
<td>Andrea</td>
<td>5</td>
</tr>
<tr>
<td>Bain</td>
<td>James</td>
<td>20</td>
</tr>
<tr>
<td>Baloch</td>
<td>Adanan</td>
<td>90</td>
</tr>
<tr>
<td>Bao</td>
<td>Stephen</td>
<td>9</td>
</tr>
<tr>
<td>Barr</td>
<td>Alan</td>
<td>5</td>
</tr>
<tr>
<td>Barrero</td>
<td>Lope</td>
<td>46</td>
</tr>
<tr>
<td>Baxter</td>
<td>Roseanne</td>
<td>48</td>
</tr>
<tr>
<td>Berger</td>
<td>Markus</td>
<td>31</td>
</tr>
<tr>
<td>Bigelow</td>
<td>Philip</td>
<td>58</td>
</tr>
<tr>
<td>Burgess-Limerick</td>
<td>Robin</td>
<td>48</td>
</tr>
<tr>
<td>Cardinal</td>
<td>Nathalie</td>
<td>83</td>
</tr>
<tr>
<td>Chen</td>
<td>Qingsong</td>
<td>88, 97</td>
</tr>
<tr>
<td>Chervak</td>
<td>Steven</td>
<td>78</td>
</tr>
<tr>
<td>Clasing</td>
<td>Jay</td>
<td>78</td>
</tr>
<tr>
<td>Cooper</td>
<td>Michael</td>
<td>5</td>
</tr>
<tr>
<td>Dahlqvist</td>
<td>Håkan</td>
<td>99</td>
</tr>
<tr>
<td>Davies</td>
<td>Huge</td>
<td>64</td>
</tr>
<tr>
<td>Dennerlein</td>
<td>Jack</td>
<td>46</td>
</tr>
<tr>
<td>Dickey</td>
<td>James</td>
<td>58</td>
</tr>
<tr>
<td>Dietze</td>
<td>Ben</td>
<td>58</td>
</tr>
<tr>
<td>Dong</td>
<td>Ren</td>
<td>12, 25, 29, 88, 97</td>
</tr>
<tr>
<td>Du</td>
<td>Bronson</td>
<td>58, 64</td>
</tr>
<tr>
<td>Eger</td>
<td>Tammy</td>
<td>33, 52, 58</td>
</tr>
<tr>
<td>Fisk</td>
<td>Karin</td>
<td>40</td>
</tr>
<tr>
<td>Ford</td>
<td>Brayan</td>
<td>14</td>
</tr>
<tr>
<td>Ganghoffer</td>
<td>Jean</td>
<td>95</td>
</tr>
<tr>
<td>Garbini</td>
<td>Joe</td>
<td>14</td>
</tr>
<tr>
<td>Gerhardsson</td>
<td>Lars</td>
<td>90</td>
</tr>
<tr>
<td>Goggins</td>
<td>Katie</td>
<td>33, 52</td>
</tr>
<tr>
<td>Grétarsson</td>
<td>Snævar</td>
<td>7, 20, 27</td>
</tr>
<tr>
<td>Hagberg</td>
<td>Mats</td>
<td>90, 99</td>
</tr>
<tr>
<td>HansonSmit</td>
<td>Riley</td>
<td>14</td>
</tr>
<tr>
<td>Author</td>
<td>Name</td>
<td>Pages</td>
</tr>
<tr>
<td>----------</td>
<td>-----------</td>
<td>--------</td>
</tr>
<tr>
<td>Haylett</td>
<td>James</td>
<td>60</td>
</tr>
<tr>
<td>Hirschman</td>
<td>David</td>
<td>76</td>
</tr>
<tr>
<td>Howard</td>
<td>Ninica</td>
<td>9</td>
</tr>
<tr>
<td>Hua</td>
<td>Yue</td>
<td>95</td>
</tr>
<tr>
<td>Jetzer</td>
<td>Thomas</td>
<td>85</td>
</tr>
<tr>
<td>Johnson</td>
<td>Peter</td>
<td>46, 50, 56, 64, 69, 76</td>
</tr>
<tr>
<td>Kia</td>
<td>Kiana</td>
<td>56</td>
</tr>
<tr>
<td>Kim</td>
<td>Jeong-Ho</td>
<td>56</td>
</tr>
<tr>
<td>Kim</td>
<td>Brian</td>
<td>67</td>
</tr>
<tr>
<td>Kowalski</td>
<td>Piotr</td>
<td>71</td>
</tr>
<tr>
<td>Krajnak</td>
<td>Kristine</td>
<td>22</td>
</tr>
<tr>
<td>Kuczyński</td>
<td>Jacek</td>
<td>71</td>
</tr>
<tr>
<td>Lemerle</td>
<td>Pierre</td>
<td>95</td>
</tr>
<tr>
<td>Lievers</td>
<td>Brent</td>
<td>33, 52</td>
</tr>
<tr>
<td>Liljelind</td>
<td>Ingrid</td>
<td>40, 91</td>
</tr>
<tr>
<td>Lindell</td>
<td>Hans</td>
<td>7, 18, 20, 27</td>
</tr>
<tr>
<td>Lin</td>
<td>Hanshen</td>
<td>88, 97</td>
</tr>
<tr>
<td>Lokeh</td>
<td>Adam</td>
<td>76</td>
</tr>
<tr>
<td>Lundström</td>
<td>Ronnie</td>
<td>16, 90, 99</td>
</tr>
<tr>
<td>Lynas</td>
<td>Danellie</td>
<td>48</td>
</tr>
<tr>
<td>Maeda</td>
<td>Setsuo</td>
<td>36</td>
</tr>
<tr>
<td>Marcotte</td>
<td>Pierre</td>
<td>73, 95</td>
</tr>
<tr>
<td>Marín</td>
<td>Luz</td>
<td>46</td>
</tr>
<tr>
<td>Martin</td>
<td>Bernard</td>
<td>5</td>
</tr>
<tr>
<td>Mayton</td>
<td>Alan</td>
<td>67</td>
</tr>
<tr>
<td>McDowell</td>
<td>Thomas</td>
<td>12, 22, 25, 29, 88, 97</td>
</tr>
<tr>
<td>McLaughlin</td>
<td>Jacqueline</td>
<td>36, 38</td>
</tr>
<tr>
<td>Milosavljevic</td>
<td>Stephan</td>
<td>62</td>
</tr>
<tr>
<td>Mori</td>
<td>Louis</td>
<td>83</td>
</tr>
<tr>
<td>Mott</td>
<td>Ryan</td>
<td>14</td>
</tr>
<tr>
<td>Nilsson</td>
<td>Tohr</td>
<td>2, 90, 91, 99</td>
</tr>
<tr>
<td>Noël</td>
<td>Christophe</td>
<td>93</td>
</tr>
<tr>
<td>Nordander</td>
<td>Catarina</td>
<td>40</td>
</tr>
<tr>
<td>Parker</td>
<td>Rob</td>
<td>76</td>
</tr>
<tr>
<td>Pettersson</td>
<td>Hans</td>
<td>91</td>
</tr>
<tr>
<td>Author</td>
<td>Name</td>
<td>Page Numbers</td>
</tr>
<tr>
<td>-------------------</td>
<td>-----------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Pierson</td>
<td>Benjamin</td>
<td>69</td>
</tr>
<tr>
<td>Rakheja</td>
<td>Subhash</td>
<td>73</td>
</tr>
<tr>
<td>Reinhall</td>
<td>Per</td>
<td>14</td>
</tr>
<tr>
<td>Rempel</td>
<td>David</td>
<td>5</td>
</tr>
<tr>
<td>Reynolds</td>
<td>Douglas</td>
<td>80, 85</td>
</tr>
<tr>
<td>Riddar</td>
<td>Jakob</td>
<td>40</td>
</tr>
<tr>
<td>Riley</td>
<td>Danny</td>
<td>20</td>
</tr>
<tr>
<td>Ryan</td>
<td>Dawn</td>
<td>69, 76</td>
</tr>
<tr>
<td>Ryou</td>
<td>Hyoung gon (Frank)</td>
<td>50</td>
</tr>
<tr>
<td>Smith</td>
<td>Suzanne</td>
<td>78</td>
</tr>
<tr>
<td>Spector</td>
<td>June</td>
<td>76</td>
</tr>
<tr>
<td>Stjernbrandt</td>
<td>Albin</td>
<td>91</td>
</tr>
<tr>
<td>Tarabini</td>
<td>Marco</td>
<td>33, 52</td>
</tr>
<tr>
<td>Trask</td>
<td>Catherine</td>
<td>62</td>
</tr>
<tr>
<td>Troell</td>
<td>Eva</td>
<td>7, 18</td>
</tr>
<tr>
<td>Turcot</td>
<td>Alice</td>
<td>83</td>
</tr>
<tr>
<td>Wahlström</td>
<td>Jens</td>
<td>43, 91</td>
</tr>
<tr>
<td>Wang</td>
<td>Fangfang</td>
<td>64</td>
</tr>
<tr>
<td>Warren</td>
<td>Chris</td>
<td>12, 25, 29, 88</td>
</tr>
<tr>
<td>Waugh</td>
<td>Stacey</td>
<td>22</td>
</tr>
<tr>
<td>Wavrin</td>
<td>Luke</td>
<td>14</td>
</tr>
<tr>
<td>Welcome</td>
<td>Daniel</td>
<td>12, 25, 29, 88, 97</td>
</tr>
<tr>
<td>Whitelaw</td>
<td>Holly</td>
<td>48</td>
</tr>
<tr>
<td>Wu</td>
<td>Chaowen</td>
<td>20</td>
</tr>
<tr>
<td>Wu</td>
<td>John</td>
<td>97</td>
</tr>
<tr>
<td>Xiao</td>
<td>Bin</td>
<td>88</td>
</tr>
<tr>
<td>Xu</td>
<td>Xueyan</td>
<td>12, 25, 29, 88, 97</td>
</tr>
<tr>
<td>Yao</td>
<td>Yumeng</td>
<td>73</td>
</tr>
<tr>
<td>Yung</td>
<td>Marcus</td>
<td>62</td>
</tr>
<tr>
<td>Zaklit</td>
<td>Wadih</td>
<td>14</td>
</tr>
<tr>
<td>Zimmerman</td>
<td>Jordan</td>
<td>20</td>
</tr>
</tbody>
</table>