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Whole-body Vibration Exposure: A Demonstration of the Importance of Artifact Removal

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Abstract: Whole body vibration (WBV) exposure is guided by standards for not only measurement and analysis, but also health guidance. Health guidance decisions are based on RMS, VDV and S_{ed} evaluations. WBV exposure data is known to typically contain some content that is not relevant to environmental origins. Non-seated time and voluntary movement of the occupant are artifacts that influence a WBV exposure analysis final result. The importance of artifact removal is gaining recognition but quantitative examples of its effect are lacking. A "gold standard" for WBV exposure evaluation is presented, with varying degrees of artifact removal. A lack of artifact removal was shown to reach 580% of a difference for WBV exposure compared with the "gold standard" and result in wrongful categorization of health guidance conclusions.

Keywords: Whole-Body Vibration, Artifact, Health Guidance Caution Zone

1. Introduction

The developing importance of removing artifact from WBV exposure evaluations has been published by various authors, including Cooperrider (2008), DiFiore (2012), Page (2016) and Weames (2016). A detailed investigation of the levels of inclusion of artifact removal have not yet been published. Importantly, artifact removal can be time consuming and may require details not discussed in associated WBV exposure standards. The objective of this study was to investigate the influence of different degrees of artifact removal using case studies of locomotive train crewmembers. This study may assist in decision making for both collecting and analyzing strategies of WBV exposure data.

2. Methods

The "gold standard" for the measurement and analysis of WBV exposure was defined as a whole-shift (in this case train run) of continuously collected WBV data with all artifacts removed. To demonstrate the impact of this definition of "gold standard" iterative steps of artifact removal were conducted.

For data collection, the locomotive seat was instrumented on four complete freight train runs for collecting WBV exposure data. Table 1 provides information on these four train runs according to their train run identification. The train runs were operated under the normal course of business, and in accordance with all operating and safety requirements, by regularly and appropriately qualified train crews. In other words, there was nothing that was mocked up or staged for data collection. WBV data was collected using two 10G NexGen Ergonomics tri-axial accelerometers connected a Biometrics DataLog MWX8 data acquisition device. The Biometrics DataLog device stores the data in real time to a multimedia card, however, only once the DataLog device was cycled through a stop/start does the data become saved. To the extent possible, a data save (i.e., stop/start) on the DataLog device was performed, over a matter of seconds, during time the crewmember was not seated, if and when it was done. An LED signal switch was also connected to the DataLog device and used to keep track of relevant occurrences during data collection. This manually controlled signal switch imbedded a signal marker on the WBV record while simultaneously illuminating an LED that was captured at the same time on the video record. This setup permitted WBV data and video record synchronization, and supported locating actual instances of interest identified by the observer. One of the 10G triaxial accelerometers was placed inside a flat, NexGen Ergonomics rubberized seat pad mount and positioned directly below the test subject's ischial tuberosities. The seat pad mount was affixed to the locomotive seat pan using duct tape. The other 10G triaxial accelerometer was affixed to the floor of the locomotive, beneath the instrumented seat. Both accelerometers were oriented as per the schematic in Figure 1. The 10G tri-axial accelerometers were set to record acceleration data in the frequency range of 0-100Hz. The sampling rate was set to 500 Hz. Sony HDR-CX550 and GoPro video cameras were used to collect a video record of the locomotive engineer's activity throughout the train run, and to collect a video record of the progress and operation status of the locomotive. The video cameras were secured with the use of suction-cup camera mounts within the cab space of the locomotive, and aimed appropriately to achieve the desired angle of the field of view. Of most importance was that the field of view included the seat pan of the locomotive seat. All data collection was achieved with adequate battery power for the DataLog device and cameras, and data storage, to record continuously from beginning to end of the train run duration. No specific requests were made of the subject of the WBV exposure measurement, except to conduct their job as they normally would. This includes performing discretionary activities such as: adjusting the seat, egressing the seat (i.e. stretching, using the lavatory, etc.), and leaning to retrieve items from their equipment bag.

Table 1. Train Run Information

Train Run Identification	Train Type	Origin & Destination (Date)	Locomotive Type (Year Built)	Seat Type/Location
YFR76_30	Yard Switcher	Fresno Town Job (April 30, 2019)	GP 60 (1988)	USSC 9010 (Side rail mount) Engineer Seat Sep. 23, 2013
CFKNR_18	Coal Through-Freight	Bill, WY - Caballo Mine (February 19, 2020)	GE C44AC (1997)	USSC G2M (Pedistal Mount) Conductor Seat Apr. 25, 2018
ZSCG1_04	Expedited/ High Priority Through-Freight	Missouri Valley, IA – Boone, IA (February 5, 2020)	EMD SD70M (2002)	USSC 9010 (Pedistal Mount) Engineer Seat Sep. 2, 2014
MNPPC_03	Manifest Through-Freight	North Platte, NE – Cheyenne, WY (December 3, 2019)	GE AC45CCTE (2008)	USSC 9010 (Pedistal Mount) Engineer Seat Feb. 7, 2017

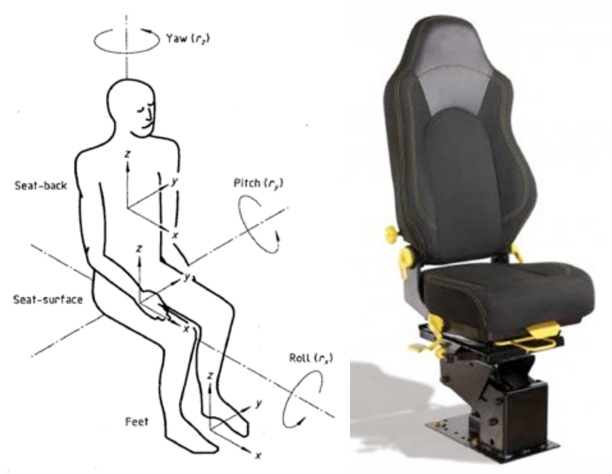

Figure 1. ISO WBV axis orientation for the placement and location of accelerometers for data collection for a seated individual. Also shown is the USSC G2M locomotive seat.

The WBV data was taken from the memory card of the data logger and copied to a computer. The WBV data files are proprietary to the NexGen Ergonomics WBV exposure analysis system, which are ".RWX" files. Each .RWX file was imported into NexGen's Biometrics Ltd. software, Version 8.51. Biometrics Ltd. software was used to find any instances within the WBV data that was due to accelerometer excitation from sources not considered WBV exposure. Common examples of artifacts that occurred during this WBV data collection effort were when the train crewmember got into and out of the seat, when seat adjustments were made, and even when bumping the arm rests. Video records and WBV exposure data were synchronized by using a marker signal, during data collection. Video records allowed the identification of non-seated time artifact. Variations in WBV exposure data recorded from the seat pan mounted, compared with the cab floor mounted, accelerometers indicated the potential presence of engineer-induced artifact. In these instances, video records were used to confirm an artifact and to categorize its characteristic. Artifact was considered to be those parts of the WBV exposure data that was not due to environment origins. It should be noted that artifact was seen on the WBV exposure trace to characteristically dominate the signal when compared to what occurred directly before and directly after the moment of the artifact occurrence. The types of artifact, for the purposes of this study, were labeled as “non-seated” (NS), “sitting down and standing up movements that generate a data spike” (SS), “movements associated with sitting down and standing up moments” (MS), and “all other seat occupant induced artifacts” (OA). NS is whenever the crewmember is not seated. SS defines the very short duration of artifact that occurred when the crewmember was in the act of getting out of the seat, or sitting down onto the seat. MS refers to seated occupant movement that typically happens before and after an SS event. For example, moving a seat in preparation for standing, or when after sitting, making additional movements to one’s seated comfort. OA includes bumping on seating armrests, making posture adjustments, and adjusting the seat while seated. Artifact categories were systematically removed in additive fashion from the WBV exposure data. The .RWX files at each step of artifact removal, including the original with no artifact removed, were each saved as a .log file.

The .log files were imported into the NexGen Ergonomics Vibration Analysis Toolset (VATS), Version 3.4.4 software. Each .log file was evaluated with the use of VATS to determine the basic vibration exposure and vibration dose value (VDV) as per the ISO Standard 2631-1, as well as the daily equivalent static compression dose (S_{ed}) as per the ISO 2631-5 (ISO 2631-1, 1997, ISO 2631-1 Amendment, 2010, ISO 2631-5, 2004).

The evaluation of WBV exposure is time dependent, to varying degrees, according to the WBV evaluation type performed (i.e., RMS, VDV or S_{ed}). Table 2 provides the measurement duration and the exposure time that were associated with each train run and according to each level of artifact removal. The measurement duration represents the total length of the WBV data that was used to calculate the RMS, VDV, and S_{ed} for each artifact removal category. The exposure time was applied to the results of the measurement duration, as an adjustment, to eliminate measurement duration as an effect on the results of WBV exposure, due to artifact removal. When removing artifact, small portions of the original WBV data are removed and the decreasing measurement durations in Table 2 for each train run demonstrate this fact. To compensate, RMS, VDV, and S_{ed} values were extrapolated to the NS measurement duration for each train run, which is the actual amount of time the crewmember was seated. When the non-seated (NS) time is removed, the seated exposure time is what remains. Note that the measurement duration and the exposure time are equivalent at the NS level of artifact removal. At higher levels of artifact removal, less data remains and the measurement duration decreases. Based on Equation #5 of ISO 2631-1 and Equations #5 and #6 of ISO 2631-5, the artifact removal categories beyond NS were extrapolated to the NS exposure time.

Table 2. Artifact Removal Measurement Duration and Exposure Time

Train Run	Artifact Removal	Measurement Duration	Exposure Time
YFR76_30	None	7:43:18	7:43:18
	NS	5:40:21	5:40:21
	NS+SS	5:39:03	5:40:21
	NS+SS+MS	5:36:14	5:40:21
	NS+SS+MS+OA	5:32:45	5:40:21
CFKNR_18	None	2:41:00	2:41:00
	NS	2:19:54	2:19:54
	NS+SS	2:19:48	2:19:54
	NS+SS+MS	2:19:40	2:19:54
	NS+SS+MS+OA	2:17:26	2:19:54
ZSCG1_04	None	2:13:01	2:13:01
	NS	2:09:43	2:09:43
	NS+SS	2:09:34	2:09:43
	NS+SS+MS	2:09:11	2:09:43
	NS+SS+MS+OA	2:07:32	2:09:43
MNPPC_03	None	8:47:48	8:47:48
	NS	8:24:51	8:24:51
	NS+SS	8:24:19	8:24:51
	NS+SS+MS	8:22:58	8:24:51
	NS+SS+MS+OA	8:11:53	8:24:51

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3. Results

Figures 1 to 3 provide the z-axis results for the 4 different train runs (YFR76_30, CFKNR_18, ZSCG1_04, and MNPPC_03) for RMS, VDV and S_{ed}, respectively. These figures demonstrate that in these four train runs, generally RMS was influenced the least by the application of artifact removal. RMS was below 0.35m/s^2 in all cases. VDV results varied substantially, from train run to train run, and a similar pattern was seen for the S_{ed} results, however, the overall impact of the degrees of artifact removal was even greater than it was for VDV. The YFR76_30 train run was a yard switching job, and evaluated a locomotive engineer. It is common for the yard job locomotive engineer to get in and out of their seat relatively more often, to move the orientation of their seat, and to make more movements when seated, compared with locomotive crewmembers operating in through-freight service, thus inducing more artifact. Most all results in Figures 1 to 3 agree that removal of artifact does reduce the RMS, VDV and S_{ed} result as the levels of artifact removal approach the "gold standard". However, it is important to note that in some cases, no artifact removal resulted in an underestimation of the "gold standard" RMS vibration exposure level. This is likely due to the fact that the RMS calculation is not time-dependent and including additional exposure time at lower levels of vibration serves to "dilute" the vibration exposure, resulting in a lower RMS acceleration calculation.

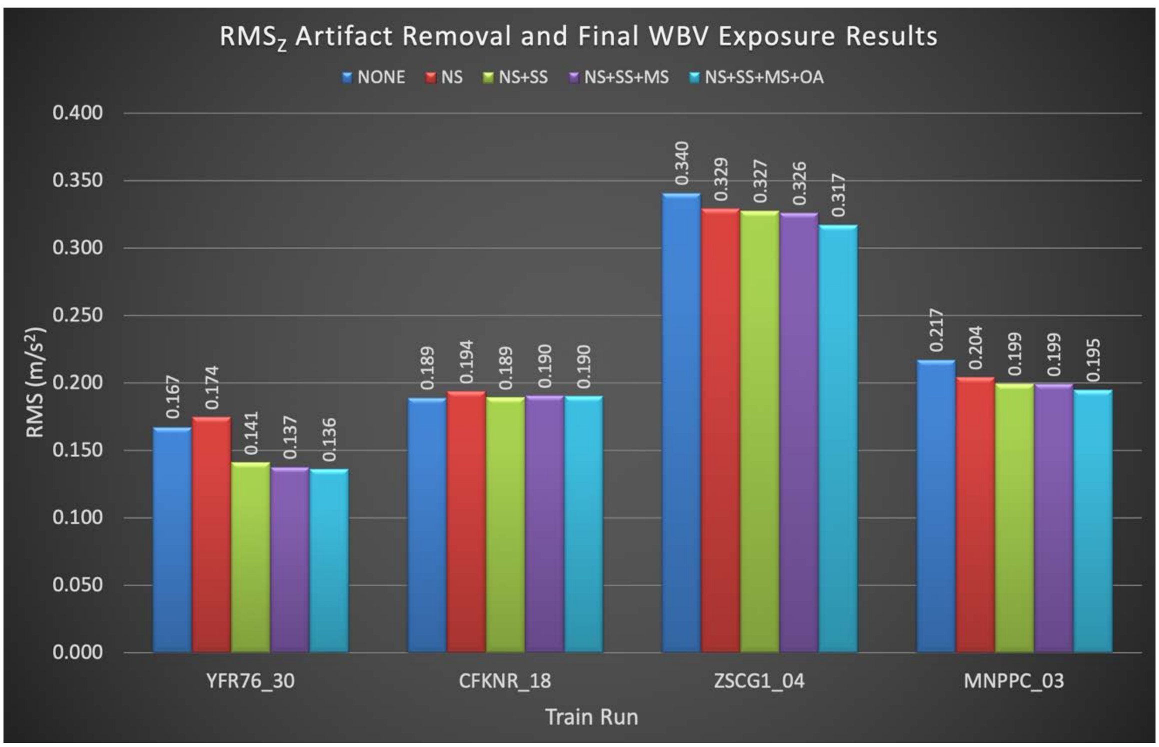

Figure 1. Final Results Due to Artifact Removal for RMS_Z

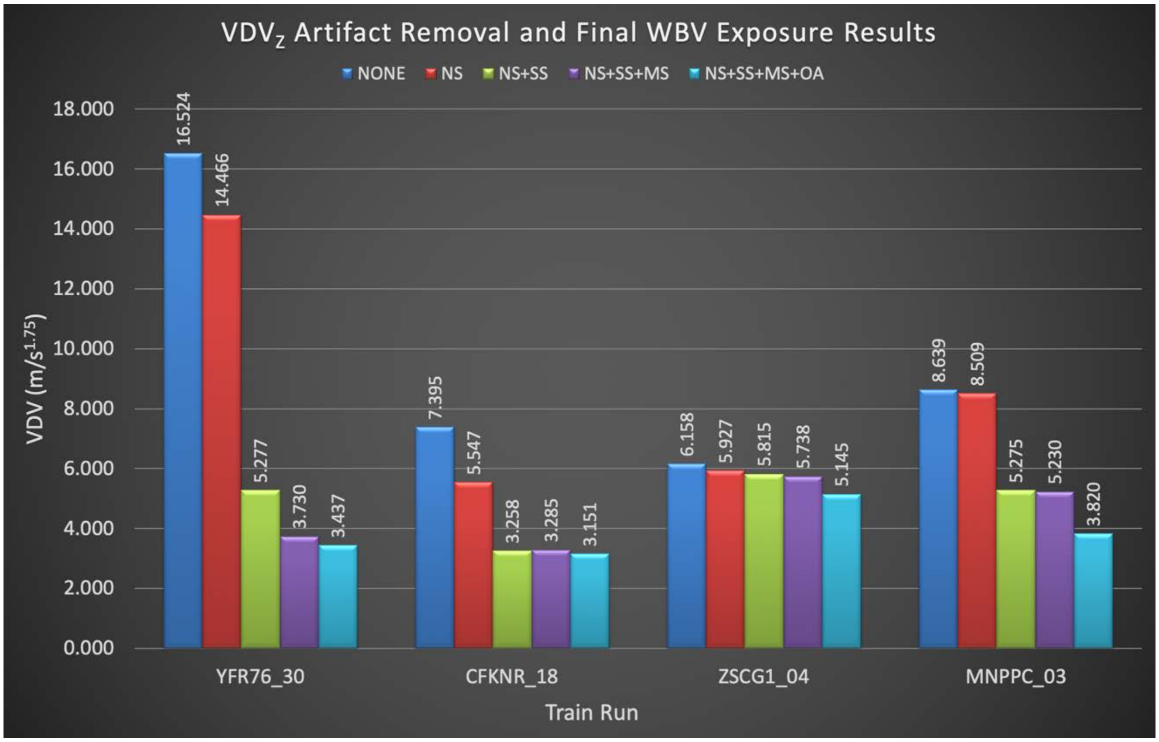

Figure 2. Final Results Due to Artifact Removal for VDV_Z

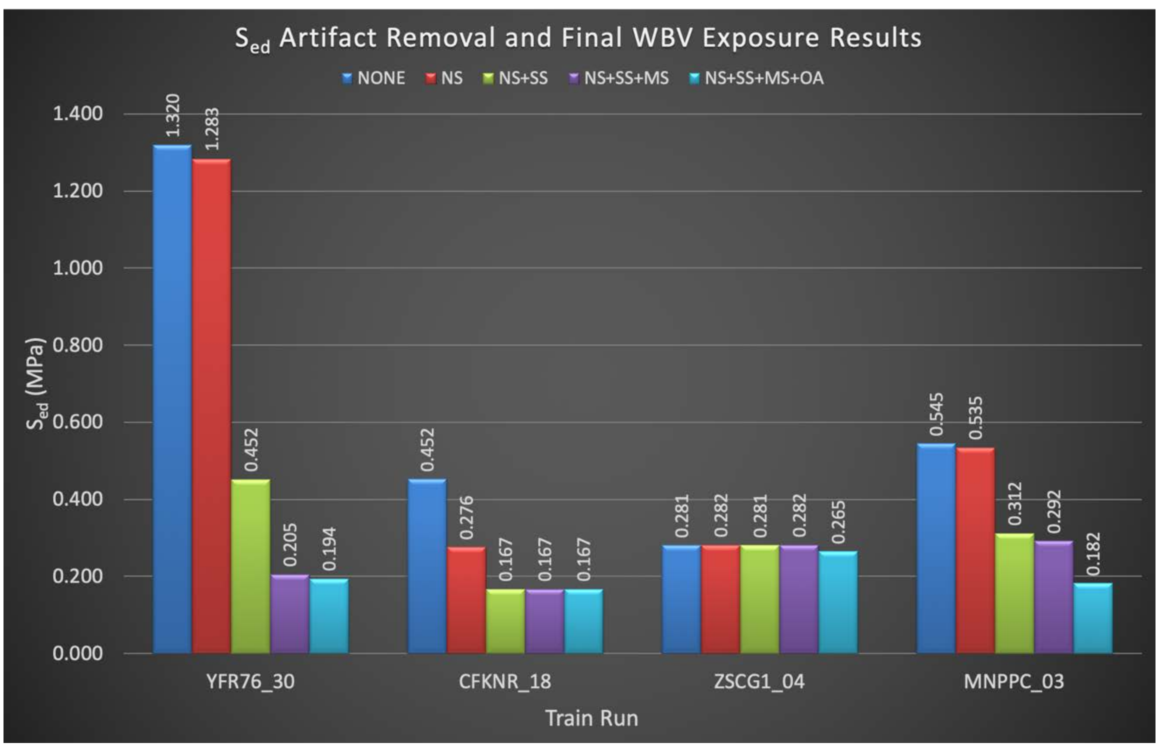

Figure 3. Final Results Due to Artifact Removal for S_{ed}

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Table 3. Health Guidance Results for Each Train Run, WBV Evaluation Type, and Artifact Removal

Train Run	Artifact Removal	RMSz	% Change from "Gold Standard"	VDVz	% Change from "Gold Standard"	S_{ed}	% Change from "Gold Standard"
YFR76_30	None	0.167	22.9%	16.520	380.7%	1.320	581.1%
	NS	0.174	28.2%	14.470	320.9%	1.283	562.3%
	NS+SS	0.141	3.7%	5.277	53.5%	0.452	133.3%
	NS+SS+MS	0.137	1.1%	3.730	8.5%	0.205	6.0%
	NS+SS+MS+OA	0.136		3.437		0.194	
CFKNR_18	None	0.189	-0.7%	7.395	134.6%	0.452	170.7%
	NS	0.194	1.9%	5.547	76.0%	0.276	65.2%
	NS+SS	0.189	-0.4%	3.258	3.4%	0.167	0.2%
	NS+SS+MS	0.190	0.2%	3.285	4.3%	0.167	0.2%
	NS+SS+MS+OA	0.190		3.151		0.167	
ZSCG1_04	None	0.340	7.4%	6.158	19.7%	0.281	6.2%
	NS	0.329	3.8%	5.927	15.2%	0.282	6.4%
	NS+SS	0.327	3.3%	5.815	13.0%	0.281	6.0%
	NS+SS+MS	0.326	2.8%	5.738	11.5%	0.282	6.5%
	NS+SS+MS+OA	0.317		5.145		0.265	
MNPPC_03	None	0.217	11.3%	8.639	126.1%	0.545	199.5%
	NS	0.204	4.8%	8.509	122.7%	0.535	193.7%
	NS+SS	0.199	2.4%	5.275	38.1%	0.312	71.3%
	NS+SS+MS	0.199	2.2%	5.230	36.9%	0.292	60.5%
	NS+SS+MS+OA	0.195		3.820		0.182	

Table 3 provides the same results as Figures 1-3 and in addition, the percent difference from the "gold standard" and color coded in accordance with ISO 2361-1 and ISO 2361-5 health guidance. All values in green are below the Lower Boundary of the Health Guidance Caution Zone for the respective WBV evaluation types. Values in yellow are above the Lower Boundary but below the Upper Boundary of the HGCZ. Values in red are above the Upper Boundary of the HGCZ. RMSz results in Table 3 are to a maximum of a 28.2% increase when comparing no artifact removal to the "gold standard" (5.9% average for all levels of artifact removal). VDV was greatly influenced on certain train runs to a maximum of a 380.7% increase (85.3% average for all levels of artifact removal) in the no artifact removal result value over the "gold standard". S_{ed} was even more influenced than VDV, to a maximum of a 581.1% increase (129.3% average for all levels of artifact removal) in the no artifact removal result value over the "gold standard".

4. Discussion

Generally, WBV exposure for crewmembers on board locomotives in freight service is characteristically low, and as such, the demonstration of artifact removal with this data resulted in a wide variety of results. Notwithstanding, artifact removal had different degrees of influence for each type of WBV exposure analysis. The behavior, of each locomotive crewmember, that generated artifact was unique, and it was not reasonable to attempt to control this behavior, particularly over extended durations. During the course of a train run, many factors can influence, seated exposure time, movement in the seat, seating adjustment and other tangible influences on the accelerometer that are not due to the vibration environment. A "gold standard" has been presented. Collecting data over the entire duration of exposure, removing non-seated measurement durations, and removing all detectable artifacts are all inclusive of a "gold standard" WBV analysis. In a previous paper, it was demonstrated that simply collecting data continuously over the course of the work day was most accurate, in comparison to various strategies that were portions of a full work day of data collection (Weames, 2016). In this paper, it has been demonstrated that even when there is an environment of relatively low environmental WBV exposure, by leaving in artifact-induced accelerometer data, the WBV evaluation result can become completely erroneous in comparison to a "gold standard" where artifact is properly identified and removed.

Artifact removal towards a "gold standard" was shown to have a meaningful impact for decision-making based on health guidance from ISO 2631-1 and ISO 2631-5. RMSz results were reasonably unaffected by artifact removal in this paper as RMSz was already very low for each train run. VDV and S_{ed} did change for 2 train runs, based on health guidance decision-making. VDV and S_{ed} emphasize the contribution of discreet shocks and/or jolts. Typically, at least for locomotive cab crewmembers, most of the largest shocks and/or jolts that were observed in the data were due to artifact. The analysis presented here demonstrates that artifact removal is both important and necessary to achieve a “gold standard” final result. Artifact removal is recommended in WBV exposure analysis efforts that are for purposes of determining health guidance.

The time and cost of achieving a “gold standard” WBV analysis, in general, is certainly a worthy analysis, compared with somewhat lesser, but effective levels of WBV analysis. The demonstration of a “gold standard” WBV evaluation presented here was relevant to crewmembers operating on board freight locomotives. However, if artifact is present in the WBV exposure data, the potential for a completely misleading result exists for any WBV exposure evaluation.

5. References

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