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Sensitivity Analysis of Artifact Removal and Sampling Period Strategies Upon Whole-Body Vibration Measurement

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Abstract: Measurement methodologies for whole-body vibration (WBV) exposure assessment at the seat pan have been established by consensus standard making organizations, including: ISO, ANSI, and SAE. These standards serve to assist ergonomists, mechanical engineers, and safety and health professionals in the measurement and evaluation of WBV. However, these standards provide for wide latitude in the determination of two important considerations: what makes a sufficient sample period? And how diligently must seating artifacts be reviewed and removed? This study aims to assess both of these questions for the operation of a North American freight locomotive. Basic vibration measured in terms of weighted acceleration in three orthogonal directions was assessed and reported in terms of their RMS values. Repeated shocks and vibration was assessed by following ISO and ANSI procedures in calculating the Vibration Dose Values in each of the orthogonal directions. The dominant axis was assessed and reported here. The measures made for the complete seated exposure time were considered the "gold standard" or 100% of the sample period, less seated artifacts. Randomized increments of the sample period were selected and assessed to illustrate the inherent variability and potential error associated with different sampling strategies. Sampling strategies included: 15 minutes, 60 minutes and the complete seated exposure period (less seating artifacts). In the second part of the study, removal of all artifacts was considered the "gold standard." One other artifact removal strategy was assessed: removal of data "spikes" attributed to getting in and out of the seat—ingress/egress. The RMS and VDV measures most sensitive where those in the vertical (z) direction. Artifact removal strategy and sampling period had the greatest effects on measures of daily equivalent static compression dose (Sed) and vibration dose value (VDV)—up to 86% and -48%, respectively for Sed. This study shows the importance of artifact removal and sampling period to ensure accurate measures of WBV.

Keywords: Whole-body vibration, artifact, sampling period

1. Introduction

The measurement of whole-body vibration has been guided by national and international standards on the topic for a number of decades. Still two topics arise whenever one measures WBV exposure: for how long should one measure, and what should be done with seat movement artifacts? The purpose of this study was to address both of these questions using previously collected WBV data for operating and riding a freight locomotive.

2. Methods

For operating and riding a freight locomotive in the locomotive cab, a train run from St. Louis, MO to Quincy, MO was analyzed. The full seated-exposure time of 5 hours and 59 minutes was assessed using tri-axial accelerometers both on the base of the seat frame and seat pan according to ISO and ANSI procedures. Per the ANSI (2002) and ISO (1997, 2010) standards for the measurement of whole-body vibration, basic vibration (RMS) and vibration dose value (VDV) were assessed in each of three orthogonal directions: vertical (z-axis), side-to-side (y-axis) and for-aft (x-axis). The results from the dominant axis (z-axis) are reported and assessed in this paper. Daily equivalent static compression dose (Sed) was also measured per ISO (2004).

The total exposure time while the freight locomotive operator was seated was determined. To assess the sensitivity of exposure time measurement, comparison of three measurement periods was made: the total seated exposure time, 15 minutes of seated exposure time, and 60 minutes of seated exposure time. The 15-minute and 60-minute sample periods were taken randomly and the exposures were normalized to the full seated exposure time. Seating artifacts were removed before selection of the sample periods and subsequent analysis were performed.

Seated artifact analysis pertains to the removal of "spikes" or specific signal noise in the WBV data attributed to getting in and out of the seat ("plops"), moving in the seat, adjusting the seat, and opening/closing the cab window. These instances of seating artifact are shocks or accelerations not attributed to the vehicle's WBV exposure. To assess the sensitivity of artifact removal, comparison of three artifact criterion was made: removal of no artifacts, removal of non-seated time and "plop" artifacts associated with getting in and out of the vehicle's seat, and removal of all artifacts—"plops" and "spikes" associated with moving to adjust body position in the vehicle's seat and opening and closing the cab window. In total 12 artifacts accounting for 2 minutes and 15 seconds were removed that occurred when the locomotive was idle. Twenty-two artifacts accounting for 3 minutes and 18 seconds were removed that occurred when the locomotive was moving. Artifacts were identified using video of the operator that was synchronized with the WBV signals for both the seat pan and seat base.

3. Results

3.1 Artifact Removal Sensitivity Analysis

Figure 1 shows the results of the sensitivity analysis of seating artifact removal for WBV exposure measures while operating a freight locomotive, including basic (RMS), vibration dose value (VDV), and daily equivalent static compression dose (Sed). Figure 2 shows the relative effect of each condition as a percent of the "gold standard"—removal of all seating artifacts (All). Figures 1 and 2 show basic vibration (RMS) to be the least sensitive to artifact removal—up to a 2.8% difference for the "none removed" condition (None) relative to the "all removed" condition (All). Daily equivalent static compression dose (Sed) was the most sensitive to artifact removal—up to an 85.8% difference for the "none removed" condition (None) relative to the "all removed" condition (All). Vibration dose value (VDV) fell between these two measures of vibration—up to a 59.2% difference for the "none removed" condition (None) relative to the "all removed" condition (All). The sensitivity of the "partial removed" condition (Partial) relative to the "all removed" condition (All) varied from a 0.8% difference for basic (RMS) vibration, to a 9.8% difference for vibration dose value VDV, to a 30.1% difference for daily equivalent static compression dose (Sed).

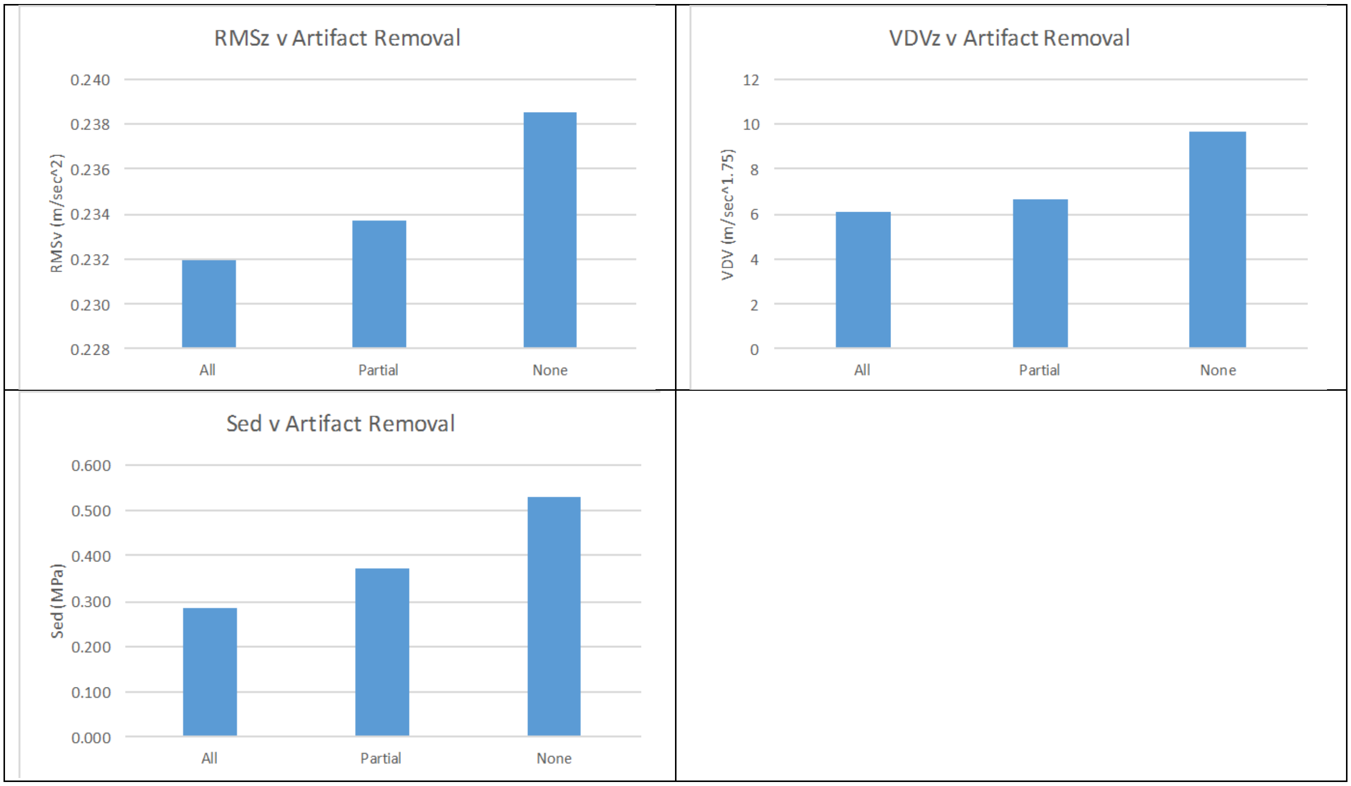

Figure 1: WBV measures v Artifact Removal Strategies.

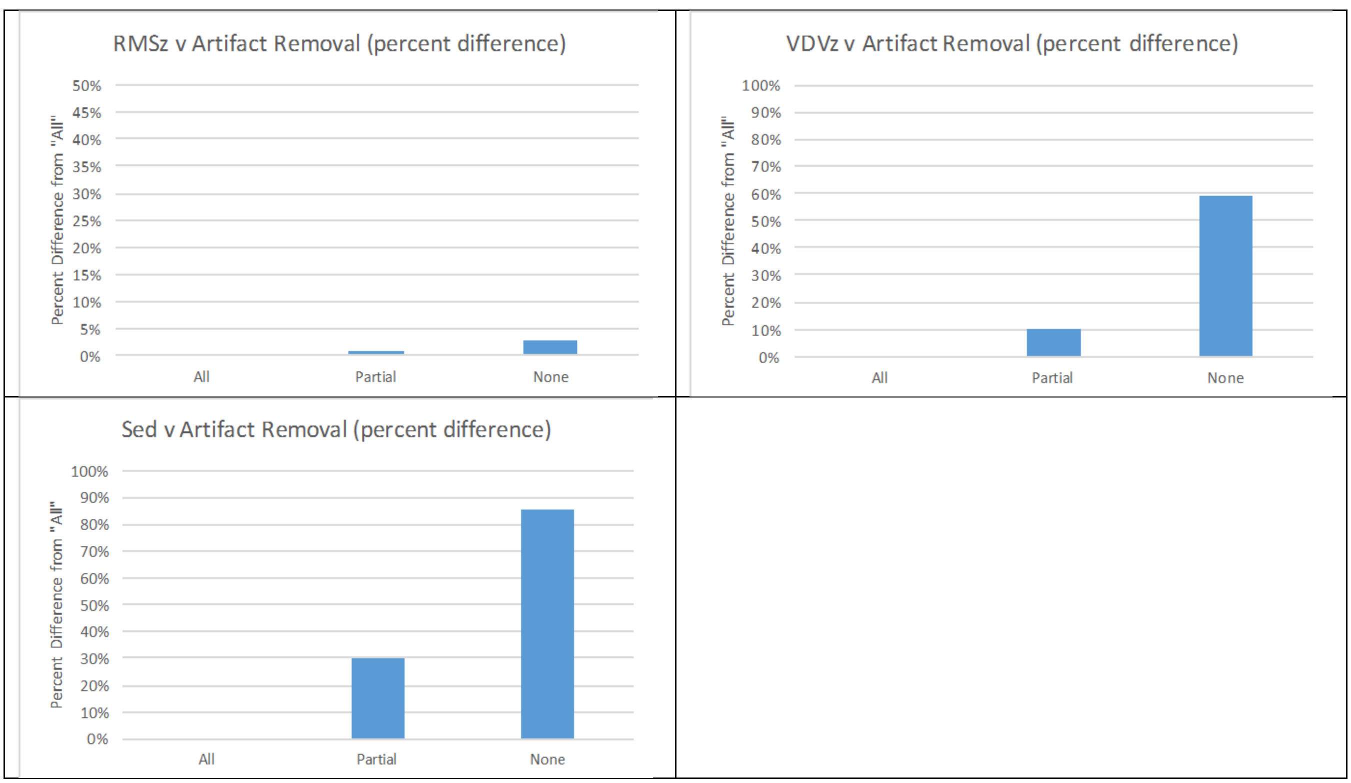

Figure 2: Effect of Artifact Removal Strategies as a Percent Difference of the Gold Standard.

3.2 Sampling Period Sensitivity Analysis

Figure 3 shows the results of the sensitivity analysis of sampling period for WBV exposures while operating a freight locomotive, including basic (RMS), vibration dose value (VDV), and daily equivalent static compression dose (Sed). Figure 4 shows the relative effect of each condition as a percent of the "gold standard"—the entire sampling period (All). Figures 3 and 4 show basic vibration (RMS) to be the least sensitive to sampling period—up to a 18.4% difference for the "15 minutes" condition relative to the "all" (i.e., full shift) sample period condition. Daily equivalent static compression dose (Sed) was the most sensitive to sampling period—up to an 48.3% difference for the "15 minute" condition relative to the "all" condition. Vibration dose value (VDV) fell between these two measures of vibration—up to a 46.3% difference for the "15 minute" condition relative to the "all" condition. The sensitivity of the "60-minute" condition varied from a 0.8% difference for basic (RMS) vibration, to a 5.6% difference for vibration dose value VDV, to a 8.3% difference for daily equivalent static compression dose (Sed) when compare to the "all" condition.

Figure 3: WBV measures v Sampling Period.

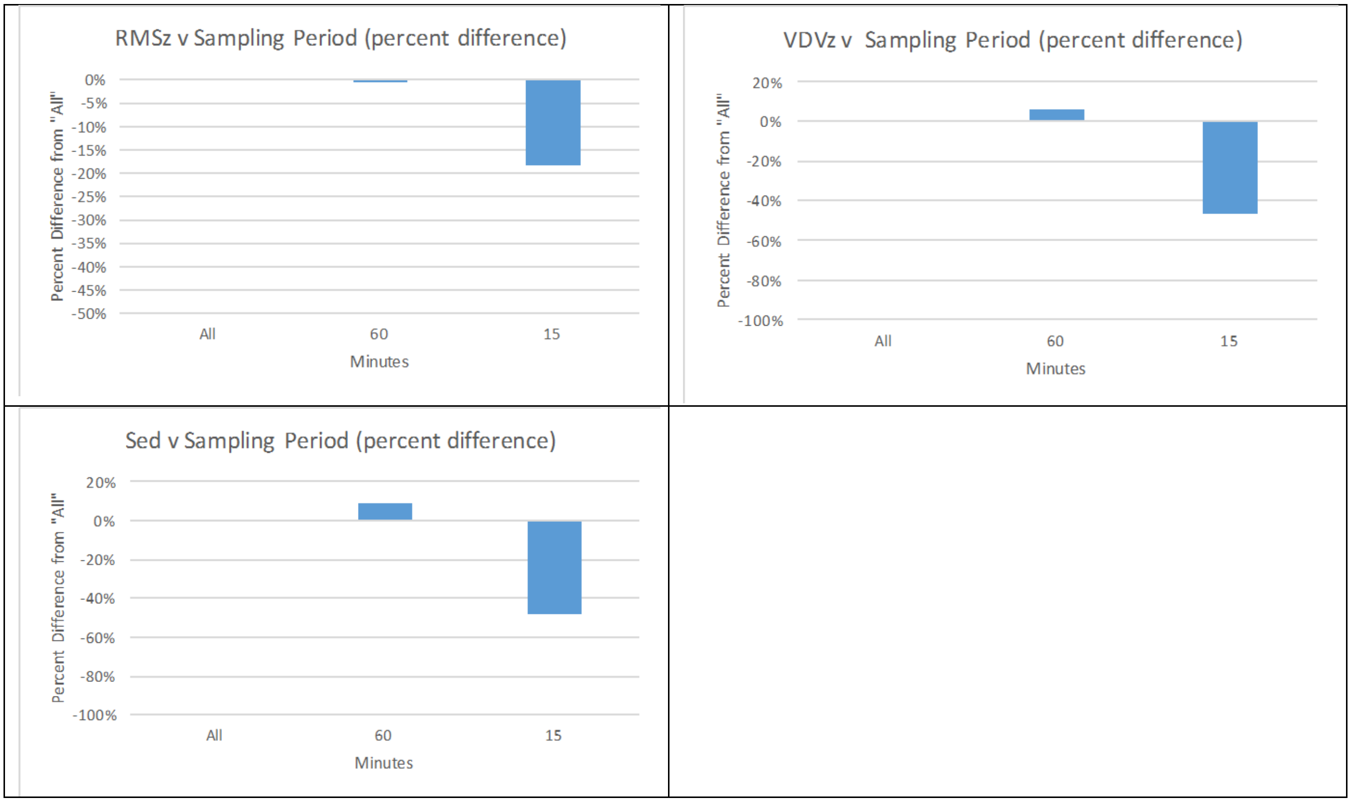

Figure 4: Effect of Sampling Period Length as a Percent Difference of the Gold Standard.

4. Discussion

The results of the analyses show that both the artifact removal strategy and the sample period length can have a significant effect on measures of WBV. Moreover, the size of the effect is more amplified with the WBV measures that are more sensitive to shock (vibration dose value (VDV) and daily equivalent static compression dose (Sed)).

The findings show that artifact removal strategy is of practical significance. If no artifact is identified and removed, Sed can be overstated by as much as 86% and VDV by as much as 59%. Sed can be overstated by as much as 30% and VDV by 10% if only the ingress/egress seating artifacts are removed. Seating artifacts need to be identified and removed to ensure accuracy of the measures of Sed and VDV.

In a similar fashion, the findings show that the sampling period is also of practical significance—although the effects upon WBV measures are not as large. Nevertheless, Sed can be understated by as much as 48% and VDV by as much as 46% if the sampling period is 15 minutes in length. Sed can be overstated by as much as 8% and VDV by 6% if the sampling period is 60 minutes in length. Sampling up to the full shift—while seated on the freight train removes these errors.

For seated freight train exposure assessment, from a practical perspective, these results show that to ensure accuracy of WBV measurement, the measurement time should be at least 60 minutes, if not longer. Moreover, all seating artifacts should be removed—not just those artifacts due to seat ingress/egress.

Use of video to assist in identifying seating artifacts was found to be a beneficial augmentation of the artifact removal method described by Cooperrider and Gordon (2008). The use of video showed the source of the artifact in comparison to the general method of comparing the WBV signals at the seat pan with that of the seat base, which identified the existence of an artifact but not its source. The video of the seated operator allows for the specific identification of the cause of the artifact.

The results of this paper are applicable to WBV exposure measurement and analysis of seated operators on board freight locomotives. Yet, little is known if other vehicle types demonstrate consistent findings regarding the treatment of WBV measurement artifact and measurement duration tendencies, as reported above or by others (Burgess-Limerick and Lynas, 2016). The findings of this research provide evidence that the treatment of artifact contained in the WBV data, as well as the decisions made regarding duration of measurement, can have a material impact on the results of the WBV exposure assessment.

Further study of these WBV exposure assessment metrics, beyond the application of the locomotive operator, is needed to help guide decision making for pragmatic but accurate and reliable WBV exposure data collection and assessment.

5. References

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