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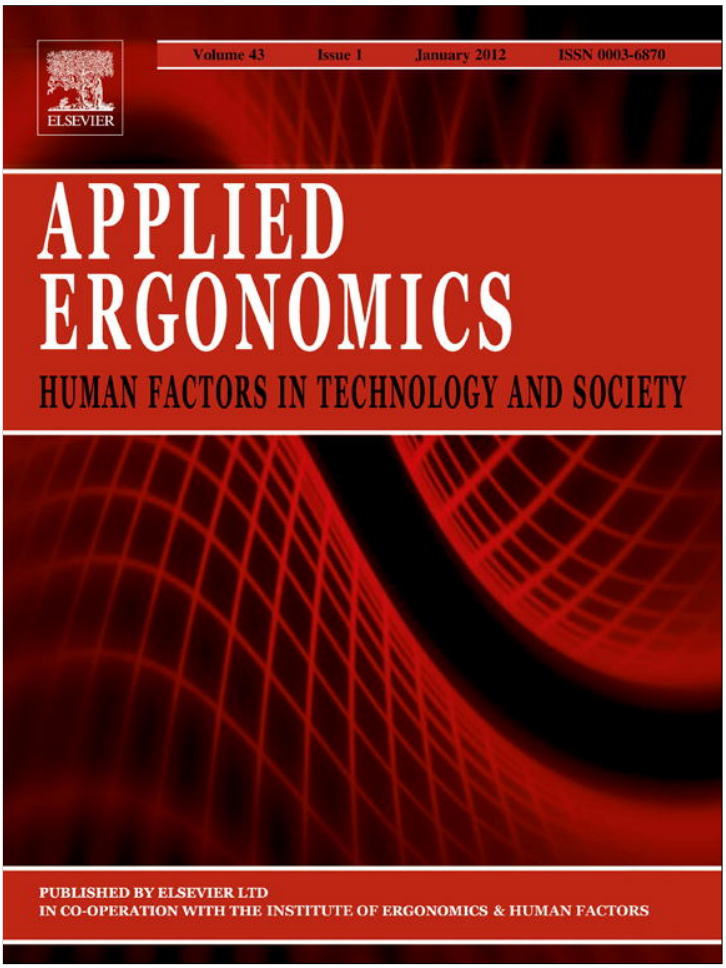

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Letter to the Editor

Some important oversights in the assessment of whole-body vibration exposure based on ISO-2631-1

In the collection and evaluation of the reported experimental data of human whole-body vibration exposure, we noticed some important oversights in the literature, which could cause systematic errors. The objective of this letter is to increase the awareness of the oversights to help reduce the potential for errors in further studies and data applications.

1. Equation oversight

Whole-body vibration exposure is frequently assessed based on the vibration total value (a_v) or the vector sum of frequency-weighted root-mean-square (rms) accelerations measured on a seat or a standing location in three orthogonal axes (International Organization for Standardization ISO 2631-1, 2010), which is defined as follows:

$$a_v = \sqrt{k_x^2 a_{wx}^2 + k_y^2 a_{wy}^2 + k_z^2 a_{wz}^2}, \quad (1)$$

where a_{wx}, a_{wy}, a_{wz} are the frequency-weighted rms accelerations with respect to the orthogonal axes x, y, and z, respectively; and k_x, k_y, and k_z are multiplying factors (International Organization for Standardization ISO 2631-1, 2010).

As recommended in the standard, the exact values of the multiplying factors applied depend on the frequency weighting selected and the specific application of the vibration total value. For health risk assessments, the applied multiplying factors are usually 1.4 for the x- and y-axis and 1.0 for the z-axis (International Organization for Standardization ISO 2631-1, 2010). Therefore, Eq.(1) has been presented in many publications as follows:

$$a_v = \sqrt{(1.4a_{wx})^2 + (1.4a_{wy})^2 + (a_{wz})^2}. \quad (2)$$

What likely stemmed from an editorial error, this equation has been incorrectly presented in some peer-reviewed journal articles (Tiemessen et al., 2008; Noorloos et al., 2008; Smets et al., 2010) as follows:

$$a_v = \sqrt{1.4a_{wx}^2 + 1.4a_{wy}^2 + a_{wz}^2}. \quad (3)$$

Unfortunately, this incorrect equation was adopted in some studies (Tiemessen et al., 2008; Noorloos et al., 2008) and some questionable data were found in the current version of a whole-body vibration database (http://www.vibration.db.umu.se/HkvSok.aspx?lang=en). As an example, Table 1 shows the comparison of the values calculated with Eqs.(2) and (3) from a set of reported accelerations in the three axes (Tiemessen et al., 2008). In this case, the average underestimation resulting from the application of the incorrect equation is more than 13%. The average underestimation is more than 11% in the data reported from another study (Noorloos et al., 2008). The error is also greater than 11% in a case (Compactor Dynapac CA-301D) identified in the database (http://www.vibration.db.umu.se/HkvSok.aspx?lang=en). Such percent errors could affect the interpretations of the results in some cases. For example, if the 8-hour vibration exposure levels for the ten drivers were the same as those listed in Table 1, their mean exposure level would exceed the exposure limit (1.15 m/s^2), but this would not be correctly assessed if the incorrect equation were used. Therefore, the a_v data calculated with the incorrect equation should be disregarded. For example, if the 8-hour vibration exposure levels for the ten drivers were the same as those listed in Table 1, their mean exposure level would exceed the exposure limit (1.15 m/s^2) (Directive 2002/44/EC), but this would not be correctly assessed if the incorrect equation were used.

2. Averaging approaches

Although Eq.(2) was correctly presented, some differences between the presented a_v values and those calculated using the equation from the component accelerations were also observed in some articles. A few examples are listed in Table 2.

The differences could partially result from the averaging approaches used in the data reduction. While the standard does not specify an averaging approach (International Organization for Standardization ISO 2631-1, 2010), some studies derived the mean total value by simply taking an arithmetic average of the total values measured with different subjects, different trials, and/or different vehicles (Tiemessen et al., 2008; Noorloos et al., 2008). Theoretically, this practice is questionable because the vibration total value is the magnitude of a vector, as defined in Eq.(1), and its averaging process should follow the rules of vector operations. In principle, the arithmetic mean is equal to or greater than the vector mean, which indicates that the arithmetic mean generally overestimates the average exposure, as also demonstrated in Tables 1 and 2. Although the differences between the values calculated with these two approaches are likely to be less than 5% for many cases, it is recommended to use the vector mean approach consistently in further studies.

3. Other oversights

The negative percent differences (−8.6% and −21.6%) presented in Table 2 obviously did not stem from the variation of the averaging

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Table 1
Comparison of the vibration total values calculated with Eqs.(2) and (3) from the *x*-, *y*-, and *z*-axis data reported in Ref. (Tiemessen et al., 2008).

Driver	a_{wx} (m/s^2)	a_{wy} (m/s^2)	a_{wz} (m/s^2)	$a_{v\text{-Eq.(3)}}$ (m/s^2)	$a_{v\text{-Eq.(2)}}$ (m/s^2)	% error
1	0.28	0.26	0.29	0.54	0.61	−11.3
2	0.60	0.62	0.53	1.15	1.32	−12.8
3	0.83	0.87	0.56	1.53	1.77	−13.8
4	0.76	0.69	0.49	1.31	1.52	−13.7
5	0.66	0.67	0.52	1.23	1.42	−13.1
6	0.65	0.90	0.43	1.38	1.61	−14.4
7	0.08	0.13	0.08	0.20	0.23	−12.4
8	0.75	0.78	0.69	1.45	1.66	−12.9
9	0.52	0.24	0.30	0.74	0.86	−13.6
10	0.37	0.25	0.34	0.63	0.71	−11.5
Arithmetic mean	0.55	0.54	0.42	1.02	1.17	−12.9
Vector mean				1.01	1.16	−13.3

Table 2
Inconsistent total values identified in some reported studies for health risk assessment.

Vehicle type	Reported frequency-weighted acceleration (m/s^2)				a_v (m/s^2), calculated with Eq.(2)	% difference	Possible reasons
	a_{wx}	a_{wy}	a_{wz}	a_v			
Fork-lift trucks (Bovenzi et al., 2002)	0.35	0.18	0.64	0.90	0.84	6.6	Averaging approach, data entry and/or editorial errors
Mobile cranes (Bovenzi et al., 2002)	0.21	0.37	0.32	0.53	0.68	−21.6	Data entry or editorial errors, or $k_x = k_y = k_z = 1.0$
Snow groomers (Rehn et al., 2005)	0.29	0.29	0.80	0.90	0.98	−8.6	Data entry or editorial errors, or $k_x = k_y = k_z = 1.0$
Snow mobiles (Rehn et al., 2005)	0.71	0.71	0.80	1.70	1.62	5.1	Averaging approach, data entry and/or editorial errors
Forest machines (Rehn et al., 2005)	0.50	0.79	0.60	1.50	1.44	4.2	Averaging approach, data entry and/or editorial errors
Arithmetic mean	0.43	0.54	0.63		1.18	2.4	Averaging approach
Vector mean					1.15		

approach. Other sources of the differences may include data entry errors, editorial errors, and/or the variation of the applied multiplying factors. Because different sets of the multiplying factors are required for various assessments (International Organization for Standardization ISO 2631-1, 2010), some of the vibration total values reported in the literature may not be directly comparable. This requires performing an examination to identify the factors used in the calculation when the reported vibration total values are adopted or used in a study. However, such an examination might not be performed in some studies.

The whole-body vibration database available on the internet is a collection of data reported by many investigators and vehicle manufacturers (http://www.vibration.db.umu.se/HkvSok.aspx?lang=en). Besides the errors resulting from the above-mentioned oversights, our preliminary evaluations also suggest that different sets of multiplying factors could have been used in the calculations of the vibration total values in the database. Therefore, some caution should be taken when those data are used. Fortunately, this database also provides the component data in the three axes. The above discussions suggest that for any specific application, it is more reliable to calculate the required total values from their corresponding component data than to directly use the vibration total values from the database.

Disclaimers

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Ren G. Dong*, Daniel E. Welcome, Thomas W. McDowell
National Institute for Occupational Safety and Health,
Engineering & Control Technology Branch,
1095 Willowdale Road, Morgantown,
WV 26505, USA
* Corresponding author. E&CTB/HELD/NIOSH/CDC,
1095 Willowdale Road, MS 2201, Morgantown,
WV 26505, USA. Tel.: +1 304 285 6332;
fax: +1 304 285 6265.
E-mail address: rkd6@cdc.gov (R.G. Dong)

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