EXPLORATORY STUDY OF WHOLE-BODY VIBRATION 'ARTEFACTS' EXPERIENCED IN A WHEEL LOADER, MINI-EXCAVATOR, CAR AND OFFICE WORKER'S CHAIR

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Abstract

Many factors need to be considered when conducting whole-body vibration (WBV) risk assessments. Complications may arise with the evaluation of the vibration profile when high acceleration events are present. These peaks could be the result of a genuine exposure to high impact events, such as driving over a pothole or when experiencing an end-stop impact. However, the event could also be the result of an alternative factor, such as the driver altering their posture on the seat and during ingress/egress: an 'artefact'.

This paper presents a study conducted to characterise the events of ingress/egress of operators. Using a range of subjects with different weights and heights, repeat measurements were made in a Mini Excavator (mechanical suspension seat), Wheel Loader (air suspension seat), Volvo car (conventional seat) and office worker's chair.

Findings demonstrated that an operator could exceed the vibration dose action value of the Physical Agents (Vibration) Directive (9.1 $ms^{-1.75}$) by artefacts alone with no 'authentic' WBV exposure. This is important to consider when carrying out autonomous logging where there is a risk that operator artefacts could be integrated with the true vibration profile. If high acceleration ingress and egress events are considered relevant to whole-body vibration risk assessments, office workers should also be included within the scope of the Physical Agents (Vibration) Directive.

1. Introduction

Once the European Physical Agents (Vibration) Directive (PAVD) has been implemented in the UK, risk assessments relating to whole-body vibration exposure will be required. The Health and Safety Executive (HSE) estimate that around 50,000 assessments of whole-body vibration (WBV) will be required in the United Kingdom. This figure is based on the assumption that 1 in 20 workers will be assessed from the 1.3 million that are exposed above the WBV exposure action value of the PAVD (0.5 ms^{-2} A(8) or 9.1 $ms^{-1.75}$ VDV) (Coles 2002; Brereton and Nelson 2003). Consequently with the increase in vibration measurements there will be an increase in the number of inexperienced individuals who are required to take such measurements. Ideally the measurements will be taken by a skilled professional who has more expertise and understanding of the complications involved with assessing vibration emission and exposure levels.

Presented at the 39th United Kingdom Group Meeting on Human Responses to Vibration, held at Ludlow, Shropshire, England, 15 - 17 September 2004

The consultative document from the Health and Safety Commission (HSC) on the proposed new Control of Vibration at Work Regulations (2005) outlines in Regulation 5 that in certain situations direct measurement of vibration will be deemed necessary. For example; where there is no currently published data, when the employer wants to evaluate the effectiveness of controls imposed or when the exposure level is around the Exposure Limit Value and the employer wants to be sure that it is not exceeded. If measurements need to be taken a competent employer or employee could conduct them, if they have received necessary training. However, their level of expertise and knowledge in this area could greatly affect the validity of the analysis and assessment.

The expertise of the individual is important as many problems can arise during whole-body vibration data collection and analysis. However, even with skilled professionals problems may arise when they are forced to use autonomous logging techniques when the operations prevent the investigator from riding along with the vehicle or requiring to measure on more than one machine at a time. This in turn increases the chances of making an error when conducting the analysis of the vibration assessment.

Complications may arise with the evaluation of the vibration profile when high acceleration events are present. These peaks could be the result of a genuine exposure to high impact events, such as driving over a pothole or when experiencing an end-stop impact. However, the event could also be the result of an alternative factor, such as the driver altering their posture on the seat and during ingress/egress: an ‘artefact’. This makes the post-analysis more challenging when the specialist is forced to make assumptions on how the peaks in the vibration data were created and whether they are a ‘true’ feature of the vibration profile or an ‘artefact’ caused by the driver. Some published literature may contain reports of erroneous measurements arising from a lack of careful inspection of these events combined with a range of other factors (Griffin 1990).

It is expected that, in the UK, the PAVD will be implemented with the VDV criteria for the exposure action value and the A(8) for the limit value. Therefore, the focus on measurements will be for the A(8). Nevertheless, VDVs will be frequently reported in future risk assessments. The VDV is, by design, more sensitive to shocks. Therefore, it is important that genuine shocks are included in an assessment, but that artefacts are removed from assessments.

When measurements of VDV will be required it will be important to understand how the driver ‘artefacts’ will distort the ‘true’ vibration profile, especially when autonomous logging is used. This paper reports on a study conducted to capture these events of ingress/egress of operators. These data were used to assess whether the PAVD exposure action value (9.1 $ms^{-1.75}$) and exposure limit value (21 $ms^{-1.75}$) for VDV could be exceeded by artefacts alone with no ‘authentic’ WBV exposure and to help understand the profile of the peaks created from such artefacts.

2. Methods

Repeat measurements of seat acceleration were made in a Mini-Excavator (mechanical suspension seat), Wheel Loader (air suspension seat), Office worker’s chair (air sprung) and a Volvo V70 estate car (conventional car seat). Five subjects were used for each separate trial, aged between 24 and 60 years. Stature ranged from 1.61 – 1.85 m with a mean stature of 1.71 ± 0.07 m (mean ± SD) and weight ranged from 57 – 100 kg with a mean weight of 77.87 ± 12.26 kg. Subjects were informed of the procedure prior to starting the trials. Males and females were used in the trials. The same subjects were used for the office chair and car but different subjects were used for each of the other vehicles.

Subjects were required to adjust the height of the seat prior to commencing the trial and the weight settings if applicable. When instructed, each subject was required to sit in the designated seat (ingress) and to remain seated until they were instructed to exit the seat (egress). They were asked to get in and out of the seat three times.

One triaxial ICP accelerometer was fitted to the seat mounted in a SAE standard flexible disc and fixed to the surface of the seat on which the worker sat, beneath the ischial tuberosities. The accelerometer was attached to a Biometrics Data logger to acquire the raw acceleration time history for all trials apart from the mini excavator trial where the accelerometer was attached to a Larson Davis HMV100 vibration meter. Raw acceleration signals were acquired to a computer running LabVIEW to acquire the raw waveform. Both platforms recorded the raw unweighted accelerations at a 500 Hz sampling frequency for the fore-and-aft (x-axis), lateral (y-axis) and vertical (z-axis).

The acceleration time histories were frequency weighted using the weightings specified in ISO2631 (1997). The peaks created during ingress/egress were isolated to calculate the vibration dose value (VDV) of these events. The peaks were analysed using a visual interpretation and further analysed using a quantitative model. Based on artefacts alone with no ‘authentic’ vibration exposure calculations were applied to the average VDV value obtained for the 5 subjects within each measurement group to determine how many times the event of ingress/egress could occur before the VDV action value (9.1 $ms^{-1.75}$) and limit value (21 $ms^{-1.75}$) of the PAVD were reached.

The equation for combining any number, n, of VDV’s to obtain an overall VDV is:

$$\mathrm{VDV_{TOTAL}} = \sqrt[4]{\sum \mathrm{VDV}_n^4}$$

where VDV_n is the VDV for the n^{th} trial. If each VDV_n is identical, then the expression becomes:

$$VDV_{TOTAL} = \sqrt[4]{VDV^4 \times n}\,.$$

VDV_{TOTAL} can be replaced with the action or limit value criteria and the equation rearranged such that the number of VDV exposures to reach the criteria can be calculated.

$$\frac{{VDV_{TOTAL}}^4}{VDV^4} = n\,.$$

3. Results and Discussion

Vibration dose values (VDV) were calculated for the three axes of vibration measured. However the VDV magnitudes in the horizontal axes were small compared to the vertical axis and only the worst axis is required for the Physical Agents (Vibration) Directive risk assessments. Therefore only the vertical (z-axis) axis of vibration is reported here. Table 1 provides a summary of the VDVs for the obtained across the four different seating conditions.

Mean values for ingress were greater than values for egress for the car and wheel loader. For the whole ingress-egress cycle, the greatest accelerations occurred for the wheel loader and the smallest occurred for the office chair.

There was no consistent relationship between the subject weight and VDVs measured during ingress or egress. However, significant positive correlations between subject weight and VDVs occurred for the office chair egress and wheel loader egress ($p < 0.05$, Pearson). These seats had the greatest suspension travel and therefore it is possible that as heavier subjects would compress the seat more, the air suspension mechanisms would require a greater amount of re-adjustment once the subject has left the seat.

A significant negative correlation occurred between the subject weight and VDV for the car ingress. It is possible that this could be due to the smaller surface area in contact with the seat for the lightest subjects. Further systematic investigation of pressures on the seat would be required to test this hypothesis.

Table 1. Individual VDV’s across all subjects and seating conditions for the vertical axis

Condition	Subject	Weight (kg)	Vibration Dose Value ms$^{-1.75}$ (z-axis)											
			Ingress				Egress				Ingress & Egress			
			1	2	3	mean	1	2	3	mean	1	2	3	mean
Office Chair	1	68	3.4	5.3	5.4	4.7	1.3	1.8	2.1	1.7	3.4	5.3	5.4	4.7
	2	89	2.3	4.0	3.5	3.3	4.8	4.3	4.2	4.4	4.8	4.9	4.6	4.8
	3	57	1.9	2.5	1.9	2.1	2.6	1.8	2.3	2.2	2.8	2.7	2.5	2.7
	4	80	1.0	2.8	3.5	2.4	2.5	4.0	3.5	3.3	2.5	4.2	4.1	3.6
	5	89	2.6	1.5	2.3	2.1	5.5	4.8	4.4	4.9	5.6	4.8	4.5	5.0
Volvo V70 Car	1	68	5.5	4.8	5.8	5.4	1.8	2.1	2.0	2.0	5.5	4.8	5.8	5.4
	2	89	9.1	1.6	0.8	3.8	1.8	2.6	2.7	2.4	9.1	2.7	2.7	4.8
	3	57	6.4	8.0	6.1	6.8	0.8	1.2	1.0	1.0	6.4	8.0	6.1	6.8
	4	80	4.4	4.1	4.0	4.2	0.4	0.7	1.0	0.7	4.4	4.1	4.0	4.2
	5	89	4.7	3.1	2.2	3.3	0.5	1.4	0.6	0.8	4.7	3.1	2.2	3.3
Mini Excavator	1	76	2.4	2.4	2.6	2.5	3.9	4.5	4.5	4.3	4.0	4.6	4.6	4.4
	2	76	2.0	1.1	1.5	1.5	4.5	4.3	4.5	4.4	4.5	4.3	4.5	4.4
	3	76	3.7	3.9	3.3	3.6	5.0	4.8	4.1	4.6	5.4	5.3	4.5	5.1
	4	68	1.9	2.2	1.3	1.8	4.7	4.2	3.7	4.2	4.7	4.3	3.7	4.2
	5	74	4.5	3.3	3.0	3.6	4.1	4.0	4.5	4.2	5.1	4.4	4.7	4.7
Wheel Loader	1	100	4.6	4.7	4.5	4.6	6.8	6.5	7.1	6.8	7.2	6.9	7.4	7.2
	2	65	5.9	5.4	4.8	5.4	4.1	3.9	2.7	3.6	6.2	5.8	4.9	5.6
	3	66	5.9	4.9	5.2	5.3	2.5	2.4	2.4	2.4	6.0	5.0	5.2	5.4
	4	92	4.3	5.2	7.9	5.8	3.2	3.0	3.5	3.2	4.6	5.4	8.0	6.0
	5	92	5.1	5.1	4.7	5.0	3.6	3.8	3.0	3.5	5.4	5.4	4.9	5.2

Figure 1 illustrates the typical peaks created by the subjects during ingress and egress. During ingress the acceleration waveform was similar across all conditions and for all subjects. The seat impact is characterised by a high-jerk negative acceleration as the seat starts to move. As the force from the stiffness in the seat (e.g. from the springs) increases the acceleration becomes positive where the seat speed decreases and it settles in its displaced position. There is some oscillation for some seats which is especially noticeable for the office chair. The most distinctive difference between the profiles was observed in the car trial where a second peak in the positive direction was recorded. This occurred for the majority of subjects and could be due to more complexity in the materials used to construct the seat. The largest peak values during ingress were created by subjects during the wheel loader trial followed by the car trial. The low seat height in the Volvo V70 car could account for the large peak values created during the car trial. Considering the distance the subject has to travel to make contact with the seat compared to the other seating conditions it is not surprising to find large peak values as the impact with the seat will be increased with the increasing velocity. For all subjects in all seats the ingress had a similar profile. Therefore it might be possible to use inspection of the waveform to assist in classification of high acceleration events as artefacts.

The vibration profiles created during egress have noticeably different characteristics compared to ingress. The characteristics of the peaks created during egress vary between the different seating conditions. Therefore it would be more difficult to classify high acceleration events as egress artefacts.

Using the average VDV values from each seating condition the influence of the artefacts described in this paper were compared to the VDV action (9.1 $ms^{-1.75}$) and limit value (21 $ms^{-1.75}$) of the PAVD. The findings (presented in Table 2) indicate that a person can get in and out of a seat a very large number of times before the limit value is reached. This suggests that artefacts of this nature will not dominate exposures that reach the limit value. Considering the fourth power nature of the VDV, ingress and egress artefacts would be unlikely to cause the limit value threshold to be exceeded. For example, if 30 ingress / egress artefacts occurred for the wheel loader, the ‘true’ vibration exposure would need to have a VDV of 20 $m/s^{1.75}$ for the artefacts to cause the VDV to exceed the VDV limit value.

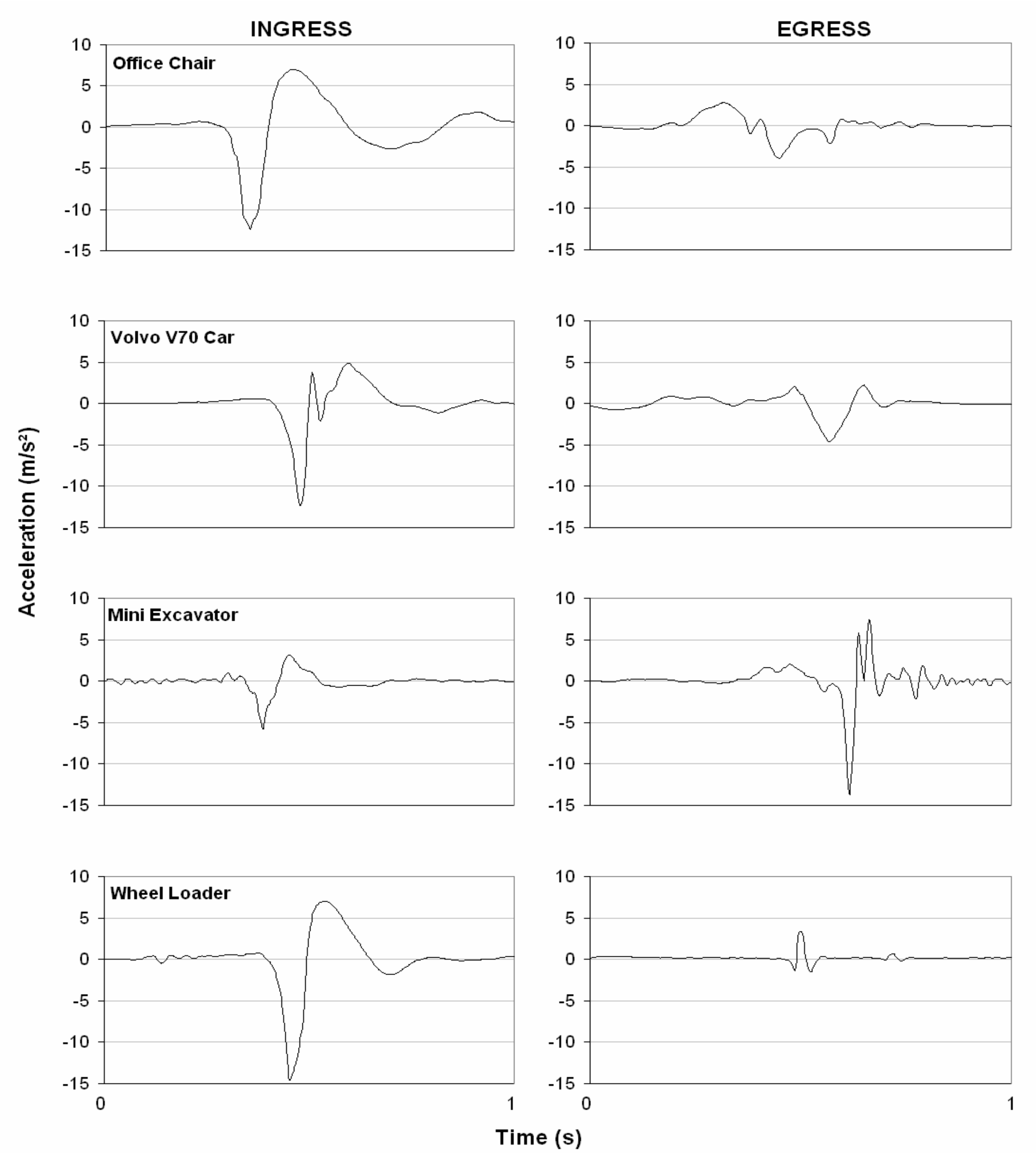

Figure 1. Typical acceleration waveforms for each seating condition during ingress and egress.

Table 2. Number of times subjects can get in and out of a seat before reaching the action value and limit value of the Physical Agents (Vibration) Directive

Seating condition	Mean VDV value ($ms^{-1.75}$)	Action value (9.1 $ms^{-1.75}$)	Limit value (21 $ms^{-1.75}$)
Office Chair	4.14	23 times a day	662 times a day
Volvo V70 car	4.90	12 times a day	337 times a day
Mini Excavator	4.57	16 times a day	446 times a day
Wheel Loader	5.87	6 times a day	164 times a day

If assessments are made according to the exposure action value, artefacts could have a significant impact on the vibration exposure assessment of the workers. The office worker could get in and out of their seat on 23 occasions throughout their working day. This would be likely to be exceeded by many office workers. The driver of a Volvo V70 car could get in and out of the seat 12 times a day before artefacts would cause the action value to be exceeded. Considering the cumulative effect of their vibration exposure whilst driving, if is feasible that artefacts could cause a car driver to exceed the action value. Getting in and out of a mini excavator on 16 occasions per day is possible in many construction environments where the mini excavator is used intermittently throughout the day. This is important to consider as this machine is one of the likely candidates for autonomous vibration logging as the cab is too small to ride along. Vibration emissions from mini-excavators are relatively high and vibration exposures could exceed the VDV action in less than an hour. Therefore, ‘true’ vibration exposures are likely to exceed the action value without artefacts. The seating condition with the minimum amount of times a person can get in and out of the seat is the wheel loader with an air suspension seat. The driver of this machine could only get in and out on 6 occasions. This is likely to be exceeded during the day for most drivers, considering breaks and other tasks that they will be required to do. As for the mini-excavator, though, all genuine exposures within wheel loaders are likely to exceed the VDV action value.

If the highest VDV from the subject range is taken for the four seating conditions then the number of times a person can sit in and out of the seat substantially reduces. The maximum values are presented in Table 3. This should be considered as there will always be operators who produce large magnitudes in the data when they get in and out of the vehicle.

Table 3. Number of times subjects with the highest VDV's can get in and out of a seat before reaching the action value and limit value of the Physical Agents (Vibration) Directive

Seating	Maximum VDV value ($ms^{-1.75}$)	Action value ($9.1\ ms^{-1.75}$)	Limit value ($21\ ms^{-1.75}$)
Office Chair	4.95	11 times a day	324 times a day
Volvo V70 car	6.80	3 times a day	91 times a day
Mini Excavator	5.03	11 times a day	304 times a day
Wheel Loader	7.13	3 times a day	75 times a day

It could be argued that the self generated seat acceleration such as these artefacts has the same effect on the low back as impacts transmitted through the seat. However, these two situations are different. When sitting down into a seat the body is prepared for the impact and muscle is toned accordingly. During egress the events studied here might not be transmitted to the occupant, as peak accelerations measured by the accelerometer could occur slightly after they have left the seat. If ingress / egress artefacts are considered as relevant to whole-body vibration risk assessments, then the Physical Agents (Vibration) Directive should also apply to office workers and further studies should be completed to quantify accelerations in all types of seated workstations.

Conclusions

The study described in this paper has aided the understanding of 'artefacts' created by operators getting in and out of seats. These 'artefacts' could have implications for the specialist or trained employee that has been assigned to measure whole-body vibration using autonomous logging techniques or when a multiple number of machines are measured at once.

Findings have indicated that artificial vibration magnitudes produced by operators can fluctuate depending on the subject. However no consistent relationship could be established between the weight of the subject and the magnitude created during ingress or egress.

The evaluation of operator artefacts compared with the Physical Agents (Vibration) Directive showed that the values had little impact on the exposure limit value. The exposure action value could be reached during a working day with artefacts alone if autonomous logging techniques are used and these high acceleration events are not removed from the analysis. Considering that the values are presented with no ‘true’ whole-body vibration exposure, artefacts could cause a measurement of vibration to cross the VDV action value threshold.

If high acceleration ingress and egress events are considered relevant to whole-body vibration risk assessments, office workers should also be included as a group where the VDV action value is likely to be exceeded.

Acknowledgements

The authors wish to acknowledge the support provided by Caterpillar Inc., Peoria, Illinois, USA. The views expressed here are not necessarily those of the sponsor. This work is part of a wider scale project on off-road machinery and whole-body vibration exposure.

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