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Abstracts

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Editorial Preface

This book contains the abstracts to the WBV 2017 – the 6th International Conference on Whole-Body Vibration Injuries, in Gothenburg, Sweden, June 19-21, 2017. The excellent work performed by the contributing scientists has made this book a first-class, up-to-date, state of the art review on what is known about whole-body vibration injuries today. The outstanding scientific quality of the abstracts was secured through the review work of scientific committees and organising committee.

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Without the excellent skills of the local organising committee – Christina Ahlstrand abstract and program management, Cecilia Andreasson (administration, layout, and technical editor), Ann-Sofie Liljenskog Hill (administration, economy, and travel) the production of this book would not have been possible. We want to express our gratitude to the contributing authors, session chairs/co-chairs and to the participants who presented papers and contributed in the discussions, for making WBV2017 an outstanding meeting.

Gothenburg in June 2017

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Theme 1 – Vibration & Shock

Predicting discomfort caused by whole-body vibration and mechanical shock

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Introduction

It can be helpful to model understanding of human responses to vibration as transfer functions that represent relationships between vibration and the response of interest. This involves identifying the independent and dependent variables, how they can be measured, and their relationships. Although it is convenient to represent understanding in a simple form (e.g. frequency weightings), the underlying mechanisms involved in human responses to vibration, and therefore the transfer functions, are far more complex than this implies [7,8].

This paper summarises methods of predicting vibration discomfort using transfer functions, the application of the approach, and also the limitations.

Basic understanding

Vibration discomfort can be caused by any or all of six axes (fore-and-aft, lateral, vertical, roll, pitch, and yaw) of vibration at the supporting seat surface (e.g., beneath the ischial tuberosities or the thighs), the back, the feet, the head, and the hands [3,7,12]. Experimental studies have determined the frequency-dependence of vibration discomfort caused by vibration acceleration at most of these locations [9,14,20]. This understanding is reflected in a simplified form as frequency weightings, weightings showing the relative importance of vibration at different locations (e.g., seat, back, feet), and weightings for different directions of vibration (e.g., fore-and-aft, lateral, vertical). There are also data for standing people [18].

The effect of duration can also be considered a weighting. This allows the accumulation of an exposure to vibration, intermittent vibration, or shocks, to be expressed by a single number (e.g., the vibration dose value, VDV) [7,10,21].

Many exposures to vibration involve multiple-frequency vibration, multi-axis vibration, and multi-input vibration. The prediction of vibration discomfort requires a way of summing the components together in a single number reflecting the likely discomfort. Experimental studies suggest a convenient method using root-sums-of-squares over axes and inputs [7,8].

The 'weighting' and 'summation' methods allow the calculation of a single value that represents vibration discomfort. Greater values indicate greater discomfort, so environments can be compared and changes can be made to reduce vibration discomfort. The changes can also be made in computer models to optimise systems and minimise the vibration discomfort.

Assumptions in basic understanding

Assumptions and simplifications made it possible to define standardised methods and construct 'human vibration meters'. Simplifications include using the same weightings for more than one direction or input and the same weightings were used for seated and standing people because there was no data showing the contrary. There were assumptions about the relative contribution of lateral and roll oscillation at frequencies less than about 1 Hz.

Experimental studies found that the relative contribution to the discomfort of different frequencies, different axes, and different locations varies with the magnitude of vibration. Similarly, the weighting for duration varies with the frequency, direction, and magnitude of vibration. Even if fully understood, incorporating these variations into a simple method seems impractical, so simple weightings and a simple fourth-power duration weighting are used.

The phase between frequencies, directions, and locations of vibration can affect discomfort but is ignored in current standards. For example, the phase between seat motion and feet motion affects discomfort around the thighs [13] and discomfort caused by low-frequency lateral oscillation can be offset by roll only when the motions are in phase [2].

Advanced understanding

At frequencies less than 1 Hz, vehicles can have sufficient rotation in roll or pitch for the acceleration measured in the plane of the floor to be influenced by gravity. At frequencies less than about 0.5 Hz, discomfort is similar if the gravitational acceleration (due to roll) is the same as the acceleration caused by translational oscillation. This allows comfort to be improved by counteracting lateral acceleration with roll (as in tilting trains). At frequencies greater than about 0.5 Hz, any roll motion will only increase discomfort [2,19].

Vertical shocks of high magnitude can cause the body can leave the seat and the greatest discomfort can occur on subsequent impact when falling back onto the seat. Predicting the severity of the shock is not simple and not taken into account by current models.

With low magnitudes, vibration at the thighs can be noticeable but the transmission of vibration to the thighs and the frequency-dependence of thigh discomfort differ from the ischial tuberosities. At high magnitudes, vibration in the torso may dominate discomfort.

Posture affects the transmission of vibration to and through the body and contact between the environment and the body. Reclining a seat back changes the orientation of the body relative to the dominant vibration, reduces the mass supported around the ischial tuberosities, and changes the frequency-dependence of discomfort caused by vertical seat vibration.

The perception of one vibration can be masked by another vibration. Masking observed with vibrotactile stimuli and with whole-body vibration varies according to the relationship between the vibration stimuli [16]. In general, there is masking when stimuli excite the same perceptual mechanism but not when they excite different perceptual mechanisms.

There are large differences in vibration perception and vibration discomfort both between individuals and within individuals but little understanding of the extent of the differences or their causes. There may be interesting unanswered questions as to how the degree of discomfort and the frequency-dependence of discomfort depends on gender, age, weight, etc.

Vibration discomfort can be influenced by noise and static seat comfort [11]. The acceptability of a vibration can be determined by factors other than vibration discomfort, including interference with visual, manual, and cognitive activities (including reading, writing, drinking, standing, walking), and motion sickness. These effects have their own evaluation methods with different weightings and are best predicted separately.

Application of understanding

Without a method of predicting vibration discomfort, it is not possible to optimise vibration environments to minimise vibration discomfort. The current model was developed so that it also identifies the frequencies of vibration causing most discomfort, the directions, and the locations causing most discomfort, and the moments in time that contribute most to discomfort. In the frequency domain, the peaks in a frequency-weighted spectrum show the frequencies causing most discomfort. In the time domain, a graphical accumulation of the fourth power of the vibration dose value of the frequency-weighted acceleration time history shows how different events contribute to overall vibration discomfort.

The overall effect of a seat on vibration discomfort is given by the SEAT value – the ratio of weighted vibration on the seat to weighted vibration if the seat were rigid [6]. Standards place limits on SEAT values of some suspension seats but only consider the transmission of vertical vibration to the ischial tuberosities. The minimization of vibration discomfort should consider the transmission of vibration to other locations and also the transmission of vibration in other axes [1]. The overall SEAT value is the ratio of the overall ride on the seat to the overall ride that would occur if the seat were rigid, where the overall ride involves weighting for frequency, direction, location, and duration and summing values as summarised above.

The model of vibration discomfort comes from experiments that yielded the relative discomfort between stimuli. Some experiments have yielded information on how vibration discomfort increases with increasing magnitude of vibration. This varies between vibration frequencies and gives rise to 'non-linearity' in the weightings [14]. Although vibration discomfort can double if the vibration magnitude doubles, this is not the case of all motions. The range of magnitudes of vibration from absolute thresholds for perception [15] to intolerability can be only about 100:1 – much less than corresponding ranges for human perception of sound and light. The magnitude change required to detect a difference can be around 10% [5] and indicates whether there will be benefit from a change to minimise vibration discomfort.

Advantages and disadvantages of representing understanding by transfer functions

Other human responses to vibration are also represented by transfer functions between vibration and its effects (e.g., apparent mass, transmissibility, and changes in performance, physiology, and pathology). There are therefore also transfer functions between the dependent variables (e.g., between vibration discomfort and apparent mass, or between vibration discomfort and pathological changes). If transfer functions are known or assumed between A and B and between A and C then a transfer function between B and C is known. The transfer function between vibration and vibration discomfort is not the same as the transfer function between vibration and an injury caused by whole-body vibration. However, the two transfer functions will be related by another transfer function. A model of vibration discomfort has the advantage and disadvantage that it is not restricted to predicting response at a single location. If neither the 'injury' nor its location is known it seems reasonable to use a model for predicting vibration discomfort to help identify relative risks of different stimuli.

Frequency weightings are implemented using filters and the frequency range of interested is bounded by high-pass and low-pass filters. The filters have convenient phases not based on an understanding of the effects of phase on human responses. With some motions, the phase will have little effect on the weighted value but for other motions (e.g., some shocks and some low frequency motions) the effects of phase can be large and merit greater attention.

The weightings and summation methods needed to model the association between vibration and vibration discomfort can be derived by systematic laboratory experiments but not from field studies. However, since the model is developed for application to field environments it's applicability to predicting vibration discomfort caused by real motions merits study in both the field and high fidelity simulations with multi-axis motions.

Conclusions

The ‘weighting’ approach to representing human responses to vibration makes assumptions and will not always be accurate, but it can identify the important variables and may give useful, and often sufficient, predictions. Alternatives to the weighting method are complex, not fully defined, and probably complex to implement. There is no known method that is generally applicable and capable of providing more accurate predictions of human response.

The weightings and the standards should not be misunderstood as a complete understanding of how to predict human responses to vibration. The critical reader will realise that understanding is far from complete and that there is a need to both assess and optimise the applicability of knowledge to specific situations.

There can be differing views as to whether the model is too complex or too simple. It can be simplified to a few axes or locations but this is insufficient where other axes or other locations contribute to discomfort. It can be more complex by including other locations (head, thighs, low or high backrest) or weightings for low and high magnitude vibration. It can be more complex by including effects on performance [7], postural stability [17], motion sickness [4]. The addition of new weightings may increase the accuracy of predictions but make it difficult to compare measurements. Modifying standards can reduce their usability.

The ultimate test is whether the method of predicting vibration discomfort is sensitive to changes in vibration that alter vibration discomfort. When the method is used to predict other responses, such as risks to health, the same test applies: Is the method sensitive to changes in vibration that alter the risks to health?

Acknowledgements

Much research on vibration discomfort has been undertaken in the Human Factors Research Unit at the Institute of Sound and Vibration Research. The research was made possible by methods and facilities developed with colleagues over four decades, but space limitations prevent individual acknowledgements or citation of all relevant publications. Regrettably, the management of the ISVR did not appoint anyone to succeed the writer before he retired in January 2016 and so the Human Factors Research Unit came to an end. Notwithstanding the unique facilities designed for the study of subjective responses to vibration and many opportunities for further experimental studies, the future of this area in Southampton remains in doubt. The writer would like to

acknowledge the efforts and expertise and the many happy hours working with colleagues who contributed to advancing understanding in this area.

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Adaptation of muscle activity and upper body kinematics after mechanical shocks in seated position

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Introduction

Driving on irregular terrain causes mechanical shocks that may be hazardous to the musculoskeletal system, especially for the neck and lower back region of the spine [1]. Postural reactions are necessary for stabilising the spine. Adaptation is important but is rarely studied for seated positions. The objective was to describe and analyse the adaptation of seated postural reactions in a short-term perspective.

Methods

Five lateral perturbations (peak acceleration ≈13 m/s^2) were delivered from a movable platform to twenty healthy male participants (18-43 yr) in a standardized seated position. Surface electromyography (EMG) was recorded bilaterally in the upper neck, trapezius, erector spinae and external oblique. Muscle activities were normalised to maximum voluntary contractions (MVC). Kinematics were simultaneously recorded with inertial sensors for the head, trunk and pelvis segments.

Results

EMG amplitudes for all muscles, except for the trapezius, significantly ($p< 0.05$) decreased by 0.2% between the first and last perturbation. Neck angular displacements were reduced by more than 2.1° but there were no other kinematic adaptations. Notably, the mean EMG amplitudes did not exceed 10% of an MVC. Muscle onset latencies remained unchanged over time.

Conclusion

The adapted neuromuscular strategy during repeated postural reactions in seated positions seems to prefer a reduced EMG amplitude with minor kinematic alterations. The modest size and the adaptation of the postural reactions for these experimentally induced mechanical shocks suggest no immediate harmful effect on muscles or joint structures.

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Seated postural reactions depends on the complexity of the mechanical shock

Stenlund, T.C. [(1)], Rehn, B. [(1)], Lindroos, O. [(2)], Häger, C.K. [(1)], Neely, G. [(3)], Lundström, R. [(4)]

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Introduction

Driving on irregular terrain causes mechanical shocks that are suggested to be hazardous to the spine and may be associated with musculoskeletal pain among professional drivers1. However, the muscle and kinematic reactions caused by mechanical shocks in seated positions are scarcely studied. Objectives: To describe and compare seated postural reactions due to single-sided mechanical shocks (SSMS) or double-sided mechanical shocks (DSMS) in healthy male adults.

Methods

Twenty healthy male participants (18 - 43 yr) were seated on a movable platform delivering 5 SSMS and 15 DSMS with accelerations of approximately 13 m/s^2. The SSMS was going solely in one lateral direction while the DSMS was initially the same but with different time delays (fast, medium or slow) followed by a lateral motion in the opposite direction (i.e. 360°). Muscle activities were recorded with surface electromyography (EMG) in the upper neck, trapezius, erector spinae and external oblique. The activities were further normalised to maximum voluntary contractions (MVC). Kinematics was simultaneously recorded for the neck, trunk, and pelvis using inertial measurement units.

Results

The evoked EMG amplitudes were significantly higher $p < 0.001$ for the fast DSMS compared the other mechanical shocks. The kinematics showed a greater range of motion of the neck and trunk during the DSMS compared to the SSMS. The most intense muscle activity was found in the external oblique’s with more than 10% of an MVC. The trapezius activity was less than 2% of an MVC.

Conclusions

Mechanical shocks with higher complexity, especially the fast double-sided mechanical shocks in lateral directions, evoked larger seated postural reactions compared to single-sided mechanical shocks. Still the small range of motions in the neck and the rather low muscle activity in superficial muscles, do not imply a high risk for musculoskeletal overload.

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Theme 2 – Marine

Boat seat testing
Lessons from other industries

Gunston, T.

VJ Technology

The introduction of the Physical Agents (Vibration) Directive and the occurrence of some very serious injuries have led to a rapidly growing market for shock isolation seating for use in fast boats.

A fast boat can expose crew and passengers to whole-body vibration magnitudes greater than any form of transport that this author has measured, military and civil; land, sea or air. The impacts between the craft and the waves, particularly when heading against the prevailing sea, cause a distinct sequence of severe repeated shocks. On a powerful boat, the severity of these shocks is often limited only by the willingness of the coxswain to tolerate the discomfort.

The use of suspension seats to reduce whole-body vibration exposures is commonplace for agricultural and industrial vehicles but, as with most vibration isolation systems, a poorly designed seat can amplify rather than attenuate.

For land vehicles, there are established laboratory test standards to help vehicle operators or manufacturers to select a suitable seat. Well-resourced organisations may then carry out subjective and objective tests of sample seats in vehicles before making a final decision.

There are no seat test standards for boats and there is some disagreement on how to take at-sea measurements in an environment that can be very hostile to both humans and measurement electronics. Sea trials of new seat designs can be particularly hazardous as inadequate seat performance may only be discovered by the occupant once the trial is in progress. Sea conditions are notoriously inconsistent, trials are expensive and some manufacturer performance claims have been misleading. A common approach is needed.

An ISO working group with membership including military boat operators (UK, US, and Canada), lifeboat operators (RNLI and KNRM), seat manufacturers and universities is working on the first marine seat test standard for laboratory testing. A laboratory test cannot replicate the complex nature of the real environment but it does allow some aspects of seat performance to be assessed in a controlled and systematic manner. This can help reduce some of the risks, costs, and uncertainties associated with full-scale sea trials.

This presentation will summarise some of the characteristics of the whole-body vibration environment experienced on fast craft and describe some documented or self-reported injuries. Aspects of seat testing from aerospace and agriculture will be related to the marine environment and progress towards a standard test for marine seats will be reported.

Musculoskeletal pain and performance impairments in marine personnel

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High-performance marine craft personnel (HPMCP) reportedly suffer from work-related musculoskeletal pain and performance degradation. One consistent element stipulated to increase the risk of these impairments is the exposure to vibration and repeated shocks (VRS). However, the extent of the adverse effects and their association with work at sea are poorly examined, and the contribution of VRS to the impairments has not been systematically established. In addition, studies are impeded by the void of suitable data collection tools. This project therefore aimed 1) to develop such tools, 2) to quantify the prevalence of musculoskeletal pain and performance impairments, and their association with work at sea, and 3) to determine the contribution of VRS to the impairments. A survey-based investigation was chosen as the most appropriate method due to its feasibility and cost-efficiency. Web-based questionnaires were developed by a consensus panel, aided by experts with either relevant knowledge in the areas of interest and research methodology, or with experience of work at sea. The questionnaires were pilot tested in the study population, with acceleration time-history co-sampled for a subgroup to allow linkage to questionnaire data. Finally, data collection preparations were conducted to allow assessments of aims 2 and 3. Two questionnaires were successfully constructed: One providing an overview of respondents and their work conditions, allowing investigation of aim 2; and one focusing on adverse effects related to VRS, allowing investigation of aim 3. The pilot tests suggested that the questionnaires had acceptable psychometric properties and were feasible, and a complete-population study of aim 2 in approximately 500 subjects is currently underway. In conclusion, a protocol for investigating work-related impairments in HPMCP was developed and preliminary tests showed promising results. The protocol is readily available to the research community, and we call for collaborations to increase the sampling depth.

Monitoring and characterising vibration and shock conditions aboard high-speed craft

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The time dependency of association between exposure to vibration containing repeated shocks and its adverse effects has made it complex monitoring and characterising vibration environments aboard high-speed craft (HSC). Health impairments related to whole-body vibration are expected to follow from weeks to years of exposure while mental and physical fatigue presumably influencing work performance in a time frame of hours, and the shock loads, typical for HSC, can cause instant acute injuries.

This complex situation, therefore, led this study to investigate appropriate measures for real-time analysis of vibration and shock conditions aboard HSC in order to feedback the crew with instantaneous and accumulated exposure severity during operations.

For that, 27, three-hour, simulated acceleration time histories representing an HSC in nine different sea states at three speeds were scrutinised for the correlations between craft acceleration characteristics based measures, computed for different short time sequences, and statistical based measures, describing the severity of each entire acceleration time history. This resulted in recognising a combination of measures adequate for real-time feedback to the crew during as short exposure as 15 seconds using acceleration characteristics based measures: Root-mean-square (RMS), Maximum Transient Vibration Value (MTVV) and Vibration Dose Value (VDV) for real-time analysis. The statistical-based measures: Maximum Probable Extreme Acceleration Peak (MPEAP), the average1/10th and 1/100th highest acceleration peaks ($a_{1/10}$ and $a_{1/100}$ respectively) were used as the severity references in order to be able to link the exposure conditions with health and performance disorders. Finally, the feedback method was verified by characterising exposure conditions of three actual HSC which showed that RMS together with MTVV are capable of analysing the instantaneous exposure conditions and VDV the accumulation in real time using MPEAP as a severity reference. This method allows HSC-crews to be satisfactorily informed about the present exposure severity based on acceleration data from the latest 15 seconds.

Engineering for balance between working conditions and hull loads at high-speed operation at sea

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Simulation-based-design for High-speed craft (HSC) at KTH started with hull loads and motions [1] for improving the structural design. The simulation model for planning craft in waves [2, 3] is now linked to a numerical crew seat model [4]. In the present framework, human response to shock and vibration is introduced for a holistic system performance view on design [5]. Moreover, acceleration peak value statistics has been surveyed improving probability analysis for expected maximum peak magnitudes [6].

In 2009, the Swedish Coast Guard initiated a study on conditions on an HSC unit. It showed that the legislated action and limit values were exceeded after short exposure [7]. Today the crew get feedback on conditions based on acceleration measurements. Nevertheless, the links are weak between mechanical exposure, human response and effects on health and work performance, and the module for evaluation of human exposure is presently in most need for improvement.

In this context, epidemiology, medicine, and health become necessary for improving engineering and the following three strategic aims will be targeted in consecutive steps: First, to prospectively identify risk factors for musculoskeletal pain disorders and reduced work performance. This is on-going. Self-rated data will be collected by tailored web-based questionnaires [8, 9] and craft acceleration recorded as the measure of exposure. Secondly, to quantify the relation between mechanical exposure and human biomechanical response. Exposure is the acceleration of the craft-human interface. At this stage, recorded human response, will be muscle activity, acceleration in the neck and lumbar regions and whole-body kinematics. The third step is to formulate assessment criteria for implementation in the simulation structure.

The research program will improve the simulation-framework ability to assessing the conditions at high speed at sea, enabling human factors integration (HFI) in the design process and open for engineering balanced high-performance marine craft.

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Whole-body vibration exposure during occupational use of high-speed craft

A comparison of standardised assessment methods

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Introduction

High-speed craft can represent a hazardous working environment [1-2]: large magnitude impacts can have short and long-term health effects [3]. This paper aims to evaluate human exposure to vibration during typical transits onboard fast naval craft according to the method for unweighted peak accelerations above 9.81 m/s^2 described in the incoming ISO 2631-5 [4].

Methods

Trials were undertaken onboard ten different craft, including 4 Rigid Inflatable Boats (RIB, 1 equipped with anti-vibration seats), and 1 jet-ski, in three different speeds: slow, medium (10-20 knots) and fast. All craft, including jet-ski, are used two/four hour per day on a daily basis to patrol coastline. Each trial was approximately 45 minutes with sea state between 0 and 1. We acquired and analysed vibrations signals according to the new ISO 2631-5 Draft Standard; R value and risk of injury has been computed for women and men with different body masses and spine endplate areas.

Results

The magnitudes of impacts measured in the present work are in line or lower than previous findings [5-8]; VDV values for fastest boats are in the range 30.5 $m/s^{1.75}$ to 42.3 $m/s^{1.75}$, and they are consistent with values reported in literature [5]. Considering that measurements have been carried out under calm sea state condition, the impacts encountered would have been larger with higher sea states.

The probability of injury risk calculated according to the new ISO 2631-5 standard is low for a big boat, while for RIB and jet-ski is moderate/high; sensible differences are observed for the different individual characteristic. The calculation is based on real reported exposures: 200 working days per year, 3 hours of daily exposure at constant S^A_D, starting at 20 y.o., while different scenarios of years of exposure are taken into account (i.e. from 5 years up to 20 years of exposure). Anti-vibration seats reduce considerably vibration exposure.

Conclusion

In this study, the risk assessment for high-speed crafts is conducted according to the incoming ISO 2631-5. We compare the predicted health risks of high-speed marine crafts according to ISO 2631-1/5 standards [4,9]. Experimental data suggest that VDV and the risk assessment arising by new ISO 2631-5 have roughly equivalent boundaries for probable health effects. However, further studies of WBV-related health risks among high-speed craft workers should be made in order to make the assessment more reliable and applicable in real exposure conditions.

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Theme 3 – Mining

Whole-body vibration exposure and interventions in mining

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Introduction

According to the International Labour Organization, approximately 30 million people are estimated to work in mining globally [1]. Through the practice of extracting metals and minerals from the earth, miners can be exposed to whole-body vibration (WBV) when sitting to operate mobile equipment such as load-haul-dumps, haulage trucks, loaders, graders, dozers, locomotives, and continuous miners. Furthermore, changes in mining practices which have removed some vibrating tools from the hands of workers by semi-automating drilling and bolting have led to an increase in the number of workers exposed to foot-transmitted vibration (FTV). Moreover, technical advances associated with battery operated, tele-remote, and semi-autonomous mobile equipment operations are projected to have a profound impact on the mining industry and worker exposure to vibration. The objectives of this paper are to, 1) briefly review the measurement standards and health risks associated with exposure to WBV and FTV, 2) review current exposure data associated with underground mining, and 3) briefly highlight control strategies shown to be effective for vibration reduction mining.

Health risks and standards

The transmission of vibration through the human body can lead to health problems, including, low back pain, neck pain, headaches, and gastrointestinal track problems. Operation of mining equipment is often associated with additional ergonomic risk factors due to prolonged periods of sitting and awkward working postures such as neck rotation and trunk flexion, lateral bend and rotation [2]. When the combined health risk of WBV exposure and posture demands are considered, it is not surprising to find higher than average reports of musculoskeletal disorders for underground mobile equipment operators than the rest of the underground mining population [2].

Health risks associated with WBV are typically compared to criterion values published in standards such as ISO 2631-1 and EU Directive 2002/44/EC; however, evaluation of health risks associated with exposure to FTV are less clear. According to ISO 2631-1 health effects associated with exposure to FTV, when standing, can be evaluated; however, several researchers have found this approach to be inadequate as the dominant frequency of exposure for miners experiencing FTV is generally above 20 Hz [3,4]. Furthermore, miners exposed to FTV are more likely to complain of tingling and numbness in the feet and clinicians have documented compromised blood flow to the toes resulting in a diagnosis of vibration-induced white-foot [5].

Vibration exposure associated with operation of mining equipment

Whole-body vibration exposures associated with the operation of surface and underground mining equipment are summarised in Table 1. Operators of 16-tonne haul-trucks, bulldozers, load-haul-dump, articulated haul-trucks, and shovels were exposed to WBV above the EU 2002/444/EC Exposure Limit Value. However, care should be taken when interpreting the reported data as a number of factors can influence vibration exposure measurements including vehicle size, vehicle maintenance, operating speed and road conditions [6,7].

Exposure data for workers exposed to FTV are limited to a few published studies [3,4,8,9,10]. Based on the available data, operators of Cavo loaders appear to be exposed to the highest magnitude of FTV (2.3 m/s^2) [9] and crusher operators the least (0.2 m/s^2) [10]. However, reports of vibration-white-foot appear to be more prevalent in bolter, jumbo drillers and raise drill miners suggesting the dominant FTV exposure frequency might be more relevant than the magnitude of exposure where the development of vibration-induced white foot is considered. For example, miners drilling off a raise platform were reported to develop vibration white-toes (dominant FTV exposure frequency reported to be 40 Hz)[8,3], a bolter was diagnosed with vibration-induced white feet (dominant FTV exposure frequency reported to be 40 Hz)[5] and a jumbo drill operator diagnosed with vibration-induced white feet was exposed to FTV with a dominant frequency at 31.5 Hz[3,4].

Table 1: Vibration exposure data reported in the literature for mining equipment. Exposures above the EU Directive 2002/44/EC exposure limit value for frequency-weighted rms acceleration (1.15 m/s^2) and vibration dose value (21 m/s^{175}) are **BOLD**. Daily exposure action value for frequency-weighted rms is 0.5 m/s^2, and 9.1 $m/s^{1.75}$ for VDV.

Equipment Type	Application	$A(8)$ m/s^2	VDV $m/s^{1.75}$	Reference
Haul Truck 16 tonne	underground nickel mine	**1.20**	----	9
Haul Truck 30 tonne	open pit mine	0.69	14.5	17
Haul Truck 36 tonne	open pit mine	0.78	16.4	17
Haul Truck 50 tonne	aggregate stone quarry	0.99	---	18
Haul Truck 70 tonne	aggregate stone quarry	0.58	---	18
Haul Truck 100 tonne	open pit mine	0.74	12.4	17
Haul Truck 136-181 tonne	open pit coal mine	0.5	11	7
Haul Truck 150 tonne	open pit mine	0.61	10.8	17
Haul Truck 190 tonne	Columbia Mine	0.37	9.1	19
Haul Truck 240 ton	overburden mining	0.71	---	20
Haul Truck 240 ton	Columbia Mine	0.39	9.0	19
Haul Truck 290 tonne	open pit coal mine	0.4	10	7
Haul Truck 320 tonne	overburden mining	0.67	---	20
Haul Truck 320 tonne	Columbia Mine	0.39	8.3	19
Haul Trucks	Barents Region	0.43	5.3	21
Bulldozer	underground nickel mine	**1.64**	---	9
Bulldozer	surface coal mine	0.59	11.8	22
Bulldozer	South African Mine	2.0	---	10
Dozer (Wheel; track)	Barents Region	0.7	8.7	21
Grader	underground nickel mine	0.79	---	9
Grader	Barents Region	0.38	4.9	21
Front end Loader	South African Mine	4.2	---	10
Wheel Loader	Barents Region	0.49	7.7	21
Dumper	coal mine	1.10	13.84	23
Dumper 100 tonne	coal mine	0.89	------	24
LHD 3.5 yard	underground gold mine	1.12	---	9
LHD 1.5-4 yards	underground gold mine	**1.7**	**34.0**	25
LHD 3-6 yards	underground gold mines	0.97	**22.96**	26
LHD 7 yard	underground nickel mine	0.52	---	9
LHD 6-8 m^3	underground nickel mine	0.74	17.41	27
LHD 6-11 yard	underground nickel mines	0.82	19.94	26
LHD 8-11 yard	underground nickel mine	1.0	**22.5**	25
Articulated haul Truck	South African Mine	**3.4**	---	10
Hydraulic Face Shovel	South African Mine	**4.4**	---	10

Control Strategies

The hierarchy of controls (elimination; substitution; engineering; administration; and personal protective equipment) should be followed to reduce the risk of adverse health effects from exposure to vibration [11]. Although elimination and substitution are preferred these controls have not always been practical; however, recent advances in tele-remote operations and semi-autonomous vehicles, which remove the worker from the vibration source, are becoming a viable option [12]. Advances in battery technology has led to an increase in the number of battery operated load-dump and haul trucks underground resulting in less vibration exposure for the operator[13]. Previous research has also shown engineering solutions such as ride-control [6], seating [6,14], and isolated platforms (for FTV) can result in less vibration exposure for the operator [3,4]. Furthermore, research continues to support vibration exposure reduction with improved road maintenance and decreased driving speed [6,7]. Researchers have also found there may be a benefit to matting as personal protective equipment for workers exposed to FTV [3]. Control strategies targeting working postures, including seat rotation[15] and the installation of cameras[16], should also be implemented to enable equipment operators to maintain a neutral sitting postures.

Conclusions

Health effects associated with exposure to WBV can be mitigated if daily exposure is kept below established criterion values (i.e. EU Directive 2002/44 EC, ISO 2631-1). This can be accomplished through implementation of effective control strategies including purchasing policies to obtain equipment with lower vibration exposure emissions, installation of seats suited to the vehicle and operating environment, maintenance of equipment and roadways, a reduction in travel speeds, and adoption of interventions to enable drivers to minimize sustained periods of neck and trunk rotation. Additional research is required to identify effective control strategies for FTV reduction.

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Whole-body vibration exposures and back pain among miners in the subarctic region

A cross-sectional analysis

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Background

Occupational exposure to whole-body vibration (WBV) is associated with an increased prevalence of self-reported musculoskeletal symptoms, especially low back pain (LBP) [1].

Objectives

The aim was to compare the prevalence of LBP among drivers of mining vehicles with non-drivers and study the exposure of WBV among male and female mine workers in the Subarctic Region.

Method

In the period from November 2012 to August 2014, this cross-sectional study was carried out at three mines in Finland, Norway, and Sweden as part of the MineHealth project [2]. The mine workers completed a questionnaire where they were asked whether they had suffered from LBP during the previous 12 months. They were also asked about their daily driving of mining vehicles (hours and type of vehicle)[3]. Measurements of whole-body vibration were conducted on 95 different mining vehicles during normal work in accordance with international standards [4].

Results

The questionnaire was completed by 453 workers of which 283 were vehicle drivers (218 male, 65 female). For the drivers, the mean daily exposure to whole-body vibration, $A(8)$, was 0,46 m/s^2 (SD 0,21 m/s^2). Female drivers had a significantly higher exposure to WBV than male drivers. The reported 12-month prevalence of lower back pain (LBP) was 68% among non-drivers compared with 60% among drivers. Female workers, both drivers, and non-drivers indicated a higher prevalence of LBP compared to male workers. Drivers with low daily exposure to WBV reported a lower prevalence of lower back pain compared with high exposed drivers, although not significant.

Conclusion

This study provided only weak support for the hypothesis that drivers of vehicles report a higher prevalence of LBP than non-vehicle drivers. There was also only an insignificant tendency towards an exposure-response relationship. The location of the mines in a subarctic region did not influence the result.

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Vibration toolkit

An occupational health intervention focused on vibration exposure in the mining industry

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Introduction

Occupational health and safety (OHS) programming is critical in influencing workers' knowledge, attitudes and/or behaviours regarding hazardous workplace exposures and occupational injuries and diseases [1]. Vibration education and management programs are scarce and their implementation within an organisation's OHS programming is underdeveloped. The objective of this study is to develop, implement, and evaluate a whole-body vibration educational toolkit to improve knowledge, attitudes, and/or behaviour beliefs associated with underground mining-related vibration exposure and ultimately to improve implementation of control strategies to mitigate exposure.

Methods

The "Vibration Toolkit" was designed to provide current evidence-based practices that could be easily implemented within existing OHS systems included safety presentations, fact sheets, safety cards, posters, and an iPod Touch with a software application to measure whole-body vibration. The resources were designed to educate workers and supervisors using a variety of media on developing symptom awareness, identifying hazards and control strategies, and fostering dialogue between workers, health and safety professionals and employers within the workplace to implement control strategies.

Results

The Vibration Toolkit will be implemented within an underground mining operation in Northern Ontario. An anticipated 100 participants will complete a baseline survey, which examines their knowledge, attitudes, and behaviour beliefs as they relate to vibration in addition to a detailed work history and discomfort rating scales. Baseline survey results will inform customization and implementation of the Vibration Toolkit resources over a period of three months. One month following the intervention, participants will repeat the survey measures. Survey results from both pre- and post-implementation of the Vibration Toolkit will be presented.

Discussion/Conclusion

Understanding worker's knowledge, attitudes and behaviour beliefs regarding vibration exposure is important to assist with education, prevention, and control strategies in the mining industry.

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Use of a free iOS application to measure and evaluate whole-body vibration at coal mines

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Introduction

Workplace management of whole-body vibration exposure requires systematic data collection in conjunction with variables influencing vibration amplitudes. The cost and complexity of commercially available measurement devices is an impediment to routine workplace data collection. An iOS application (WBV – ergonomics.uq.edu.au/wbv) installed on a fifth-generation iPod Touch provides an accurate means of measuring whole-body vibration [1-4].

Methods

Long duration measurements (N=135) were obtained from a range of surface coal mining equipment and 62 measurements from underground coal mining equipment. ISO2631.1 describes procedures for measurement of whole-body vibration and provides guidance regarding the evaluation of health effects, defining a “Health Guidance Caution Zone” (HGCZ). The WBV application calculates both VDV and rms values for comparison with the HGCZ for a range of exposure durations.

Results

65 measurements were initially obtained from surface equipment during normal operations. The highest measurements were obtained from dozers prompting collection of a further 70 measurements. The majority of measurements exceeded the HGCZ with 25 exceeding the VDV(10), and 20 exceeding both VDV(10) and rms. values. 62 measurements were obtained from a range of underground equipment during normal operations. The majority of measurements exceeded the HGCZ with highest values obtained from shuttle cars and Load-Haul-Dump equipment.

Discussion/Conclusion

As well as allowing valid assessments of health risks to be undertaken in the workplace, identifying the combinations of factors leading to elevated vibration amplitudes provides valuable insight into potential means of implementing effective risk control interventions. The ability to easily collect whole-body vibration data allows the potential effectiveness of proposed control measures to be assessed across different occupational groups as part of the risk management process.

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Health economic and whole-body vibration

Reducing risk and costs associated with back pain among bus and truck drivers

Successful interventions

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Seat research has shown that the type of seat matters, and affects how much terrain-induced vibration is transmitted to a bus or truck driver. Around 60 years ago, it was typical for bus and truck seats to only adjust in height; there was no shock-absorbing capability built into seats. In the 1960's, mechanical suspension seats were introduced, air-suspension (passive) seats followed in the late 1970's, and these seat advancements were thought to reduce whole-body vibration (WBV) exposures. In 2010, active-suspension truck seats became commercially available. Research has shown that the majority of the industry-standard air-suspension truck and bus seats used today only attenuate between 5 to 15% of the vehicle-transmitted vibration. In a one-year Randomized Controlled Trial, two groups of truck drivers with self-reported low back pain received different seating interventions; one group (n = 20) received industry-standard air-suspension seats, and the other group (n = 20) received active-suspension seats. The active-suspension seat group had a 50% reduction in WBV exposures, self-reported over a 30% reduction in low back pain (an amount considered clinically meaningful) and self-reported several other improvements in health outcomes. In contrast, the drivers that received the air-suspension seats had a 15% reduction in WBV exposures and self-reported little to no change in other self-reported health outcomes. Since activesuspension seats have a notable impact on WBV exposures, a claims database containing fifteen years of data from a regional bus municipality was used to perform predictive cost-utility analysis (CUA), to determine whether the installation and use of different types of bus driver seats would affect workers compensation costs. A decision-analytic Markov model was part of the CUA and predicted the probability and the cumulative costs of bus drivers filing low back and/or neck claims over the 15 years (the duration that buses were kept in operation). In the 1,500-bus fleet, the active-suspension seat was estimated to lower WBV exposures, reduce low back pain claims, and save the bus municipality $4.8 million dollars. A static, height-adjustable seats without a shock absorbing suspension did not alter WBV exposures but were estimated to save $2.0 million dollars over the same period, through reduced seat maintenance costs. A renaissance in seat suspension design is starting to occur, where seats have not only been shown to substantially reduce WBV exposures, but also appear to reduce self-reported low back pain. CUA's can demonstrate that the savings in health claims likely outweigh increased costs of purchasing higher performing seats.

Theme 4 – Driving I

Development of a multi-body model of the seated human body to predict spinal forces during vertical whole-body vibration

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Introduction

Whole-body vibration increases the mechanical loads in the spine associated with low back pain and risks of spinal injury. Muscle activity required to maintain postural stability can contribute to the mechanical loads [1]. This study developed a multi-body model of the seated human body with muscles to predict forces in the spine during vertical whole-body vibration.

Methods

An eight degree-of-freedom multi-body model of a subject (69 kg, 168 cm) in a normal sitting posture was developed and optimised to reflect measured biodynamic responses (apparent masses and transmissibilities [2]). Muscle forces were represented as force vectors acting on the thoracic spine and the pelvis.

The spinal forces in the vertical and fore-and-aft directions at the L5/S1 intervertebral disc were estimated from the sum of the predicted static and dynamic forces in both directions. The static spinal forces were predicted from a lever-arm representation of the upper body above the L5/S1 disc. Frequency-dependent transfer functions between the vertical seat acceleration and the dynamic forces in the spine were predicted.

Results

The transfer functions between vertical acceleration at the seat pan and vertical and fore-and-aft spinal forces showed a resonance around 5 to 6 Hz, similar to the principal resonances in the vertical in-line apparent mass and the fore-and-aft cross-axis apparent mass.

The contributions from muscles to the static spinal forces were comparable to the forces from gravity acting on the mass of the body supported on the intervertebral disc. During vertical whole-body vibration the predicted dynamic muscle forces made significant contributions to the dynamic spinal forces in both vertical and fore-and-aft directions.

Discussion

The vertical and fore-and-aft spinal forces predicted by transfer functions close to 0 Hz should approximate the static spinal forces predicted with the lever-arm system to maintain postural stability.

Conclusions

Modelling of muscle forces is necessary in biodynamic models in predicting spinal forces.

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Effectiveness of tractors certified seats for attenuation of whole-body vibration

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Introduction

The European legislation (Commission Delegated Regulation N° 1322/2014) and the international standards (ISO 5007) currently require the use of only z-axis for the certification of agricultural and forestry tractors seats. However, it is known as well as stresses on the other axes (x, y, roll, pitch, and yaw) are very important for the operator's exposure to WBV. This study aims to verify the efficacy of these standards in operational conditions and to investigate the vibrational response of the seats also to all translational and rotational axes.

Methods

Several types of seats (mechanical and pneumatic) certified according to current regulations were subjected to laboratory (on a six degree of freedom shaking table) and field tests with multiaxial vibratory signals. The tests were carried out by two operators with very different physical characteristics on different types of tractors of category A and class II (unladen mass of 3600 - 6500 kg). For each seat, the relative vibration ratios were calculated. For each operator, main dose indices from ISO 2631 were calculated.

Results

The results show that, on the field, some seats seem to amplify the vibratory signal and generate total vibratory dose values on operator greater than those calculated in the laboratory with the standard certification protocols.

Conclusion

Hence the need to consider a review of the certification rules of agricultural and forestry tractors seats.

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About the risk of exposure to whole-body vibrations among motorised drivers trucks in logistics

Supply of an occupational health service

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Introduction

A technical and medical team from the ACMS company, the biggest occupational health service of the Paris area, has focused on logistics. Based on the assessment of whole-body vibrations (WBV) generated by motorised trucks, the question is how to assist companies and their employees in the prevention of occupational diseases?

Methods

WBV measures were made using tri-axial accelerometers during 15 to 40 minutes (standardised to an eight-hour reference period), one located on the forklift's seat and two others, one on the platform and one for detecting the presence of the rider on the lift pallet truck.

Results

Data were collected between 2012 and 2016 in 15 various firms and referred on 72 motorised trucks: 33 forklift trucks and 39 lift pallet trucks. The results of working exposure were classified according to daily action exposure (0,5m/s^2) and limit value (1,15m/s^2) defined by the UE directive 2002/44/EC and French decree 2005-746: 4 measures above 1,15 m/s^2 for standing drivers exclusively on lift pallet trucks, 32 measures between 0,5 and 1,15 m/s^2 and 36 measures below 0,5 m/s^2. Therefore, 50% of measures were above the regulatory threshold, triggering the prevention process. 50% of standing trucks and 50% of forklift trucks reported measures above 0.5m/s^2 during loading or unloading activities (86%). The axis fully responsible for the risk was the vertical axis (98,6%).

Discussion

In order to reduce the effects of whole-body vibrations and their consequences on health, our recommendations are fourfold: equipment (replacement of outdated equipment, preventive maintenance, speed reducing devices), working environment (floor maintenance, dock leveller, lighting), working organisation (optimisation of inventory flows, traffic plan, driving time), driver behaviour (adapted driving, seat adjustment).

Conclusion

Results and recommendations have been explained to employers and employees. They have led to the coconstruction, for each company, of an action plan. The latter will be monitored regularly by the ACMS team.

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Whole-body vibration of drivers and co-drivers in trucks

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Introduction

Whole-body vibration (WBV) while driving trucks is discussed as a risk factor for lumbar spine disorders of drivers and co-drivers. The aim of this study is to investigate the effect of the suspension of both seats in the cab on the exposure in 54 trucks by field measurements.

Methods

The exposures of WBV were measured for professional seated drivers on the seat surface and on the seat mounting point during a representative working task (DIN EN 14253 and ISO 2631-1). It was, therefore, possible to measure the transmission factors of the driver's and co-driver's suspension seats. The Power-Spectral-Density (PSD) of the acceleration measured at the seat mounting point offers the possibility to create a test curve for a laboratory seat test (DIN 45678:1994).

Results

The vibration measurements from trucks at the seat surfaces of the driver's and co-driver's seats resulted in vertical whole-body accelerations below $a_w \leq 0.45$ m/s². However, since the co-driver's seats were in most cases not equipped with suspension systems, the exposure of the co-drivers was on average larger than for the drivers. The PSD shows the maximum of the amplitude at a frequency of 2.1 Hz.

Discussion

The amplification of the acceleration by the non-suspended seats could lead to WBV exposures above the action limit of the European Union for large exposure durations (e.g. 19h per day when driver and co-driver switch their position during the day). On the basis of the PSD results, it is possible to redesign the test curve illustrated in DIN 45678:1994, which can be used for seat testing.

Theme 5 – Driving II

Understanding working conditions of long-haul drivers: A crucial step

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Introduction

Truck driving represents the second most prevalent occupation for men in Canada [1]. Truck drivers are exposed to long hours of sedentary work and sitting postures, lack of sleep, noise, whole-body vibration (WBV) and psychosocial risks such as stress related to traffic, financial stress, regulations and waiting times. Health problems such as obesity, high blood pressure, diabetes, sleep apnea, low back pain and road accidents have been described [2-8]. The objectives of this study are to document the impact of long working hours on cardiovascular health, the prevalence of compensated cardiovascular diseases, the risk of road accident related to fatigue and fatigue induced by WBV among Quebec professional drivers.

Methods

We performed a literature review in Ovid MEDLINE(R), from 1946 to 2016 in English scientific articles focusing on the keys words: cardiac disease, heart disease, coronary heart disease (CHD), long working hours, fatigue, WBV. We analysed a database of professional drivers who applied for compensation for a cardiac disease to the Quebec workers' compensation board (1997-2015) and a register of 83 fatal road accidents in which fatigue was the primary cause and/or a contributory factor (1990-2015).

Results

Truck drivers are exposed to unhealthy working conditions leading to fatigue [8]. The literature review suggests an excess of CHD risk and stroke for employees working long hours [9-10]. WBV can further cause fatigue [11-12].

The database reveals nine CHD compensated cases in truck drivers compared to 89 CHD compensated cases in other professions. Among 83 fatal road accidents (including other professions), eight were related to fatigue.

Conclusion

Truck drivers are exposed to many occupational risk factors that are inter-related and difficult to disentangle. Long working hours are related to an increase risk of cardiovascular disease, accidents, and musculoskeletal disorders. On the basis of this study, a holistic approach should be developed.

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Analytical and experimental studies on human comfort in a combat vehicle (cv) during steady state runs and firing

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Introduction and objectives

Extremely uncomfortable levels of vibration are produced in a CV as it moves over an uneven terrain, thereby imposing a considerable amount of physical stress upon the crew. The aim of the present work is to assess ride comfort at crew locations in a tracked CV during steady state ground runs and firing.

Methodology

Studies during steady state runs

The vehicle chosen for the study was a military tank with six wheel stations and torsion bar suspensions on either side. Many earlier studies have used rigid body models [1,2]. In the present study, a full multibody dynamics (MBD) model of the CV and Sinusoidal and Aberdeen Proving Ground (APG) tracks were generated using MSC ADAMS (ATV) software. Accelerations at driver's, commander's and trooper's locations were computed during a run at 15 km/h and were compared with those obtained from measurements at the same locations. Also, the root mean square (RMS) accelerations in 1/3 octave bands were compared with ISO 2631 for assessment of ride comfort. Daily exposure values, *A*(8) and vibration dose values (VDV) were also calculated.

Studies during firing

These studies were conducted experimentally with the CV remaining stationary at the test firing facility at Ordnance Factory, Medak, The firing was conducted in two modes: single shot and rapid fire of 8 rounds, the locations of measurement being the same as for the steady state runs and VDV was computed.

Results and discussion

There is a good correlation between computational and experimental results from the steady state runs. The vibrations levels are higher on the Sinusoidal track than on the APG. Responses on both the tracks revealed distinct high magnitude peaks in the 0-6 Hz range, irrespective of the location and direction of the measured vibration. The acceleration at the commander's seat touched the 2.5 hour ISO fatigue decreased proficiency (FDP) boundary on the Sinusoidal track. At other locations, the FDP touched 4 hours on Sinusoidal track and 8 hours on APG track, respectively. The mean *A*(8) values based on seat vibration of the CV exceeded the recommended action value of 0.5 m/s^2 but remained below the exposure limit of 1.15 m/s^2, irrespective of the track considered.

In the firing studies, magnitudes of vibration were higher than those generated during the steady state runs; besides, vibrations were higher during rapid firing. The maximum acceleration was obtained in the longitudinal direction at all crew locations, with highest values at the driver's seat. Besides, the VDV exceeded the daily exposure action value at the driver's seat owing to its proximity to the gun barrel but was found to be well below the daily exposure limit value.

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Thin and lightweight suspension seat for small trucks using polyurethane foam as suspension

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Background

Trucks and buses are often equipped with suspension seats to reduce various health risks to drivers as well as fatigue and discomfort due to vibration. However, cab-over small trucks don't have enough space for conventional suspension seats with thick suspension units.

Purpose

The purpose of this study was to develop a new space-saving suspension seat with good vibration absorbability.

Method

To reduce the height of the suspension unit, we adopted a polyurethane foam pad with low spring constant, high damping and high durability as suspension, and attached it to a contoured shell which supported the seat pad. To evaluate the dynamic performance, vibration levels of three types of occupied truck driver's seats were measured and compared: a normal seat (full foam), a mechanical suspension seat and the thin suspension seat which we developed.

Results

The suspension seat which we developed was approximately 70 mm thinner and 13% lighter than conventional suspension seats. It demonstrated significantly higher performance in terms of vibration isolation than the normal seat and the conventional suspension seat ($p<0.01$), and the magnitude of frequency -weighted acceleration transmitted to the human body was about 25% less in the seat we developed than in the normal seat. This means the time duration of the equivalent vibration exposure doubles by using the thin suspension seat [1].

Conclusions

We developed a new thin and lightweight suspension seat by replacing a mechanical spring and a damper with a polyurethane foam pad. This seat enabled the installation of a suspension seat to a cab-over small truck even though it traditionally has insufficient space for a seat suspension unit.

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New hydraulic Active Vibration Control Seat for vibration protection of agricultural operators

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Introduction

The typically marketed seats have either passive vibration control systems which usually do not prevent the whole-body vibrations risk or hybrid dampening system where the counter-vibration action is actuated via an oil-hydraulic cylinder while the position control is executed via an air spring acting in parallel. The INAIL Research Center close to Rome has developed a seat prototype with a purely active control system, i.e. which does not need, to generate the signal of counter-vibration and of equilibrium position control, of other actions besides that exerted by the oil-hydraulic actuator ruled by a microprocessor.

Methods

The Active Vibration Control (AVC) system of this seat pertains the vertical axis only, the control actuation is realized by a hydraulic system and thanks to an innovative “self-levelling” technique, to the counter-vibration signal is summed the restore signal of the static level of the seat, the control of which is necessary to assure the maximum dynamics. The passive interventions on the vibrations to the operator give, indeed, the best performances in medium-high frequency regions; the active control device on this seat, instead, is able to give satisfactory performances also at low frequencies.

The seat with AVC system activated, anchored to a vibrant table able to generate signals along 6 degrees of freedom, has been excited with sinusoidal signals of peak-to-peak amplitude of 20 mm, from 2 to 6 Hz, and accelerometer data have been acquired on the vibrant table and on the seat.

Results

The attenuation measured on the seat, for the various frequencies, is always greater than 60%. Excellent attenuation results are being obtained by exciting it with random signals from 2 to 5 Hz.

Conclusions

From the first experimental measurements, it emerges an effective vibrations reduction at low frequencies, due to the AVC system.

Determination of vibration and stress induced by random excitation in different parts of the human body using finite element method

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Introduction and Objectives

Whole-body vibration occurs when vibrations from a vehicle are transferred to the human body through seat, feet or hands, producing different effects such as motion sickness, low back pain, etc. The aim of this research is to compute the accelerations and stresses induced in a standing and seated human body when subjected to random excitation using finite element (FE) analysis.

Methodology

Anatomically accurate FE models are developed from the solid model procured from TurboSquidTM. Meshing of these models is done in Altair - Hypermesh using 10-noded tetrahedron elements. Two FE models are used: (i) bone only model and (ii) model with bones and tissues. Both the models are analysed in two different positions: (i) standing human fixed at the feet and (ii) seated human fixed at the pelvis. The bones are connected to each other using CELAS1 and rigid elements, with stiffness properties of ligaments and bones taken from literature [1,2]. Inputs to these models are the random signals from bus, truck and military tank, imparted at the feet to the standing human body and at the pelvis to the seated human body.

Results

Natural frequencies and mode shapes are obtained for both models and for both positions. Natural frequencies of the standing human bone only model are as follows:- head: 2.6 Hz, pelvis: 5.9 Hz, shoulder: 3.9 Hz, thorax: 12.7 Hz, spine: 18.4 Hz, hips, and legs: 26.8 Hz. Displacements, accelerations, and stresses are obtained at different parts over a range of frequencies. Frequency of maximum accelerations for different parts subjected to random vibration analysis, taking truck power spectral density as input are as follows:- pelvis: 6 Hz, head: 3 Hz and 11 Hz, neck: 21 Hz, legs: 21 Hz and 69 Hz. Acceleration responses from bus and military tank input are plotted in 1/3 octave bands and compared with ISO 2631 reduced comfort boundary, while accelerations from truck are compared with ISO 2631 fatigue decreased proficiency boundary. Maximum exposure time is also computed. Vibration-sensitive parts are identified in standing and seated positions by analysing the stresses induced at different frequencies.

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Theme 6 – Back pain I

Low back pain and exposure to whole-body vibration and mechanical shocks

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Background

Low back pain (LBP) is a symptom frequently complained by people over their lifetime. Surveys of the general population have reported that the one-year prevalence of LBP ranges from 0.8% to 82.5% (mean: 38.1%) [1]. The one-year incidence of LBP ranges between 1.5 and 36%, and recurrence at 1 year varies from 24 to 80%. The fifth European Working Condition Survey (EWCS, 2010) has reported that among 35476 subjects who had been at work (as an employee or employer/self-employed) during the past week, the overall one-year prevalence of back pain was 46.1% (95% CI 45.5-46.6) [2]. The prevalence of back pain by occupation varied from 32.7% (armed forces) to 62.3% (agricultural, fishery and related labourers).

In epidemiological studies of occupational groups, (low) back disorders have been found to be related to exposures to whole-body vibration (WBV) [3]. In the 2010 EWCS investigation, prolonged working time with exposures to vibration ("almost all of the time" or "all of the time") was associated with a prevalence of back pain of 61.2% [2]. Drivers and mobile-plant operators showed the highest adjusted prevalence ratio for back pain (aPR 1.36; 95% CI 1.18-1.58) when compared with the reference group of teaching professionals. In some European Countries (e.g. Belgium, France, Germany, Italy, The Netherlands), (low) back disorders occurring in workers exposed to WBV are considered to be an occupational disease which, under certain conditions regarding intensity and duration of exposure, may be compensated.

Lower back disorders and WBV exposure

Epidemiological reviews have suggested that there is strong evidence for an association between occupational exposure to WBV and an increased risk of (low) back pain, sciatic pain, and degenerative changes in the spinal system, including lumbar intervertebral disc disorders [3]. In a personal meta-analysis of cross-sectional studies published between 1986 and 2014, the combined prevalence odds ratio (POR), adjusted at least for age, for 12-month LBP was 1.87 (95% CI 1.52-2.30) in 28 driver groups with exposure to WBV from agricultural, industrial or public utility vehicles when compared with unexposed control groups. In 12 driving occupations, the combined POR for 12-month prevalence of sciatic pain was 1.67 (95% CI 1.25-2.23).

The role of WBV in the etiopathogenesis of low back injuries is not yet fully clarified since occupational exposure to harmful WBV is often combined with postural load as in professional driving. Individual characteristics (age, anthropometric characteristics, smoking habit, constitutional susceptibility), and previous back traumas are also recognised as important predictors for low back disorders, while the influence of psychosocial risk factors is still uncertain. Since injuries in the lower back are disorders of multifactorial origin, it is hard to separate the contribution of WBV exposure to the onset and the development of low back troubles from that of other individual and ergonomic risk factors. Nevertheless, epidemiological studies of specific driving occupations (e.g. drivers of industrial machinery or off-road vehicles) have consistently shown significant associations between lower back disorders and exposure to WBV when this latter has been measured and evaluated with appropriate metrics of intensity and duration of vibration [3].

To protect the workers against the risk from exposure to vibration at the workplace, the EU Directive on mechanical vibration [4] has established daily action values and daily exposure limit values for WBV, expressed in terms of either $A(8)_{max}$ in ms^{-2} rms or VDV_{max} in $ms^{-1.75}$. In a committee draft of ISO/CD 2631-5, a method is proposed to estimate internal spinal forces for occupational exposures to vibration containing multiple shocks [5]. The lumbar spine response to vibration is assessed by means of dynamic finite element models anatomically adapted to the anthropometry and posture of the exposed workers. The assessment of health risk is based on the calculation of the daily compressive dose, S_{ed} (MPa), and the risk factor R (non-dimensional units), derived from the relation between dynamic and static internal spinal forces under consideration of individual variables such as the age of the subject at which exposure started, the daily and lifetime duration of exposures to WBV, the body mass, the body mass index and the posture of the driver.

In a prospective cohort study of low back outcomes in professional drivers of the VIBRISKS project, the performance of the measures of daily WBV exposure established by the EU Directive to predict the occurrence of low back disorders was compared with that of the measures of internal lumbar load according to ISO/CD 2631-5 (Table 1).

A measure of goodness-of-fit suggested that the measures of internal lumbar load (S_{ed}, R factor) performed better for the prediction of low back disorders than the EU Directive measures $A(8)_{max}$ and VDV_{max}. Since these latter are measures of “external” vibration exposure, it may be assume that they reflect only partially the spinal forces acting on the lumbar structures while the measures of internal lumbar load, which are calculated on the basis of individual characteristics, working postures and intensity and duration of vibration exposures, seem more appropriate to predict the likelihood of low back disorders. The VIBRISKS study is the first one which investigated the validity of the ISO method to assess the health effects of vibration containing repeated mechanical shocks. Further studies are needed to validate epidemiologically the ISO/CD 2631-5 proposal [5].

Table 1. Relationships of 12-month low back outcomes to measures of external WBV exposure according to the EU Directive ($A(8)_{max}$, VDV_{max}) and measures of internal lumbar load according to ISO/CD 2631-5 (S_{ed}, R factor). Odds ratios, crude (cOR) or adjusted by confounders (aOR) and robust 95% confidence intervals (95% CI) are estimated by means of transition longitudinal logistic models.

12-month outcomes	Measures of WBV exposure	cOR (95% CI)	aOR (95% CI)
Low back pain	$A(8)_{max}$ ($ms^{-2}\times10^{-1}$)	1.06 (0.92–1.21)	1.03 (0.89–1.19)
	VDV_{max} ($ms^{-1.75}$)	1.01 (0.96–1.07)	1.00 (0.95–1.06)
	S_{ed} (MPa × 10^{-1})	1.20 (0.97–1.49)	1.17 (0.90–1.51)
	R factor (units × 10^{-1})	**1.22 (1.04–1.43)**	**1.25 (1.05–1.50)**
Sciatic pain	$A(8)_{max}$ ($ms^{-2}\times10^{-1}$)	**1.14 (1.00–1.29)**	1.13 (0.99–1.29)
	VDV_{max} ($ms^{-1.75}$)	1.03 (0.98–1.09)	1.04 (0.98–1.10)
	S_{ed} (MPa × 10^{-1})	**1.33 (1.10–1.60)**	1.25 (0.99–1.56)
	R factor (units × 10^{-1})	**1.26 (1.09–1.46)**	**1.21 (1.03–1.43)**

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Lumbar and cervicocranial symptoms in a car test driver – a case report

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Background

A 47-year old male was referred to the clinic of occupational and environmental medicine at the University Hospital in Gothenburg. He had worked as a test-driver of Volvo cars from 1987 to 1999 at a Volvo test facility about 60 km from Gothenburg. The test facility had more than 15 test tracks simulating different types of road surfaces and weather conditions. Since 1995, he had suffered from lumbago and cervicocranial syndrome and from 1999 from meralgia paresthetica. In 2003, he underwent surgery for meralgia paresthetica in the right groin. In 2007, the condition was complicated by myalgia in the right hip region and muscle strain in the right leg. The patient has been on full-time sick leave since 1999. Despite treatment at the rehabilitation centre, he has not been able to return to work

Methods

The patient passed a physical examination showing pain in the neck muscles, the right hip region and the right groin. Work history and previous vibration exposure were obtained through an investigation by an occupational hygienist.

Results

The patient had been exposed to whole-body vibrations (Aeq) on different test tracks between 0.54-1.1 m/s^2 during 6.2 to 7.4 hours per day. The estimated A(8) value during testing at two tracks from 1987 to 1994 was 0.97 m/s^2 and 0.91 m/s^2, respectively. The corresponding values for two other test tracks during the period 1987 to 1999 was 0.50 m/s^2 and 0.63 m/s^2, respectively. Furthermore, the patient was exposed to repeated shocks during test-track driving. Sometimes he was driving with insufficient shock absorption when that part should be developed.

Discussion/Conclusion

The patient was diagnosed as meralgia paresthetica, myalgia, lumbago and cervicocranial syndrome. Several studies including meta-analyses have reported an increased risk for lumbago after exposure to whole-body vibration. There are also case reports observing an increased risk for meralgia paresthetica in the groin after use of tight and pressing equipment such as four point harness seat belts. After the investigation, the patient's appeal was approved by the Administrative Court in southern Sweden, which concluded that the patient had been exposed to whole-body vibration of such magnitude that it with high probability had caused the patient's neck and lumbar symptoms.

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Does professional driving, including exposure to whole-body vibration, increase the risk of lumbosacral radiculopathy?

Systematic review and meta-analysis

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Objective

To assess whether lumbosacral radiculopathy (LRS) can be attributed to work. This review describes to what extent work-related risk factors are associated with LRS. Special attention is given to professional driving and/or being exposed to whole-body vibration.

Methods

A systematic review was performed of the scientific literature in the databases PubMed and Embase. Inclusion criteria were that LRS was diagnosed by a clinician and a risk estimate was reported or could be calculated. The GRADE (Grades of Recommendations, Assessment, Development and Evaluation) framework for prognostic and etiologic studies was used to assess the quality of evidence for the relationship between the work-related risk factors and LRS that were included in the meta-analyses.

Results

The search resulted in 5916 references and 24 studies fulfilled the inclusion criteria: 19 studies were rated as having a high risk of bias and five as having a low risk of bias. The median number of LRS participants per study were 209 (IQR 124-504) and the total number of participants was 10,142. In total, five studies were dealing with professional driving and/or WBV. The meta-analysis revealed significant ORs for heavy physically demanding work (2.03, 95%CI 1.48-2.79), bending and/or twisting of the trunk (OR=2.43, 95%CI 1.67-3.55), and in combination with lifting and carrying (OR=2.84, 95%CI 2.18-3.69). No significant associations were found for professional driving and/or exposure to WBV (OR=1.46, 95% CI 0.90-2.35) and sitting (OR=1.08, 95%CI 0.49-2.38).

Discussion

The available evidence suggests that professional driving or exposure to WBV might not be a strong risk factor for LRS in itself, although future studies presenting new data, especially with better exposure characterization might change this point of view.

Whole-body vibration and lumbar disc herniation

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Introduction

Lumbar disc herniation is believed to be caused by both individual and environmental factors. A recent systematic review found increased risks for low back pain (LBP) and sciatica among persons exposed to whole-body vibration (WBV), but the knowledge about WBV as a risk factor for lumbar disc herniation is sparse [1]. The objective was to examine if exposure to WBV increased the risk of hospitalisation due to lumbar disc herniation.

Methods

The study basis is a cohort of 288 926 Swedish construction workers. Job title, smoking habits, body weight, height and age were registered at health examinations at the occupational health service between 1970 and 1992. Exposure to WBV was graded on a scale from 1–5 and we constructed a job-exposure matrix (JEM). The occurrence of hospitalisation due to lumbar disc herniation from January 1st, 1987 until December 31st, 2010 was collected from a linkage with the Swedish Hospital Discharge Register. Poisson regressions were used to estimate the relative risk, using white-collar workers and foremen as a reference group. The analyses were adjusted for age, height, BMI and smoking.

Results

There was an increased risk (RR 1.35 95% CI 1.12-1.63) for hospitalisation due to lumbar disc herniation for workers in the construction industry exposed to medium to high WBV compared to white-collar workers and foremen

Discussion

Our study is the first study as far as we know that have used hospital discharge registers to study lumbar disc herniation and the association with exposure to WBV. Our results show that workers exposed to WBV had an increased risk of hospitalisation due to lumbar disc herniation.

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Theme 7 – Back pain II

Meta-analysis of health effects of whole-body vibration

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Background

Systematic literature reviews and meta-analysis shows that workers who are exposed to whole-body vibration (WBV) have an increased risk of adverse health effects compared to non-exposed groups. The foremost health hazards presented are low back pain, back pain and sciatica. There are hitherto 9 systematic reviews on adverse low back pain effects from WBV that have been published in the English-speaking domain during the last 20 years. During the same period, more than a six-fold higher number of internationally published systematic reviews and meta-analysis has been published on possible beneficial effects from whole-body vibration, including benefits from reducing low back pain. These, the health promoting reviews, have focused on the effect of WBV on the prevention of osteoporosis, loss of neuro-muscle function, loss of muscle strength, loss of neurological integrity and loss of pulmonary function. Their overall goal aims at finding efficacious rehabilitation intervention and treatment.

Aim

This paper focuses primarily on various aspects of reviews of papers analysing adverse health effects from exposure to whole-body vibration related to work.

Methods

Systematic reviews are evaluated according to their docility following the "PRISMA statement" for reporting systematic reviews and meta-analyses [1]. Adhering to Prisma's guidelines regarding the application of its 27-point checklist, terminology, flow and reporting scores these reviews higher.

Aspects of risk of bias

For studies where the objective is to identify or estimate the risk of back pain, the trust in the results may be threatened by methodological bias. The risk of bias could be due to a lack of precision when defining the outcome, the choice of design, and inappropriate assessment of exposure. Early studies reported a risk of bias in particular as the concept, "quality of study", while more recent publications adapt to the concepts of bias. In addition to methodological bias, there is a possible threat to the conclusions from publication bias when interpreting the results of whole-body vibration research.

Aspects of search and study selection

When the data collection process relies exclusively on search engines, the result has shown that filtering might result in incomplete sets of eligible publications. Most reviews have used selection or filtering criteria such as "human" or "English language" which excludes all studies that have not been indexed, irrespective of the relevance of the content. The criteria for including or excluding studies in the reviews vary among the different authors.

Aspects of exposure assessment

The methods and protocol for exposure assessment have varied over time, introducing difficulties in relating the results from studies from different time periods to each other. The chosen contrast between exposed and unexposed groups introduces another source of variance. Many of the original studies compared WBV-exposed workers with manual workers or office workers not exposed to WBV. Only in a few cases have investigators attempted to control for confounding exposures by taking into account other ergonomic strains (e.g. prolonged sitting or unfavourable working postures). One strategy to overcome this difficulty has been to compare within the same groups of vibration-exposed workers, but with varying exposure levels.

Aspects of synthesis

Statistical syntheses (meta-analysis) is criticised for a multitude of flaws, but also for a better estimation of effect sizes [2]. Critics have argued that narrative reviews might provide more intuitive results, but also the opposite due to a lack of transparency and systematics. We found that irrespective of the method of synthesis, the results remained fairly consistent [3]. It can be noted that more or less comparable results have been presented in both the narrative synthesis and the reviews with statistical syntheses through meta-analysis, [3–11] although there has been a clear difference in the inclusion and exclusion criteria, and the reviews have covered both early and more recently published articles.

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A cost-utility analysis of bus driver seating alternatives

Assessing the health and claims costs of whole-body vibration exposures

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Background

Whole-body vibration (WBV) is a risk factor for low back pain (LBP), a leading cause of disability and claims costs among professional vehicle operators. As bus driver seats have a notable impact on WBV exposures, a predictive cost-utility analysis (CUA) was used to determine if the installation and use of different bus driver seats would affect driver quality of life and worker compensation claim costs at a regional bus municipality.

Methods

Three seating alternatives were compared with the industry-standard practice of installing and using a passive, air-suspension seat for the 15-year life of the bus: 1) installation of an active-suspension driver seat that would reduce WBV exposures up to 50%; 2) installation of a static, suspension-less driver seat that would not alter WBV exposures but would reduce seat maintenance costs; and 3) replacement of the industry-standard bus driver seat every 5 years to reduce seat-related increases in WBV exposures. Using the costs and injury probabilities from 15 years of actual claims data, a decision-analytic Markov model was used to predict the probability and the cumulative, 15-year costs of bus drivers filing low back and/or neck claims.

Results

Installation of an active-suspension seat was estimated to lower WBV exposures, reduce LBP claims and save the bus municipality $4.8 million over the life of their 1500 bus fleet. The static seat was estimated to save $2.0 million over the same period through reduced maintenance costs. The purchase and

periodic replacement of passive, air-suspension seats every 5 years were estimated to increase costs by $2.4 million.

Discussion

These findings indicate that the adoption of active-suspension seats could improve bus driver health and also reduce the transit agency's claims costs. However, given the range of vehicle costs, claims costs, and vehicle service lives in the transportation sector, caution with the generalizability of these findings is merited.

Evaluation of multi-axial suspension seat in reducing whole-body vibration exposure and associated muscle loading in low back muscle in agricultural tractor application

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Introduction

As agricultural equipment operates in off-road terrain, agricultural equipment operators are likely to be exposed to a high level of WBV exposures with predominant exposure on either fore-aft (x) or lateral (y) axis [1]. Because of substantial mass above the low back, non-vertical (x or y-axis) components of WBV exposures may further increase low back muscle loads among agricultural vehicle operators. Therefore, this laboratory study evaluated an off-road vehicle seat equipped with multi-axial (vertical + lateral) suspension to determine whether a multi-axial suspension seat was more effective in reducing overall WBV exposures and associated low back muscle loading compared to a conventional vertical (z-axis) suspension seat.

Methods

While playing field-collected floor vibration profiles from agricultural tractors into a motion platform (MB-E-6DPF, Moog, NY), we collected WBV per ISO 2631-1 from a conventional vertical (z-axis) and multi-axial (y and z-axis) suspension seat. Electromyography (EMG) was collected from erector spinae (ES) muscle using an 8-channel data logger (ME6000; Mega Electronics; Finland) and surface electrodes (Ambu; Denmark) at a sampling rate of 1000 Hz.

Results

A(8) and VDV(8) values on both seats were predominant on lateral (y) axis and above the EU daily action limits (A(8): 0.5 m/s^2 and VDV(8): 9.1 $m/s^{1.75}$). While the WBV exposures on fore-aft and lateral axes were not different between the seats, the multi-axial suspension seat tended to show lower y-axis A(8) and VDV(8) values measures compared to the vertical suspension seat;

however, the differences were not statistically significance. The low back EMG mirrored this trend.

Conclusion

The results indicate that the lateral suspension may reduce overall WBV exposures and associated low back muscle loading. However, the lack of significant differences implies that the current mechanical lateral suspension systems should be further improved to more effectively reduce lateral WBV exposures.

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Active and passive seat dampening systems – effects on fatigue development in lower back

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Introduction

An association between whole-body vibration (WBV) and low back pain (LBP) has been presented [1]. An active vibration cancelling seat (EAVC) has been introduced which may reduce drivers WBV exposure, and potentially the prevalence of LBP. The aim was to determine whether there are differences between an EAVC and a passive, air-ride seat in WBV dampening and development of muscular fatigue in the lower back.

Method

Eight males and 8 females sat in a passive, air suspension seat (PS) and the EAVC for 30 min each. The seats were mounted on a vibration platform simulating WBV (average RMS 0.91 m/s^2 in z-direction). A control seat without WBV was mounted on the floor. Between exposures, the subjects had a 30 min resting period. Before and after each exposure EMG from the erector spinae was collected while performing a standardised submaximal contraction, as well as subjective fatigue in the lower back. The difference in normalized EMG (ΔEMG_{RMS} and ΔEMG_{MPF}), as well as Borg CR-10 between before and after each seat was analysed using a mixed model analysis of variance ($p<0.05$), and Tukey HSD for post-hoc analysis.

Results

The vibration levels in the EAVC seat was significantly lower than the PS seat (0.24 vs. 0.71 m/s^2, $p<0.01$). There was a significant difference in ΔEMG_{MPF} between the two seats, where it increased by 3.9 Hz after exposure in the EAVC seat while decreasing by 2 Hz in the PS seat. The EMG-parameters did not change for the control seat. The self-reported low back fatigue increased more after exposure in the PS seat compared to both the EAVC seat and the control seat, with a trend towards significance ($p=0.06$).

Conclusion

The EAVC seat reduced vibration exposure more than the PS seat and showed indications of reducing the development of muscle fatigue in the lower back.

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A musculoskeletal spine model for predicting spinal muscle forces of a human body exposed to whole-body vibration

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Vibration transmitted to and through the body may cause degeneration of spinal region; deformations especially occur at the lumbar region [1]. Due to practical and ethical restrictions, in-vivo muscle forces spanning the spine during whole-body vibration cannot be experimentally obtained. To determine the adverse effect of different characteristics of vibration on human spine, biodynamic musculoskeletal models have been developed and analysed iteratively to predict the force sharing among muscles. In some literature, a musculoskeletal dynamic model has been developed to predict muscle forces [2-4]. To assess the risk factor of spinal injury, prediction of muscle forces plays an essential role. It has been reported that muscle forces substantially increase the compression and shear forces on the spine and cause a risk of spinal injury [5].

The aim of this study was to predict the force distribution among muscles crossing the lumbar spine using musculoskeletal simulation software, Opensim. This is an open sourced software capable of analysing multibody musculoskeletal models with a static optimisation method to predict muscle forces [4,6]. In Opensim, which allows to built up various muscle models as well as user defined muscle models, the Hill type muscle model is generally used. Hill type muscle model is implemented as Thelen model in Opensim and adopted in this study [7,8].

For the purpose of this study, a set of biodynamic response data of human body was used for the analysis. The experimental data from a recently published research were measured from a subject sitting upright without backrest exposed random vertical vibration between 0.5 to 15 Hz in 1.0 m/s^2 rms [3]. The accelerations in the vertical and fore-and-aft directions at T5, L3, L5, pelvis and seat were recorded using accelerometers, while the forces in the vertical and fore-and-aft directions were simultaneously recorded at the rigid seat pan with a force plate. A musculoskeletal spine model from Opensim library was modified by scaling the model to the height of the upper body of the subject [9]. The musculoskeletal upper trunk multibody model consists of rigid pelvis-sacrum, L5, L3-L4, L2-L1-torso segments and abdominal, lumbar erector spinae, psoas major, quadrates lumborum and multifidus muscles. The acceleration data were converted to displacements and served as the input to the model for determining kinematic motions of the spine, while the force data were used as the kinetic input to the musculoskeletal spine model. Properties of Hill type muscle models were drawn from literature [6-13]. The objective function of the optimisation was defined as minimising the sum of the squared muscle activations. The muscle forces (based on activation, muscle fibre length and muscle fibre velocity) at each individual location were then predicted during the optimisation procedure. The muscle activation depends on the muscle forces and muscle parameters.

Following the method by Christoph and et. al., suitability of the model was tested by checking if the predicted moment arm of the muscles is within the range of motions physically allowed [9]. The moment arm of the muscles calculated in Opensim is the distance from the muscles to the centre of rotation. The muscle produced torques which are dependent on the moment arm enable the bones to rotate around the joints. The moments arm is a parameter for validating the musculoskeletal model [14].

The predicted muscle forces under the random vibration were mutually compared. The effects of random vibration on the muscles were investigated. The results showed that the maximum force of erector spinae muscle group was larger in Newton scale than the other lower back muscle forces. Since smaller muscle forces were found in the abdominal region than at the lower back, it was deduced that the abdominal muscles group may be negligible in the next step of developing a detailed finite element model of the musculo-skeletal system. The results obtained from this study constitute the first part of the predicted spinal loads. It has also been recognised that in the current study there are two limitations which need to be taken into consideration in the next study: No statistical analysis was performed and the model verification was only performed with experimental data from one subject. Electromyography data may also be used in the future study.

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Theme 8 – Seating I

Vibratory sensation-evaluation of a seated human

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Introduction

In order to evaluate and assess the effects of whole-body vibration on health, comfort, perception and motion sickness, ISO 2631-1 [1] provides frequency weighting curves and selection rules of the frequency weighting curves according to exposure conditions (human posture, input location of the body and direction of vibration). However, the exposure conditions don't include the vibration amplitude. The evaluation values based on the frequency weighting curve don't always match feelings of the vibration amplitude especially in the high-frequency range and/or small acceleration amplitude such as the assessment of automobile and railway vibrations [2]. Therefore, the purposes of this study are to re-examine a frequency weighting curve itself and to investigate vibration amplitude dependency of a frequency weighting curve we obtained.

Methods

A Subject was seated on a shaking table and vibrated in the vertical direction. The subject compared the amplitude of comparison vibration with a reference vibration. The frequency of the reference vibration is 20 Hz. There are seven comparison vibrations which frequencies are chosen from 5 to 100 Hz. The subject changes the acceleration amplitude of the comparison vibration so as to be perceived as similar to the magnitude of the reference vibration. The equivalent sensation contour was made by plotting the relation between the accelerations and the frequencies. The contours were made in four different acceleration amplitudes of the reference vibration. And an absolute perception threshold at each frequency is also measured. The subjects were twenty healthy male.

Results and discussions

The larger the acceleration amplitude of the reference vibration is, the larger an inclination of the contour is in the frequency range higher than 31.5 Hz. Therefore, it is confirmed that there is the vibration amplitude dependency.

Then, a frequency weighting curve surface was created based on the determined equivalent sensation contours at four reference vibration amplitudes.

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Gender and anthropometric effects on whole-body vibration power absorption of the seated body

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The gender and anthropometric effects on vibration absorbed power characteristics of the seated body are investigated through measurements with 31 males and 27 females considering two different back support conditions and three levels of vertical vibration (0.25, 0.50 and 0.75 m/s^2 rms acceleration) in the 0.5–20 Hz frequency range. The absorbed power responses for the males and females revealed strong gender effect, which could be mostly related to differences in body mass of the two groups. Subsequent analyses were conducted considering different datasets grouped corresponding to three ranges of the body mass-, build- and stature-related parameters for both the males and females. Notable differences were evident in the absorbed power responses of the males and females with comparable anthropometric dimensions. Males revealed significantly higher peak and total absorbed power responses compared to the females of comparable anthropometric dimensions, except for the lean body mass. The differences, however, were relatively small in the data for males and females of comparable body mass. The peak power for the females, invariably, occurred at a lower frequency than that for the males. The total absorbed power responses revealed some degree of correlations with the body mass, lean body mass, body fat and hip circumference (r^2>0.60), irrespective of the back support condition and excitation magnitude for both the genders.

A multi-body dynamic model of seat-occupant system for predicting seat transmissibility with combined vertical, fore-and-aft and pitch vibrations

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Seat backrest support can have a significant influence on vibration comfort, fatigue and health of drivers and passengers [1]. It was found that pitch vibration at the seat base could cause non-negligible motions at the backrest in both the vertical and fore-and-aft directions [2], which may result in a potential risk of musculoskeletal disorders (e.g. low back pain) especially in the case of long-term driving or seating. This study aimed to develop a multi-body dynamic model of seat-occupant system to predict vibration transmission from the seat base with combined vertical, fore-and-aft and pitch excitations to the seat pan and to the backrest.

A 7 degree-of-freedom multi-body dynamic model including soft seat and a human body was built up with masses and inertias, linear translational and rotational springs and dampers. The parameters of the seat were identified by measuring the dynamic stiffness of the seat pan and backrest, while the parameters of the human body were obtained by matching the biodynamic responses between the laboratory measurements and the model predictions of vertical and fore-and-aft inline apparent masses with 6 male subjects.

The vertical and fore-and-aft inline seat transmissibilities from the seat base to the seat pan and to the backrest predicted with the developed model showed good agreements with the measured results. Sensitivity analysis of the model parameters indicated the importance of backrest dynamic stiffness, inclination angle and subjects weight on the vibration transmission of the seat-occupant system and the comfort and health estimation of seated persons.

The model is capable of predicting the vibration transmission to the seat pan and to the backrest with combined vertical, fore-and-aft and pitch excitation, which may be integrated with a vehicle model for further evaluating ride quality and comfort. The model may assist in the vehicle and seat design for reducing the health risks of drivers and passengers in the exposure of real-world multi-axis vibrations.

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Equivalent comfort contours for fore-and-aft, lateral, and vertical whole-body vibration in the frequency range 1 to 10 Hz

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The discomfort caused by whole-body vibration depends on the frequency of vibration and the direction of vibration. Recent studies have indicated that the mechanisms involved in causing vibration discomfort are also dependent on the magnitude of vibration [1-5].

This study was designed to investigate how vibration discomfort depends on the frequency of vibration (11 frequencies in the range 1 to 10 Hz), the direction of vibration (fore-and-aft, lateral, and vertical), the magnitude of vibration (0.09 to 3.48 ms^{-2} rms), and the nature of the rigid surface on which people sit.

Twenty-four subjects sat on a rigid flat seat with no backrest and with and without a beanbag, which adjusted naturally to the contours around the ischial tuberosities without altering the transmission of vibration. Using the method of absolute magnitude estimation, subjects judged their vibration discomfort for each of the sinusoidal vibration stimuli. For every frequency and direction, and both seat conditions, regressions were used to calculate the rate of growth of discomfort with increasing magnitude of vibration and determine equivalent comfort contours over a range of magnitude estimates of vibration discomfort.

The rate of growth of discomfort with increasing magnitude of vibration differed between the three directions of vibration and differed across the eleven frequencies of vibration within each of the three directions. The dependence of discomfort on the frequency of vibration and the direction of vibration therefore differed according to the magnitude of vibration. There was no systematic effect of the beanbag on either the frequency-dependence or the direction-dependence of vibration discomfort.

The magnitude-dependence of the frequency-dependence and the direction-dependence of vibration discomfort shows that weightings for frequency and direction of vibration should only be considered appropriate for a limited range of vibration magnitudes. It may be appropriate to consider the development of different ‘weightings’ for low and high magnitude vibration.

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Vehicle-specific seat suspension using kineto-dynamic design optimisation

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A two-stage kineto-dynamic design optimisation methodology is proposed to obtain optimal vehicle-specific designs of the seat suspension system. For this purpose, a kineto-dynamic model of a seat-suspension system is formulated to obtain relations for effective vertical suspension stiffness and damping characteristics considering variations in seated mass and seated height. The relations are verified through simulations of a multi-body dynamic model in the ADAMS platform, and the model validity is demonstrated using laboratory-measured frequency response characteristics of an air seat suspension. A two-stage optimisation methodology is formulated to derive vehicle-specific optimal designs considering excitations due to different classes of earthmoving vehicles. In the first stage, coordinates of the air spring are sought to achieve nearly constant natural frequency for different seated body mass and seat height. In the second-stage, vehicle-specific optimal damping characteristics are identified considering excitations due to different classes of earthmoving vehicles, defined in ISO-7096. The shock and vibration isolation performance potentials of the optimal designs are evaluated under selected vehicle vibration excitations superimposed with shock motions. Results show that the vehicle-specific optimal designs could provide substantial reductions in the *SEAT* and *VDV* values for the vehicle classes considered. The identified optimal air spring coordinates resulted in nearly constant suspension natural frequency during the deflection cycle, irrespective of the seated body mass and driver-selected seated height. The optimal damping properties, identified in the second stage, provided substantial reductions in seat effective amplitude transmissibility (*SEAT*) and vibration dose values (*VDV*) for all classes of earthmoving vehicles considered in the study. The proposed kineto-dynamic model and optimisation method could thus serve as an important tool for designing vehicle-specific suspension seats.

Theme 9 – Seating II

Characterising whole-body vibration exposures during neonatal ground transport

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Background

Newborn infants delivered in a compromised health state often require transport between a secondary care and Level I paediatric hospital. Neonates experience high levels of mechanical vibration and shocks during inter-hospital ground transport [1], but it is not clear how the transport equipment affects these whole-body vibration (WBV) exposures. WBV exposures, when high, may impact the infants' near and longer-term health outcomes [2].

Objectives

The objective of this study was to measure and characterise WBV exposures during inter-hospital ground transport using a simulated newborn infant in order to determine how vibration is transmitted from the floor of the ambulance through the chain of equipment used to support newborn babies (the stretcher, aluminium transfer tray and isolette).

Methods

This study used an ambulance, stretcher, and transport isolette with gel mattress to support a 1.3 kg simulated, newborn infant. Measurements were taken during a 46-minute ground ambulance transport between two hospitals. Six accelerometers were placed across the chain of equipment starting at the ambulance floor and ending at the mattress used to support the simulated, newborn infant [3]. The predominant, z-axis average weighted (A_{eq}) and Vibration Dose Values (VDV) WBV exposures were calculated.

Results

A_{eq} and VDV exposures at the mattress level were 0.98 m/s^2 and 15.6 $m/s^{1.75}$, respectively, above the daily action limits prescribed by the ISO and European Union Vibration directive. The VDV exposures were more time limiting and reduced the time to reach the daily action limits to 55 minutes, a 17-fold reduction, relative to the time to reach daily action limits based on the WBV exposures measured at the floor of the ambulance.

Discussion/Conclusion

Further research is needed to better understand the amplification of the WBV exposures across the equipment used in ambulance transport and whether there are equipment solutions that can reduce the WBV exposure that newborn infants are exposed to.

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Combined exposures of whole-body vibration and awkward posture

A cross-sectional investigation among occupational drivers by means of simultaneous field measurements

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Introduction

Multifactorial workloads such as whole-body vibration (WBV), awkward posture and heavy lifting are potential predictors for low back pain (LBP). So far, there is no epidemiological study investigating posture quantitatively via measurements. In this study, we investigate the association between LBP and these exposures among 102 professional drivers by field measurements.

Methods

The combined exposures of WBV and posture were measured for 58 professional drivers at different workplaces (DIN EN 14253 and ISO 2631-1). These measured data were extrapolated for subjects with the same workplaces and job tasks. The CUELA measuring system [1] was used to capture and analyse the exposure of the posture, which was assessed by criteria following ISO 11226 and DIN EN 1005-4. Further, the percentage of time spent in a non-neutral angular range was used to describe the upper body posture. Health and personal data, as well as information about lifting tasks, were collected by a questionnaire.

Results

The daily vibration exposure value (odds ratio 1.69) and an index for non-neutral posture (odds ratio 1.63) show significant association with the occurrence of LBP. Awkward posture and heavy lifting appear to be more strongly associated with sick leave than WBV exposure. Furthermore, a combination of the measurement results of whole-body vibration and awkward posture into one quantity also shows a significant correlation to LBP.

Discussion

For the first time, quantitative measures combining whole-body vibration and awkward posture exposures have shown to correlate with the occurrence of LBP significantly. These exposures can be described in terms of the daily vibration exposure and the index for non-neutral posture. This validates the proposed quantities and measurement methods, which can be used in the assessment of workplaces and assist in the design of further studies which are necessary to establish a causal exposure-response relationship in the future.

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Vibration exposure standards are NOT relevant for impact exposure

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Introduction / Background / Objectives

An increasing number of impact-induced injuries, caused by slamming events on board high-speed boats have lead rule makers to search for a standard possible to use for setting limits for dangerous exposure. In the absence of a relevant standard, a non-relevant standard, the ISO 2631:5, has been adopted as the basis for the EU-directive on “physical agents (vibration)”.

This is not based on relevant impact exposure data, but still only on mean values of vibration.

Method

The medical scientific literature has been searched for data supporting any of new algorithms developed in order to use mean values of whole-body vibration, to measure and quantify exposure to whole body impact, in order to assess and limit risks of impact induce injuries.

Results

Vibration can most probably speed up the reduction of disc height by increasing the rate of depletion of fluid in the intervertebral discs. This reduces disc/spine flexibility and vibration might even cause structural fatigue in anatomical structures.

However, vibration is not described to have caused acute structural failure, such as vertebral compression fractures of or disc ruptures. These are the acute injuries normally seen in direct conjunction with severe impacts at sea. Statistics is lacking, but numerous cases are reported.

The resonance frequencies in spine specimens, described in continuous sinusoidal compression vibration, might be relevant for exposure to such low-frequency vibration.

No support has however been found, indicating any medical relevance of these resonance frequencies, in the exposure to discrete stochastic impacts of amplitudes high enough to potentially cause injuries.

To convert impact exposure to various “mean values of vibration”, possible to relate to vibration standards, several assumptions and methods are used. These all lack any evidence-based scientific proof of being associated with risks of acute injury. Examples are rms, VDV, Crest Factor, Sed8, SEATvalue etc.

None of these algorithms shows the magnitude of the relevant - highest impacts. Nor can they be used to quantify or assess the magnitude of the dangerous forces acting on the human body.

Another common mistake is also the low-pass filtering of impact exposure data, excluding frequencies above 20 or 30 Hz, and thus disregarding the significance of rise-time.

The rise time in filtered signals becomes that of the filter, not the rise time of the impact.

No evidence has been presented justifying filtering out higher frequencies (30-150 Hz) in the impacts, as being irrelevant for the risk of structural failure in anatomical structures.

Discussion / Conclusion

When compression-, bending-, torsion- or shear forces exceed the structural integrity of anatomical structures these will fail and injury occurs.

New exposure values are suggested. To be relevant for risks of anatomic structural failure, these must be based on the impact properties, which determine the forces acting on the structures. These include peak g-value, rise time, duration, energy content, numbers and period. Exposure limits based on these can help protect people from injuries.

References

hsbo.org/references

Theme 10 – Modelling

Biomechanical adjustments to shock-induced vibrations during running.

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While running, the impacts of the feet on the ground generate vibrations propagating toward the entire body. The properties of these vibrations depend on the running conditions (e.g. velocity, soil type, downhill/uphill) [1]. These repetitive solicitations have been reported related to a risk of injuries (e.g. tibial stress fractures, joint and cartilage degeneration) [2]. As a consequence, runners are expected to adapt their running technique to cushion the impact without affecting their performance. This study aims at investigating the biomechanical properties runners adjust to managing shock-induced vibrations. A dedicated experimental procedure was carried out in order to collect the biomechanical response of participants running over a force platform. The biomechanical response consisted in the whole-body kinematics, as well as the joints' dynamics, and the electromyographic signals from ten muscles of the lower limb. Simultaneously, the three-dimensional shock-induced vibrations have been collected at the third metatarsal bone, the tibial plateau, the knee joint, the hip joint, and the 7th cervical. The task was investigated for two running velocities in shod and barefoot conditions. Results outlined how the shock-induced vibrations are affected by the running conditions at the energetic and spectral level. A noticeable outcome is that a higher intensity of the solicitation will not affect the intensity at the upper areas of the human body, revealing is the strategy set up by the neuro- musculoskeletal system to protect upper areas of the human body.

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Resonant frequency identification at the foot when standing in a natural upright position during vertical vibration exposure

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Introduction

Exposure to vibration entering the body through the feet is associated with whole-body vibration (WBV) health effects such as low-back pain [1] and segmental effects that impair circulation to the toes [2,3]. 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 volunteer participants stood on an electromagnetic shaker that produced a 30 mm/s sine sweep from 10-200 Hz 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 estimator [4] For each point, the resonant frequency was identified as the value at which the average maximal transmissibility occurred.

Results and Discussion

The experimental results show that the vibration response varied dramatically throughout different parts of the foot. Generally, resonant frequency and transmissibility magnitude decreased when moving from the toes to the heel. For example, values at the most distal point of the first toe (resonance = 135 Hz, transmissibility magnitude = 1.48) were greater than at the medial mid-foot (35 Hz, 1.35) and at the heel (10 Hz, 1.08). These preliminary results provide evidence that the ankle and toes must be treated separately with regards to isolation strategies for protecting from harmful exposure, as vibration-induced injury to the toes is likely associated with higher frequency exposures than those of the ankle. Since the large range of resonant frequencies observed in the foot exceeds those associated with dangerous WBV exposure, future research must study the applicability of WBV standards (i.e. ISO 2631-1, 1997) to the feet.

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Evaluation of vibration transmitted to the feet when standing on different outsole and insole material

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Introduction

Vibration transmitted through the foot can lead to vibration white feet resulting in blanching of the toes and disruption of blood circulation [1,2]. To mitigate health risks associated with occupation exposure to foot-transmitted vibration (FTV) some workplaces are using personal protective equipment (PPE) such as mats and insoles. However, controlled studies identifying PPE characteristics effective at attenuating FTV exposures are lacking. The objective of this study was to evaluate vibration transmissibility to the foot when standing on six different PPE materials.

Methods

Twenty-one participants volunteered for the study. Participants stood on an electromagnetic shaker that produced a constant velocity sweep from 10-200 Hz. Transmissibility was measured with a Laser Doppler Vibrometer at 10-points on the right foot while participants randomly stood barefoot (baseline) and on one of four outsoles and one of three insoles with different mechanical characteristics. The transmissibility was measured (H1 estimator [3]) at each point. Average and standard deviation were reported.

Results and Discussion

Transmissibility varied across the frequency range tested and appeared to be less effective at the toe region of the foot then the heel. At baseline average transmissibility to the heel reached a high of 1 between 10-20 Hz and a low of 0.3 between 150-200 Hz. Between 10-20 Hz all outsoles resulted in an average transmissibility of 0.9 and all insoles 0.8 with the greatest transmissibility reduction occurring between 20-50 Hz when standing on an air insole. The average transmissibility at baseline for the first toe was 1 between 10-50 Hz and increased to a max of 1.4 between 100-150 Hz. At the first toe, none of the

PPE reduced transmissibility between 100-150 Hz and the air insole resulted in an increase in transmissibility (1.8). Future research should identify an out-sole and insole material combination effective for protecting both the toes and the heel regions of the foot.

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Muscular activation in vibration perturbed human walking

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People walking on vibrating floor, like sea workers, are deemed to work under whole vibration exposure. Superimposition of walk and vibration may induce early muscular fatigue [1]. This study is aimed to assess leg muscular activetion and stride phases during walking while exposed to whole body specific vibration frequencies. Results were compared with those obtained without exposure.

Subjects walked on a treadmill positioned on a 6-DOF vibrating table. Four frequencies were administered (4, 8, 12, 16 Hz); walking speed was set at 1.25 m/s. Surface electromyography (sEMG) of four muscles was recorded on both legs. Stride phases were recorded using foot switches and stride length was calculated. Acceleration signals were acquired in several body districts. All measurements were related to the un-vibrated walking condition.

Preliminary results show that vibration does not affect stride length and step phases. Muscular activation patterns present some frequency related modification, in terms of sEMG bursts amplitude and timing.

The stance phase admits transmission of vibration along the leg, causing interference with the muscular activation pattern of non-vibrated walking. Vibration triggers a tonic vibration reflex (TVR) that is related to mechanical frequencies [2]. TVR is also related to the motor task because of the mechanical coupling between vibrator and biological apparatus [3]. These facts could explain the modifications in leg muscle activation revealed with sEMG.

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Inter-subject variability and intra-subject variability in walking and running forces

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Inter-subject variability and intra-subject variability during walking and running provide parameters that describe the walking and running forces. With regard to inter-subject variability, parameters induced by different pedestrians are pacing frequency, step length and magnitude of the walking and running forces. These parameters are analysed as a function of the pacing frequency. With regard to intra-subject variability, dynamic loading, caused by a moving pedestrian, may be considered as a periodic force F(t). The force F(t) can be represented as a Fourier series. Typical vertical force patterns for different types of human activities (as a slow walk, normal walk, brisk walk, fast walk, slow jog and running) are represented by deterministic force models. The Fourier decomposition provide dynamic load factor (DLF), activity rate, phase shift of the each harmonic. DLFs are formulated as a function of step frequency and as function of person's velocity.

Posters

Association between alternative cumulative lifetime vibration doses and low back outcomes

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Background

Previous analyses revealed that the *daily* compressive dose S_{ed} based on internal lumbar forces might be a better predictor of low back pain (LBP) outcomes than *daily* doses based on acceleration (daily vibration exposure $A(8)$, vibration dose value VDV) [1,2]. The aim of the current study was to investigate whether acceleration-based *lifetime* doses differ from force-based *lifetime* doses for the prediction of LBP outcomes.

Method

The data obtained in the VIBRISKS project (cohort of 537 male drivers) [1,2,3] were used for the recalculation of seven types of lifetime dose. The relationship between dose values and LBP outcomes (12-month occurrence of LBP, chronic LBP and sciatic pain) was assessed by means of the generalised estimating equations (GEE) method ('time-lag' model). The Quasi-likelihood Information Criterion (QIC) was used to compare the fit of GEE longitudinal models including alternative lifetime doses (7 dose values x 3 outcomes = 21 models).

Results

In 19 of 21 models, the adjusted odds ratios (aOR) for LBP outcomes significantly increased with increasing lifetime doses (continuous models: aOR 1.15 (95% CI 1.02-1.29) to aOR 2.46 (95% CI 1.46-4.17); quartile based models, fourth quartile vs first quartile: aOR 1.92 (95% CI 1.05-3.53) to aOR 4.12 (95% CI 1.70-10.0)). The findings suggest the following sequence for the fit of the continuous models, where > means better than:

$\sum[F_{dyn,total,rms}{}^2 t]$, $\sum[F_{dyn,total,rms} t]$ (force-rms doses) > $\sum[F_{dyn,total,peak}\, t^{1/6}]$, $\sum[S_{ed}\, t^{1/6}]$, R factor (force-peak doses) > $\sum[a_{wz}{}^2 t]$, $\sum[A(8)_z{}^2 t]$ (acceleration doses)

Discussion

The models with force based doses showed a better fit than those with acceleration based doses. Hence, it might be worth including lumbar internal forces in the risk assessment of LBP outcomes in vibration-exposed workers. The differences between the models with force-based doses suggest that the cumulative health effect might depend on the integrated resulting total force over the entire time rather than primarily on the force peaks.

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Development of a multidisciplinary evidence-based guideline on decreasing exposure to whole-body vibration in order to prevent low back pain

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Objective
To give guidance for professionals in the field of occupational safety and health (OSH) in advice on decreasing exposure to whole-body vibration (WBV).

Methods
An evidence-based guideline in OSH is ’a document with recommendations to assist OSH practitioners and OSH users, intended to optimize quality of care, based on a systematic review of evidence and an assessment of the benefits and harms of the various care options, supplemented with expertise and experiences of OSH practitioners and OSH users’ [1]. After an invitational conference with employers, employees and OSH-professionals the most important bottlenecks for daily practice were formulated and translated in six entry questions: How to measure and evaluate WBV exposure? How to diagnose potential health effects? Which workplace-related measures are effective in decreasing exposure? Which worker-related measures are effective? Specific risk groups to identify? Content of a health surveillance programme. The guideline development group, consisting of experts and representatives of the professional societies of occupational physicians, industrial hygienists, safety engineers, ergonomists, and labour organisation experts, performed a systematic literature review and discussed the evidence regarding the entry questions. Additional discussions and external comments on the practicality and feasibility of the evidence in daily practice led to the formulation of recommendations and subsequently to a guideline, authorised by the societies.

Results
In 2014, the guideline was published [2]. In total, the guideline consists of 22 recommendations divided over the entry questions, and four addenda: The VIBRISKS health questionnaire [3], a proposal for a health surveillance programme, a list of performance indicators and a glossary and a scientific justification in a background document.

Discussion

The guideline was received well and may improve the quality of preventive practice and increase the impact of OSH advice, but adequate implementation will remain the Achilles heel.

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Optimisation of the contact damping and stiffness coefficients to attenuate vertical whole-body vibration

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A lumped mass human model is proposed to minimise the energy absorption at the feet and hip level of the human body, subjected to vertical vibration. The optimum damping and stiffness coefficients of shoes are evaluated by the dynamic response of the human body. The contact forces are modelled as stiffness and damping forces. The coefficients are optimised such that the human body responses in the frequency domain assumes the minimum energy. The optimisation technique is based on the quasi-Newton method to estimate optimal coefficients of the contact forces. As before mentioned, the optimal solution of the body's response is obtained in the frequency domain 0-15 Hz. In the standing postures, the frequency response shifts the peak of resonance of each human body segment from 3-4 Hz to 2-2.5. The coefficients of the damping and spring forces for the minimum energy associated with displacement, velocity, acceleration and internal forces are, respectively, kopt=0.1 kNs/m and kopt=10kN/m. In addition, the optimal parameters reduce drastically total energy during contact conditions. The future development of this research can be manufactured optimised shoes.

Metrological characterization of low-cost systems for the evaluation of posture at the workplace

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Introduction

Health effects associated with exposure to whole-body vibration (WBV) are assessed with ISO 2631-1 or EU Directive 2002 44/EC via the health guidance caution zone (HGCZ) and daily exposure limit value (ELV) respectively. Despite evidence to support an increased injury risk[1-3], neither standard/directive considers a reduction in HGCZ or ELV when workers are exposed to vibration with non-neutral working postures. Previously, the ability to simultaneously collect posture and vibration data was a challenge due to camera[2] and inertial motion sensor[3] limitations. With advances in motion tracking, the ability to monitor working postures today is improved. This paper will provide an overview of how two commercially available motion tracking systems can be used to evaluate working postures associated with exposure to WBV.

Methods

Two systems (Microsoft Kinect V2; Notch Motion Capture) underwent a metrological calibration procedure in order to understand their measurement uncertainty and their usability at the workplace. Two different setups were used for calibration. The Kinect observed a fixed mannequin from 39 different positions [4], in different light conditions and with different mannequin clothes. The figure of merit was the capability of measuring the same length of the body segments and the same angles independently from the measurement configuretion. The Notch was used to estimate upper limb angles, which were compared with those measured by a digital inclinometer. The systems were also evaluated under simulated working conditions associated with exposure to WBV.

Results and Discussion

Preliminary results found both systems to have less than a 5-degree error in the measurement of body angles. The primary limitation of the Kinect is that the subject must always be visible from the camera; however, it does not require the worker to wear sensors as is the case with the Notch. At less than 500€ each the systems are also cost effective.

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Sickness absence among workers exposed to whole-body vibrations – a prospective study

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Objective

To investigate the association between whole-body vibrations and future sickness absence

Methods

Data from the Swedish work environment survey from the years 2009, 2011, and 2013 and sickness absence (>14 days) one years later from Longitudinal integration database for health insurance and labour market studies (LISA). The study base was general Swedish working population.

Results

During the three rounds, 19 054 participated in Work Environment survey. The study sample consisted of 8931 (47%) men and 10 123 (53%) women. The majority (88%) of these participants also responded to a work-related disorder survey. Exposure to whole-body vibration at least 50% of the working time (WBV-exposed) was significantly more common among men (8%) than among women (1%). Whereas sickness absence (more than 14 days) (SA) during one-year follow-up was significantly lower among men (7%) than among women (13%). WBV-exposed men had an SA prevalence of 12% and WBV-exposed women had an SA prevalence of 18%. WBV-exposure had an association with SA one-year after, the prevalence ratio (PR, 95% CI) for WBV-exposed men was 1.7 (1.3, 2.0) and for WBV-exposed women was 1.4 (0.9, 2.1).

Comparing the objective outcome 'Sickness Absence from official registers' with self-reported sickness absence (RSA) due to work related disorders (WRD) reveal interesting results. RSA due to WRD during the last 12 months was significantly lower among men (5%) than among women (7%)

WBV-exposure had an association with RSA, the PR (95% CI) for WBV-exposed men was 1.8 (1.4, 2.4) and PR (95% CI) for WBV-exposed women was 1.7 (0.9, 3.2).

Conclusion

SA during 1-year follow-up was more common in WBV-exposed workers than unexposed workers were. Sickness absence due to work-related disorder was also more common in WBV-exposed workers than unexposed workers were; the result holds true for both men and women workers. Other personal and work environment factors might confound the obtained results.

Positive health effects of exposure to whole-body vibration

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In recent years peer review publications have demonstrated health effects of exposure to whole-body vibrations (WBV). A review of different types of health effects of WBV was done with the attempt to understand mechanism and exposure levels.

A selection of health effects of WBV published in recent years was improvement in bone mineral density, improvement in muscle strength and prevention of decompression illness (diving).

Improvement of bone mineral density (BMD) in postmenopausal women: A review of nine studies concluded that WBV in elderly women can reduce BMD [1]. The mechanism suggested is mechanical stimulation of bone tissue in the legs and hip. Exposure was between 0,3g and 18g. A typical exposure was maximum 30 min every second day for 6 months [2]. A level of 2,3g corresponds to 22 m/s^2 corresponding to A(8)=5,5 m/s^2 (above the EU TLV).

A systematic review of 38 studies found beneficial effects on proxies of muscle strength in old adults compared to both control and conventional strength training [3]. The mechanism suggested is sensorimotor effect. Exposure varied between studies both type of vibration, intensity and duration. In several studies, the duration of daily exposure was short; 2-10 minutes.

Pre-dive exposure to WBV prevents the formation of circulation bubbles post-dive and thus reduce the risk of decompression sickness [4]. The mechanism is suggest to mechanical dislodgement or enhanced lymphatic elimination of gas nuclei which could prevent their transformation into circulation bubbles. The exposure is done by a commercial vibration mattress where the diver is exposed during 30 minutes with an interval of 30 minutes before dive. There is no information on vibration levels.

Conclusion

The three examples of different health effects of WBV all have different exposure profiles compared to occupational exposures related to WBV injuries. A measure that could relate to both health and hazardous effects of WBV would be desirable. The mechanisms of the health effects are not yet clear.

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Study of impact exposure on humans working onboard high-speed boats

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Purpose of Study

The purpose of the intended study is to establish what levels of exposure and what impact characteristics are dangerous. This is needed to understand how to best reduce the risks for impact-induced injuries and physical fatigue on professionals operating high-speed boats.

Method

Collecting exposure data on boat-hulls and on the bodies of a number of test persons, while they operate High-Speed boats and simultaneously logging any development of pain over time, can give the required information.

Impact exposure will be logged simultaneously on hulls and humans and pain will be monitored with a smartphone app, PainDrawing.

Pain is the only physiological parameter, possible to monitor at scale and over time, which can be used as an indicator of risks of injury. It is a physiological function, serving to protect us from harm. One can have pain without injury, but normally not any injury without pain.

Procedure

The proposed study will be conducted parallelly in a number of professional agencies in different countries, using the same method, routines, data collection hardware and protocols. This way a critical number of platforms and human subjects can be monitored and the results can be shared and compared between the participating agencies. The method can also objectively monitor operator skills/capacity to produce smooth travel.

The program is open to professional agencies operating High-Speed Boats.

Results

The expected results can be useful to define relevant human exposure limits and even to relevantly calibrate boat-mounted exposure indicators, telling operators when hull impacts exceed safe levels, by green, yellow or red signals.

The results can also ultimately lay the basis for a new relevant standard, defining allowable and dangerous exposure to Whole Body Impact, WBI. In order to protect people from injury, such a standard must be based on the forces acting on the human body at sea.

Comparing whole-body vibration exposures across active and passive truck seats

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Background

Whole-body vibration (WBV) is associated with several adverse health and safety outcomes including low-back pain and driver fatigue. Recently introduced active suspension truck seats have been shown to reduce WBV exposures by up to 50% relative to industry standard air-suspension seats. The objective of this study was to evaluate and compare the efficacy of four commercially-available truck seats for reducing truck drivers' exposures to WBV.

Methods

Twenty truck drivers operating over a standardised route were recruited for this study, and an active suspension seat and three less-expensive comercially available air suspension seats were evaluated. The predominant, z-axis average weighted vibration (Aw) and Vibration Dose Values (VDV) were calculated and normalised to represent eight hours of truck operation. In addition, the Seat Effective Amplitude Transmissibility (SEAT), the ratio of the seat-measured vibration divided by the floor-measured vibration, was compared across the four seats.

Results

The active suspension seat had significantly lower WBV exposures compared to the other three air-suspension seats. The Aw -based SEAT values, calculated over the whole route (which was predominantly on-road) indicated that the active suspension seat reduced WBV exposures by 75%, two of the air-suspension seats reduced WBV exposures by 25%, and the other air-suspension seat only had a 9% reduction in WBV exposures.

Discussion

The performance differences across seats may have important practical implications for truck procurement and overall truck driver health. Compared to

the lowest performing air-suspension seat, the active suspension seats increased the driving time to reach EU daily vibration action limits by 4-fold and the other two air-suspension seats doubled the amount of time drivers could operate their trucks before reaching action limits. Seat suspension-based design differences accounted for the WBV performance differences.

Lumbar disc herniation in a bus driver – a case report.

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Background

A 63-year old male was referred to the clinic of Occupational and Environmental Medicine at the University Hospital in Gothenburg. He worked as a bus driver of city buses from 2001 to 2011. He was suddenly stricken by lumbar disc herniation when riding over a speed bump July 2011. After spinal stenosis surgery March 2012 he was back in work August 2012.

Exposure assessment

Vibration measurement was performed by an occupational hygienist while the patient was driving the bus during a regular tour with passengers. Vibration meter Larson • Davis HVM 100 was used which presents frequency-weighted vibration acceleration level according to the standard ISO 2631:1998. The triaxial seat sensor DYTRAN 5313A was placed on the driver's seat. A(8) (the daily vibration exposure for 8-hours) and the vibration dose value VDV (a cumulative vibration dose sensitive to shocks) were recorded.

Exposure evaluation

Exposure evaluation was performed by the same occupational hygienist. Our patient's A(8) whole-body vibrations in bus seats for over 10 years from 2001 to the accident July-11 was estimated to 0.23 m/s^2 and is not exceeding European action value (0.5 m/s^2). $VDV_{8\ hrs}$ for the "worst case" has been estimated to 6.9 $m/s^{1.75}$ and is not exceeding the action value 9.1 $m/s^{1.75}$.

Discussion/conclusion

The patient's whole-body vibration exposure was below the action value but new science [1] concludes that the current limits underestimate health risks where there are multiple shocks. Measures of internal lumbar load, such as S_{ed} and *R* factor, might be better predictors of back injuries. It is likely that the mechanical shock has caused the herniated disc.

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Occupational LBP of mobile machinery operators

Field measurement campaign of whole-body vibration, static positions and body movements.

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More than 1 800 000 French workers are driving mobile machinery on a regular basis (dumper, loaders, excavators, etc.). They are exposed to whole-body vibration (WBV) which may lead to musculoskeletal disorders (low back pain, herniated lumbar discs, bone fatigue). More than 400 occupational diseases are recognized each year, representing a direct cost of 12 million euros.

The current procedure for the WBV risk assessment does not take into account the physical stress on the back, shoulders and the neck caused by maintained seated positions and body movements. In order to improve the prevention of occupational diseases, their effects on health have to be investigated.

Combined measurements of WBV and body postures have been performed at the driving position of 125 vehicles during typical working tasks. WBV measurements were carried out according to the ISO 2631-1 standard. Body postures were measured with the CUELA system (computer assisted registration and long-term analysis of muskulo-skeletal workloads) developed by IFA (German institute for occupational safety and health) using the ISO 10687 standard.

For each type of machine, differences in posture were observed both in the static positions and in the movements of the drivers. The body segments with the largest deviations from one vehicle family to the other were identified.

Future work will focus on the development of a combined risk assessment method. The dynamic response of the body will be measured in the laboratory for postures similar to those measured in the field. Their severity will be integrated based on the hypothesis that the greatest mechanical stresses between the lumbar vertebrae appear at the resonant frequencies of the segments concerned.

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