Whole-Body Vibration Exposure Study in U.S. Railroad Locomotives—An Ergonomic Risk Assessment

Whole-body vibration exposure of locomotive engineers and the vibration attenuation of seats in 22 U.S. locomotives (built between 1959 and 2000) was studied during normal revenue service and following international measurement guidelines. Triaxial vibration measurements (duration mean 155 min, range 84–383 min) on the seat and on the floor were compared. In addition to the basic vibration evaluation ($a_w$ rms), the vector sum ($a_v$), the maximum transient vibration value (MTTV/$a_w$), the vibration dose value (VDV/$a_wT^{1/2}$), and the vibration seat effective transmissibility factor (SEAT) were calculated. The power spectral densities are also reported. The mean basic vibration level ($a_w$ rms) was for the fore-aft axis $x = 0.18$ m/sec$^2$, the lateral axis $y = 0.28$ m/sec$^2$, and the vertical axis $z = 0.32$ m/sec$^2$. The mean vector sum was 0.59 m/sec$^2$ (range 0.27 to 1.44). The crest factors were generally at or above 9 in the horizontal and vertical axis. The mean MTTV/$a_w$ was 5.3 ($x$), 5.1 ($y$), and 4.8 ($z$), and the VDV/($a_wT^{1/2}$) values ranged from 1.32 to 2.3 ($x$-axis), 1.33 to 1.7 ($y$-axis), and 1.38 to 1.86 ($z$-axis), generally indicating high levels of shocks. The mean seat transmissibility factor (SEAT) was 1.4 ($x$) and 1.2 ($y$) and 1 ($z$), demonstrating a general ineffectiveness of any of the seat suspension systems. In conclusion, these data indicate that locomotive rides are characterized by relatively high shock content (acceleration peaks) of the vibration signal in all directions. Locomotive vertical and lateral vibrations are similar, which appears to be characteristic for rail vehicles compared with many road/off-road vehicles. Tested locomotive cab seats currently in use (new or old) appear inadequate to reduce potentially harmful vibration and shocks transmitted to the seated operator, and older seats particularly lack basic ergonomic features regarding adjustability and postural support.

Keywords: ergonomics, locomotives, railroads, seat, shock, whole-body vibration
TABLE I. Locomotive and Engineer Seat Descriptive Information

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Model (Power)</th>
<th>Unit No.</th>
<th>Built (hp)</th>
<th>Manufacturer</th>
<th>No. Locomotives In Service</th>
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*Second locomotive unit.

**hp** = horse power or diesel engine.

*Cf* = freight.

*P* = passenger.

*n/d* = no data.

recognized factors such as lifting, forceful movement, heavy physical work, and awkward posture. The scientific evidence of recognized occupational risk factors and clinical approaches to low-back disorders have been reviewed elsewhere. The purpose of this study was to evaluate whole-body vibration exposure of locomotive engineers under normal operating conditions and comparing different locomotives, seats, and operating conditions.

Fixed guideway transport systems such as subway trains have been shown to have relatively high lateral vibration due to unique track-bound vehicle characteristics. In the past, primarily vertical vibration measurements have been made for a variety of road and off-road vehicles. The current study utilized modern, state-of-the-art vibration measurement equipment and current measurement guidelines to assess whole-body vibration and shock exposure of seated locomotive engineers and to study the effectiveness of seat vibration dampening (vibration transfer function). There are two basic cab designs in use, the traditional cab with controls diagonal to the front/left of the operator (American Association of Railroad [AAR] control stand) and the modern cab design with a control panel in front of the operator (i.e., desktop console in the new generation "wide body locomotive"), posing unique ergonomic challenges for the locomotive engineer regarding operational requirements and body posture (curvature and torsion of the spine). Depending on the control panel design, seats were attached to the floor or the right wall of the cab (cantilevered seat) to allow the operator seat adjustments and bidirectional use of the unit. Diesel-electric locomotive cab styles, design, and general technical information have been described elsewhere in further detail.

**MATERIALS AND METHODS**

The goal of the study was to assess whole-body vibration exposure to locomotive personnel during normal and routine train-operating conditions. Measurement of periodic, random, and transient vibration and shocks were done following national and international guidelines for measurement of human exposure evaluation to whole-body vibration (ISO 2631-1 [1997]). Vibration acceleration was measured in three directions on the seat pad and on the floor or wall near the seat attachment. A frequency range of 0.5 to 80 Hz was analyzed as recommended for health assessment. The three seat accelerometers (low-mass piezoresistive accelerometers from Endevco, Type 7265A-HS; sensitivity 25 mv/g with a full scale of 20 g) mounted in a seat pad (semi-elastic material) were placed on the seat surface (buttock area) used by the locomotive operator to simultaneously measure vibration at the interface of human body and the source of the vibration in the fore-aft direction (horizontal axis [x]), the lateral direction (side-to-side horizontal axis [y]), and the vertical direction (up-down axis [z]). The triaxial transducers (Endevco, Type 7265A-HS) measuring the vehicle floor/wall vibration were placed in a metal cube that was glued to the cab floor or wall. Vibration signals were recorded with a digital tape recorder (TCD-D7 16 Channel PCM unit) and analyzed using a signal processor and amplifier (PSC 16, KMT). The signal processing, computation, and vibration analysis (amplitude recording, a values and frequency analysis) were done with the following equipment: a fast recorder (TA 11, Gould), an amplitude statistics and signal analyzer (model 4426; Brüel & Kjær), a whole-body filter according to ISO 2631-1:1997 for vibration measurement in direction x, y, and z (GA-KÖ-FI, BIA); and a frequency analyzer (model 35670A, Hewlett Packard). The duration of the measurement depended on the completion of the locomotive engineer’s job task and generally lasted several hours from the origination to the destination yard/train station (Table 1). The measurement duration (mean 155 min; range 84 to 383 min) was sufficient to ensure reasonable statistical precision and that the recorded vibration and
shocks are representative of the locomotive engineer's exposure during a normal work shift. Measurements were done during normal revenue service operation of the freight or passenger locomotives throughout the United States railroad system (Amtrak, CSX [Conrail; CN], BN, UP/SP) utilizing mainline track in the northeast corridor, the Midwest, and California. The track conditions and maximal train speed varied from measurement to measurement depending on regional maximal speed limitations, specific track class, and locomotive characteristics. One set of vibration measurements was made for each ride; however, several seats were measured simultaneously if possible (engineer's, conductor's, or fireman's seat) in addition to the floor/wall measurements. The normally scheduled locomotive engineers (with job seniority of approximately between 10 to 30 years) were instructed to remain seated and minimize voluntary movements to avoid artifacts, but to operate the train and locomotive in a routine fashion according the given schedule and dispatcher instructions. The vibration recording was screened for possible artifacts and any unclear signals were removed before the data analysis.

The goal of this study was not primarily to correlate the train speed with the vibration, but to study vibration exposure utilizing a variety of locomotive and random track conditions (mostly continuous welded rail and wooden ties or cement ties, Amtrak passenger service track/rail). None of the train measurements were made on the same track at all times, but some locomotive models were repeatedly tested on different tracks with different speeds. The average speed varied between the measurements and was close to the given allowable maximal speeds set by the railroad company (Table I), but was not specially measured, because the relationship of speed and vibration was not a focus of this study.

Basic vibration evaluation according to ISO 2631-1 includes the measurement of the weighted root-mean-square (rms) acceleration and is expressed in meters per second squared following the frequency-weighting curves for the various directions as recommended in the current ISO 2631-1 standard annexes. The seat or floor vibration was described in relation to its effect on the locomotive operator, the calculated crest factors (ratio of the maximum instantaneous peak value of the frequency weighted acceleration signal to its rms value) are reported. If crest factors exceed 9 according to ISO 2631-1 (1997), reporting of the basic vibration evaluation may not be sufficient and may underestimate the severity, because vibration-containing occasional shocks are not adequately described and additional methods to describe the magnitude should be utilized. The authors calculated the maximum transient vibration value (MTVV), the vibration dose value (VDV), and the vibration seat transfer factor. According to Chapter 6.3 of ISO 2631-1: 1997, the proposed methods are the running rms method (here the MTVV) or the fourth power VDV. The running rms evaluation method takes into account occasional shocks and transient vibration by use of a short integration time constant. The MTVV is defined as the highest magnitude of \( a_w \) \( (t_0) \) during the measurement period. According to the ISO standard, the fourth power VDV is more sensitive to peaks than the basic evaluation method by calculating the fourth power instead of the second power of the acceleration time history as the basis for averaging. The critical ratio values triggering additional evaluation and reporting requirements according to the ISO 2631-1 (1997) are for 

\[
\frac{MTVV}{a_w} = 1.5
\]

and

\[
\frac{VDV}{a_w \cdot T^{1/4}} = 1.75
\]

(\( T \) = measurement duration). For an overview of the vibration analysis methods see Figure 1.

The ratio of vibration on the operator's seat pad and the vibration at the mounting point of the seat is described as the seat effective amplitude transmissibility (SEAT) according to ISO 10326-1: 1992.\(^{(1)}\) The SEAT factor shows the ability of the seat

### Table I. Extended

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<th>Sampling Time</th>
<th>Rail</th>
<th>mphmax</th>
<th>Seat/Control Panel Mounting</th>
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<th>Material</th>
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\[^{c}\) Corrections for seating and vibration are applied.

\(T = \) measurement duration.
to diminish the input vibration caused by the vehicle (vibration reduction for SEAT <1) and the actual vibration level transmitted at the operator's buttocks level (output). A value of 1 indicates that all input vibration would be transferred without any damping effect and a value >1 would indicate an amplification of the transmitted vibration to the operator's buttocks and lower spine.

Although the assessment of the effect of vibration shall be made independently along each axis (i.e., highest frequency-weighted acceleration), the vector sum may be used when vibrations in two or more axes are comparable and one value \( a_v \) is desired to describe the overall vibration exposure. The vector sum \( a_v \) is calculated from the weighted rms acceleration of the \( x, y, \) and \( z \)-axis and a multiplying factor \( k \) (for health \( k = 1.4 \) for \( x \) and \( y \) axis, and one for \( z \) axis):

\[
a_v = \sqrt{a_{\text{rms}}^2 + a_{\text{rms}}^2 + a_{\text{rms}}^2}
\]

The power spectral densities (PSD) show the distribution of vibration over the frequency range of 0 to 80 Hz. The relation between the PSDs on the seat and at the seat mounting point provides information about the vibration attenuation effectiveness of the seat and its transfer function at a given frequency. Good seats have a resonance frequency that should be at least 1.4 times lower than the dominant resonance frequency of the vehicle where the seat is mounted. A typical PSD diagram for seat and floor recordings and seat transfer function is shown in Figure 2.

Statistics were calculated with the Microsoft Excel 2000 program. Associations between accelerations in the three directions (\( x, y, z \), and the vector sum score) and the year of locomotive manufacturing, maximal speed, and type of seat attachment (floor versus wall mounting) were calculated.

**RESULTS**

Twenty-two locomotive vibration measurements were conducted (in eight passenger trains) on the cab floor and the engineer's seat level with an average sampling time of 155 min during normal revenue service with a variety of track conditions (mostly continuous welded rail and wooden ties) and speeds (maximum 120 mph). Descriptive information about the locomotives, cab design, and seats is listed in Table I. The majority of the locomotives were built about 30 years ago, with seven units built less than 4 years before the time of measurement. The seat design and type of mounting varied in all locomotives, with the newer units having seats with more adjustments (i.e., height and fore-aft position, back support angle), having arm rests, and some type of shock-damping systems. Locomotives built before the mid-1970s often had seats with round foam/vinyl pads (17-inch diameter) that allowed very few adjustments by the train operator and occasionally had arm rests but had no special lumbar supports. Many seats were loose at the mounting points due to design failures, malfunctioning equipment, or lack of maintenance, allowing great play in all directions triggered by train or operator motion. Control panels (labeled “side” in the Table I) with the brakes and acceleration handles (throttle) positioned to the left/front (about 45 to 90°) (the “AAR control stand”), typically resulted in a rotated spinal position and a slightly forward twisted posture of the locomotive operator. This forced operator's posture and affected the body axis in the horizontal plane (\( x \) and \( y \) direction) and also in the vertical axis (\( z \)).

Results of the vibration measurements for the three measurement directions (\( x, y, z \)) at the engineer's locomotive seat level (weighted acceleration \( a_v \)), the vector sum calculations, the seat mounting point, the SEAT, crest factor (CF), MTVV/\( a_v \), and VDV/(\( a_v \) T^{1/4}) are listed in Table II.

The mean vibration levels for the lateral (\( y \)) and the vertical (\( z \)) axis were almost of the same magnitude (mean 0.28 m/sec² and 0.32 m/sec², respectively), compared with a lower vibration level in the fore-aft direction (\( x \)-axis) with 0.18 m/sec². The mean vibration vector sum calculation for all measured locomotives was 0.59 m/sec² (range 0.27 to 1.44). Because the calculated CFs were generally higher than 9 in the \( x \) and \( z \) directions, additional measurements to the basic vibration value method are listed. The mean MTVV/\( a_v \) was 5.8 (\( x \)), 5.1 (\( y \)), and 4.8 (\( z \)) (range and SD; see Table II). The VDV/(\( a_v \) T^{1/4}) values for the respective measuring times that the engineer sat in his seat ranged from 1.32 to 2.8 (\( x \)-axis), 1.33 to 1.7 (\( y \)-axis), and 1.38 to 1.86 (\( z \)-axis). Several of MTVV/\( a_v \) and VDV/(\( a_v \) T^{1/4}) values exceeded the critical ratio values (1.5 and 1.75, respectively) listed for health and comfort in the ISO 2631-1 (1997) standard. These results indicate a high rate of strong shocks and impulses in the measured direction.

The manufacturing year of the locomotive and the maximum speed were moderately correlated \((r = 0.61; p < 0.01)\). Floor-mounted seats tended to have less fore-aft (\( x \)); 0.12 versus 0.23; \( p = 0.103 \) and lateral vibration (\( y \)); 0.22 versus 0.34, \( p = 0.07 \), but higher vertical vibration (\( z \)); 0.35 versus 0.28 \( p = 0.06 \) than wall/side mounted seats.

The investigated seats were made of steel/iron with a foam-wood cushion (some with steel spring support) or had a suspension system with a crossbar (X) damping device (spring or hydraulic shock absorber) to attenuate vertical vibration and shocks. Regardless of the age or make, all seats did not appear to provide information about the vibration attenuation effectiveness of the seat and its transfer function at a given frequency. Good seats have a resonance frequency that should be at least 1.4 times lower than the dominant resonance frequency of the vehicle where the seat is mounted. A typical PSD diagram for seat and floor recordings and seat transfer function is shown in Figure 2.

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In this study of 22 locomotive cabs during typical and normal operations it was found that the measured vibrations transmitted to the seated engineer's lower spine were similar in the lateral and vertical direction and higher compared with the fore-aft direction based on a basic vibration analysis in the ISO 2631-1 (1997) standard. The mean vibration value of 0.32 m/sec² in the vertical direction appears equal or lower compared with data from some road and off-road vehicles\(^{1,12}\), however, the authors' detailed analyses suggest a high frequency of shocks and irregular vibration because of the CFs and MTVV/\( a_v \) or VDV/(\( a_v \) T^{1/4}) values, which are higher than the reference values listed in the ISO 2631-1 (1997) standard. As previously stated, if the CF exceeds 9, and the ratio MTVV/\( a_v \) exceeds 1.5 or the VDV/(\( a_v \) T^{1/4}) exceeds 1.75, then the basic rms vibration method and reporting is not
sufficient because it may underestimate the effects of vibration (see paragraph 6.3.3 of ISO 2631-1: 1997). That means that the human vibration exposure health risk should probably be assumed to be higher, although the measured basic vibration values (rms vibration data) may still be below a recommended threshold limit in a specific direction. Therefore, the measurements of basic vibration measurement alone are not sufficient to assess the possible associated health risk. Results of simultaneous measurements on the conductor’s or fireman’s seats in the same locomotive cabs were in a similar range (data not listed); however, additional measurements under different working conditions may provide further information about the validity of these findings or additional knowledge of the vibration exposure in rail-bound vehicles.

In the European Union (EU), a health directive is currently in final discussion requiring medical surveillance and prevention measures if the basic vibration values exceed the proposed action limit of 0.5 m/sec² for an 8-hour work shift exposure duration.\(^{14-18}\) Health disorders are thought to be influenced by peak vibration.
well as duration of exposure, have been associated with an increase
In general, increased exposure levels of vibration and shock, as
found in epidemiological studies.\[^{12}\].

The effect threshold has not been established, and a quantitative rela-
tionship between vibration and adverse health effects has not been
established in epidemiological studies.\[^{13}\]

There are about seven million workers in the United States
exposed to whole-body vibration, which may cause discomfort,
decreased performance and vigilance, and present a health and
safety risk. In general, long-term exposure to whole-body vibration
has been associated with low-back pain and back disorders
(accelerated spinal degeneration effects, disk herniation, and nerve
root damage [sciatica]). Some studies have also demonstrated as-
associations with gastrointestinal and renal system abnormalities;
musculoskeletal, neck, and shoulder disorders; and problems of
the female reproductive system, peripheral veins, and the vestibular
system. The human spine appears to be particularly sensitive to
vibration in the 4 to 12 Hz range (resonance range). The seated
operator's spine stretches most in this frequency range, which
results in an increased vibration effect (stressor). Vibration experts
cautions that excessive and prolonged whole-body vibration ex-
posure should be avoided because the human body does not de-
velop a tolerance or training effect to whole-body vibration. Even
“occupational work-hardening programs” are not appropriate for
prevention of adverse effects in a work environment with high
vibration levels.\[^{15}\]

In terms of vibration exposure duration, no exact and inde-
pendent data is available to assess the typical duration of the en-
gineers' work. Based on information provided by union health and
safety officials, it should be considered that a great number of
locomotive engineers reportedly work more than 40 hours per
week and more than 20 plus years due to pay and railroad regu-
lations. By U.S. federal law there must be a minimum of 8 hours
of rest period between locomotive rides and many engineers work
irregular work shifts. It appears that U.S. locomotive engineers
have not been adequately studied in the past regarding common
musculoskeletal disorders and ergonomic hazards, specifically re-
related to whole-body vibration.

Although many of the newer generation seats have improved
ergonomic seating features (i.e., easier position and height adjust-
ability, lumbar adjustability, pan length adjustment, back recline,
flip-forward backrest, seat contours to support the body posture
[back shell] and more elaborate vibration dampening systems),
these did not appear to make any difference in the measured levels
of vibration on the seat. Older seats tended to have less body
contour support and adjustability. The seats were typically made
of iron, wood, rubber/foam, and vinyl material. In several of the
investigated seats, the operator's body was traveling in the hori-
izontal direction on top of the cushion with increased movement
comparing to the vehicle excitation. The result was a vibration aug-
mentation in the horizontal and vertical directions.

Currently there is no study about American locomotive vibration
measurements in the generally cited peer reviewed publications
available on the Medline data base, although one industry-
sponsored study has been published in a professional society
journal.\[^{16,19}\] In an earlier Finnish study, vibration of the seat and
the body in a diesel locomotive and an electric locomotive were
measured while driving on the railways of Eastern Finland.\[^{20}\]
At the speed of 120 km/hour for the diesel locomotive and 140 km/
hour for the electric locomotive (the highest permissible speeds),
the vibration of the seat was close to the "fatigue-decreased pro-
ciciency boundary" of the international standard ISO 2631-1/1(1)
from 1985 in the side-to-side direction in one-third octave bands
1–1.6 Hz. The results of the Finnish study cannot be directly
compared with the present study, because the weighting and cal-
culation methods have changed slightly in the currently applicable
standard ISO 2631-1 issued 1997. Similar to this study, in the
Finnish study the frequency response measurements between the
body of the locomotive and the seat indicated that the seat did not
reduce side-to-side vibration of the body at low frequencies
where the vibration may be most harmful. The Finnish report
lacked specific information about the CF, MTVV, VDV/(\(\ddot{a}\), T^4) values
and further shock analysis.

In a study conducted by Cooperrider and Fries for the Union
Pacific (UP) railroad it was found that all measured locomotives
were well below the 8-hour fatigue-decreased proficiency bound-
ary except for two locomotives at a total of four speeds (utilizing
the ISO 2631 from 1985 with a slightly different weighting
formula). Equivalent total exposures for all locomotives were
calculated to be below the fatigue-decreased proficiency. It was
concluded that the locomotive ride quality compared favorably to

![Power Spectral Density](A)

![Seat transfer function (SEAT)](B)

**FIGURE 2.** Typical PSD and seat transfer function in the vertical
direction of a modern suspension seat in U.S. locomotive (from
measurement No. 2, UP 8056, SD90/43C, freight train, main line
track). Note: (A) Solid line = seat level vibration; dotted = cab
floor vibration.
the ride quality of other low impact road vehicles (passenger luxury cars). This was concluded although the CF of 6 (ISO 2631-1 (1985)) was exceeded in many locomotive measurements (mean was 7, SD 2.4), and the ISO 2631 standard from 1985 stated that if the CF exceeds 6, the recommended vibration evaluation method by the standard may underestimate the effect of the motions.

No MTTV or VDV/(a, T^4) were calculated as listed in the 1997 ISO 2631-1 standard. This study found the highest seat accelerations in the vertical direction, but lower levels in the longitudinal and lateral direction (no values for comparison are provided in the publication).

In the current study the mean vibration vector sum calculation for all 22 measured U.S. locomotives was approximately 0.6 m/sec^2. In accordance with the proposed EU action limit of 0.5 m/sec^2 (8-hour workday), the introduction of focused occupational medical surveillance and vibration protective measures would be prudent. Prevention measures could include technical intervention (vibration reduction through better tracks, locomotive cab design, suspension seats with optimal postural support and control), health monitoring and education of engineers, and reduced exposure periods (less overtime work and more rest periods between long locomotive rides).

Reports of back problems among locomotive operators were described in a French study as early as 1954, and in the late 1960s by the head physician of the Swiss Railroad, and in the Slovakia in the 1970s. In the United States ergonomic issues in the railroad industry have gained interest in the last two decades partly as a way of controlling costs through reduction of accidents and injuries, with an initial focus on "macro-ergonomic" issues (see Clean Cab standard from 1974 and later with a shift to "micro-ergonomic" analysis (cab air, diesel exhaust, and back injury prevention related to material handling, rail car hand brakes, switch operations). However, other than a "selection and training of locomotive engineers" no specific ergonomic research priorities have been listed by the authors of the Safety Research Division of the Association of American Railroad.

The results of the present study would justify and support ergonomic efforts to improve cab working conditions including the positioning of control handles, the display panels, communication equipment, and the seat attachment. Successful interventions and ergonomic improvements in road and off-road vehicles in the last decades have resulted in significant reduction of vibration and shock exposure through better cab and seat design. Modern tractor seats are now achieving better than 50% vibration reductions (mean SEAT factor 0.42) and other off-road vehicles a SEAT factor of about 0.8. However, locomotive cab conditions and job requirements would need specific engineering and administrative control measures. Vibration and shocks unique in rail vehicles are caused by or related to a combination of locomotive chassis/track interaction; slack action of cars; speeds; track conditions and maintenance; and the locomotive engineer's training, experience, and operational style. The vibrations experienced by the locomotive operators also result from the seat own response (augmentation) to the vibration input, as this study has shown.

Currently, a specific standard (see ISO 2631-4:2001) for rail
vehicle whole-body vibration measurement and analysis is in preparation by an ISO technical committee (ISO/TC 108/SC 2), but is not yet implemented. The ISO 2631-1 standard needs to be utilized for vibration and shock exposure assessment, although rail vehicles have vibration characteristics that are unique compared to road and off-road vehicles. Only a limited number of studies covering evaluation methods of passenger comfort measurements is available.\(^{(22)}\) Recently, a guideline by the ISO technical committee for the evaluation of passenger and crew comfort was published.\(^{(24)}\)

The special considerations for fixed-guideway transport systems (railroads) outlined in the report may provide important information that is applicable for locomotive seats of engineers. Rail-guided transport vehicles produce significant repetitive and/or vibration with translational and rotational (roll) motions. Factors including noise levels, visual stimuli, temperature and humidity, and possibly air pollutants (diesel exhaust) interact with perceived vibration and comfort by the passenger and probably also the locomotive engineer. Newer locomotive cabs have integrated climate-control systems (although the authors observed that often the vents blow cold air directly onto the muscle [body] parts, which also may adversely affect the musculoskeletal system) and the ambient noise is reduced if the cab windows are closed.

Important for a health assessment are the actual daily vibration exposure duration periods and possibly cumulative exposure over 10 to 20 years. Ergonomic control and prevention strategies in locomotive cabs should include these factors, although an improved cab and seat design may be beneficial in the short-term to reduce overall whole-body vibration. Additional exposure and epidemiological studies will be useful to gather more information about ergonomic conditions and risk in U.S. railroads.

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