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Guide to the Effects of Vibration on Health - Quantitative or Qualitative Occupational Health and Safety Prevention Guidance? A Scoping Review

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Review

Guide to the Effects of Vibration on Health - Quantitative or Qualitative Occupational Health and Safety Prevention Guidance? A Scoping Review

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Abstract

This systematic review examined the health risk assessment methods of studies of whole-body vibration exposure from occupational vehicles or machines utilizing the International Standard ISO 2631-1 (1997) and/or the European Machine Directive 2002/44. This review found inconsistent reporting of measurement parameters in studies on whole-body vibration (WBV) exposure. Although many authors tread the ISO 2631-1 HGCZ as a medical health standard with defined threshold levels, there is no epidemiological evidence for these limits. Similarly, the EU Directive offers risk management guidance and numeric limits without supporting evidence. Authors note discrepancies between international and national standards. Future publications should report all relevant parameters from ISO 2631-1 and clearly stating study limitations, exercising caution when applying ISO 2631-1 HGCZ in health and safety assessments.

Keywords: vibration 1; ISO 2631-1 2; EU machine directive 2002/44/EC 3; health guidance 4; occupational health 5; safety assessment 6; prevention 7;

1. Introduction

The International Standard Organization (ISO) develops standards based on consensus of representatives of government agencies, companies, individual experts, and professional organizations from around the world to determine acceptable practices, equipment, measurement methodology and criteria for preventing occupational injuries and illnesses. [1,2] The international standard ISO 2631-1 (1997) (Mechanical vibration and shock – evaluation of human exposure to whole-body vibration, Part 1) provides in the 'informative' Annex B guidance for the assessment of whole-body vibration (WBV) with respect to health risk and suggesting a 'health guidance caution zones' (HGCZ) figure B.1 for use. [3] In 2002, the Parliament and Commission of the European Community agreed to 'minimum health and safety requirements for the exposure of workers to the risks arising from vibration' (Machine Directive 2002/44/EC). [4,5] The EU Directive defines qualitative requirements and quantitative requirements in the form of ''exposure action values'' and ''exposure limit values''.[4,6,7] These guidelines are referenced in industrial hygiene and epidemiological studies and used for comparison in a health risk assessment by the authors. However, there appears to be often a lack of full understanding of the guidance and their limitations regarding the suggested quantitative norms in respect to the assessment of health risk and intervention requirements. The Standard ISO 2631-1 is currently under revision. A review of the scientific basis of the numeric guidance for basic vibration (rms) or suggested parameter for vibration containing multiple shocks (VDV) exposure appears to be needed. The potential benefit of qualitative guidance in an occupational risk assessment and intervention of WBV exposure will be appraised in this scoping review of the available health science literature. [8] The objective of this review is to

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examine if the provided guidance to 'ISO 2631-1' (1997) described in the informative Annex B (Guide to the effects of vibration on health) and/or the 'EU Directive 2002/44/EC' in published peer-reviewed WBV field exposure studies of various vehicles and equipment discussion of its limitations by the investigators/authors. Furthermore, it will be assessed if the numeric vs qualitative guidance generally accepted by the experts are considered by the authors (numeric values vs guidance on reducing risk to a minimum) ? [9] Are models of WBV intervention strategies offered by the published studies? [10] The description of study limitations provides meaningful information for the reader and may guide future research. Complete and honest discussion of the study is considered an obligation and mandatory by many Journals and their editors and improves the quality of the study. [11,12] Since many experts have pointed out inconsistencies and methodological shortcomings regarding the ISO 2631-1 (1997) Standard such a discussion of study limitations in field studies addressing health risks of workers appears prudent.[9,13–18]

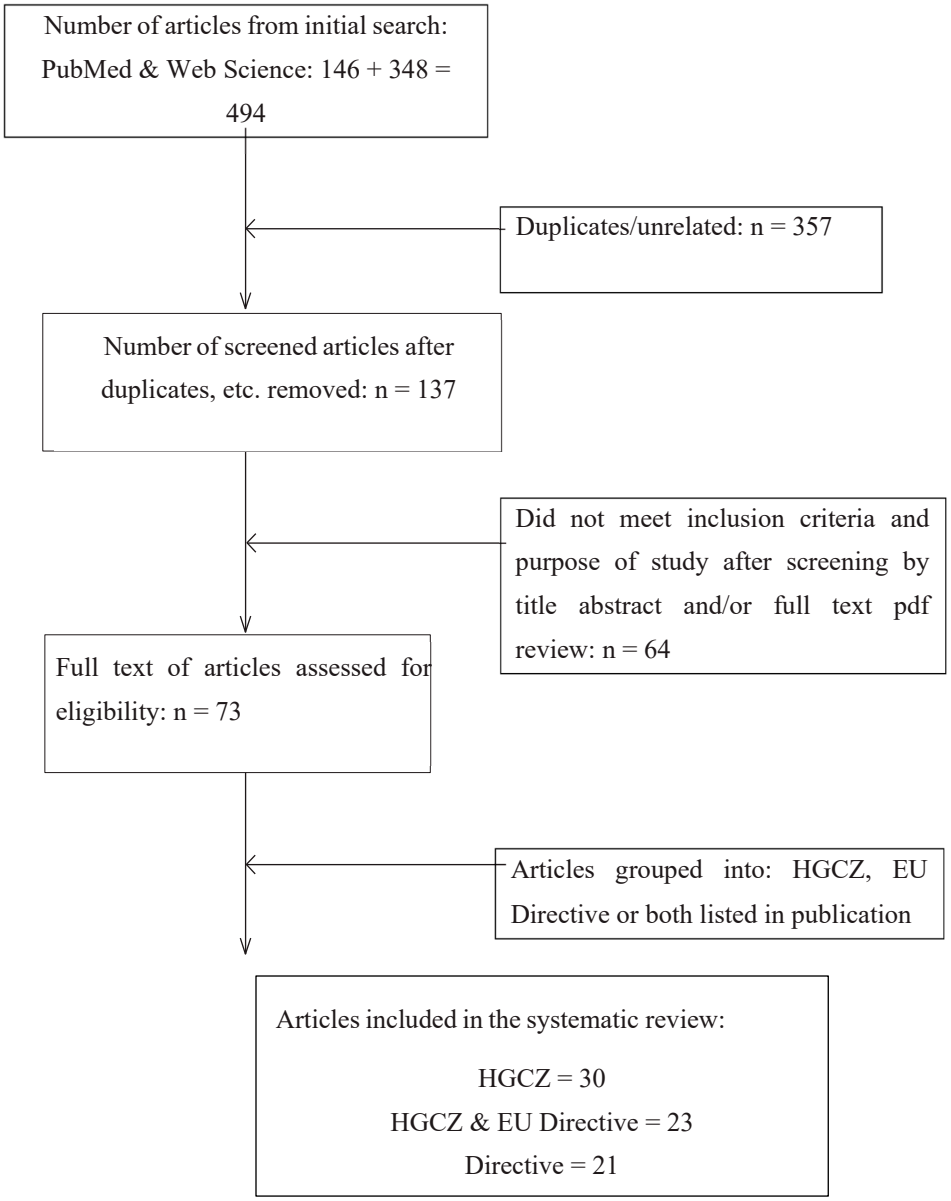

Figure 1. Study selection process.

 doi:10.20944/preprints202508.2222.v1

2. Materials and Methods

The protocol was drafted using the 'Preferred Reporting Items for Systematic Reviews and Meta-analysis Protocols' (PRISMA-ScR). [19] The final protocol was registered prospectively with the Open Science Framework on 6/23/2025.

To be included in this review, papers needed to list either ISO 2631 and/or the EU Machine Directive 2002/44/EC in the searchable text fields *Title, Abstract, All fields" of an institutional available search engine (Endnote™ 2025, built 19000) providing online searches of PubMed and Web of Science). Citations covered human WBV and subjects, vehicle testing, epidemiological and occupational health studies, intervention studies, all published in English. Only peer-reviewed and online available publication dates from the year 1997 (ISO 2631 Standard Year) to 2025 (current 6/25) were considered. Papers were excluded if they did not fit into the conceptual framework of the study. Excluded were specifically citations that dealt with non-occupational exposure to WBV (i.e., medical treatments utilizing vibrating devices, laboratory/experimental and methodological studies), hand-arm vibration (HAV), building or comfort related studies, laboratory studies, motion sickness, animals and children's studies [20] as well as studies employing the older version of ISO 2631-1 from 1985.

The final search results were exported into the reference manager software Endnote™ 2025, duplicates were removed and grouped according to referencing either the "health guidance caution zone" (HGCZ) from ISO 2631-1 Annex B, the EU Directive or both. Furthermore, any discussions regarding study limitations in the determination and assessment of risks were checked (i.e., listing of the Crest Factor, VDV, typical driver posture). Papers were examined if the guidance provisions of the EU directive 2002/44 were considered (i.e.: *The assessment of the level of exposure to vibration is based on the calculation of daily exposure A(8) expressed as equivalent continuous acceleration over an eight-hour period, calculated as the highest (rms) value, or the highest vibration dose value (VDV) of the frequency-weighted accelerations, determined on three orthogonal axes (1,4a* $_{wx}$ *, 1,4a* $_{wy}$ *, a* $_{wz}$ *for a seated or standing worker) in accordance with Chapters 5, 6 and 7, Annex A and Annex B to ISO standard 2631-1(1997)* [Directive 2002/44/EC Annex B.1] [13].

Guidelines exist for publishing observational studies that suggest including consideration of study bias, data limitations, confounding effects, reproducibility, objective assessment of the findings, avoid overinterpretations and suggest recommendations for future research. [21–23] Each study was checked for a discussion of study limitations either as a separate paragraph or embedded within the discussion. Furthermore, the listing of the application and limitations cited in the ISO 2631-1 Annex B was examined.

The results of text analysis and the data-charting were tabulated in a MS spreadsheet (Excel™) and summarized (available upon request).

3. Results

A total of 137 publications from 1997 to June of 2025 listed the measurement Standard ISO 2631 in the searchable title or abstract in PubMed or in Web of Science. Of these, seventy-three publications were reviewed regarding the use of the health risk assessment by either the ISO 2631-1 (1997) Annex B guidance with the HGCZ, or the EU Directive 2002/44 of both. Table 1 shows a breakdown of the studied vehicles and usage/industries and the utilized risk assessment guidance. Studies utilizing the HGCZ for a risk assessment [24–52] involved heavy vehicles used in mining compared to studies of vehicles in construction and transport that tended to utilize the EU Directive [53–73] or both risk assessment guidance [74–96].

Table 1. Studies of vehicles and usage/industry and the utilization of the risk assessment guidelines following the ISO 2631-1 Annex B guidance or the EU Directive.

Machinery/Vehicle	Usage / Industry	HGCZ	HGCZ & EU-Directive	EU Directive

 doi:10.20944/preprints202508.2222.v1

1	tractor, combine, horse	agriculture	1	3	4
2	helicopter, propeller aircraft	aviation	2	0	0
3	truck, dumper, skidder	construction	3	1	5
4	forest machine, frame saw, timber harvester	forestry	1	1	1
5	ambulance, wheelchair, MRI	health / medical	4	2	2
6	fork lift, platform, pot hauler	industrial	1	1	0
7	dumpster, haul truck, earth mover, dozer	Mining	15	4	0
8	ski, snowboards, bicycle, kite	sport	0	0	2
9	bus, cars, taxi, All-Terraine-Vehicle, rail	transport	3	9	7
		Sum	30	21	21

Studies included a wide variety of vehicles and situations including heavy earthmoving [16,24,27,41] or agricultural vehicles [44,73,79,96], transport (taxi, rail, buses) [55,61,66,83], aviation (helicopter)[42,81], sport devices [70,71], horses [95], wheelchairs [26,34,38], ambulances [53] and medical devices (MRI) [60]. The majority of the health outcomes studied ranged from WBV exposure related to back disorders[56,63,64] or to neck disorders [68], but also to neonatal head and torso impact [53], feet [31], the circulatory system [84], and semen quality[52].

WBV exposure was explored in epidemiological investigations of vehicle operators [24,27,51,57,63,78,81,82,97]. Several studies focused on comparison of operators' seat design [29,49,55,62,80,98–100].

Most publications used quantitative (numeric) guidance (73%), while others (27%) followed qualitative recommendations for vibration reduction. Studies referencing the HGCZ and EU Directive most often included qualitative guidance (39%).

The ISO 2631-1 (1997) provides under paragraph 6 a "basic evaluation method" using weighted root-mean-square acceleration (rms). All studies, except for one, reported numerical "rms" values for the basic evaluation method. Furthermore, the standard describes the "applicability" of the basic evaluation method using the HGCZ guidance if the peak vibration crest factor (CF) ("describing the severity of the vibration in relation to its effects on human beings") is less than 9 (ISO 2631-1 6.2) and additional evaluation parameters are suggested such as the fourth power Vibration Dose Value (VDV) (ISO 2631-1 6.3.2). Only 52 % of the publications utilized the HGCZ guidance listed the crest factor in their publications and only 14% of the studies referring to the EU Directive as well as the HGCZ guidance in their risk assessment. The additional evaluation method suggesting the fourth power VDV was listed by 76% of the studies utilizing the HGCZ risk assessment and 61% using the EU Directive.

Several studies n=35 also reported the values for an additional proposed risk analysis method for vibration containing multiple shocks described in ISO 2631-5 (2004 or 2018).

In terms of clearly addressing study limitations as suggested by editors and Journals guidelines only 48% of all publications objectively described such limitations of their findings and only 4 % specifically referred to the guidance limitations described in Annex B of ISO2631-1 (1997). (Table 2)

Table 2. Studies utilizing risk assessment guidance, reported parameters, discussion of limitations and quantitative (numeric) versus qualitative risk assessment.

	All studies	**%**	**HGCZ**	**%**	**HGCZ & EU Directive**	**%**	**EU Directive**	**%**
Total No of studies	74	100%	30	100%	23	100%	21	100
RMS listed	73	99	30	100	22	96	21	100
Crest factor listed	38	51	17	57	14	61	7	33
VDV listed	52	70	22	73	17	74	13	62
ISO 2631-5 included	17	23	5	17	6	26	6	9
Study limitation included	36	49	16	53	10	43	10	48
ISO 2631-1 Annex B limitation	3	4	2	7	1	4	n/a	n/a
Quantitative guidance	54	73	25	83	14	61	15	71
Qualitative guidance	20	27	5	17	9	39	6	29

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4. Discussion

This systematic review examined the health risk assessment methods of studies of whole-body vibration exposure from occupational vehicles or machines utilizing the International Standard ISO 2631-1 (1997) and/or the European Machine Directive 2002/44. The Standard is currently under review by the Technical Committee ISO/TC 108/SC 4. The Standard ISO 2631, consists of following parts, under the general title *Mechanical vibration and shock - evaluation of human exposure to whole-body vibration: Part 1: General requirements*, which primary purpose is to define methods of quantifying whole-body vibration in relation to "human health and comfort", and Annexes A to E. Annex B titled "Guide to the effects of vibration on health", which is explicitly "for information only", is commonly used for a quantitative (numeric) risk assessment by investigators and apparently considered by many authors like a health standard. Although the Standard states that there is no clear and universally recognized dose-response relationship or "threshold" effects of vibration on health, Annex B provides under B.3 boundaries of "health effects" which are "clearly documented and/or objectively observed" and "above the zone health risks are likely". However, there are no defining references cited in the Standard that support this statement for the basic evaluation method (rms) as well as the vibration dose value (VDV) lower and upper boundaries. Regardless, it is recognized that WBV with increasing levels of exposure and duration an increased risk for low back pain (LBP), sciatic pain, and degenerative changes in the spinal system, including lumbar intervertebral disc disorders and the connected nervous system. [101–104]

It appears that almost all the authors implying the HGCZ have not considered the specific conditions and limitations set forth in Annex B in their risk assessment, namely that it applies to "people in normal health" and that only measurements of the vertical axis (z=axis) should be compared to the caution zones only if the crest factor is below 9 the HGCZ boundaries otherwise it may underestimate "health disorders". It is remarkable that only half of the studies reported the crest factor. The alternative risk assessment method under ISO 2631-1 using the estimated vibration dose value (VDV) has been reported by 70 % of the studies. However, the corresponding lower and upper bounds of the zone have also not been referenced or validated with epidemiological studies and the source of the suggested values is unknown. The recommendation of the HGCZ in Annex B is "mainly *based on exposures in the range of 4 to 8 hours"*, which none of the reviewed studies mentioned and many studies do not specify typical exposure durations. Modifying or confounding factors such as operator's posture, temperature, draught, age and gender, rest periods are not considered in the algorithm of the HGCZ. In a laboratory study age and gender were found to have significant effects on fatigue strength of the spine, with gender differences extending beyond those accounted for by endplate area disparities. [105] These are factors that should have been discussed in the study limitation section to help the reader to better understand numeric values and to avoid under- or overestimating the true health risk.

In the European Union, the Directive 2002/33/EC was adopted in 2002 addressing "minimum health and safety requirements regarding exposure of workers to the risks arising from physical agents (vibration)". [5–7,13] It is a framework for national standards within the EU that builds on employers' duties to manage risks to health and safety of employees. It uses exposure action (EAV) and limit values (ELV) for whole body vibration and introduces a risk management approach for professional drivers and machine operators by setting minimum requirements for the prevention of vibration related health problems. These EAV and ELV of the EU Directive have been used by the authors in this review to quantify risks but only 27% of the reviewed studies proposed qualitative guidance with recommendation for prevention. Griffin (2004), pointing out discrepancies of the ISO 2631 with the EU Directive and the British Standard 6841 (1987) requirements was advocating a "qualitative guidance" (reducing risk to a minimum) rather than quantitative (numeric) guidance. Such a health surveillance and monitoring program has been described by Hulshof et al (1993) and others. [106] A "holistic approach" to reduce WBV exposure to professional drivers in context with other risk factors, such as postural concerns and manual handling operations was detailed by Nelson (2005). [5]

 doi:10.20944/preprints202508.2222.v1

The key challenges in establishing limits for occupational medicine regarding whole-body vibration (WBV) include inconsistencies in exposure assessment methods, limited consideration of individual differences, and a lack of integration of long-term cumulative effects. There is notable variability among standards and regulatory frameworks, such as the European Directive 2002/44/EC and ISO 2631-Part 1 or 5. These standards employ different metrics (e.g., A (8), VDV, Sed, Risk Factor R), which can produce differing risk assessments for identical exposure scenarios and may complicate the determination of safe exposure thresholds. Existing limits often do not fully account for factors like body mass index, posture, and anthropometric differences that can impact susceptibility to WBV-related health effects. most regulatory limits focus on short-term (daily) exposure, neglecting the cumulative effects of WBV over a worker's career. Musculoskeletal disorders and other adverse outcomes may result from long-term, repeated exposure, which is not adequately captured by daily exposure limits [9,41,77]. There is a lack of consensus on the best way to characterize and measure WBV exposure, especially regarding impulsive versus continuous vibration, predominant versus non-predominant axes, and the translation of exposure metrics to actual health outcomes. This introduces uncertainty in risk prediction and complicates the implementation of effective preventive measures.

In the USA, no Occupational Safety and Health Administration (OSHA) regulation or standard specifically for WBV exists and there are no numeric guidelines for EAV or ELV. The National Institute for Occupational Safety and Health (NIOSH) and regulatory agencies have adopted the qualitative approach of keeping exposure as low as technically possible in the workplace and musculoskeletal disorders should be generally addressed with ergonomic programs. [107,108] The American National Standards Institute (ANSI) has adopted key portions of ISO 2631 as a consensus standard under S3.18. The ANSI S3.18/ISO 2631 standard is strictly voluntary and should not be considered a health standard such as those issued by the Occupational Safety and Health Administration (OSHA) regulations. The 'American Conference of Governmental Industrial Hygienist' (ACGIH), a professional organization, has proposed the concept of 'Threshold Limit Values' (ACGIH-TLVw) as industry guidelines for the control of WBV at the workplace, which are also voluntary guidelines and not enforceable by law in the USA. The Navy and Marine Corps Force Health Protection Command issued a "Human Vibration Guide 2023" for industrial hygienist and safety professionals but mischaracterize that ISO has established occupational exposure limits (OELs) along with the ACGIH and ANSI and refers to the HGCZ.[109]

In several European countries spinal injury caused by WBV is recognized as an occupational disease and may be compensable. The WBV-related injury claims process includes a review of the work history, and a workplace exposure assessment which is typically based on measurements following the ISO 2631 Standard. [110]

Much of the research that is the background of the HGCZ relates to back disorders in workers with very high WBV exposure, seated and healthy subjects in laboratory experiments and therefore the use of the HGCZ boundaries for other outcomes i.e., semen, circulative, cognitive function and infants or children is clearly questionable and would not be supported by the data.

5. Study Limitations

This study considered publications in English and cited in only two common online citation resources (PubMed maintained by the National Center for Biotechnology Information (NCBI) at the U.S. National Library of Medicine (NLM) and Web of Sciences) accessed online and with a reference manager software. There are other citations and reference manager available that may have produced more and other publications with the desired keywords. However, PubMed and Web of Science are well-known tools used by occupational health professionals to quickly assess the availability of peer-reviewed literature.

Publications cannot be clearly divided into qualitative or quantitative guidelines; classification depends on the reviewer's interpretation of the discussion, conclusion, and data, which may introduce bias.

 doi:10.20944/preprints202508.2222.v1

The description of study limitations is not a requirement for all Journals in some situations it may be omitted for a variety of reasons. Nevertheless, a superior quality study nowadays should not be without a clear description of objective shortcomings, biases, and confounders.

The Standard ISO 2631 does not mandate the reporting of certain, or all parameters defined in the text, such as rms, crest factor, MTVV, VDV and measurement parameters such as the magnitude or duration of sampling, driver posture, weight, height, gender or age and it is up to the authors, peer reviewers and editors to provide guidance. However, proper reporting of all collected data will help the reviewer to make a better assessment of the provided exposure information and application to occupational health risk evaluation

6. Conclusions

This review found inconsistent reporting of measurement parameters in studies on whole-body vibration (WBV) exposure. Although the ISO 2631-1 HGCZ is often treated as a medical standard with threshold levels, there is no epidemiological evidence for these limits. Similarly, the EU Directive offers risk management guidance and numeric limits without supporting evidence. Authors note discrepancies between international and national standards. In summary, the primary challenges include methodological inconsistency, limited individualization, insufficient assessment of cumulative exposure, and ongoing uncertainty regarding the relationships between exposure and health outcomes. We recommend reporting all relevant parameters from ISO 2631-1 and clearly stating study limitations, exercising caution when applying ISO 2631-1 HGCZ in health and safety assessments.

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