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Effects of vibration at workplaces – Characteristic values of hand-arm and whole-body vibration –

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Abstract

The effects of vibration when working with handheld and hand-guided devices (Hand-Arm Vibration – HAV) and when driving mobile work machines and vehicles (Whole-Body Vibrations – WBV) can endanger the health and safety of employees. Damage to bones and joints and circulatory problems in the hand and arm systems as well as disc damage to the spine as a result of the effects of vibrations are recognised occupational diseases. Since the entry into force of the EC Vibration Protection Directive 2002/44/ EC in 2002 there has been an obligation on companies throughout Europe to assess the risks of jobs with vibration. The statutory provisions and their implementation in Germany are explained in this Report. It supports companies in identifying and assessing the risks and in choosing appropriate preventive measures by providing tables with data. It describes the key data of the EC directive, which are not identical to the key data previously used in Germany to assess vibration. Conversions of these key data into the new key data systems are explained using practical examples. Software available on the internet to identify the assessment key data can also be used to plan technical and organisational preventive measures. Annexes 1 and 2 to the Report bring together key data ranges for many devices, work machines and vehicles relevant to vibration. Annex 3 includes the measurement results for the vibration-reducing effect of seats on mobile machines and vehicles as a preventive measure to aid choice for WBV.

Vibrationseinwirkung an Arbeitsplätzen – Kennwerte der Hand-Arm- und Ganzkörper-Schwingungsbelastung

Kurzfassung

Vibrationseinwirkung bei der Arbeit mit handgehaltenen und handgeführten Geräten (Hand-Arm-Vibrationen – HAV) und beim Führen mobiler Arbeitsmaschinen und Fahrzeuge (Ganzkörper-Vibrationen – GKV) kann die Gesundheit und Sicherheit von Arbeitnehmern gefährden. Knochen- und Gelenkschäden und Durchblutungsstörungen im Hand-Arm-System sowie Bandscheibenschäden der Wirbelsäule durch berufliche Vibrationseinwirkung sind anerkennungsfähige Berufskrankheiten. Seit Inkrafttreten der EG-Vibrationsschutz-Richtlinie 2002/44/ EG im Jahr 2002 besteht europaweit für Unternehmer die Verpflichtung zur Gefährdungsbeurteilung für Arbeitsplätze mit Vibrationseinwirkung. Die gesetzlichen Bestimmungen und ihre Umsetzung in Deutschland werden in diesem Report erläutert.
Er unterstützt Betriebe bei der Ermittlung und Bewertung der Risiken und der Auswahl geeigneter Präventionsmaßnahmen durch Tabellen mit Belastungsdaten. Dazu werden die Kennwerte der EG-Richtlinie beschrieben, die nicht mit den bisher in Deutschland zur Vibrationsbeurteilung angewendeten K-Werten identisch sind. Umrechnungen dieser K-Werte in das neue Kennwertsystem werden anhand praktischer Beispiele erläutert. Im Internet verfügbare Software zur Bestimmung der Beurteilungskennwerte kann auch für die Planung technisch-organisatorischer Präventionsmaßnahmen genutzt werden. Die Anhänge 1 und 2 des Reports stellen Kennwertbereiche für zahlreiche vibrationsrelevante Geräte, Arbeitsmaschinen und Fahrzeuge zusammen. Im Anhang 3 werden Messergebnisse über die vibrationsmindernde Wirkung der Sitze als Präventionsmaßnahme der Wahl bei GKV auf mobilen Maschinen und Fahrzeugen wiedergegeben.

Effets des vibrations sur lieux de travail – Paramètres des vibrations transmises au système main-bras et au corps entier

Résumé

Les effets des vibrations lors du travail avec des outils à mains (vibrations main-bras) et lors d'utilisation de machines mobiles et véhicules (vibrations au corps entier) peuvent représenter un danger pour la santé et la sécurité de l'employé. Des dommages au niveau des os et des articulations, des problèmes de circulation sanguine dans le système main-bras ainsi que des dommages au niveau du disque intervertébral de la colonne vertébrale causés par des effets de vibrations aux postes de travail sont des maladies pouvant être reconnues comme professionnelles. Depuis la mise en œuvre de la directive européenne 2002/44/CE relative aux vibrations, en 2002, il existe, au niveau européen, une obligation pour les employeurs d'évaluer le risque encouru sur les lieux de travail exposés aux vibrations. Les dispositions légales et leur mise en pratique en Allemagne sont expliquées dans ce rapport. Il aide les entreprises à établir et évaluer les risques et à choisir les mesures de prévention adéquates grâce à des tableaux de données d'exposition. Y sont aussi décrits les paramètres de la directive européenne qui ne sont pas identiques aux paramètres utilisés jusqu'ici en Allemagne pour l'évaluation des vibrations. Les conversions de ces paramètres dans le nouveau système de paramètres sont expliquées à l'aide d'exemples pratiques. Le logiciel disponible sur Internet, permettant de déterminer les paramètres d'évaluation, peut-être aussi utilisé pour planifier les mesures de prévention au niveau technique et organisationnel. Les annexes 1 et 2 de ce rapport regroupent les ensembles de paramètres pour de nombreux appareils, machines de travail et véhicules produisant des vibrations. Les résultats expérimentaux concernant les sièges réduisant les vibrations, utilisés sur les machines mobiles et véhicules, sont présentés dans l'annexe 3, comme mesure de prévention en cas de vibrations au corps entier.

Efecto de las vibraciones en los puestos de trabajo – Parámetros de vibraciones transmitidas al sistema mano-brazo y al cuerpo entero

Resumen

El efecto de las vibraciones en el trabajo con equipos sujetados y conducidos a mano (vibraciones transmitidas al sistema manobrazo – HAV) y en la conducción de máquinas móviles de trabajo y vehículos (vibraciones transmitidas al cuerpo entero – WBV) puede poner en riesgo la salud y seguridad de los trabajadores. Lesiones en los huesos y las articulaciones y problemas vasculares en el sistema mano-brazo, así como lesiones discales y de la columna vertebral debido a la exposición laboral a las vibraciones son enfermedades profesionales susceptibles de reconocimiento. Desde la entrada en vigor de la Directiva 2002/44/CE sobre vibraciones en el año 2002, los empresarios en toda Europa tienen la obligación de evaluar los riesgos en los puestos de trabajo expuestos a vibraciones. Las disposiciones legales y su transposición en Alemania son objeto de este Informe. El mismo apoya a las empresas en la determinación y evaluación de los riesgos y en la elección de medidas preventivas adecuadas mediante tablas con datos de exposición. Para ello se describen los criterios de valoración de la directiva CE que no son idénticos con los valores K empleados hasta ahora en Alemania para la evaluación de las vibraciones. La conversión de estos valores K al nuevo sistema de criterios de valoración se explica mediante ejemplos prácticos. El software para la determinación de los criterios de valoración, disponible en la Internet, se puede utilizar también para la planificación de medidas preventivas técnicas y organizativas. Los anexos 1 y 2 del Informe recopilan los alcances de los criterios de valoración para numerosos equipos, máquinas de trabajo y vehículos relevantes para las vibraciones. En el anexo 3 se reproducen, como medida preventiva optional relativa a las vibraciones transmitidas al cuerpo entero, los resultados de las mediciones con respecto al efecto reductor de las vibraciones de los asientos en máquinas móviles y vehículos.

Content

Preface to the English edition

The present translation of the BGIA-Report 6/2006 „Vibrationseinwirkung am Arbeitsplatz“ gives access to a unique collection of hand-arm and whole-body vibration data for a broader, European audience. Using the data, one can compare and classify different sources of human vibration for a given work place. Consequently, one can focus the risk assessment and the prevention activities on those machines, tools and vehicles that cause the largest exposure. In addition, one can check, whether vibration data of other sources are plausible or not. Finally, this report describes the average effect of the altered frequency weighting in ISO 2631-1:1997 for different classes of vehicles and mobile machinery by means of conversion factors, which allows to use old acceleration data.

There are, however, minor effects on the content due to, e. g., the replacement of the machinery directive 98/37/EC by the directive 2006/42/EC since 29th December 2009.
On the other hand, the application of the directive 2002/44/EC (vibration exposure at workplaces) is still a current process and far from being complete. Therefore, in order to support employers in their prevention activities without further delay, these effects will be considered in a future edition.

1 Introduction

The exposure of the hand-arm-shoulder system to vibration during work involving vibrating (rotating or percussive), hand-held or manually guided machines is generally described as **hand-arm vibration (HAV)**. By the same token, all forms of exposure to vibration transmitted through the feet or buttocks to the whole body of standing or seated workers on mobile machinery and vehicles is termed **whole-body vibration (WBV)**.

Vibration exposure is a hazard to the health and safety of employees. In the case of HAV, it causes circulatory disorders, osteo-articular injury, neurological and muscular disorders; in the case of WBV, it causes back pain and spinal injury [1; 2]. In Germany, three diseases caused by vibration exposure have been included to date in the list of formally recognized occupational diseases: BK 2103 (HAV – osteo-articular injury) in 1929; BK 2104 (HAV – circulatory disorders) in 1975; and BK 2110 (GKV – discogenic disorders of the lumbar spine) in 1993 [3].

Only since the entry into force of the EU Vibration Directive [1] in 2002 has a blanket statutory prevention regulation existed in Germany for workplaces at which vibration exposure presents a health and safety hazard. The EU Vibration Directive was to be transposed into national law by the Member States of the European Union within three years. In Germany, its implementation takes the form of a regulation pursuant to Section 18 of the German Occupational Health and Safety Act (Arbeitsschutzgesetz) [4]. A prevention regulation governing workplaces associated with vibration exposure had already been in force within the scope of the German Mining Act (Berggesetz) since 1991. In 2005, this regulation was brought into line with the new provisions of the EU Vibration Directive [5]. With the transposition of this directive, employers whose employees are exposed to vibration are obliged to determine and assess the risks at their workplaces. Should the exposure limit values and action values of the EU Vibration Directive be exceeded, measures for avoidance or reduction of the vibration exposure must be planned and implemented. In addition, prevention and early diagnosis of disorders must be assured by targeted health surveillance. More detailed practical information on implementation in companies of the new prevention regulations governing exposure to workplace vibration can be found on BG expert committee information sheet 008 [6].

For technical and/or organizational measures against hazardous vibration exposure to be effective, validated knowledge is needed of the exposure situation in specific cases (hazard analysis). The EU Machinery Directive makes an essential contribution in this context: on the one hand, it obliges manufacturers to reduce vibration to a minimum; on the other, it assists operators in selecting machinery with the lowest possible transmission of vibration to the human body, owing to the manufacturers' obligation to state vibration emission parameters [7]. Manufacturers' efforts to minimize vibration are however constrained in cases where machinery intentionally generates vibration in order to perform its function.

As early as 1988, the BG Institute for Occupational Safety and Health (BIA) documented the situation at the time by publishing the results of numerous workplace vibration measurements in table form in BIA-Report 2/88. The report's purpose was to support companies in which stationary machines, mobile machinery and vehicles exposed employees to vibration, by providing information on possible hazards to health and safety in consideration of the vibration protection regulations which were anticipated at that time. However, the draft vibration directive published in 1993 by the European Commission was not adopted by the European Parliament and the European Council until 2002. In the meantime, the IFA's database has been extended considerably with the addition of results from numerous further studies at workplaces involving vibration. The standards on the basis of which measurements were formerly performed were revised and substantially amended in consideration of new findings concerning the impact of vibration upon the human body. Adoption of a new system of vibration assessment was necessary, not least owing to harmonization with the EU Vibration Directive. The "K values", a conversion system for the measured vibration acceleration values which had been used for decades in Germany in order to simplify vibration assessment, were abandoned. This new edition of the BIA-Report 2/88, which has given consideration to all changes in measurement technology and in particular to many new measurement results, is therefore to support the pending implementation of the EU Vibration Directive in companies. The extended data tables based upon workplace measurements are particularly useful for small and medium-sized enterprises without vibration analysis equipment of their own, since they provide sound guideline information on whether the stationary machines, mobile machinery and vehicles in use may present a hazard. Measurement data and exposure durations over a working shift enable the time-based vibration assessment values to be calculated and compared with the exposure limit values and action values of the EU Vibration Directive. If it may be assumed that the latter will be exceeded, more comprehensive determining and evaluation of the risks is necessary in accordance with the provisions of the directive (corresponding information can be found in Chapter 6, Page 25).

2 Vibration parameters in standards and statutory regulations

2.1 Vibration acceleration parameters

The parameters shown in the tables of exposure data in Annexes 1 and 2 (see Pages 33 and 47) are energy-equivalent mean values of the frequency-weighted vibration acceleration. They were determined in accordance with VDI Guideline 2057 [8] from measurements of the instantaneous exposure at the point of vibration transmission to the human body over a duration determined by the work procedure (work cycle, repetitions). The parameters are therefore representative for the work performed with the stationary machine, mobile machinery or vehicle in question. They do not describe the hazard to health and safety over an entire working shift. For determination of the latter, the entire duration of the specific vibration exposure must be considered.

In order to facilitate comparison between the parameters and the exposure limit values and action values of the EU Vibration Directive, different presentations were selected for the hand-arm and whole-body vibration parameters. In accordance with the annexes to the EU Vibration Directive, the exposure to a vibration hazard is to be assessed by calculation of the daily exposure value A(8) over a standardized period of eight hours (see Chapter 6). The value from which the daily exposure is calculated is in all cases the root-mean-square of the frequency-weighted acceleration a_{wT}, which in accordance with VDI Guideline 2057, Parts 1 and 2 [8] must be measured over a period representative of the work process. The root-mean-square (energy-equivalent) value is defined as

$$a_{wT} = \sqrt{\frac{1}{T}\int_0^T a_w{}^2(t)dt}$$

where $a_w(t)$ is the frequency-weighted acceleration as a function of the time, and T is the duration of measurement.

For assessment of the vibration hazard in cases of hand-arm vibration, the total of the root-mean-square values of the frequency-weighted acceleration in the three orthogonal axes a_{hwx}, a_{hwy}, a_{hwz} (Figure 1) must be used. The directive refers in this context to ISO 5349-1:2001 [9].

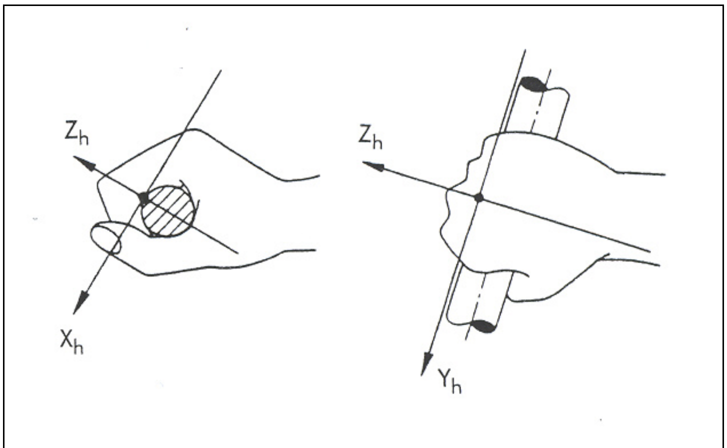

Figure 1:
Handle-based system of co-ordinates for the x, y and z axes of measurement for hand-arm vibration exposure

This corresponds to the vibration total value a_{hv} (vector sum) in VDI Guideline 2057, Part 2, which is to be calculated in accordance with the following formula:

$$a_{hv} = \sqrt{a_{hwx}^{2} + a_{hwy}^{2} + a_{hwz}^{2}}$$

The measured values a_{hv} for hand-arm vibration shown in the tables in Annex 1 are vibration total values calculated by means of this formula.

In certain machines on which the vibration exposure in a single axis of measurement is dominant, measurement was performed in the past only for this axis. Examples include percussive machines such as impact hammers, hammer drills and vibratory rammers. For such cases, VDI Guideline 2057, Page 2 states a formula for estimation of the vibration total value:

$$a_{hv} = k \cdot a_{hw}$$

The root-mean-square value of the frequency-weighted acceleration in the dominant axis of vibration a_{hw} is multiplied by a correction factor k, which in accordance with ISO5349-1 should lie between 1.0 and 1.7. VDI Guideline 2057, Part 2 supports these correction factors with a table (Table 1).

Table 1:
Correction factors for estimation of the total vibration value where acceleration occurs in the dominant axis of vibration [8]

	Examples	Correction factor k
Percussive machines	Chisel hammers Paving breakers Pneumatic picks Needle descalers	1.2
Rotating and oscillating machines	Hammer drills Percussion drilling machines Angle grinders Straight-line grinders Vertical grinders Orbital sanders Pneumatic drilling machines Jig saws Circular saws	1.4

The vibration total values shown in the tables in Annex 1 were calculated by means of the relevant correction factors in Table 1 for machines for which a measured value was available only for the dominant axis of vibration.

For assessments of the exposure to whole-body vibration, the daily exposure value A(8) must be determined based upon the maximum root-mean-square values of the frequency-weighted accelerations in the three orthogonal axes of 1.4 a_{wx}, 1.4 a_{wy}, a_{wz} for seated or standing working postures (Figure 2). The directive refers in this context to ISO 2631-1 [10].

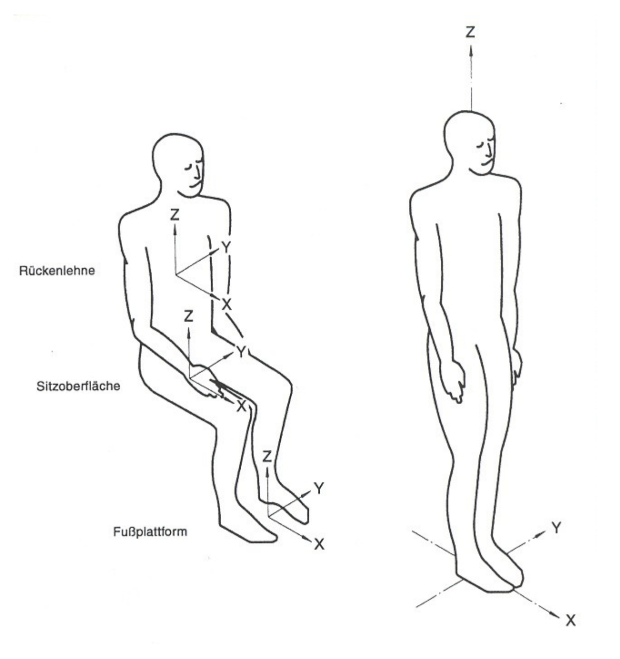

Figure 2:
System of co-ordinates for the x, y and z axes of measurement for whole-body vibration exposure during sitting and standing

The a_w values shown in the tables in Annex 2 for whole-body vibration measured on the seat surface are therefore stated separately for the three axes of measurement, x, y and z (seat surface). The values measured for a_{wx} and a_{wy} were multiplied by the factor 1.4 in accordance with the provisions of the EU Vibration Directive. Since in general, only the seat provides scope for preventing the transmission of whole-body vibration to the human body, the measured values are also stated for the three axes at the seat mounting point on the machine or vehicle chassis. These values yield information on the current state of protection against vibration, by enabling a seat to be selected according to its vibration characteristics.

2.2 K-values to VDI Guideline 2057, Part 1:1987

Prior to the revision of VDI Guideline 2057 in 2002, the vibration acceleration values measured at workplaces were converted to dimensionless K values. The advantage here was that all forms of vibration exposure could be assessed by application of a single guideline value. Conversely, the other EU Member States and also other countries outside the EU prefer the measured values to be stated directly in m/s² as acceleration values *a*. For this reason, the proven K value system was abandoned during revision of VDI Guideline 2057 in 2002. This does not render the K values obtained from past measurements obsolete, however; they can be converted easily to the original acceleration values [8; 11].

The K values were calculated by multiplication of the frequency-weighted root-mean-square vibration acceleration values a_w in m/s² with specific factors which take account of the form of transmission and the axis of measurement. The following factors were employed for this purpose for the three orthogonal axes of measurement.

Hand-arm vibration (Figure 1):
For all three axes of measurement $\dfrac{6.3}{m/s^2}$

Whole-body vibration (Figure 2):
For the x and y axes $\dfrac{28}{m/s^2}$

For the z axis $\dfrac{20}{m/s^2}$

By means of these factors, used in this case as quotients, it is possible to convert existing K values to root-mean-square vibration acceleration values a_w. In the case of whole-body vibration, this is possible only for K values for the discrete axes of vibration, owing to the different quotients. For hand-arm vibration, the conversion quotient is the same for all three axes of measurement; consequently, both the values for the discrete axes of measurement and vibration total values formed by vector summation of the discrete axes of measurement can be converted.

Example calculation of K values to frequency-weighted acceleration for hand-arm vibration:

Paving breaker (demolition work): K_{Zh} = 66

(z axis with the maximum weighted vibration K)

Root-mean-square value of the frequency-weighted acceleration in the z axis:

$$a_{hwz} = \frac{K_{Zh}}{\dfrac{6.3}{m/s^2}} = \frac{66}{6.3}\ m/s^2 = 10.5\ m/s^2$$

Vibration total value a_{hv} (see Section 2.1):

$a_{hv} = k \cdot a_{hw} = 1.2 \cdot 10.5\ m/s^2 = 12.6\ m/s^2$

where k = 1.2 (from Table 1)

Example calculation of K values to frequency-weighted acceleration values for whole-body vibration:

Driver of a fork-lift truck on a construction site: KZ = 28

(highly uneven terrain, unfavourable seat with amplification of the vibration)

Root-mean-square value of the frequency-weighted acceleration in the z axis:

$$a_{wz} = \frac{KZ}{\dfrac{20}{m/s^2}} = \frac{28}{20}\ m/s^2 = 1.4\ m/s^2$$

Since the value measured in the z axis was the highest root-mean-square value of the frequency-weighted acceleration, it is to be used for calculation of the assessment acceleration. The factor 1.4, to be used for the horizontal axes of measurement, is not applicable in this case.

Since it may be assumed that the acceleration values *a* in the form of m/s² and K will coexist for a transitional period, K value scales have also been entered on the x-axes of the exposure data tables (Annexes 1 and 2) for the purpose of comparison.

2.3 Seat Effective Amplitude Transmissibility (SEAT)

Measurement of the vibration acceleration simultaneously on the chassis of the machine or vehicle and the seat (Figure 3) permits calculation of the seat effective amplitude transmissibility (SEAT).

Figure 3:
Attachment of the acceleration sensors to the seat mounting point (P) and the seat squab (S)

The SEAT is calculated as the quotient of the acceleration value a_{wS} on the seat surface and the acceleration value a_{wC} at the seat mounting point on the chassis. The mean SEAT values in Annex 3 for the seats on mobile machines and vehicles (Annex 2) were determined from the measured vibration acceleration values for the vertical (z) axis of vibration.

3 Hand-arm vibration exposure at workplaces

Annex 1 shows the results of measurement of vibration exposure during work involving vibrating hand-held and manually guided machines. The machines are grouped according to their primary use in the following sectors:

- Construction
- Woodworking
- Metalworking
- Landscaping and gardening

This does not exclude these machines being used in other sectors of the economy with comparable measurement results. Where the mass and form of drive of the equipment and the power of its drive have a decisive influence upon the vibration exposure, as is the case for example for impact hammers and hammer drills, nail drivers and grinding machines, the machines have been grouped accordingly. Machines featuring antivibration systems (AVS) have been assigned to groups of their own for the purpose of comparison. Examples include concrete breakers, vibratory plates, lettering hammers (Figure 4) and angle grinders [12].

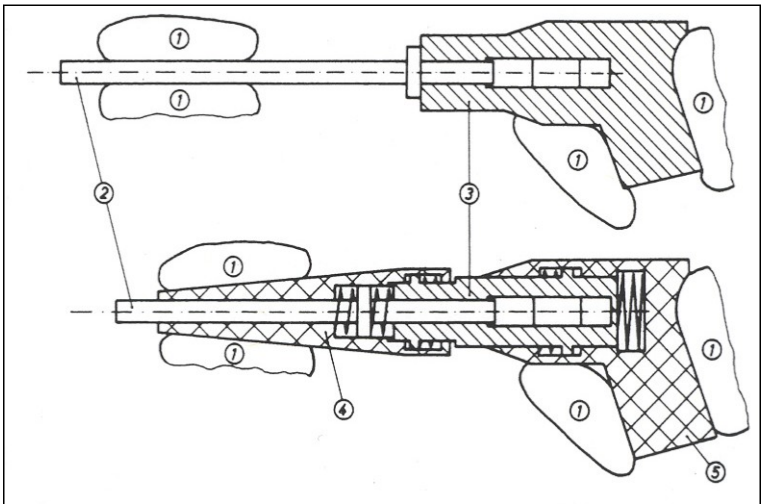

Figure 4:
Conventional (top) and low-vibration (bottom) pneumatic hammer (schematic diagram from [13])
1 = guiding hand, 2 = hammer bit,
3 = working cylinder,
4 = guide sleeve, 5 = handle

Transmission of vibration through the workpiece held by the hand is also known to present a hazard to health. Additional measurements were therefore taken on fixed machines (pneumatic and spring hammers, drill presses). Although fewer than five data records have been obtained to date for certain machines, they have nevertheless been included in Annex 1, since they provide at least an approximate indication.

The entry "KHV" on the K value scales is intended to indicate that this K value represents the vector sum of all three axes of measurement. The VDI Guideline 2057 edition published in 1987 and in use prior to 2002 did not contain such a "KHV" sum K value, since at that time the vibration was assessed according to the greatest value of a single axis of measurement.

If the exposure limit value of 5 m/s² and action value of 2.5 m/s² of the EU Vibration Directive are assumed without consideration of the daily exposure duration, they are found to be exceeded, barring a few exceptions, even under the most favourable working conditions – corresponding to the lower limit of the data field. Owing to the wide scatter of the values, the data fields are frequently very wide, as can be seen from the strong correlation between the vibration exposure and the working method in question. This is particularly important where exposure is assessed based upon the vibration parameters stated by the manufacturer (see Chapter 6). At the same time, it reveals an important prevention aspect: changes in the working method may reduce what was originally a high level of exposure to the lower region of the data field.

The limit values of the EU Vibration Directive apply to vibration exposure over an eight-hour period. Since the duration of exposure only constitutes part of the duration of use and in practice is always substantially shorter than eight hours, high values measured during performance of the work yield lower assessment values, in some cases below the limit values, following conversion according to the specific exposure duration (see Chapter 6). Further information can be found in [14].

4 Whole-body vibration exposure at workplaces

Annex 2 (see Page 47) shows the results of measurement for the vibration exposure during the driving of mobile machines and vehicles. Mobile construction machines, which cause strong exposure to vibration particularly during use on loose ground, form the largest group (Figure 5).

Figure 5:
Tracked bulldozer
in use on loose ground

Fork-lift trucks in various guises are employed in virtually all sectors of the economy. In the transport sector, goods vehicles, buses and coaches form the largest group, frequently with long durations of exposure [15]; in agriculture and forestry, tractors are the largest group. For all mobile machinery and vehicles shown, the vibration acts upon seated operators. Since the EU Vibration Directive employs the highest value of the frequency-weighted acceleration in the three orthogonal axes of measurement in Annex B for assessment of exposure, the measurement results for the three axes x, y and z (see Figure 2) have been shown separately for whole-body vibration, in contrast to those for hand-arm vibration. The exposure in the vertical (z) axis (axis of the spine in a seated posture) is frequently greater than that in the two horizontal (x and y) axes. In the graphical presentations, the latter were multiplied in accordance with Annex B of the EU Vibration Directive by a factor of 1.4 for direct comparison with the frequency-weighted acceleration in the z axis.

The new version of VDI Guideline 2057 published in 2002 was also accompanied by a change in the frequency weighting for whole-body vibration. As a consequence, the measured value for certain mobile machinery and vehicles has changed from the earlier measurements obtained with the frequency weighting in accordance with the 1987 version of VDI Guideline 2057. In a study, the IFA has determined factors which can be used for approximate conversion of the values measured in accordance with VDI 2057:1987 to those which could be expected with application of the new frequency weighting to VDI 2057:2002 (Table 2).

In order to permit comparison between the vibration acceleration values and the former K values, a K value x axis is also entered on all diagrams in Annex 2. In this case, distinction between the K values for the individual axes of measurement is not necessary, since the factor of 1.4 for the horizontal axes of measurement, x and y, has already been considered in the acceleration value a_{we}.

Table 2:
Factors for the conversion of values determined with frequency weighting to VDI 2057:1987 to values determined with the new frequency weighting to VDI 2057-1:2002

Mobile machinery, vehicle	Factor for conversion from the old to the new frequency weighting, axis of measurement (seat)		
	x	y	z
Mobile heavy equipment			
Wheel loaders	1.15	1.12	0.95
Compact loaders	1.20	1.10	1.02
Wheel dozers	---	---	0.95
Soil and landfill compactors	1.18	1.13	0.94
Tracked dozers, tracked loaders	1.11	1.10	1.20
Hydraulic excavators (tracked and mobile excavators)	1.05	1.05	1.15
Cable excavators	1.10	1.10	1.10
Excavator loaders	1.08	1.09	1.02
Graders	1.20	1.08	0.95
Scraper dozers	1.07	1.16	1.16
Scrapers	1.12	1.24	0.95
Dump trucks	1.14	1.18	0.95
Road-rollers (for seated operators)	1.14	1.23	1.00
Road millers, pavers	1.06	1.07	1.25
Industrial trucks, cranes, mobile equipment			
Straddle carriers (VanCarriers, CoilCarriers)	1.15	1.20	0.95
Fork-lift trucks, rough-terrain fork-lift trucks, sideloaders	1.15	1.10	1.00
Reach fork-lift trucks, high-rack stackers, four-directional lift trucks, low-level pallet trucks, electric pallet trucks	1.20	1.20	1.15
Bridge cranes, gantry cranes, tower cranes	1.10	1.10	1.10
Truck cranes	1.10	1.20	0.95
Transverse shuttles	1.12	1.03	1.50

Table 2: continued

Mobile machinery, vehicle	Factor for conversion from the old to the new frequency weighting, axis of measurement (seat)		
	x	y	z
Road vehicles on the public highway, railbound vehicles			
Goods vehicles on the public highway	1.15	1.15	1.00
Light goods vehicles on the public highway	1.26	1.28	0.96
Goods vehicles on construction sites	1.05	1.09	0.95
Articulated vehicles on the public highway	1.10	1.15	0.95
Articulated vehicles on construction sites	1.10	1.15	0.95
Unimogs	1.16	1.20	1.00
Roadsweepers	1.23	1.13	0.93
Tractors for agriculture and forestry	1.05	1.15	0.90
Narrow-track tractors, reel and rotary mowers	1.05	1.15	0.90
Buses on the public highway	1.30	1.25	1.00
Locomotives, railcars, railbound machinery	1.20	1.05	1.05
Trams and underground rail units	1.40	1.16	0.97
Motor cars	1.53	1.45	1.03
Other			
Ships	1.10	1.04	1.30

If the K value of 16 (a statutory limit value applicable since 1991 in the German Regulation on Health Protection in Mining (Bergverordnung)), which was applied in the past as a guideline value for assessment in accordance with VDI Guideline 2057, is assumed, an equivalent exposure value (reference period of 8 hours per day) in the future will be a daily assessment acceleration of 0.8 m/s² for the z axis. For the horizontal x and y axes of vibration, the value of 1.15 m/s² from the EU Vibration Directive was adopted. These limit values had already assumed legal force by the amendment to the Regulation on Health Protection in Mining [5] enacted on 11 August 2005. For numerous mobile machines for construction site use, industrial trucks, and also vehicles in service on the public highway, the upper regions of the data fields in Annex 2 exceed these limits. At the same time, the values at the lower limits of the data fields are frequently substantially below the limit values. This reflects a strong correlation between the vibration exposure and, in the first instance, the form of work carried out, and also the nature of the ground over which the machine or vehicle travels and the driving style of the operators. It is important to note that the vibration exposure levels shown here are considered typical for the type of work concerned, i.e. for relatively brief periods of exposure. Whether the limit values are in fact exceeded in a specific application is dependent upon the duration of exposure during a working shift (see Chapter 6). For further information, see [16].

5 Vibration attenuation by means of suitable seats

Since the damping properties of the seats on mobile machinery and vehicles decisively influence the level of vibration to which their operators are exposed, the results of measurements performed at the seat mounting point on the chassis have also been included in the diagrams. Comparison between the mobility-related vibrations at the seat mounting point with those transmitted to the human body through the surface of the seat reveals whether selection of a suitable seat has resulted in a reduction in the exposure. Particular attention must be paid to the z axis, since the seats generally attenuate the vibration only in this axis. Since considerable vibration components, often additionally including a shock component, were measured in the horizontal axes on certain mobile machines, such as wheel loaders, excavators or fork-lift trucks, it will be necessary to make seats available which also possess horizontal damping properties. A general guide to the current state of seat damping is provided by the table of mean SEAT values (see Section 2.3) in Annex 3. Since not all exposure measurements also included the recording of values at the seat mounting point, the diagrams in Annex 2 are almost always based upon a different number *n* than for the values measured at the seat surface. The first number *n* is the number of values measured at the seat mounting point; the second, the number *n* of values measured at the seat surface. Since the number of measured values is not always the same for the given axes of measurement, a range of values is produced in many cases rather than a single value for the seat mounting point and another for the seat surface. Since consideration could be given during calculation only to the measurements for which corresponding pairs of values were available, the SEAT values may deviate from those in the diagrams for the data fields for the z axis of measurement.

Values greater than 1.00 show that the frequencies of the chassis vibrations cause resonance in the seats. As a result, transmission of the vibration into the operator's body is greater than the excitation vibration at the seat mounting point. Values below 1.00 describe an attenuation in vibration by the seat. Only in a small number of cases were values below 0.70 recorded; these can be attained where the damping characteristics of the seats are adjusted favourably to the vibration frequencies at the seat mounting point.

6 Instructions for the assessment of vibration

6.1 Terminology in standards and statutory regulations

The parameters shown in the diagrams in Annexes 1 and 2 are energy-equivalent mean values of the frequency-weighted vibration acceleration, measured over a brief period which is typical for the type of work being carried out (exposure segment according to VDI Guideline 2057, Parts 1 and 2 [8]). As part of the risk assessment of workplaces subject to vibration in accordance with the German Occupational Health and Safety Act, the assessment acceleration must be calculated from the values of all exposure segments of a working day in consideration of the duration of exposure for the case concerned. In accordance with the provisions of the EU Vibration Directive, the assessment period is defined as eight hours. The assessment variables for vibration exposure over an eight-hour period of exposure exhibit differences in some cases between the statutory provisions and VDI Guideline 2057 (Table 3).

Table 3:
Exposure variables in the EU Vibration Directive and in VDI Guideline 2057

	EU Vibration Directive	VDI Guideline 2057
Characteristic exposure segment	Root-mean-square values of the frequency-weighted acceleration for HAV: a_{hwx}, a_{hwy}, a_{hwz} WBV: 1.4 a_{wx}, 1.4 a_{wy}, a_{wz}	Root-mean-square values of the frequency-weighted acceleration for HAV: a_{hwx}, a_{hwy}, a_{hwz} WBV: 1.4 a_{wx}, 1.4 a_{wy}, a_{wz}
Assessment variable for exposure	HAV: Daily exposure value A(8) WBV: Daily exposure A(8)	HAV: Daily vibration exposure $a_{hv(8)}$ WBV: Assessment acceleration $a_{w(8)}$

In exceptional cases, for example where the daily exposure values vary considerably, the assessment acceleration may also be determined for a period of 40 hours for five working days in a week.

6.2 Measurement of the exposure variable

For measurement of the frequency-weighted vibration acceleration, the EU Vibration Directive refers to the standards ISO 5349-2 [9] for hand-arm vibration and ISO 2631-1 [10] for whole-body vibration. These international standards have been implemented in Germany in VDI Guideline 2057 [8] and in DIN EN 14253 [17]. The results of measurements shown in Annexes 1 and 2 were obtained in accordance with these standards or converted to comparable values from earlier measurements of K values.

6.3 Estimation of the exposure variable

The EU Vibration Directive does not require measurements to be performed in all cases in order for parameters for individual exposure to be determined; it permits estimation based upon manufacturers' data and observation of the specific methods of working.

Under the provisions of the EU Machinery Directive [7], manufacturers are obliged to state data for the hand-arm vibration exposure (emitted vibration) in the information for use of hand-held/manually guided machines and the controls of mobile machinery when the value of the frequency-weighted acceleration exceeds 2.5 m/s^2; where this value is not reached, this fact must also be stated in the information for use. In the case of mobile machines, the information for use must contain figures for the whole-body vibration exposure (emitted vibration) when the frequency-weighted acceleration exceeds 0.5 m/s^2. Should this value not be reached, this fact must also be stated. During measurement of vibration emissions, manufacturers should give preference to European standards which define uniform measurement and operating conditions, in order to enable purchasers to compare machines according to their anticipated vibration exposure. Examples of such standards are DIN EN 1032 [18], a framework test standard for mobile machines governing determining of the vibration emission value, and DIN EN 13059 [19], an application of this framework standard governing the method for vibration measurement on industrial trucks. For measurement of the vibration emissions on hand-held and manually guided machines, the relevant standard is DIN EN ISO 20643 [20], which provides a framework measurement method, and various individual test standards for a large number of machines such as hammers, drills, grinding machines, screwdrivers, rammers, tackers, etc. Manufacturers and purchasers may however agree upon operating conditions on a case-by-case basis for the measurement of vibration emissions where this corresponds more closely to typical use.

This also illustrates the particular issue of the use of manufacturers' data rather than direct measurement during risk assessment. The wide data fields in Annexes 1 and 2 document the strong dependency, in individual cases, of the vibration exposure upon the nature of the work being performed, the tools used, the personal manner of working, etc. During measurement of the vibration emission on concrete breakers in accordance with the European standard, for example, a steel ball energy absorber is employed in the measurement laboratory for reasons of reproducibility. During practical use of these items of equipment, however, a higher vibration exposure certainly arises. The results of a risk assessment may be feared incorrect when the real-case conditions of use at the workplace deviate from the standard conditions of use in the measurement laboratory. In order to enable the vibration exposure to be assessed nevertheless by estimation of exposure variables with the aid of the manufacturers' data, a technical rule for hand-arm vibration exposure was drawn up by the CEN European standards committee which explains the most important boundary conditions to be observed and provides guidance on application [21].

6.4 Duration of use, exposure duration

The daily exposure duration is of decisive importance during determining of the daily exposure values. It is always only a part of the total duration of use of a machine or vehicle. During use, work is generally interrupted by down times and rest breaks, during which no vibration exposure occurs. The exposure duration is therefore only the time during which vibration is actually transmitted to the hands or the whole body. The Mechanical engineering, manufacturing systems and structural steel engineering expert committee (FA MFS) has made expert committee information sheet 017 available on the Internet. This document covers the issue of the actual exposure duration and also practical aspects of using manufacturers' data [22].

6.5 Daily assessment acceleration

The concept of the “daily assessment acceleration”, employed in the only statutory implementation of the EU Vibration Directive in Germany to date [5], describes the parameter which permits assessment of the total daily vibration exposure at work based upon the exposure limit values (see Section 6.1). The daily assessment acceleration is calculated for hand-arm vibration and whole-body vibration in accordance with VDI Guideline 2057 from a range of exposure parameters, for a standardized eight-hour daily period of exposure.

A user-friendly software tool for calculation of the daily hand-arm vibration exposure $a_{hv(8)}$ is available from the IFA. This hand-arm vibration parameter calculator requires input of the vibration total values a_{hv} for all exposure segments of one day, together with the associated exposure durations (www.dguv.de/ifa, Webcode: d3245, in German only).

For calculation of the assessment acceleration $a_{w(8)}$ for whole-body vibration exposure, the "whole-body vibration exposure calculator" is available from the FA MFS on the Internet at (http://www.bg-metall.de/index.php?id=180). The root-mean-square values of the frequency-weighted acceleration (the largest value of each axis of measurement) of all mobile machinery and/or vehicles used during one day must be entered together with the associated exposure durations. In the course of implementation in German law, the exposure limit value A(8) of 1.15 m/s² stated in the calculator as a guideline value for all three axes of measurement is modified. In the transposition in 2005 in the form of the German Regulation on Health Protection in Mining [5], the exposure limit value (described there as the daily assessment acceleration) for the x and y axes was defined as A(8) = 1.15 m/s² and for the z axis as A(8) = 0.8 m/s².

6.6 Prevention measures

The daily exposure duration is of great importance for determining of the daily exposure to both hand-arm and whole-body vibration. Changes in the technology employed or in organization of the work with the objective of reducing the exposure duration may potentially enable the limit values to be observed. The IFA's hand-arm vibration parameter calculator and the whole-body vibration exposure calculator of the BG's FA MFS expert committee (see Section 6.5) enable the daily exposure durations to be changed during input, and thus different, theoretical scenarios to be analysed and evaluated with regard to their potential for implementation in the company.

Further sources of information for the prevention of hand-arm and whole-body vibration can be found in [11; 12; 22 to 27].

7 References

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[19] DIN EN 13059: Sicherheit von Flurförderzeugen; Verfahren zur Schwingungsmessung. Ausg. 10/2002. Beuth, Berlin 2002

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http://www.isvr.soton.ac.uk/hrv/vibguide.htm

Annex 1:
Hand-arm vibrations

Measured hand-arm vibration on hand-held and manually guided equipment, listed in alphabetical order, grouped by application in the areas of construction, woodworking, metalworking, and landscaping and gardening

Content **Page**

Abbreviations used in the following diagrams:

el. = electric; pn. = pneumatic; hy. = hydraulic; br. = combustion engine

AVS = anti-vibration system

a_{hv} = total vibration value

KHV = K value of the vector sum of the three axes of measurement x, y and z

For explanations of the diagrams see Chapter 3, Page 17

Table A1:
Hand-arm vibration on hand-held and manually guided equipment

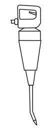
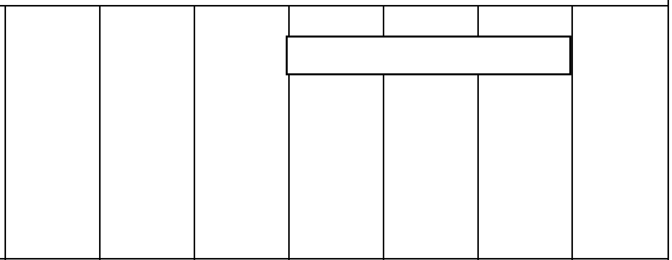
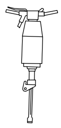
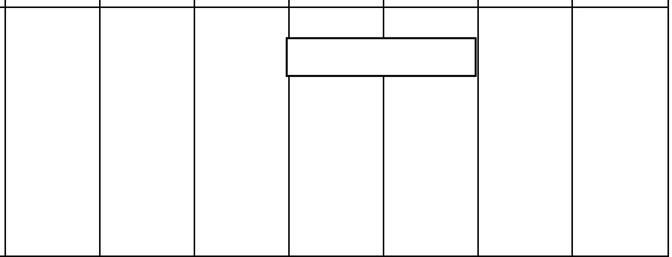
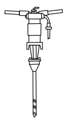
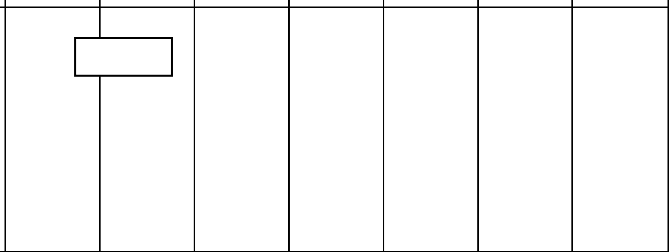
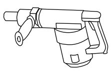
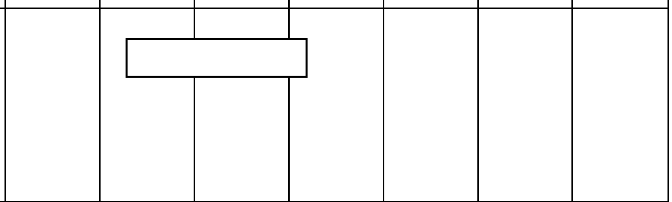
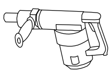
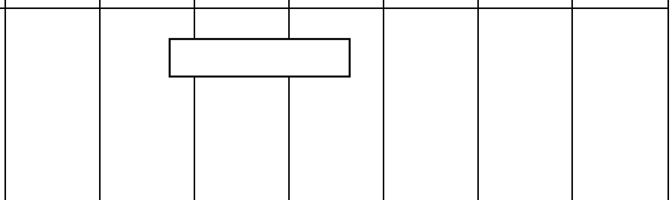
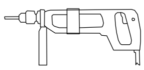
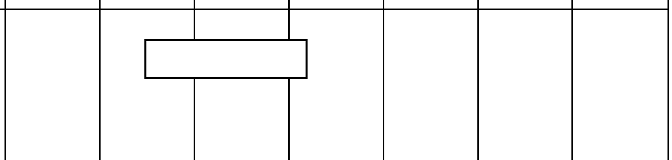
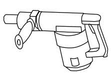
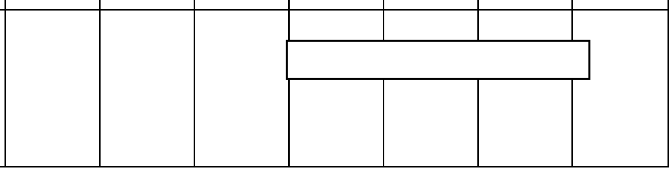
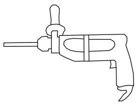
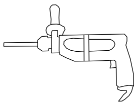
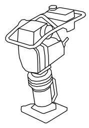
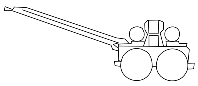
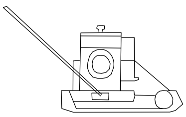
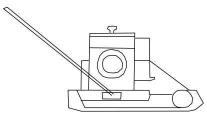
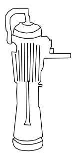
		a_{hv} in m/s² 0 5 10 15 20 25 30 35
Equipment primarily used in construction Demolition and fastenings		
Impact hammers (pn.), concrete breakers  *n* = 23	10 to 20 kg without AVS	
Impact hammer (pn.), concrete breakers  *n* = 13	> 20 kg without AVS	
Impact hammers (pn.), concrete breakers  *n* = 9	> 20 kg with AVS	
Impact hammers (el.), combi hammer drills  *n* = 21	< 1 kW without AVS	
Impact hammers (el.), combi hammer drills  *n* = 12	1 to 1.5 kW	
Rotary hammers (el.)  *n* = 17	250 to 800 W without AVS	
Rotary hammer (el.)  *n* = 6	6 to 30 kg without AVS	

Table A1: continued

		a_{hv} in m/s²
Hammer drills (el.)  *n* = 5	400 to 700 W without AVS	
Stud guns (br.)  *n* = 2	Drive cycle 3 s without AVS	
Soil compaction		
Vibratory rammers for soil compaction (br.)  *n* = 11	50 to 122 kg	
Vibratory rollers (br.)  *n* = 21	580 kg to 1 t without AVS	
Vibratory plates (br.)  *n* = 12	2 to 5 kW without AVS	
Vibratory plates (br.)  *n* = 5	4 to 10 kW with AVS	
Frog rammers (br.)  *n* = 5		

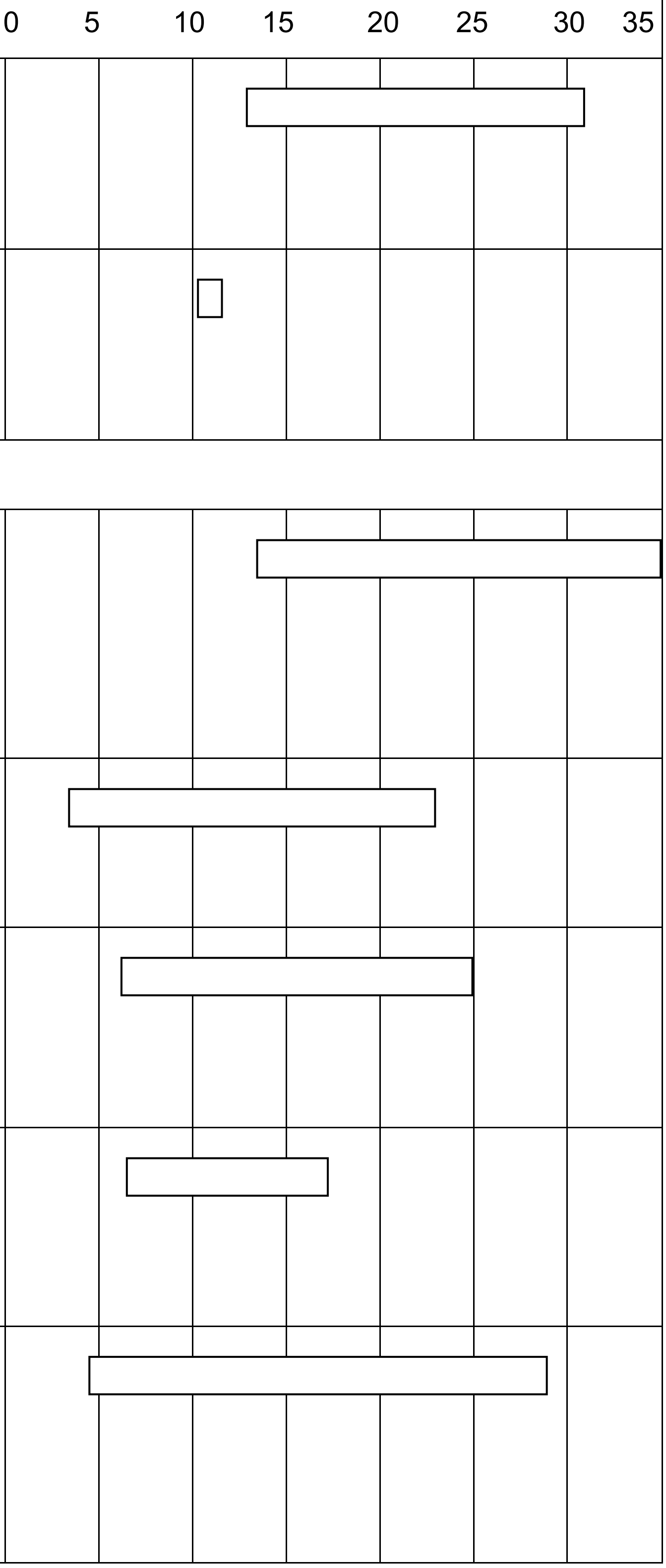


Table A1: continued

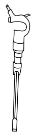
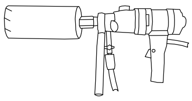
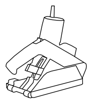
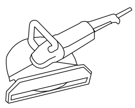
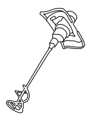
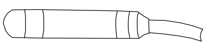
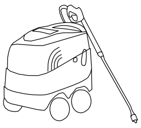
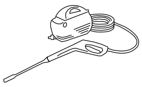
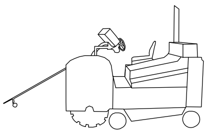
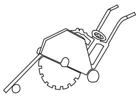
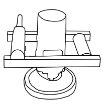
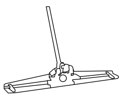
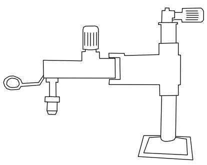
		a_{hv} in m/s² 0 5 10 15 20 25 30 35
Stone and masonry work		
Impact hammers (pn.), lettering hammers  *n* = 32	1 to 4 kg without AVS	
Impact hammers (pn.), lettering hammers  *n* = 16	1 to 4 kg with AVS	
Core drilling machines (el.)  *n* = 1	1.5 kW without AVS	
Wall chasers (el.)  *n* = 12	800 W to 2 kW without AVS	
Parting-off grinders (el.)  *n* = 5	1.4 to 3 kW without AVS	
Agitators (el.)  *n* = 11	700 W to 5 kW without AVS	
Internal vibrators/ poker vibrators (el.) n = 3 	800 W to 1 kW without AVS	

Table A1: continued

		a_{hv} in m/s² (0 5 10 15 20 25 30 35)
High pressure cleaners (br. and el.) > 250 bar  *n* = 15	without AVS	
High pressure cleaners (br. and el.) < 250 bar  *n* = 9	without AVS	
Joint cutters (br.)  *n* = 1	ca. 1.5 t without AVS	
Joint cutters (br.)  *n* = 1	ca. 250 kg without AVS	
Concrete grinders (el.)  *n* = 4	without AVS	
Power screeds (br.)  *n* = 15	without AVS	
Grinding machines with pivot arm (el.)  *n* = 8	Floor-standing machine without AVS	

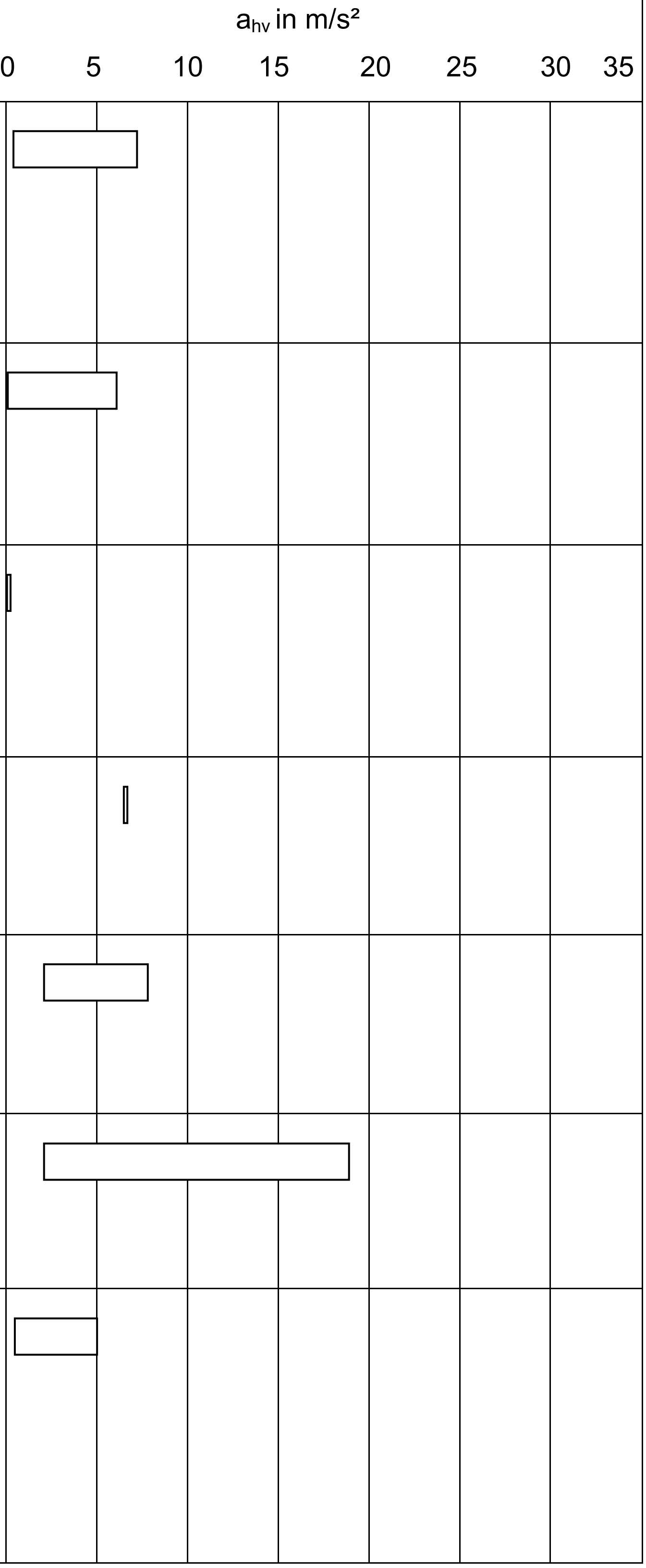


Table A1: continued

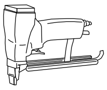
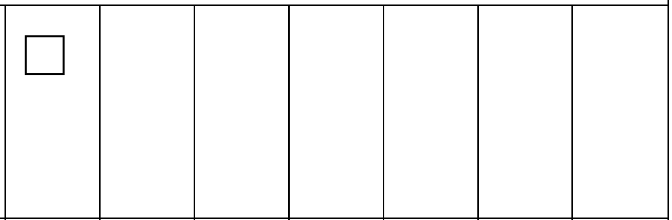
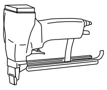
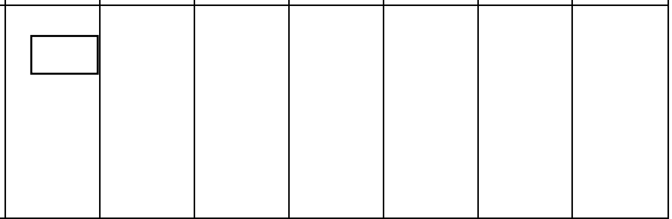
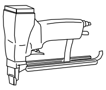
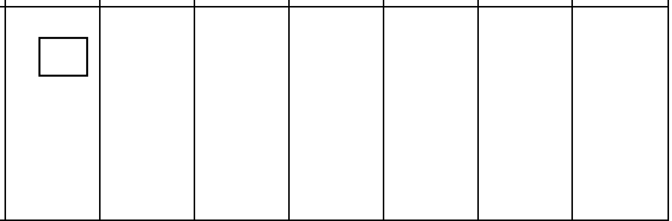
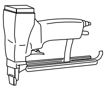
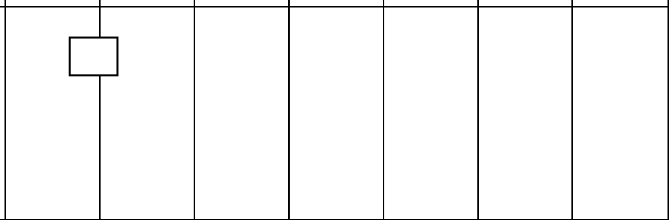
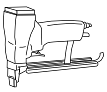
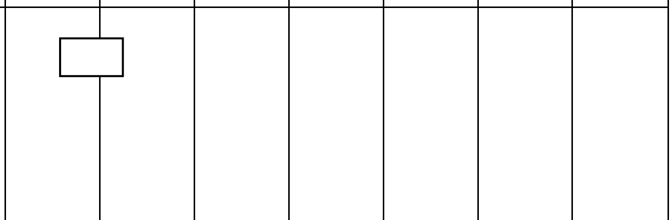
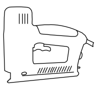
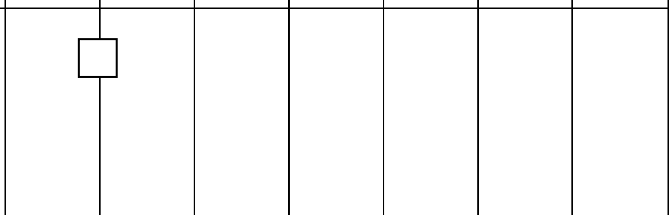
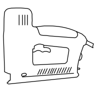
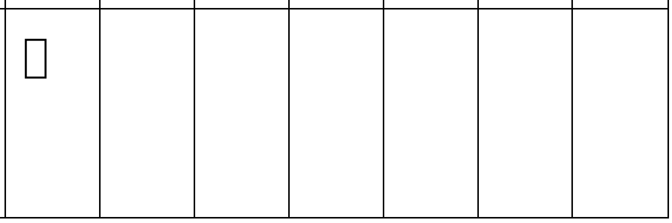
		a_{hv} in m/s² 0 5 10 15 20 25 30 35
Equipment primarily used in woodworking		
Nail guns (pn.) drive cycle 3 s  *n* = 16	1 to 2 kg without AVS	
Nail guns (pn.) drive cycle 3 s  *n* = 22	> 2 to 3 kg without AVS	
Nail guns (pn.) drive cycle 3 s  *n* = 12	> 3 to 4 kg without AVS	
Nail guns (pn.) drive cycle 3 s  *n* = 12	> 4 to 5 kg without AVS	
Nail guns (pn.) drive cycle 3 s  *n* = 4	> 5 to 7 kg without AVS	
Tackers (el.) drive cycle 3 s  *n* = 2	Staples 8 to 30 mm without AVS	
Tackers (pn.), drive cycle 3 s  *n* = 4	Staples 16 to 40 mm without AVS	

Table A1: continued

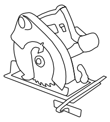
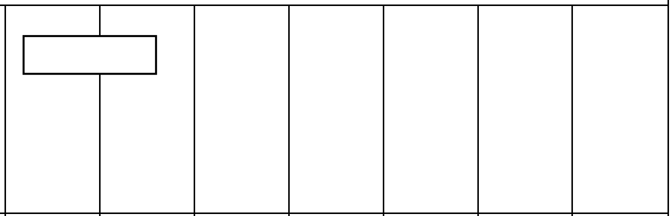
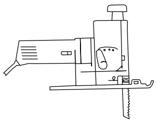
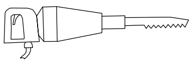
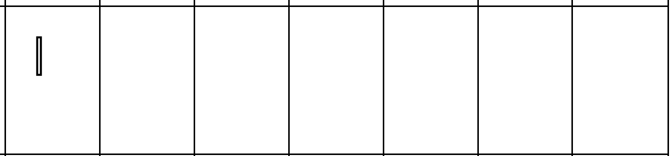
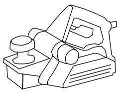
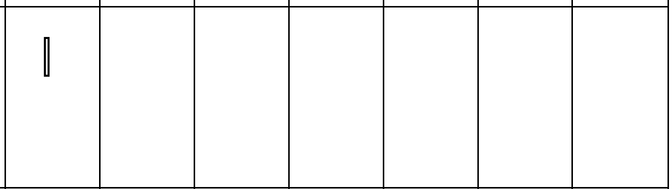
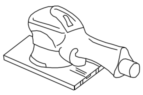
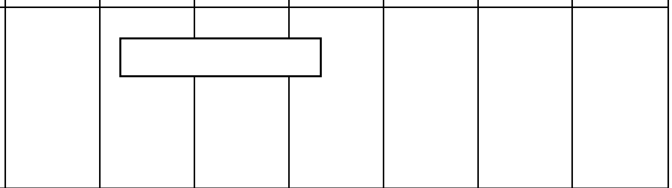
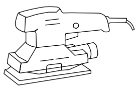
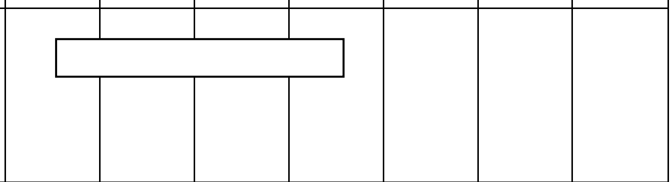
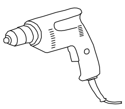
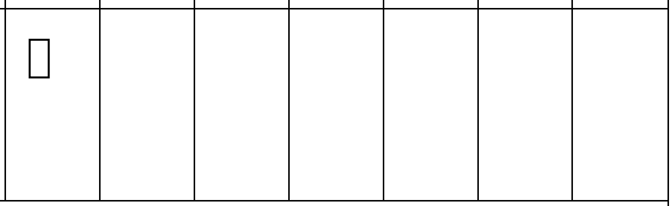
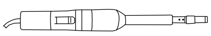
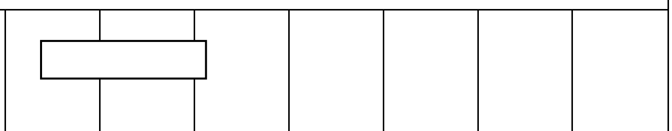
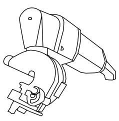
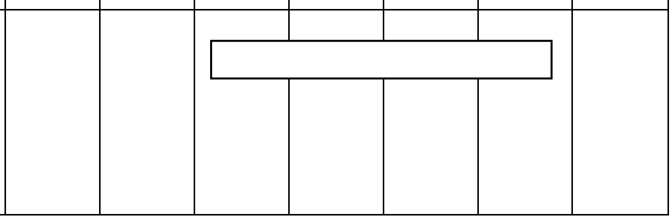
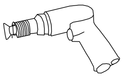
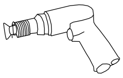
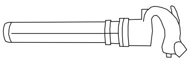
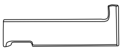
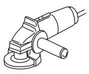
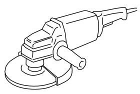
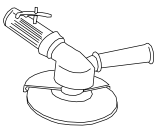
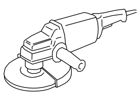
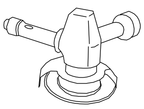
		a_{hv} in m/s² 0 5 10 15 20 25 30 35
Hand-held circular saws (el.)  *n* = 3	without AVS	
Jig saws (el.)  *n* = 2	without AVS	
Reciprocating saws (el.)  *n* = 1	without AVS	
Electric hand planers (el.)  *n* = 2	900 W to 1 kW without AVS	
Orbital sanders (pn.)  *n* = 9	1 to 3 kg without AVS	
Orbital sanders (el.)  *n* = 14	100 to 300 W without AVS	
Hand drills (el.)  *n* = 2	without AVS	
Equipment primarily used in metalworking		
Planers/scrapers (el.) *n* = 9 	100 to 400 W without AVS	
Bevellers (el.)  *n* = 7	2 to 3 kW without AVS	

Table A1: continued

		a_{hv} in m/s² (0 – 5 – 10 – 15 – 20 – 25 – 30 – 35)
Riveting hammers (pn.) (aluminium rivet)  *n* = 10	1 to 3 kg without AVS	
Riveting hammers (pn.) (aluminium rivet)  *n* = 10	1 to 3 kg with AVS	
Riveting hammers (pn.) (steel rivet)  *n* = 1	1 to 2 kg without AVS	
Riveting dollies  *n* = 8	< 2 kg without AVS	
Angle grinders (el.)  *n* = 20	≤ 900 W without AVS	
Angle grinders (el.)  *n* = 34	≥ 1 kW without AVS	
Angle grinders (pn.)  *n* = 11	1 to 7 kg without AVS	
Angle grinders (el.)  *n* = 3	Sungrip	
Vertical grinders (el.)  *n* = 4	4 to 5 kg without AVS	

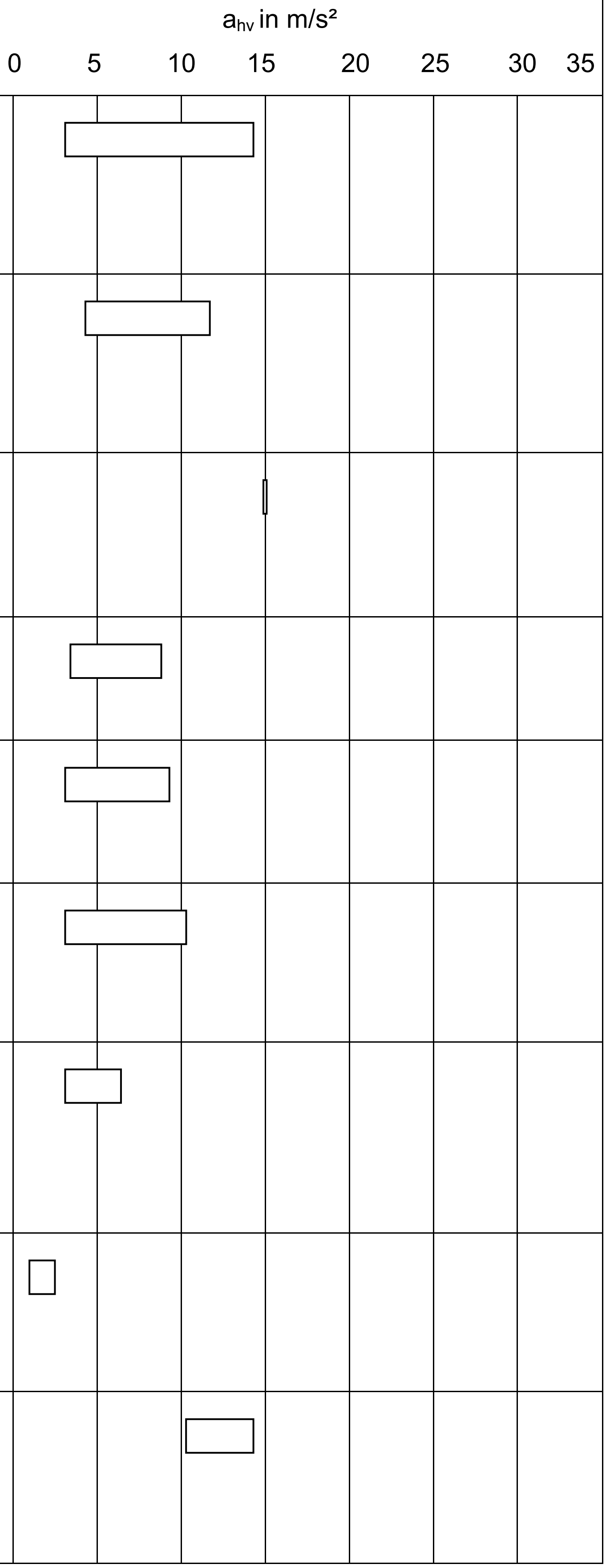


Table A1: continued

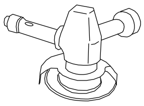
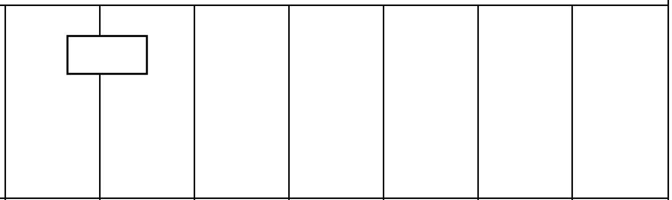
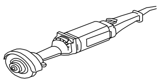
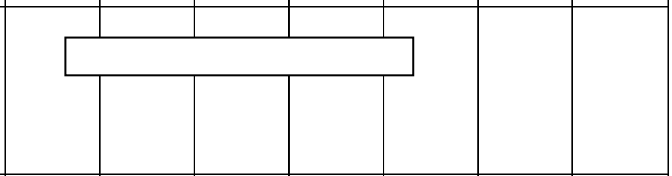
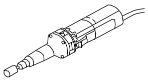
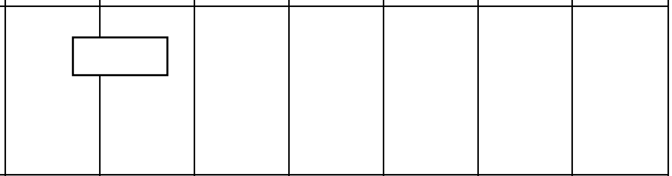
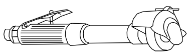
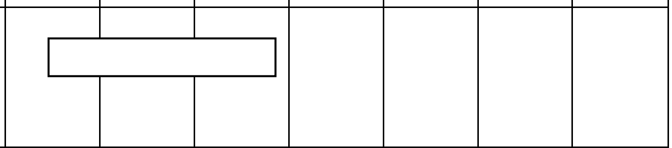
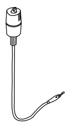
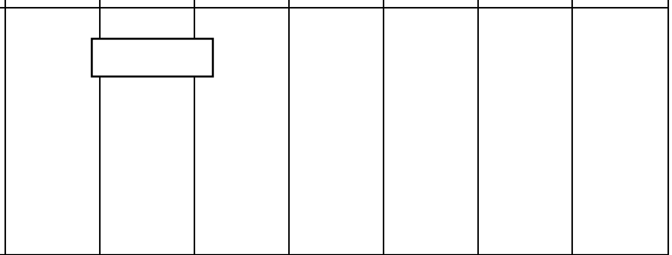
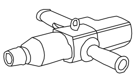
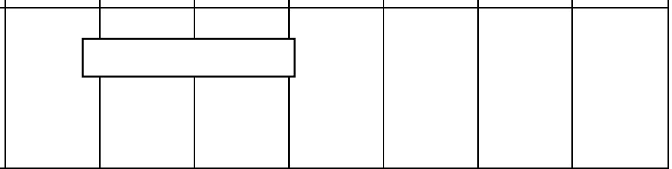
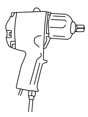
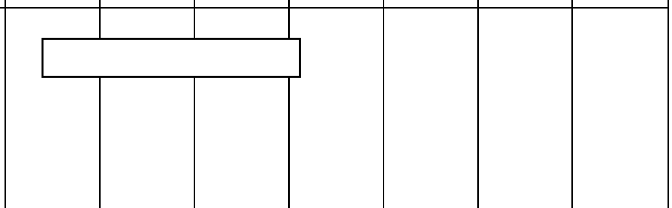
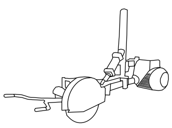
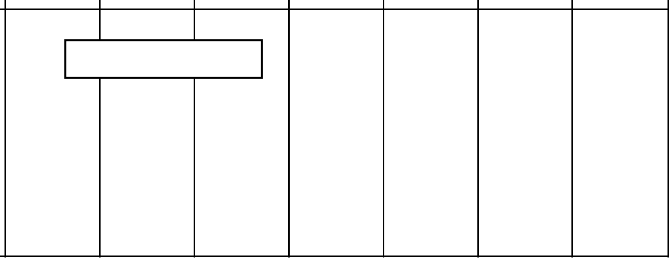
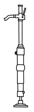
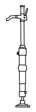
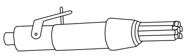
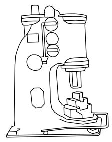
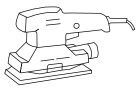
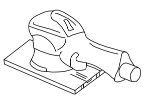
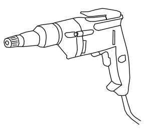
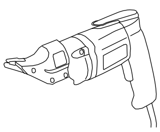
		a_{hv} in m/s² 0 5 10 15 20 25 30 35
Vertical grinders (pn.)  *n* = 10	2 to 6 kg without AVS	
Straight line grinders (el.)  *n* = 9	3 to 9 kg without AVS	
Straight line grinders (el.)  *n* = 9	1 to 2 kg without AVS	
Straight line grinders (pn.)  *n* = 17	1 to 5 kg without AVS	
Straight line grinders (with flexible shaft el.)  *n* = 5	700 to 800 W without AVS	
Impact screwdrivers (el.)  *n* = 9	300 W to 1.5 kW without AVS	
Impact screwdrivers (pn.)  *n* = 11	1 to 10 kg without AVS	
Pendulum grinding machines (el.)  *n* = 30	4 to 19 kW without AVS	

Table A1: continued

		a_{hv} in m/s² (0 · 5 · 10 · 15 · 20 · 25 · 30 · 35)
Vibratory rammers (Metalworking pn.)  *n* = 9	2 to 11 kg with AVS	
Vibratory rammers (Metalworking pn.)  *n* = 8	8 to 13 kg ohne AVS	
Needlegun scalers (pn.) *n* = 6 	2 to 4 kg without AVS	
Pneumatic and spring hammers  *n* = 7	Point of transmission: tool	
Orbital sanders (el.)  *n* = 4	without AVS	
Orbital sanders (pn.)  *n* = 9	1 to 3 kg without AVS	
Mechanical screwdrivers  *n* = 7	1 to 3 kg without AVS	
Plate shears (el.)  *n* = 3	150 to 400 W without AVS	

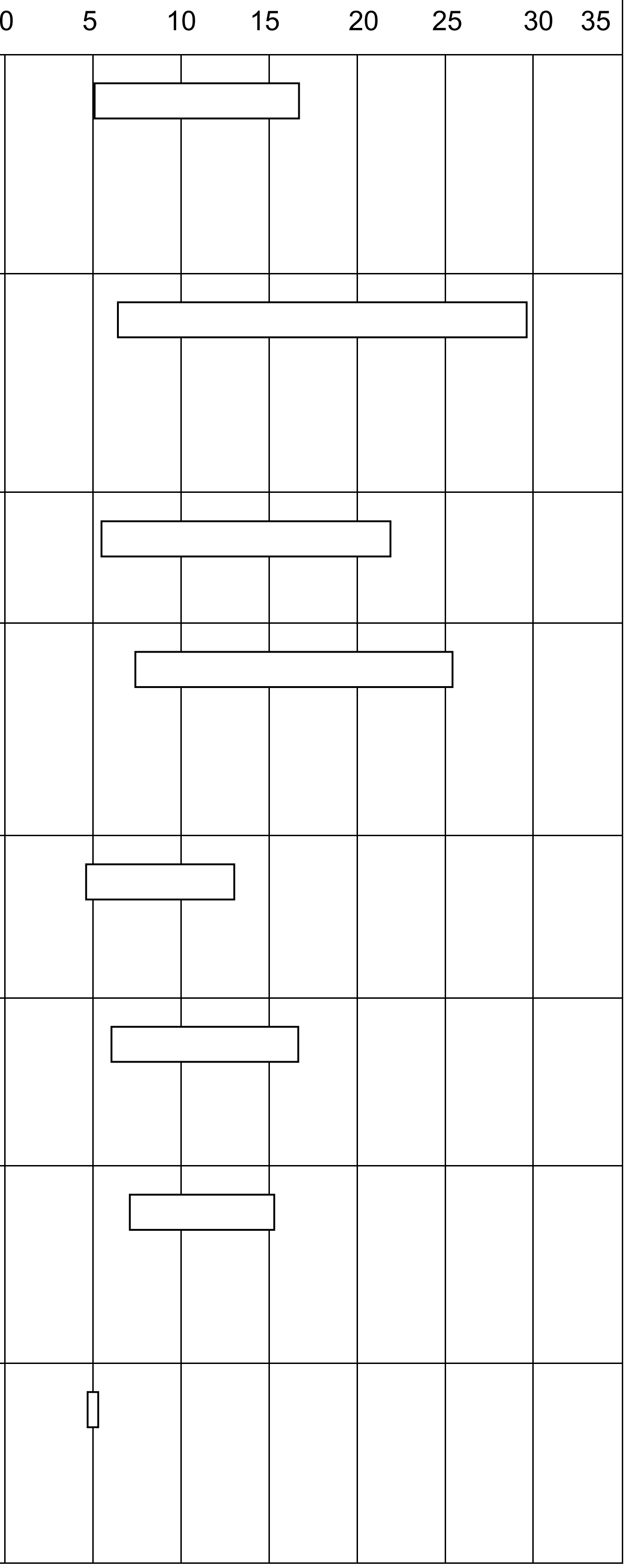
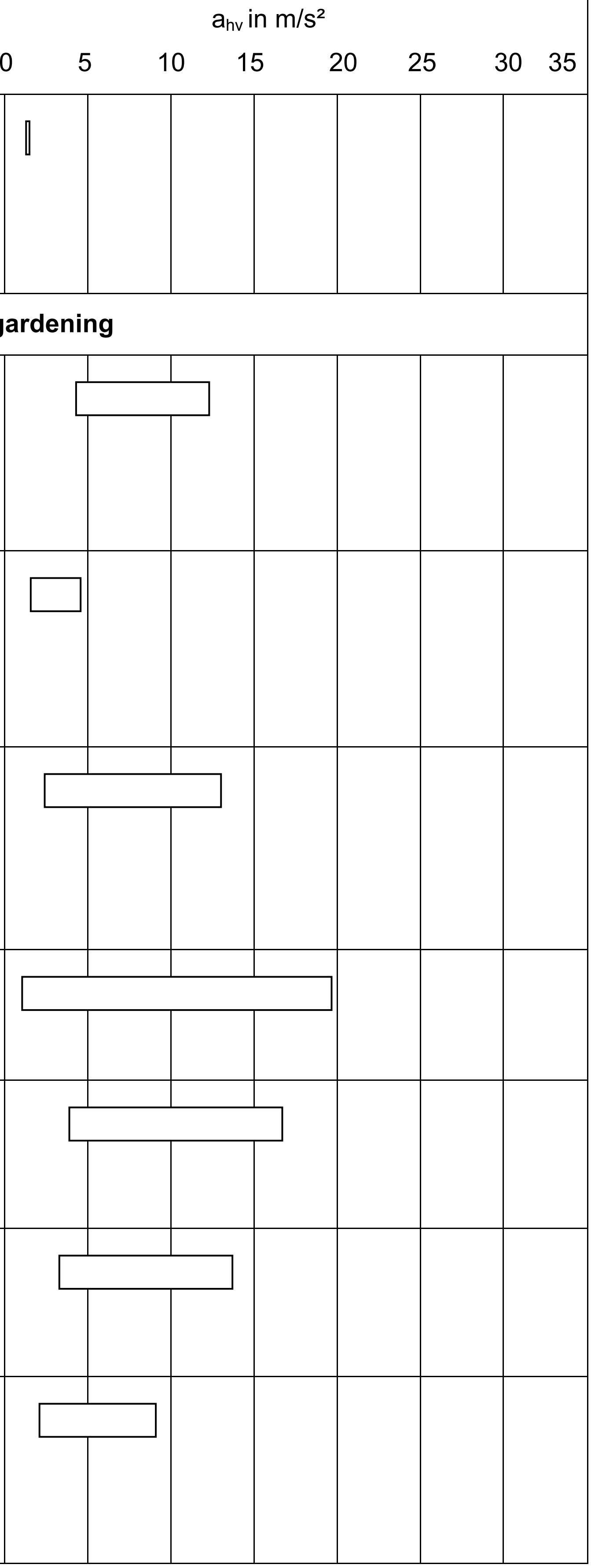


Table A1: continued



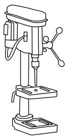
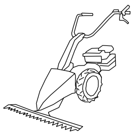
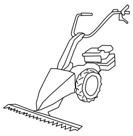
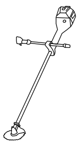
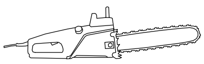
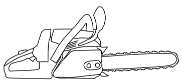
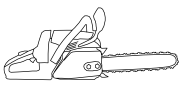
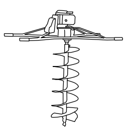
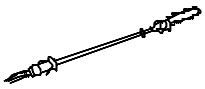
Drill presses  *n* = 2	3 to 4 kW without AVS	
Equipment primarily used in landscaping and gardening		
Power sickle bar mowers (br.)  *n* = 14	5 to 9 kW without AVS	
Power sickle bar mowers (br.)  *n* = 16	5 to 9 kW with AVS	
Lawn trimmers (br.)  *n* = 75	0.5 to 3 kW with and without AVS	
Chainsaws (el.) *n* = 11 	3 to 6 kg without AVS	
Chainsaws (br.) *n* = 54 	1 to 3 kW with AVS	
Chainsaws (br.) *n* = 27 	> 3 to 5 kW with AVS	
Earth augers (br.)  *n* = 4	8 to 26 kg with and without AVS	

Table A1: continued

		a_{hv} in m/s²						
		0	5	10	15	20	25	30 35
Tree pruners (hy.)  *n* = 1	5.4 kg without AVS							

Annex 2: Whole-body vibrations

Whole-body vibrations of mobile heavy equipment and vehicles, in alphabetical order

Content **Page**

For legends to the following diagrams, see Chapter 4, Page 19

Table A2:
Mobile heavy equipment and vehicles

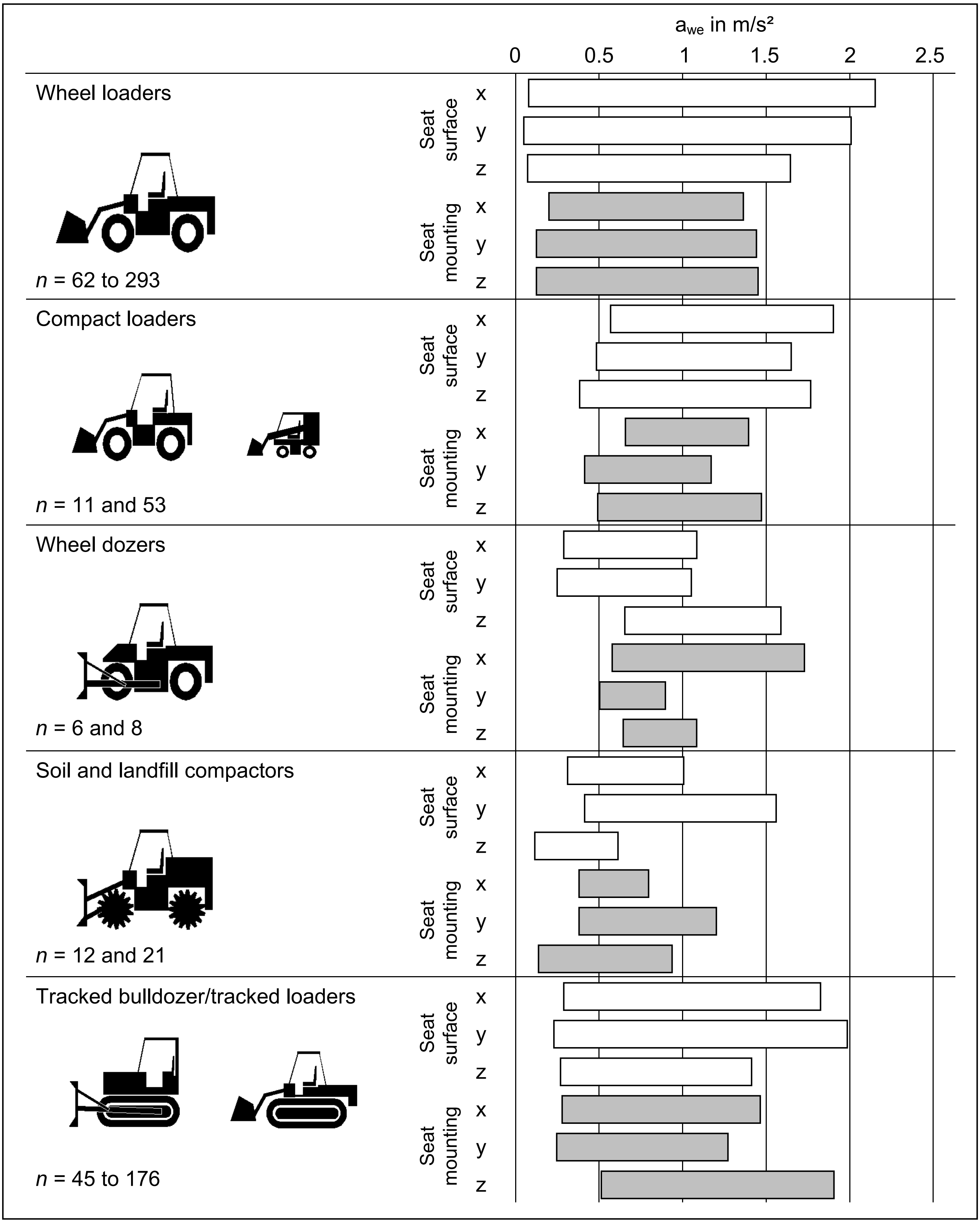


Table A2: continued

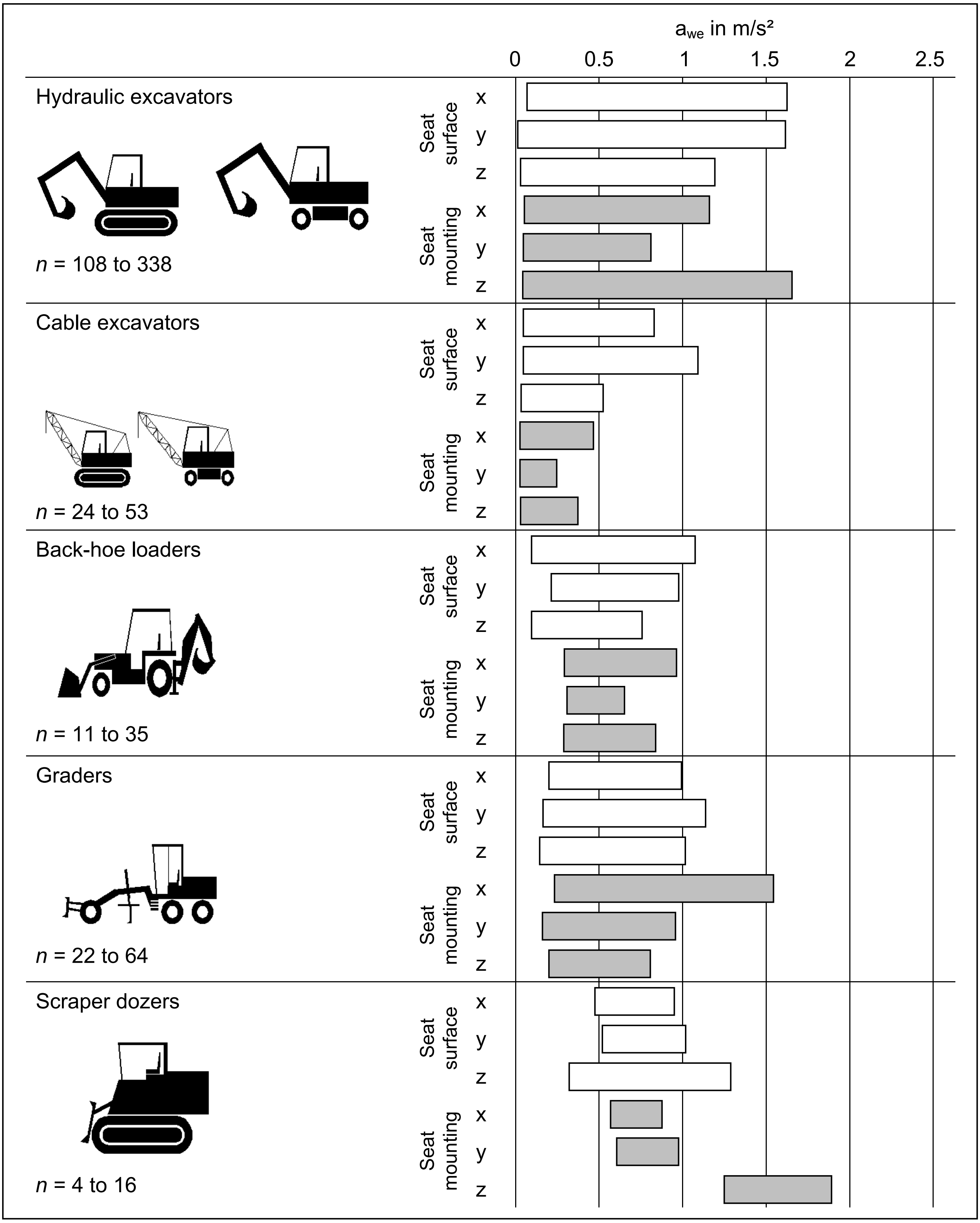


Table A2: continued

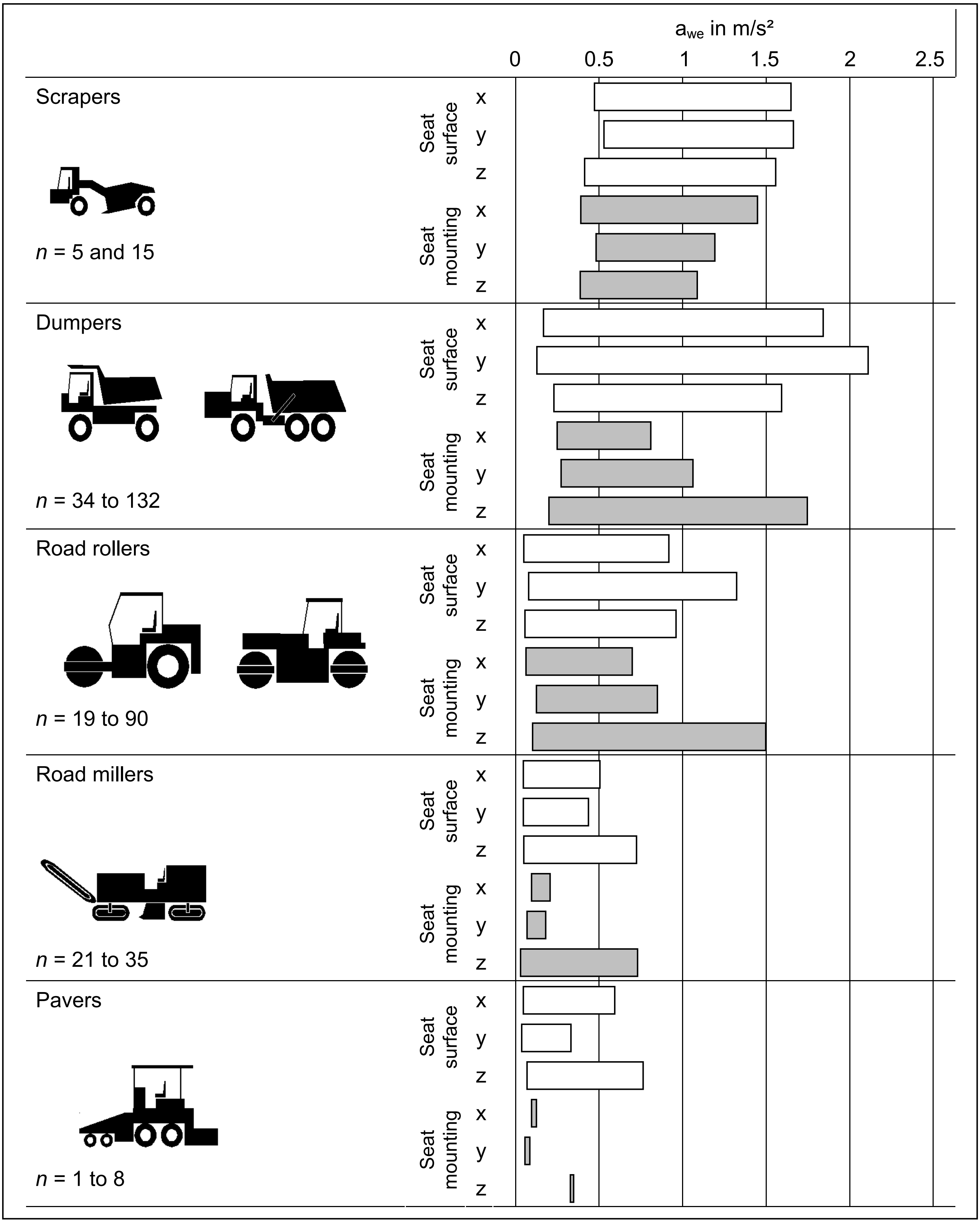


Table A2: continued

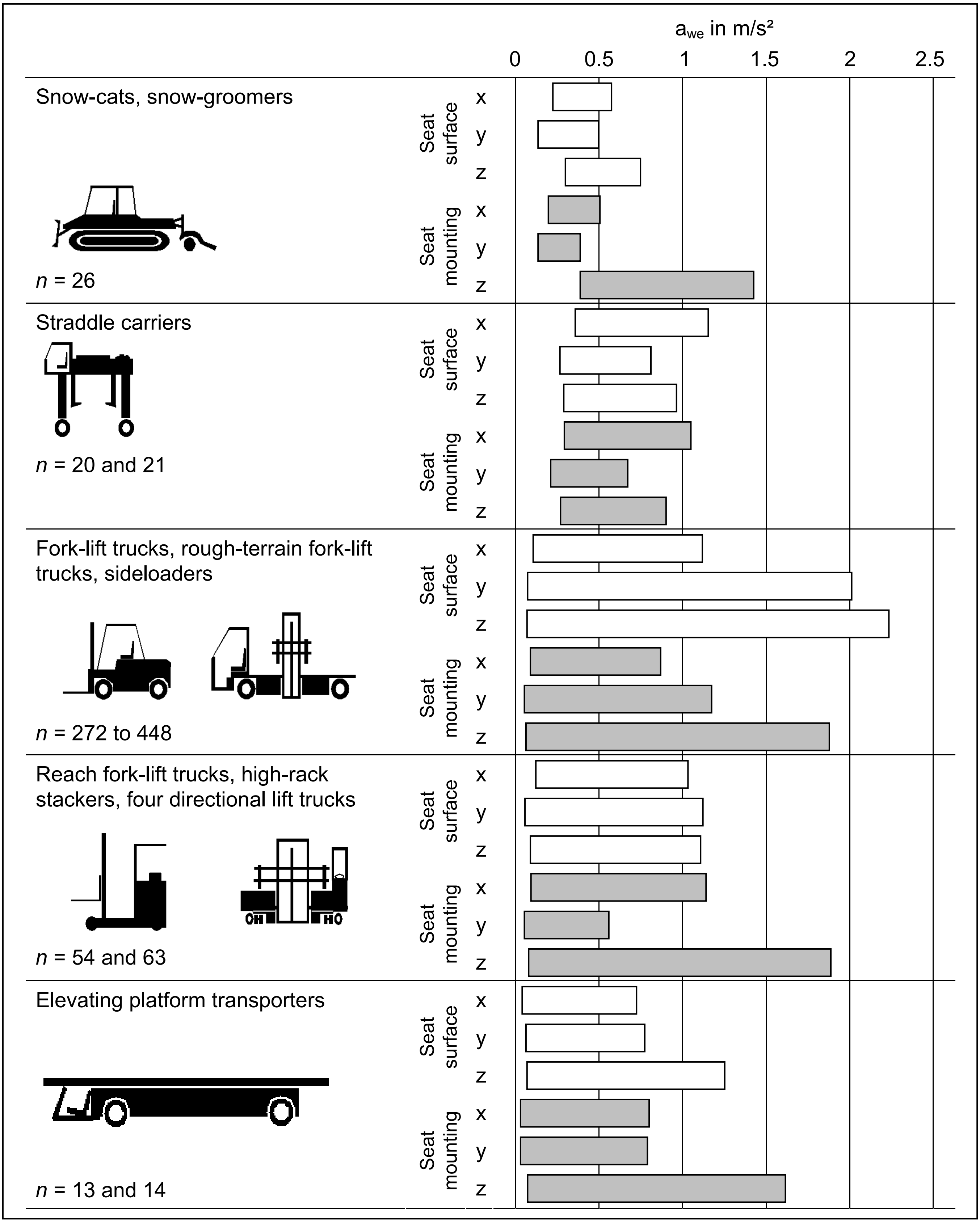


Table A2: continued

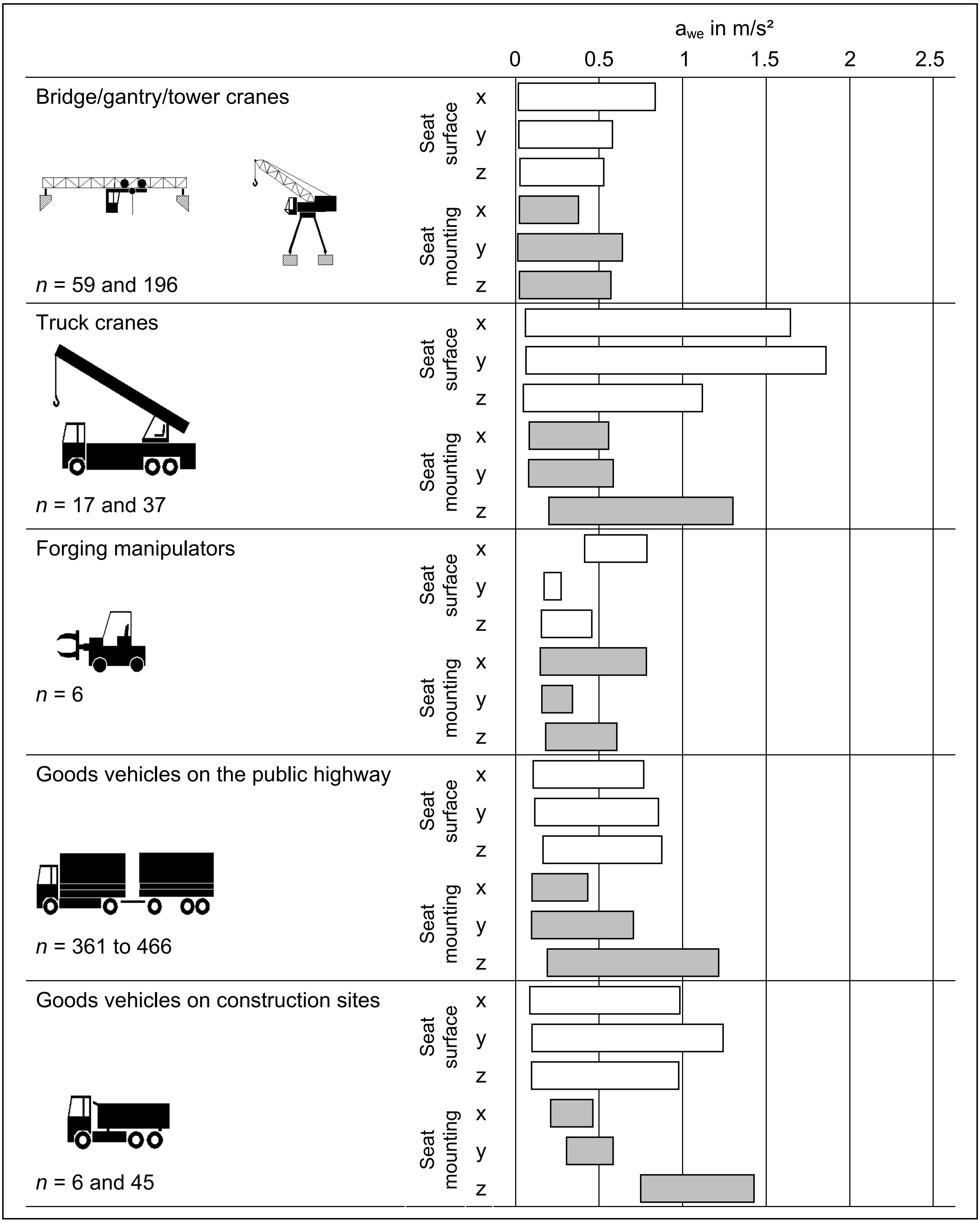


Table A2: continued

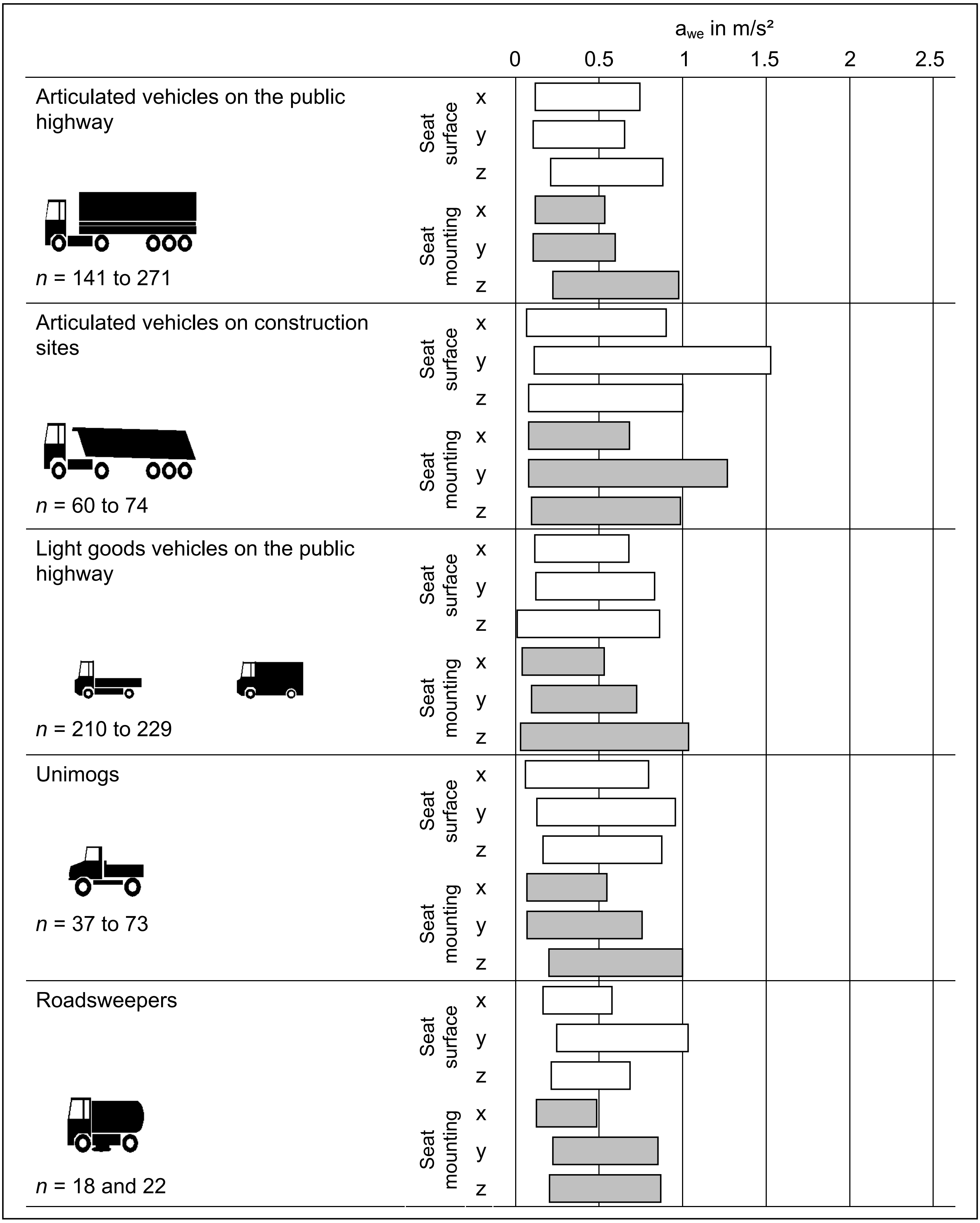


Table A2: continued

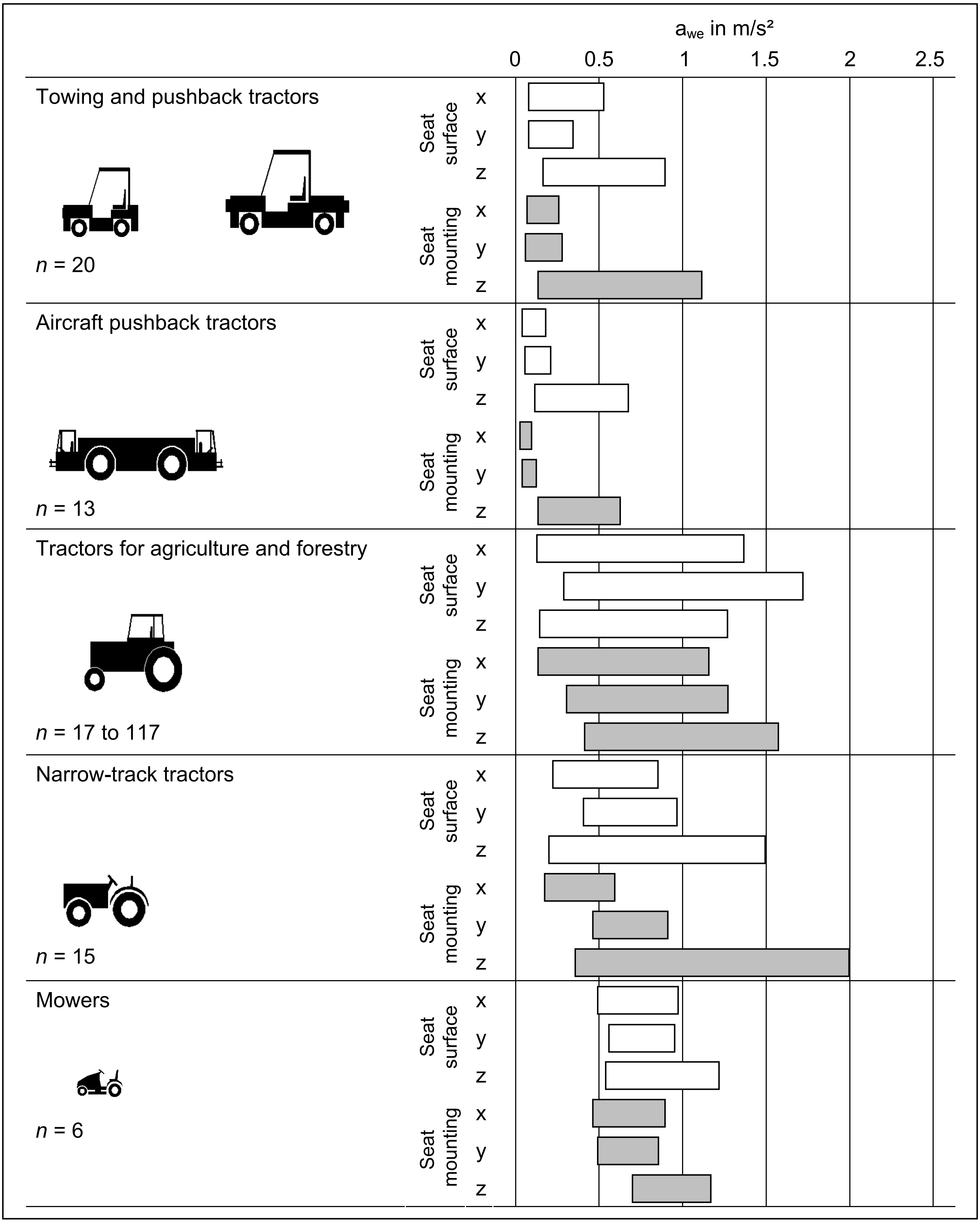


Table A2: continued

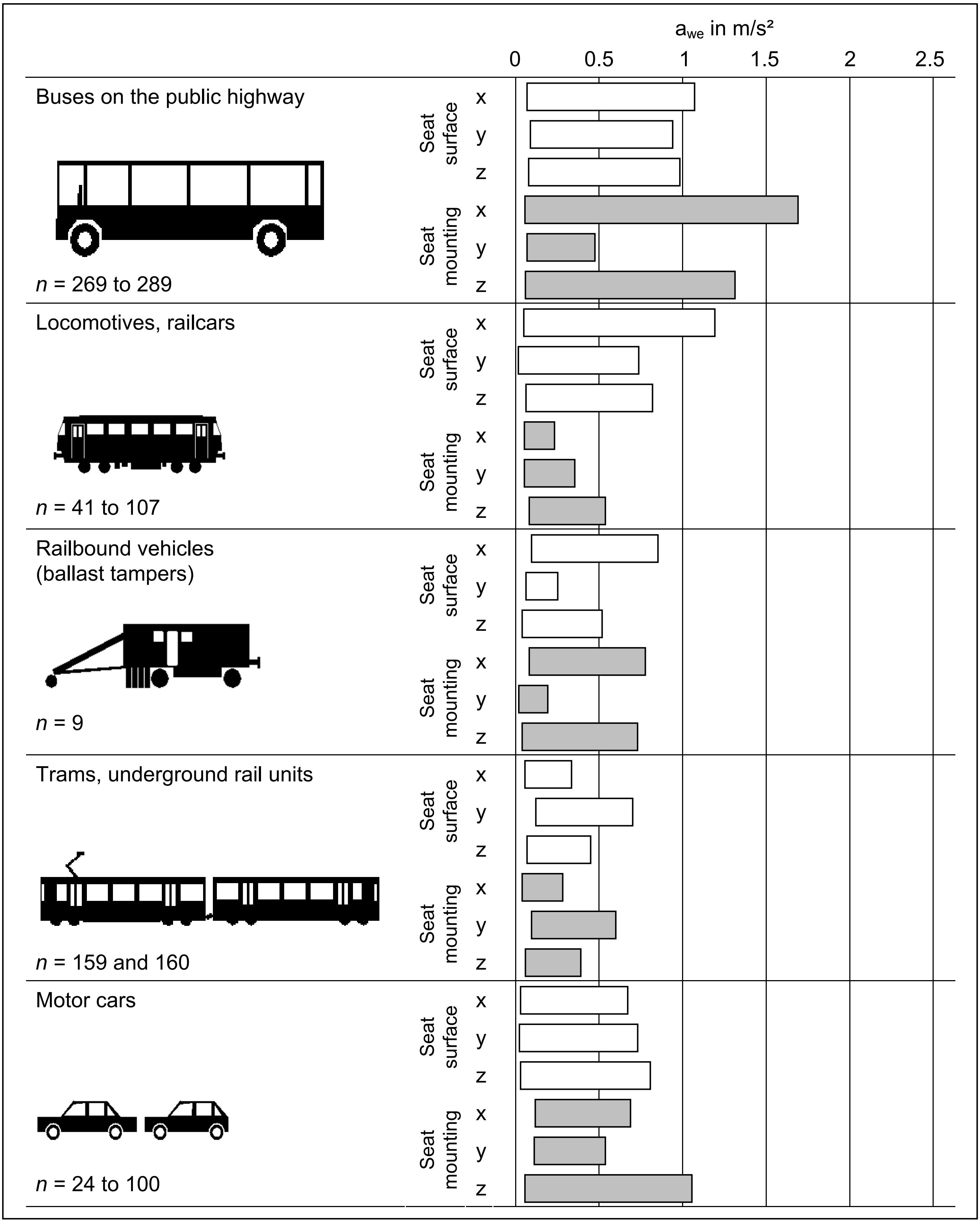
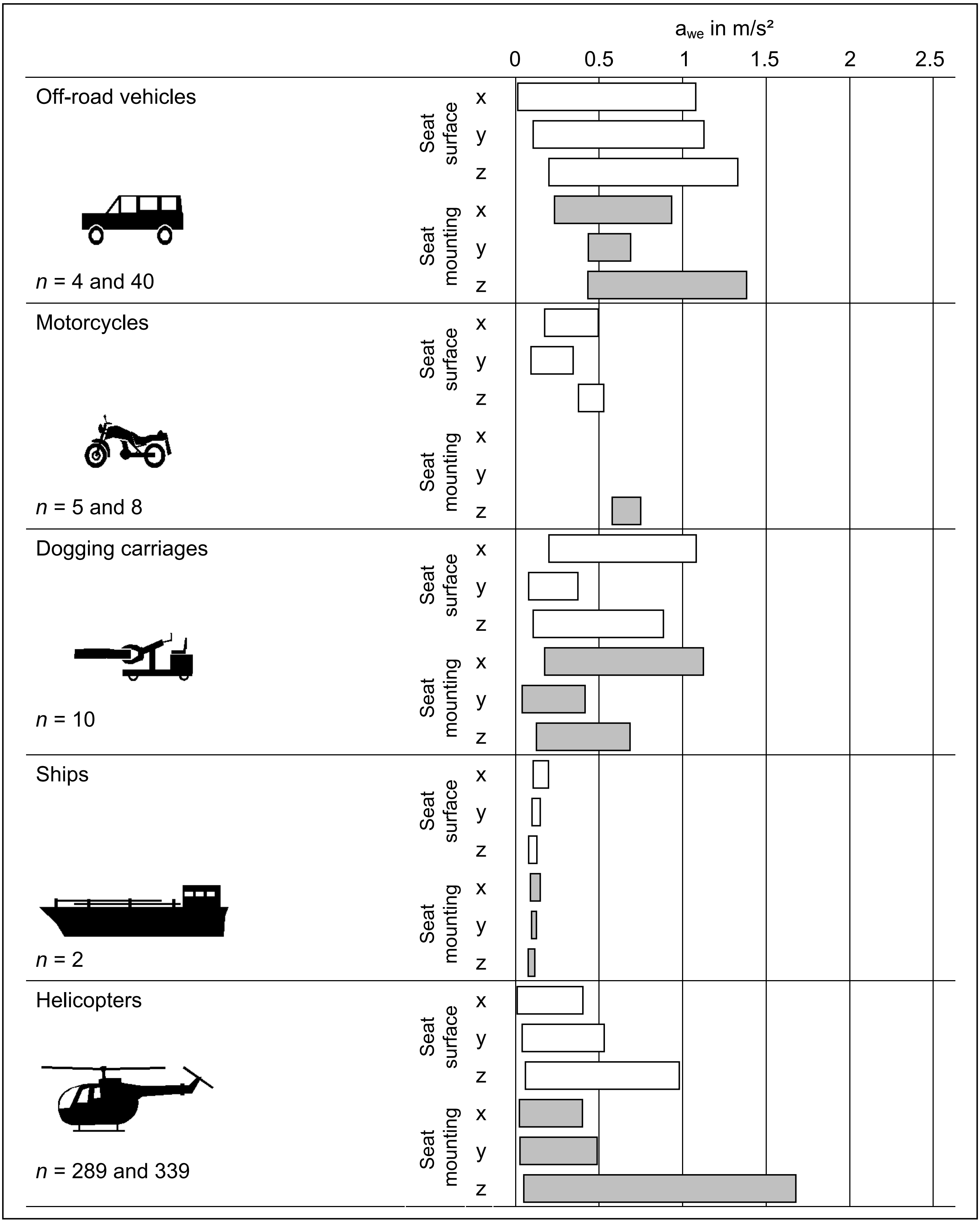


Table A2: continued



Annex 3:
SEAT values

Table A3:
SEAT values for vehicles (in alphabetical order)

Vehicle	SEAT	*n*
Aircraft pushback tractors	0.99	13
Articulated vehicles on construction sites	1.03	60
Articulated vehicles on the public highway	0.86	141
Back-hoe loaders	0.82	11
Bridge/gantry/tower cranes	0.94	59
Buses on the public highway	0.84	269
Cable excavators	1.03	24
Compact loaders	0.85	11
Dogging carriages	1.06	10
Dump trucks	0.98	34
Elevating platform transporters	1.05	13
Fork-lift trucks, rough-terrain fork-lift trucks, sideloaders	0.86	272
Goods vehicles on construction sites	0.69	6
Goods vehicles on the public highway	0.95	361
Graders	1.07	22
Helicopters	0.78	289
Hydraulic excavators	0.87	108
Light goods vehicles on the public highway	0.90	210
Locomotives, railcars	1.01	41
Motor cars	0.89	24
Motorcycles	0.65	5
Mowers	0.91	6
Narrow-track tractors	0.69	15
Off-road vehicles	1.00	4
Pavers	0.41	1
Railbound vehicles	0.74	9
Reach fork-lift trucks, high-rack stackers, four-directional lift trucks	0.74	54
Road millers	0.87	21

Table A3: continued

Vehicle	SEAT	*n*
Road-rollers	0.63	19
Roadsweepers	0.94	18
Scraper dozers	0.66	4
Scrapers	1.17	5
Snow-cats, snow-groomers	0.77	26
Soil and landfill compactors	0.81	12
Straddle carriers	0.87	20
Towing and pushback tractors	0.98	20
Tracked bulldozers, tracked loaders	0.72	27
Tractors for agriculture and forestry	0.85	17
Trams and underground rail units	1.10	159
Truck cranes	1.02	17
Unimogs	0.88	37
Wheel loaders	0.87	62