Using a high resolution motion capture system to determine 6-DOF whole-body vibration accelerations

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Comprehensive investigations of the human response to vibration require many markers, accelerometers, and electrodes. The use of multiple measurement systems can result in time intensive subject preparation, large memory requirements for data storage and processing, skin motion artifacts, and subject encumbrance. The purpose of this study was to determine if a VICON™ motion capture system could reliably and accurately measure translational and rotational acceleration levels produced by mobile machines, thereby eliminating the need for accelerometers and potentially minimizing the aforementioned problems. Simulating these vibration exposures in a laboratory, it was found that translational displacements ≥ 0.1 mm produced absolute peak and RMS average acceleration measurement differences less than 5% between the VICON™ system and an accelerometer. The absolute peak and RMS rotational accelerations determined by the VICON™ system and those produced by a PRSCO™ hexapodrobot differed by 5.44 ± 3.87% and 3.57 ± 2.44% respectively. Accounting for the vibration attenuation of the human body, the VICON™ system also appears well suited for determining 6-DOF acceleration levels in laboratory seat-to-head vibration transmission studies.

1. INTRODUCTION

Operators of mobile equipment (i.e. transport vehicles, dozers, haulage trucks, load-haul-dump vehicles, forklifts, tractors, locomotives, buses) are exposed to potentially harmful levels of whole-body vibration (WBV) [1, 2]. These harmful levels of vibration — which depend on the magnitude, direction (axis), frequency, and duration of exposure to vibration [3, 4] — can be either directly or indirectly connected to many health problems [1, 3, 5]. It is therefore necessary to study how the body responds to vibration under a number of conditions in order to implement effective strategies to reduce these health risks. Jack and Oliver [6] highlight the need for such studies to investigate the interacting effects of posture, muscle activity, and WBV exposures on vibration transmission through the body. Presently, the literature on WBV transmission is limited with respect to; the amount of muscle activation, the types of postures, the exposure levels and types of exposures, used as well as the location of and amount of acceleration measurements made on the body. This leaves many gaps in the knowledge needed to fully understand how the body responds to WBV. In order to get a better understanding of the body's response to WBV a more detailed study needs to be undertaken, where many levels of the spine are measured for translational and rotational vibration transmission in concert with several muscle activation measurements and postures adopted.

In order to measure accurately the various spinal positions, acceleration levels and muscle activity levels at several different locations; many markers, accelerometers, and electrodes will need to be placed on the subject. Not only will this be time consuming, require a lot of memory for data storage and processing, be potentially costly, and hinder subject recruitment; it can also adversely affect the results. The large number of wires and attachments can be cumbersome and may affect how the subject reacts to vibration exposure because of altered muscle activation patterns associated with discomfort from all the measurement devices attached to them. This notion is supported by Rahmatalla *et al*. [7]. Furthermore, inaccuracies in measurements can result from increased skin motion (skin or soft tissue artifacts) with increased mass on the skin. Wires can also be a problem by restricting and altering normal motion patterns (subjects may respond differently than normal in order to avoid pulling on wires or the unfamiliar feel of having many wires attached to them). Furthermore, experimental errors can potentially be introduced if one of the wires were to become caught on something, thereby impeding or inducing motions which augment the results. In addition, studies that intend on using motion analysis in combination with vibration and muscle activation measurements will use many digitization markers, electromyography (EMG) electrodes, and accelerometers mounted on the skin. All of these skin mounted devices will result in a lot of clutter. This clutter can influence the subject's natural motions, introduce skin motion artifacts, and cause some of the markers to not be visible to the cameras. All of the aforementioned can introduce errors into the study (i.e. lost markers introduce errors in the three dimensional (3D) reconstruction of two dimensional (2D) camera data with direct linear transform calculations leading to missing data that needs to be interpolated). The ability to eliminate some of the measurement devices (i.e. the accelerometers, and their wires) could reduce some of these problems.

If a high sample rate/high resolution camera system could reliably and accurately reproduce vibration measurements (both translational and rotational), one could reduce skin motion errors as well as problems related to the use of wires and the encumberment of the subject. The use of cameras also eliminates the need to control for accelerations detected due to the angular motions of an accelerometer, since gravity is not used as a reference. Thus, the purpose of this study was to determine if a VICON™ 460 motion capture system could be used to determine translational and rotational WBV accelerations in a laboratory setting.

2. PART 1 – TRANSLATIONAL ACCELERATION MEASUREMENT ACCURACY

2.1. METHODS

A Bruel and Kjaer™ 4810 electromechanical shaker (controlled with a Bruel and Kjaer™ 2706 power amplifier and a Brule and Kjaer™ 2010 hydrodyne analyzer) and a mechanical lever arm (253.5 mm × 8.0 mm × 8.0 mm aluminum; Figure1) were used to produce RMS average accelerations of 10.69 ± 1.08 m/s^2, 7.26 ± 0.59 m/s^2, 3.24 ± 0.59 m/s^2, and 1.28 ± 0.10 m/s^2 in the Z-axis (vertical axis) at each of 30 Hz, 25 Hz, 20 Hz, 15 Hz, 10 Hz, 5 Hz, and 3 Hz frequency levels. A VICON™ 460 motion capture system (with six M^{2}mcam cameras) recorded a reflective marker (at the end of the lever arm) vibrated at each amplitude and frequency combination while a Crossbow™ CXL04LP3 accelerometer (+/–4 g range, 0–100 Hz bandwidth) also recorded the accelerations. Each amplitude and frequency combination was recorded for 5 seconds with a sampling rate of 250 Hz and a pixel resolution of 1020 × 656 (horizontal × vertical). The six cameras were mounted on a ceiling high railing system (rigidly affixed to the walls) that encircled the electromechanical shaker with an average distance of 3 m between the cameras and shaker.

The raw digitized VICON™ and accelerometer data were fourth order zero lag Butterworth filtered (cutoff

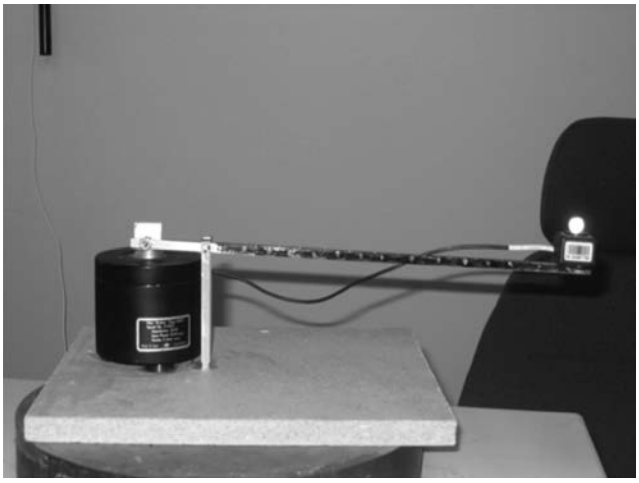

Figure 1. Bruel and Kjaer 4810 electromechanical shaker with a Crossbow CXL04LP3 accelerometer and a reflective marker attached to a mechanical lever arm.

frequency of 45 Hz; ISO 2631-1:1997 [8]). The VICON™ data were then double differentiated to provide acceleration values. The accelerometer data were corrected for acceleration changes due to the angular motion of the lever arm. A 1/3-octave band-pass filter was then applied to the VICON™ and accelerometer data and peak and RMS average acceleration levels were calculated for 1/3 octave bands with center frequencies ranging from 3.15 Hz to 31.5 Hz, for each combination of the input acceleration and frequency level [8]. The accelerometer data was double integrated (high-pass filtered at 0.5 Hz) to determine the amplitude of vibration displacements for each 1/3 octave band (3.15 Hz to 31.5 Hz) and each combination of acceleration and frequency.

The absolute percent difference between the VICON™ and accelerometer peak and RMS average acceleration values were then calculated for all 1/3 octave bands, input acceleration and frequency combination. The displacement needed in order to determine accelerations from the cameras within 5% absolute difference of the accelerometer was determined and then the minimum peak, RMS average, and ISO 2631-1:1997 weighted RMS average accelerations that the camerasystem can resolve in the Z-, Y-, and X-axes using that displacement for each 1/3 octave center frequency was calculated.

2.2. RESULTS

It was found that displacements equal to or greater than 0.1 mm produced differences less than 5% between the VICON™ 460 motion capture system and an accelerometer for both absolute peak and RMS average accelerations (Table 1). The minimum peak and RMS average accelerations that the VICON™ 460 motion capture system can determine using peak-to-peak displacements of 0.1 mm for frequencies ranging from 1 Hz to 31.5 Hz can be seen in Table 2.

3. PART 2 – ROTATIONAL ACCELERATION MEASUREMENT ACCURACY

It has been determined that the VICON™ 460 motion capture system can accurately andreliably resolve displacements of 0.1 mm. This information along with some Pythagorean math can be used to determine the separation of markers required to resolve a given angle. For example, Two 9 mm markers placed 1 cm apart (center-to-center) will have an

Table 1. Absolute percent errors between the VICON™ 460 motion capture system determined and the accelerometer determined peak and RMS average accelerations associated with various input displacements

	Absolute Percent Error (%)	
Input Displacements (mm)	Peak Acceleration	RMS Average Acceleration
0.2	2.73 ± 2.28	2.03 ± 1.68
0.15	3.11 ± 2.93	1.93 ± 1.71
0.125	3.79 ± 3.87	2.61 ± 2.80
0.1	4.81 ± 6.56	3.09 ± 3.76
0.075	5.39 ± 6.72	3.66 ± 4.45
0.05	5.60 ± 7.02	3.76 ± 4.55
0.025	9.88 ± 13.14	6.06 ± 8.27

Table 2. Minimum peak and RMS average translational accelerations that the VICON 460 motion capture system can determine†

Frequency	**Peak acceleration (m/s^2)**	**RMS acceleration (m/s^2)**	**ISO Weighted RMS acceleration (m/s^2)**		
(Hz)	**Z-, Y-, and X-axis**	**Z-, Y-, and X-axis**	**Z-axis**	**Y-axis**	**X-axis**
1	0.002	0.001	0.000	0.001	0.001
1.25	0.003	0.002	0.001	0.002	0.002
1.6	0.005	0.004	0.002	0.003	0.003
2	0.008	0.006	0.003	0.005	0.005
2.5	0.012	0.009	0.005	0.007	0.007
3	0.018	0.013	–	–	–
3.15	0.020	0.014	0.011	0.009	0.009
4	0.031	0.022	0.021	0.011	0.011
5	0.049	0.035	0.036	0.014	0.014
6	0.071	0.050	–	–	–
6.3	0.078	0.055	0.058	0.018	0.018
7	0.096	0.068	–	–	–
8	0.125	0.088	0.091	0.022	0.022
9	0.157	0.111	–	–	–
10	0.193	0.137	0.135	0.029	0.029
11	0.233	0.165	–	–	–
12	0.276	0.195	–	–	–
12.5	0.298	0.211	0.190	0.034	0.034
13	0.322	0.228	–	–	–
14	0.371	0.263	–	–	–
15	0.423	0.300	–	–	–
16	0.479	0.339	0.260	0.042	0.042
17	0.537	0.380	–	–	–
18	0.597	0.423	–	–	–

Continued

Frequency	Peak acceleration (m/s²)	RMS acceleration (m/s²)	ISO Weighted RMS acceleration (m/s²)		
(Hz)	Z-, Y-, and X-axis	Z-, Y-, and X-axis	Z-axis	Y-axis	X-axis
19	0.660	0.467	–	–	–
20	0.724	0.513	0.326	0.051	0.051
21	0.793	0.561	–	–	–
22	0.862	0.610	–	–	–
23	0.933	0.660	–	–	–
24	1.006	0.712	–	–	–
25	1.027	0.764	0.392	0.061	0.061
26	1.155	0.817	–	–	–
27	1.231	0.871	–	–	–
28	1.308	0.926	–	–	–
29	1.386	0.981	–	–	–
30	1.462	1.036	–	–	–
31	1.543	1.091	–	–	–
31.5	1.582	1.119	0.453	0.071	0.071

† Values calculated using 0.1 mm peak-to-peak displacements at the frequency of interest.
†† Values calculated in accordance with the health guidelines from the ISO 2631-1:1997 Standard, "Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration — Part 1: General requirements".

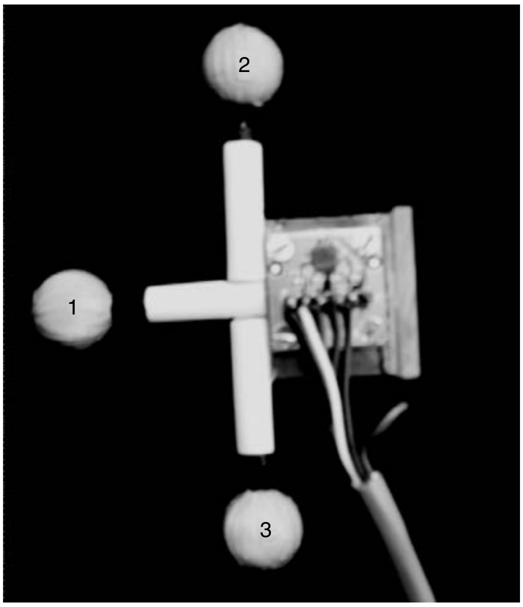

Figure 2. Marker triad. Note: the center-to-center distance between marker 1 and 2, as well as 1 and 3 is 5.5 cm. The distance between marker 2 and 3 is 8.5 cm.

angular resolution of 0.01 radians (or 0.57°) assuming that one marker travels 0.1 mm (the requirement to maintain a 95% accuracy with the camera system) relative to the other in a given plane of motion. Placing those same markers 2 cm apart will have an angular resolution of 0.005 radians (or 0.29°). Therefore, the greater the separation between two markers, the greater the system's rotational resolution.

With the above in mind, a triad of markers was created (Figure 2) were the greatest separation between any two markers was 8.5 cm. This separation was chosen because it afforded a compact set-up while providing a marker separation that

Table 3. Minimum peak and RMS average rotational accelerations that the VICON 460 motion capture system is expected to determine†

Frequency (Hz)	Peak acceleration (rad/s^2) Roll, Pitch, and Yaw	RMS acceleration (rad/s^2) Roll, Pitch, and Yaw	ISO Weighted RMS acceleration (rad/s^2) Roll	Pitch	Yaw
1	0.020	0.014	0.012	0.012	0.012
1.25	0.031	0.022	0.017	0.017	0.017
1.6	0.044	0.031	0.020	0.020	0.020
2	0.079	0.056	0.029	0.029	0.029
2.5	0.123	0.087	0.036	0.036	0.036
3	0.177	0.126	–	–	–
3.15	0.195	0.138	0.045	0.045	0.045
4	0.315	0.223	0.056	0.056	0.056
5	0.490	0.348	0.070	0.070	0.070
6	0.705	0.499	–	–	–
6.3	0.777	0.550	0.088	0.088	0.088
7	0.958	0.678	–	–	–
8	1.246	0.882	0.110	0.110	0.110
9	1.572	1.113	–	–	–
10	1.929	1.368	0.137	0.137	0.137
11	2.328	1.648	–	–	–
12	2.757	1.952	–	–	–
12.5	2.984	2.112	0.169	0.169	0.169
13	3.219	2.278	–	–	–
14	3.712	2.627	–	–	–
15	4.227	2.997	–	–	–
16	4.786	3.388	0.212	0.212	0.212
17	5.365	3.798	–	–	–
18	5.970	4.226	–	–	–
19	6.600	4.671	–	–	–
20	7.238	5.133	0.257	0.257	0.257
21	7.926	5.609	–	–	–
22	8.618	6.099	–	–	–
23	9.329	6.602	–	–	–
24	10.055	7.116	–	–	–
25	10.805	7.639	0.305	0.305	0.305
26	11.548	8.172	–	–	–
27	12.311	8.711	–	–	–
28	13.083	9.257	–	–	–
29	13.861	9.806	–	–	–
30	14.615	10.359	–	–	–
31	15.427	10.914	–	–	–
31.5	15.821	11.192	0.354	0.354	0.354

† Values calculated using 0.001 radian peak–to-peak angular displacements at the frequency of interest. †† Values calculated in accordance with the comfort guidelines from the ISO 2631-1:1997 Standard, "Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration — Part 1: General requirements".

did not impair the VICON™ marker reconstructions necessary to provide 3D marker coordinate data. In other words, the markers were all visible with no overlap. This 8.5 cm marker spacing meant that the system would have a rotational resolution of 0.001 radians (or 0.057°). Using this angle as the peak-to-peak rotational resolution, Table 3 outlines the minimum peak, RMS average, and ISO 2631–1:1997 [8] weighted RMS average angular accelerations that the VICON™ 460 motion capture system can theoretically determine with this marker set-up and the same 1020 × 656 pixel resolution used in Part 1.

The marker set-up and VICON™ 460 motion capture system combination outline above provide a viable tool for determining angular accelerations. However, the aforementioned set-up ought to be validated under actual experimental conditions and angle calculations procedures (matrix rotation calculations). The experiment outlined below addresses this necessity.

3.1. METHODS

A Parallel Robotic Systems Corporation (PRSCO) 6-degree-of-freedom (DOF) hexapod robotic platform was used to produce peak rotational accelerations of 0.17 rad/s^2, 0.70 rad/s^2, and 1.75 rad/s^2 in the Yaw-axis (vertical axis) at each of 1 Hz and 2.5 Hz. Peak rotational accelerations of 0.17 rad/s^2 and 0.70 rad/s^2 were also produced at 5 Hz. A VICON™ 460 motion capture system (with six M^{2}mcam cameras) recorded the motion of a rigid triad of reflective marker (Figure 2) vibrated at each amplitude and frequency combination. The VICON™ motion capture data were recorded for 10 seconds with a sampling rate of 250Hz and a pixel resolution of 1020 × 656.The six cameras were mounted on fully extended Manfrotto™ tripods, placing the cameras at ceiling height. The cameras encircled the PRSCO robot with an average distance of 3 m between the cameras and robot.

The raw digitized VICON™ data were fourth order zero lag Butterworth filtered. The cutoff frequencies were set to 1.5-times the frequency of interest (i.e. 1.5 Hz, 3.75 Hz, and 7.5 Hz; ISO 2631-1:1997 [8]). The filtered data was then entered into a custom Matlab™ program utilizing matrix rotation calculations outlined in Hamill and Selbie [9]. The angle time histories calculated were then double differentiated to provide rotational acceleration values. These rotational acceleration time histories were then compared the original rotational acceleration time histories used for input commands to the robot. The percent difference between the absolute peak and RMS accelerations of the two rotational acceleration time histories were then calculated.

3.2. RESULTS

The mean percent difference between the absolute peak and RMS rotational accelerations determined by the VICON™ 460 motion capture system and those produced by the PRSCO™ robot were 5.44 ± 3.87% and 3.57 ± 2.44% respectively.

4. DISCUSSION

This study based its measurements on a sampling rate of 250 Hz, a 1020 × 656 pixel resolution, and camera fields of view in the order of 1.5 m x 1.2 m. This field of view was used as it completely captures a seated subject.Under the aforementioned configuration the VICON™ 460 motion capture system provided absolute peak and RMS average accelerations within 5% of the known input when the vibration displacements were 0.1 mm or greater. Thus, motions with displacements less than 0.1 mm cannot be accurately resolved with the current motion capture set-up. Note, that by focusing the cameras onto a smaller field of view, the resolution of the system can be increased. Thus, smaller acceleration levels can be measured if the cameras are focused in on a smaller area. Increasing the camera field of view or increasing the sampling rate will reduce the resolution of the system thereby inducing more errors in the determination of acceleration levels when the displacements are near 0.1 mm. In such a case the amplitudes of the various vibrations will have to be larger in order for the VICON™ 460 motion capture system to accurately determine the higher frequency accelerations. Thus, higher frequency vibrations present challenges for the VICON™ 460 motion capture system as well. The acceleration levels that can be determined using a motion capture system will be unique to each situation and should be established prior to any formal testing. The attainment of those minimal acceleration levels can be done using a similar method to this study.

It is important to note that the 5 Hz, 0.17 rad/s^2 exposure tested corresponds to a peak-to-peak angular displacement of 0.0035 radians or 0.02°. This resolution is nearly three times greater than that originally predicted. Although some additional error (9% and 7% for the absolute peak and RMS rotational accelerations) was found for the smallest angular motion exposure, the camera system still resolved the marker triad rotational accelerations accurately. Using this new angle as the peak-to-peak rotational resolution, Table 4 outlines the minimum peak, RMS average, and ISO 2631-1:1997 weighted RMS average angular accelerations that the VICON™ 460 motion capture system has been determined capable of measuring with a sampling rate of 250 Hz, a 1020 × 656 pixel resolution, 1.5 m × 1.2mcamera fields of view, and marker triad set-up.

Similar to the 0.1mm threshold for accurate linear measurements, angular displacements less than 0.02° represent motions that cannot be accurately resolved with the current VICON™ 460 motion capture system and marker triadset-up. Note that by making the marker triad larger, the motion between markers will be greater, improving the motion capture system's ability to determine smaller angular displacements. As with linear vibrations each situation is different and angular acceleration levels that can be determined using a motion capture system will need to be established prior to any formal testing.

When using a camera system to determine WBV levels on the human body, the body's natural attenuation of vibration must be taken into account to ensure that the WBV exposure levels will not be attenuated to a level that will induce large errors if a camera system is used todetermine those vibrations. Translational seat-to-head transfer functions from Wilder et al. [10], Paddan and Griffin [11, 12], Wilder et al. [13], Zimmerman and Cook [14] and Jack and Eger [15] were combined with the results in Table 2 and compared to field exposure data from Parsons, Whitham and Griffin [16], Village, Morrison and Leong [2], Marsili, Ragni and Vassalini [17], Kumar et al. [18], Salmoni et al. [19], Rehn et al. [20], Cation *et al*. [21] and Jack [22], to determine if the VICON™ 460 motion capture system could be used in transmissibility studies utilizing field exposures as inputs. Similarly, rotational seat-to-head transfer functions from Paddan and Griffin [23] and Paddan and Griffin [24] were combined with the results in Table 4 and compared to field exposure data from Parsons, Whitham and Griffin [16], Cation et al. [21] and Jack [22]. It was determined that studies using RMS average input accelerations found at the operator/seat interface of several vehicles (standard automobiles, much machines and load-haul-dump vehicles from mining, skidders and forwarders from forestry, tractors in agriculture) could use the VICON™ 460 motion capture system to determine vibration

Table 4. Minimum peak and RMS average rotational accelerations that the VICON 460 motion capture system can determine†

Frequency	Peak acceleration (rad/s^2)	RMS acceleration (rad/s^2)	ISO Weighted RMS acceleration (rad/s^2)		
(Hz)	Roll, Pitch, and Yaw	Roll, Pitch, and Yaw	Roll	Pitch	Yaw
1	0.007	0.005	0.004	0.004	0.004
1.25	0.011	0.008	0.006	0.006	0.006
1.6	0.018	0.012	0.008	0.008	0.008
2	0.027	0.019	0.010	0.010	0.010
2.5	0.430	0.030	0.012	0.012	0.012
3	0.062	0.044	–	–	–
3.15	0.068	0.048	0.016	0.016	0.016
4	0.110	0.078	0.020	0.020	0.020
5	0.170	0.121	0.024	0.024	0.024
6	0.245	0.245	–	–	–
6.3	0.270	0.270	0.043	0.043	0.043
7	0.333	0.333	–	–	–
8	0.434	0.434	0.054	0.054	0.054
9	0.547	0.547	–	–	–
10	0.671	0.671	0.067	0.067	0.067
11	0.810	0.810	–	–	–
12	0.959	0.959	–	–	–
12.5	1.038	1.038	0.083	0.083	0.083
13	1.120	1.120	–	–	–
14	1.292	1.292	–	–	–
15	1.471	1.471	–	–	–
16	1.666	1.666	0.104	0.104	0.104
17	1.867	1.867	–	–	–
18	2.078	2.078	–	–	–
19	2.297	2.297	–	–	–
20	2.519	2.519	0.126	0.126	0.126
21	2.758	2.758	–	–	–
22	2.999	2.999	–	–	–
23	3.246	3.246	–	–	–
24	3.499	3.499	–	–	–
25	3.573	3.573	0.143	0.143	0.143
26	4.019	4.019	–	–	–
27	4.284	4.284	–	–	–
28	4.553	4.553	–	–	–
29	4.823	4.823	–	–	–
30	5.086	5.086	–	–	–
31	5.369	5.369	–	–	–
31.5	5.506	5.506	0.174	0.174	0.174

† Values calculated using 0.001 radian peak-to-peak angular displacements at the frequency of interest.
†† Values calculated in accordance with the comfort guidelines from the ISO 2631-1:1997 Standard, "Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration — Part 1: General requirements".

levels in laboratory seat-to-head transmissibility studies. The VICON™ 460 motion capture system can be used to detect head vibrations below 10Hz for most translational exposures that one might reproduce from the field.

Depending on the exposure level and axis, translational head vibrations can be detected up to 25 Hz with the motion capture system used in this study. Rahmatalla et al. [7] found that their motion capture system could accurately detect head motions up to 16 Hz while subjects were exposed to simulated heavy construction machine vibrations. As for rotational vibrations, the VICON system can detect head vibrations as high as 5 Hz when exposed to simulated field vibrations. Knowledge of exposure levels used and potential vibration attenuation by the researcher will be important in drawing conclusions. Furthermore, coherence calculations should be conducted to verify that attenuated accelerations at superior levels of the spine are still linearly related to the input vibrations. Low coherence values can be indicative of inaccurate vibration measurements.

This study has demonstrated that a high sample rate/high resolution camera system like the VICON™ 460 motion capture system can be used to determine translational and rotational WBV acceleration levels found at the operator/seat interface of industrial vehicles and the head of individuals exposed to those acceleration levels in laboratory investigations. Unfortunately, the VICON™ 460 motion capture system examined in the present study is a fairly large system, which limits its ability to be used in the field. Such a large camera system cannot be set-up within the operator cab of a vehicle. Note that any camera system with similar specifications to the VICON™ 460 motion capture system studied here has the potential to provide similar results, but should be validated with a procedure similar to the one used in the present study to verify its accuracy. A more compact camera system validated for use in WBV exposure and transmission studies could be used in field studies if desired.

The current study focused on the measurement of simulated field acceleration levels seen in mobile equipment, and as mentioned above, the study is limited to the specific laboratory set-up used. Future studies should explore the limits of cameras with a higher resolution and higher sampling rate. Such systems should provide a wider band of frequency measurement. As well, the effectiveness of different marker configurations at improving rotational acceleration measurement capabilities should also be investigated. Furthermore, the effectiveness of using markerless methodologies for camera based motion capture systems instead of the markers used in the current study should also be evaluated. Eliminating the need for markers will further detract from the number of items affixed to the subject's skin. This will further reduce skin motion artifacts, subject encumbrance, and subject preparation time. Finally, attempts should be made to expand the use of camera systems from the laboratory to the field.

5. CONCLUSION

The VICON™ 460 motion capture system (with six M^{2}mcam cameras, a sampling rate of 250 Hz, a 1020 × 656 pixel resolution, and camera fields of view in the order of 1.5m x 1.2m) appears to be well suited for the capture of peak and RMS average acceleration levels associated with WBV exposures found at the operator/seat interface of mobile machines. The system also appears to be well suited for 6-DOF transmission studies in the laboratory using WBV exposures from many industrial machines up to 10Hz for translational and 5 Hz for rotational accelerations (depending on exposure levels). The VICON™ system does have the capacity to be used for translational studies up to 25 Hz depending on the input exposure utilized.

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ONE ENVIRONMENTAL STEP FORWARD, ONE ENVIRONMENTAL STEP BACKWARD

A nightclub has limited the number of people using its smoking area after complaints about noise. Mayhem, in Warrior Square, Southend, had complaints from nearby residents. Claims that smokers outside the club were causing a noise nuisance, prompted Southend Council to holda review. Mayhem is now limiting the number of people using the outside smoking area to 30 at a time. Manager Gary Stokes said: “We’ve made some changes in the way we do things. We have signage advising customers of the residents and they are to keep the noise down. We are very conscious of the fact there are residents in the immediate location and we are happy to do everything to ensure they get a good night’s sleep.” Other conditions imposed include providing a direct line to the management of the club, signs advising revellers they may be ejected out if they cause too much noise in the smoking area, a member of staff to check people in and out of the smoking area.

SAN CLEMENTE PASTOR CHARGED OVER NOISE

An anonymous neighbor – or neighbors – of the Talega Life Church pastor and San Clemente resident Pondo Vleisides has complained several times to the Orange County Sheriff’s Department about excessive noise at Vleisides’ home during youth Bible studies and other social gatherings. Now, after the latest incident, Vleisides is facing a misdemeanor charge of disturbing the peace. Vleisides said sheriff’s deputies have visited his house seven or eight times in the past three months and more than 20 times in the past five years because of noise complaints. He said the neighbor hasn’t talked to him directly or sought mediation through their homeowners association. “The man hides behind the anonymous-call law, so I never have seen his face nor know who he is,” Vleisides said. He said he thinks the person knows he’s a pastor and that many of his gatherings are church-oriented. “I feel harassed for having clean gatherings and also because I’m a pastor,” Vleisides said. He said complaints have been made even when only two people were talking outside. “Many calls of this nature have anonymous informants who only want the excessive noise … to stop,” said Lt. John Coppock, San Clemente’s chief of police services. “They are not generally interested in initiating any formal criminal action. Whoever called on the pastor must be tired of the frequent disturbances and demanded we take criminal action.”