8. TERMS, DEFINITIONS AND EQUATIONS

1. Displacement: A vector quantity that specifies the change of position of an object or part of it with respect to a reference frame (in metre, m).
   Usually displacement is determined in three specified axes.

2. Velocity: A vector quantity that specifies the rate of change of displacement (in ms^{-1}).
   Usually velocity is determined in three specified axes.

3. Acceleration: A vector quantity that specifies the rate of change of velocity (in ms^{-2}).
   Usually acceleration is determined in three specified axes.

4. Sinusoidal function: A function that is a sinus as a function of time. It is specified by

$$y(t) = A \sin (2\pi f t + \phi)$$

in which:

A	amplitude;
t	time in s;
f	frequency in Hertz;
ϕ	phase angle.

5. Equations for sinusoidal motion: For sinusoidal motion, the relations between acceleration, velocity and displacement are as follows. Let the acceleration be:

$$a(t) = A \sin 2\pi f t \qquad (\phi = 0 \text{ at } t = 0).\ [ms^{-2}]$$

$$\textit{velocity } v(t) = -\frac{A}{2\pi f} \cos 2\pi f t \quad [ms^{-1}]$$

$$\textit{displacement } x(t) = -\frac{A}{(2\pi f)^2} \sin 2\pi f t \ [m]$$

6. Root-mean-square value (r.m.s.): The r.m.s. value of a function, x(t), over a time interval between t_1 and t_2 is specified by the following formula:

$$x_{r.m.s.} = \frac{1}{t_2-t_1}[\int_{t_1}^{t_2} x^2(t)dt]^{½}$$

7. Root-mean-quad value (r.m.q.): The r.m.q. value of a function, x(t), over a time interval between t_1 and t_2 is specified by the following formula:

$$x_{r.m.q.} = \frac{1}{t_2-t_1}[\int_{t_1}^{t_2} x^4(t)dt]^{¼}$$

8. Peak value: The maximum value of a function during a given time interval. The peak value is usually taken as the maximum deviation from the mean value; the positive peak value is the maximum positive deviation and the negative peak value is the maximum negative deviation. For sinusoidal motion, the peak value is equal to the amplitude.

9. Equations for sinusoidal motion: For sinusoidal motion, the following equations apply:

$$a_{r.m.s.} = \frac{A}{\sqrt{2}} \quad [ms^{-2}],$$

where a r.m.s. is the r.m.s. value of the acceleration and A the amplitude of the acceleration. (Similar equations hold also for velocity and displacement).

$$a_{r.m.q.} = (3/8)^{¼}A \quad [ms^{-1.75}]$$

where $a_{r.m.q.}$ is the r.m.q. value of the acceleration.

Therefore:

$$a_{r.m.q.} = (3/8)^{1/4} \, (2)^{1/2} \, a_{r.m.s.}$$

$$a_{r.m.q.} \approx 1.107 \, a_{r.m.s.}$$

with $a_{r.m.q}$ in $ms^{-1.75}$ and $a_{r.m.s.}$ in ms^{-2}.

10 Frequency weighting: A transfer function used to modify a signal according to a required dependency on frequency.

11. Crest factor: The ratio of the peak value to the r.m.s. value of a function over a specified time interval. (In many applications the function is frequency-weighted prior to the formation of the ratio). For a sinusoidal function the crest factor is √2. For broadband random noise the crest factor is about 4.

12. Vibration acceleration level (L_a): The vibration acceleration level is a logarithmic measure of acceleration magnitude, specified by:

$$L_a = 20 \log \left(\frac{a}{a_o}\right) \; [dB]$$

in which:

a_o the reference acceleration value specified in ISO 1683 (1983) as 10^{-6} ms^{-2}. Also other reference acceleration values are in use.

13. Vibration velocity level: The vibration velocity level (L_v) is a logarithmic measure of velocity magnitude, specified by:

$$L_v = 20 \log \left(\frac{v}{v_o}\right) \quad [dB]$$

in which:

v_o the reference velocity value, specified in ISO 1683 (1983) as 10^{-9} ms^{-1}. Also other reference velocity values are in use, such as 5.10^{-8} ms^{-1}.

Usually the vibration acceleration level and vibration velocity level do not refer to the same vibration magnitude. For sinusoidal motion, these levels are equal only if $2\pi f = 10^3$ (f is equal to 159.16 Hz), since for sinusoidal motion:

$$L_a = L_v + 20 \log (2\pi f \times 10^{-3}) \quad [dB]$$

14. Vibration dose value (VDV): A cumulative measure of vibration received by a person during a specified period. The VDV is specified by:

$$VDV = \left[\int_{t=0}^{t=T} a_w^4(t)dt\right]^{1/4} \quad [ms^{-1.75}]$$

in which:

a_w (t) the frequency-weighted acceleration in ms^{-2};

t time in seconds;

T the period over which VDV is determined.

15. Estimated vibration dose value (eVDV): A cumulative measure of vibration received by a person during a specified period; e VDV is defined by

$$eVDV = 1.4\ a_{r.m.s.}\ T^{1/4} \qquad [\ ms^{-1.75}]$$

in which:

T the period over which eVDV is determined;

$a_{r.m.s.}$ the frequency-weighted r.m.s. acceleration value in ms^{-2}.

For environmental vibrations (e.g.: from railway and road traffic) with crest factors not exceeding about 6, eVDV is about equal to VDV. VDV is overestimated by eVDV for sinusoidal motion and underestimated by eVDV for motions with high crest factors (for sinusoidal motion $VDV \approx 1.107\ a_{r.m.s.}\ T^{1/4}$ and $eVDV = 1.4\ a_{r.m.s.}\ T^{1/4}$).

16. Acceleration of gravity(g): The acceleration produced by the force of gravity at the surface of the earth, standardized at 9.80665 ms^{-2}.

17. Periodic vibration: A vibration whose values recur for equal increments of time. The fundamental period is the smallest increment of time for which the function repeats itself.

18. Quasi-periodic vibration: A vibration which deviates only slightly from a periodic vibration.

19. Random vibrations: A vibration whose magnitude cannot be predicted precisely for any given instant of time.

20. Broad-band random vibration: Random vibration having its frequency components distributed over a broad frequency range (e.g. one octave or greater).

21. Steady-state vibration: A steady-state vibration exists if the vibration is a continuing periodic vibration.

22. Transient: A phenomenon that occurs during the change of a system from one steady state to another.

23. Shock motion: A transient motion resulting from a shock excitation. Mechanical shock exists when a force or acceleration is suddenly changed so as to excite transient disturbances in a system.

24. Impulsive vibration: Vibration consisting of rapidly repeated mechanical shocks.

25. Time-constant: The time taken by an exponentially decaying quantity to decrease in magnitude by a factor of 1/e (= 0.3679....).

26. Vibration KB-value: The value of a vibration at time t defined by:

$$KB_\tau(t) = [\frac{1}{\tau} \int_{x=o}^{t} e^{-(t-x)/\tau} \, KB^2(x)dx]^{½}$$

in which:

KB(x) the frequency-weighted vibration velocity at time x;

τ time-constant.

27. Vibration maximum KB-value (KB_{Fmax}): the maximum KB-value occurring during a specified period, with the KB-value determined with time constant τ equal to 0.125 s.

28. Vibration KB_{FTi}-value: the KB_{Fmax}-value occurring during a period T_i of 30 s. To that end the observation period is divided into periods T_i of 30 s, i indicating the i-th 30 s period.

29. Vibration effective KB_{Fmax} value (KB_{FTM}): the value specified by:

$$KB_{FTM} = [\frac{1}{N} \sum_{i=1}^{N} KB_{FTi}^2]^{1/2}$$

in which:

N number of periods during the total observation period.

30 Sound: a phenomenon with alternating compression and expansion of air which propagate from a noise source in all directions. At a given location these compressions and expansions represent pressure variations around atmospheric pressure. The pressure variations of a pure tone are described mathematically as a sinusoidal function of time.

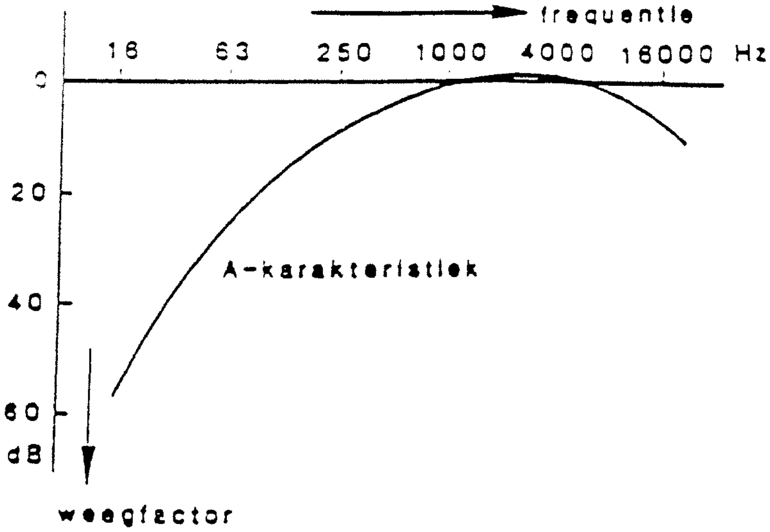
31 Frequency of a sound: the number of pressure variations per second is the frequency of a sound and is expressed in hertz (Hz). The frequency determines the pitch of a sound: a high pitched one (e.g. 4000 Hz) has a squeaking sound, a low pitched tone (e.g. 200 Hz) a humming sound.

32 Sound pressure level: a sound has not only a frequency, but also a level (L). The level is related to the sound pressure (p). In practice, sound pressures range from less than 20 Pa up to more than 200 Pa, a range of 1 to 10 million. Therefore, in acoustics, the logarithm of the sound pressure relative to a reference sound pressure (p_o) is usually taken as a basis for the noise measure. A reference sound pressure of 20 Pa was chosen. It usually represents an average tone just audible at 1000 Hz for someone with normal hearing. The sound pressure level is expressed in decibels (dB) and can be calculated from:

$$L = 10\log\frac{p^2}{p_o^2} \quad dB \ (p_0 = 20\mu Pa)$$

33 Sound level: the human hearing organ is not equally sensitive to sounds with the same sound pressure level but with different frequencies. Therefore, to take this sensitivity into account, it is common practice when noise is measured, to use a noise filter which rates the sound pressure levels at the different frequencies. There are several noise filters with a so-called A, B, C or D characteristic. In figure A1 the A-characteristic is plotted as a function of frequency. When the sound pressure levels of a sound are measured, using the A-filter, the result is the A-weighted sound pressure level. In this report the A-weighted sound pressure level is shortly indicated by sound level.

Figure 8.1 Frequency weighting of noise.



34 Equivalent sound level: When the sound level fluctuates with time, the equivalent sound level over a period of time is determined for a number of acoustic applications. This equivalent sound level can be expressed as follows:

$$L_{Aeq,T}=10\log\frac{1}{T}\int_0^T\frac{p_A^2(t)}{p_0^2}dt \quad dB(A)$$

in which:

. p_A (t): the A-weighted sound pressure at time t

. T: duration of the period considered.

35 Equivalent sound level over 24 hours ($L_{Aeq,24h}$): The equivalent sound level over 24 hours is the equivalent sound level due to an exposure of 24 consecutive hours.

36 Day-night level (L_{dn}):

$$L_{dn}=10\log[\frac{15}{24}\ 10^{L_{Aeq,d}/10}+\frac{9}{24}10^{(10+L_{Aeq,n})/10}]\quad dB(A)$$

in which:

- d (day-time) is the period from 07.00-22.00 h
- n (night-time) is the period from 22.00-07.00 h

The day-night level is the equivalent sound level over 24 hours, with the sound levels during the night increased by 10 dB(A).

37 Day-evening-night level (L_{den}):

$$L_{den}=10\log[\frac{12}{24}10^{L_{Aeq,d}/10}+\frac{3}{24}10^{(5+L_{Aeq,ev})/10}+\frac{9}{24}10^{(10+L_{Aeq,n})/10}]\quad dB(A)$$

in which:

- d(day-time) is the period from 0700-19.00 h
- ev(evening) is the period from 19.00-22.00 h
- n(night-time) is the period from 22.00-07.00 h

The day-evening-night level is the equivalent sound level over 24 hours, with the sound levels during the evening increased by 5 dB(A) and during the night by 10 dB(A).

38 Etmaalwaarde (24-hours value):

$$L_{etm}=\max(L_{Aeq,d}\ ,\ L_{Aeq,ev}+5,\ L_{Aeq,n}+10)\quad dB(A)$$

in which:

- d(day-time) is the period from 0700-19.00 h
- ev(evening-time) is the period from 19.00-23.00 h
- n(night-time) is the period from 23.00-07.00 h

The etmaalwaarde ('24-hour value') is the maximum of one of three equivalent sound levels during certain parts of the 24-hour period, with the sound levels during the night increased by 10 dB(A) and those during the evening by 5 dB(A).

39 <u>Sound exposure level of a noise event</u>:

$$\mathbf{SEL = L_{Aeq,t} + 10 \log t \quad dB(A)}$$

in which:

t is the exposure time in seconds.

40 <u>Effective duration of a noise event</u>:

The effective duration is specified in the following equation:

$$\mathbf{SEL = L_{A,max} + 10 \log \tau \quad dB(A)}$$

in which:

. τ is the effective duration in seconds.

REFERENCES

ALLEN DL, SWALLOW JC. Annoying floor vibrations: diagnosis and therapy. Sound Vibr 1975;-(3):12-7.

ANSI (American National Standard Institute) American National Standard Guide to the evaluation of human exposure to vibration in buildings. New York: ANSI, 1983. S3.29-1983.

ARNBERG PW, BENNERHULT O, EBERHARDT JL. Sleep disturbances caused by vibrations from heavy road traffic. J Acoust Soc Am 1990;88(3):1486-93.

BAUGHAN CJ, MARTIN DJ. Vibration nuisance from road traffic at fourteen residential areas. Crowthorne: TRRL, 1981. TRRL laboratory report 1020.

BAUGHAN CJ, HEDGES B, FIELD J. A national survey of lorry nuisance. Crowthorne: TRRL, 1983. TRRL supplementary report 774.

BERGLUND B, HASSMEN P, SOAMES JOB RF. Health effects of low-frequency noise. Proceedings 15th International Congress on Acoustics Trondheim, Norway 26-30 June 1995. Vol 2: 17-20.

BONGERS P, BOSHUIZEN HC, HULSHOF CTJ, KOEMEESTER AP. Gezondheidsklachten als gevolg van lichaamstrillingen bij het rijden op landbouwtrekkers en andere trillende voertuigen. Voorburg: DGA, 1989a. Studiereeks S 58-6.

BONGERS P, BOSHUIZEN HC, HULSHOF CTJ, KOEMEESTER AP. Expositie aan trillingen en schokken en de WAO. Voorburg: DGA, 1989b. Studiereeks S 82.

BONGERS P, BOSHUIZEN HC, HULSHOF CTJ. Langdurig ziekteverzuim en WAO-toetreding en expositie aan trillingen en schokken bij landbouwtrekkerbestuurders. Voorburg: DGA, 1989c. ICG Rapport LA-DR-10-12.

BONGERS P, BOSHUIZEN H. Back disorders and whole-body vibration at work. Proefschrift Universiteit van Amsterdam, 1991.

BONGERS PM, HULSHOF CTJ, BOSHUIZEN HC. Normen voor het meten en beoordelen van lichaamstrillingen. T Toegepaste Arbowetenschappen 1992;5(1):210.

BRADLEY JS, JONAH BA. The effects of site selected variables on human responses to traffic noise. Part I: type of housing by traffic noise level. J Sound Vib 1979a;66(4)589-604.

BRADLEY JS, JONAH BA. The effects of site selected variables on human responses to traffic noise. Part II: road type by socio-economic status by traffic noise level. J Sound Vib 1979b;67(3)3-95-407.

BRADLEY JS, JONAH BA. The effects of site selected variables on human responses to traffic noise. Part III: community size by socio-economic status by traffic noise level. J Sound Vib 1979c-;67(3)409-423.

BREDERODE PJ van. Invloed verkeerstrillingen op gebouwen. Leidschendam, Ministerie VROM, 1987. ICG-rapport nr. GF-DR-05-01.

BSI (British Standard Institute). British Standard guide to measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock. London: BSI, 1987. BS 6841: 1987.

BSI. British Standard guide to evaluation of human exposure to vibration in buildings (1 to 80 Hz). London: BSI, 1992. BS 6472:1992.

CAWTHORN JM, DEMPSEY TK, DELOACH R. Human response to aircraft-noise-induced building vibration. Helicopter Acoustics, Noise Conference publication 2052, 1978.

CHRIST E, KAULBARS U. Schwingungseinwirkung an Arbeitsplätzen von Kraftfahrern auf Nutzfahrzeugen: Vorstudie zur Pfüfung und Auswahl von Führersitzen. Sankt Augustin: BIA, 1986. Rapport 3/86.

CLARKE MJ. A study on the available evidence on duration effects on comfort and task profciency under vibration. J Sound & Vibr 1979;65(2):107-23.

COERMANN RR. The mechanical impedance of the human body in sitting and standing position at low frequencies. Human Factors 1962;4:227-53.

CORBRIDGE C, GRIFFIN MJ. Vibration and comfort: vertical and lateral motion in the range 0.5 to 5.0 Hz. Ergonomics 1986;29(2):249-72.

DAWN TM. The wayside vibration from trains. Proceedings of the Institute of Acoustics, 1989 Spring Conference, 1989;11(5):111-9.

DEMIC M. A definition of influence of quasi-random and repeated shock vibrations on human fatigue. Int J Vehicle Design 1992;13(5/6):475-85.

DIN (Deutsches Institut für Normung). DIN 4150, Teil 2, 1992. Erschütterungen im Bauwesen Einwirkungen auf Menschen in Gebäuden. Berlin: DIN, 1992.

DIECKMANN DD. A study of the influence of vibration on man. Ergonomics 1958a;1:347-55.

DIECKMANN DD. Einfluss horizontaler mechanischer Schwingungen auf den Menschen. Int Z Angew Physiol einschl Arbeitsphysiol 1958b;17:83-100.

DONATI P, GROSJEAN A, MISTROT P, ROURE L. The subjective equivalence of sinusoidal and random whole-body vibration in the sitting position. Ergonomics 1983;26(3):251-73.

DRIMMELEN D van. Trillen en schokken tijdens het werk. T Soc Gezondh 1983;61(8):275-6.

DRIMMELEN D van, VOS H. De invloed van trillen en schokken tijdens het werk op het vrouwelijk lichaam. T Soc Gezondh 1983;61(8):276-8.

DUISIT R. Rapport de l'etude sur la gene causee aux riverains par les vibrations engendrees par le trafic routier. Bron, IRT/CERN, 1978.

DUPUIS H, HARTUNG E, LOUDA L. Vergleich regelloser Schwingungen eines begrenzten Frequenzbereiches mit sinusformigen Schwingungen hinsichtlich der Einwirkung auf den Menschen. Ergonomics 1972;15(3):237-65.

DUPUIS H, ZERLETT G. Beanspruchung des Menschen durch mechanische Schwingungen. Bonn: Hauptverband der gewerblichen Berufsgenossenschaften e.V., 1984.

FIELDS JM. Railway noise and vibration annoyance in residential areas. J Sound Vibr 1979;66(3):-445-58.

FIELDS JM, WALKER JG. The response to railway noise in residential areas in Great Britain. J Sound Vibr 1982;85(2):177-255.

FINDEIS H. Zur Bewertung von Vibrationsimmissionen in Wohnungen. Z Ges Hyg 1980;26(9):6-55-60.

FLEMING DB, GRIFFIN MJ. A study of the subjective equivalence of noise and whole-body vibration. J Sound Vibr 1975;42(4):452-61.

FOTHERGILL LC, GRIFFIN MJ. The use of an intensity matching technique to evaluate human response to whole-body vibration. Ergonomics 1977a;20(3):249-61.

FOTHERGILL LC, GRIFFIN MJ. The evaluation of discomfort produced by multiple frequency whole-body vibration. Ergonomics 1977b;20(3):263-76.

FOTHERGILL LC, GRIFFIN MJ. The subjective magnitude of whole-body vibration. Ergonomics 1977c;20(5):521-33.

FRANCKEN AJ. Trillinghinder: een literatuurstudie. Leidschendam: Ministerie VROM, 1981. ICG Rapport IL-HR-12-01.

FüRST P. Eine Einfürung in die Probleme der Vibrationsimmissionen im kommunalen Bereich. Z ges Hyg 1979;25(2):175-9.

GIERKE HE von. Response of the body to mechanical forces: an overview. Ohio: American Medical Research Laboratories,1966. Report AMRL-TR-66-251.

GRETHER WF. Vibration and human performance. Human Factors 1971;13(3):203-16.

GRIFFIN MJ. A survey of human response to vibration research in Great Britain. Southampton: ISVR, 1973. Technical report 60.

GRIFFIN MJ. Vertical vibration of seated subjects: effects of posture, vibration level, and frequency. Aviation, Space Env Med 1975a;46:269-76.

GRIFFIN MJ. Levels of whole-body vibration affecting human vision. Aviation, Space Env Med 1975b;46:1033-40.

GRIFFIN MJ. Eye motion and whole-body vertical vibration. Human Factors 1976a;18(6):601-6.

GRIFFIN MJ. Subjective equivalence of sinusoidal and random whole-body vibration. J Acoust Soc Am 1976b;60(5):1140-5.

GRIFFIN MJ. Methods of predicting community response to building vibration. Control of odours and noise in the process industries - 1978.

GRIFFIN MJ. The prediction of community response to building vibration. Proceedings of the Institute of Acoustics. Paper presented at the Spring Conference 1979 held at Southampton.

GRIFFIN MJ. Evaluation of vibration with respect to human response. Warrendale: SAE, 1986. SAE Technical Papers 860047.

GRIFFIN MJ. International Standard 2631 and British Standard 6841: a comparison of two guides to the measurement and evaluation of human response to whole-body vibration and repeated shock. Paper presented at the United Kingdom and French Joint Meeting on Human Response to Vibration, held at INRS, Vandoeuvre, 26-28 September 1988.

GRIFFIN MJ. Handbook of Human Vibration. London (etc.): Academic Press, 1990.

GRIFFIN MJ, LEWIS CH. Review of the effects of vibration on visual acuity and continuous manual control, part I: visual acuity. J Sound & Vibr 1978;56(3):383-413.

GRIFFIN MJ, STANWORTH CG. The generation and perception of vibration from rail traffic. Paper presented at the Conference of the Institute of Civil Engineers, University of Nottingham, 11-13 July 1984.

GRIFFIN MJ, WHITMAN EM. Duration of whole-body vibration exposure: its effect on comfort. J Sound & Vibr 1976;44(3):333-9.

GRIFFIN MJ, WHITMAN EM. Assessing the discomfort of dual-axis whole-body vibration. J Sound & Vibr 1977;54(1):107-16.

GRIFFIN MJ, WHITHAM EM. Individual variability and its effect on the subjective and biodynamic response to whole-body vibration. J Sound & Vibr 1978;58(2):239-50.

GRIFFIN MJ, WHITMAN EM. Discomfort produced by impulsive whole-body vibration. J Acoust Soc Am 1980a;68(5):1277-84.

GRIFFIN MJ, WHITHAM EM. Time dependency of whole-body vibration discomfort. J Acoust Soc Am 1980b;68(5):1522-3.

GUNDRY AJ. Thresholds of perception for periodic linear motion. Aviation, Space Env Med 1978;49(5):679-86.

HEIJNEN GWJ. Basisdocument Trillingen veroorzaakt door treinverkeer. Utrecht: NS, Centrum voor Technisch Onderzoek, 1990. Rapport CTO/6/10.009/074.

HEIJNEN GWJ. Overzicht van door NS uitgevoerde onderzoeken van trillingen in woningen, veroorzaakt door treinverkeer, met beschouwingen ten aanzien van overdrachten, schade en hinder gerelareerd aan DIN 4150. Utrecht, NS Centrum voor Technisch Onderzoek, 1992. Rapport CTO/6-/10.009/0011.

HEMPSTOCK TI, SAUNDERS DJ. Subjective response to mixed noise and vibration environments.

HIRAMATSU K, GRIFFIN MJ. Predicting the subjective response to nonsteady vibration based on the summation of subjective magnitude. J Acoust Soc Am 1984;76(4):1080-9.

HOFFER F. Hinder en schade ten gevolge van verkeerstrillingen. Delft: TU Delft, Wetenschapswinkel, 1990.

HOOD RA, GREER RJ, BRESLIN M WILLIAMS PR. The calculation and assessment of ground-borne noise and perceptible vibration from trains in tunnels. Paper presented at the fifth international workshop on railway and transit system noise. Voss, 1995:3.5.1-14.

HOWARTH HVC. A study of the relative importance of noise and vibration from railways. Paper presented at the United Kingdom Informal Group Meeting on Human Response to Vibration, Derby, September 1985.

HOWARTH HVC. A review of experimental investigations of the time dependency of subjective reaction to whole-body vibration. Paper presented at the United Kingdom Informal Group Meeting on Human Response to Vibration, September, 1986, University of Technology, Loughborough.

HOWARTH HVC, GRIFFIN MJ. The frequency dependence of subjective reaction to vertical and horizontal whole-body vibration at low magnitudes. J Acoust Soc Am 1988a;83(4):1406-13.

HOWARTH HVC, GRIFFIN MJ. Human response to simulated intermittent railway-induced building vibration. J Sound & Vibr 1988b;120(2):413-20.

HOWARTH HVC, GRIFFIN MJ. The relative importance of noise and vibration from railways. Appl Ergonomics 1990a;21(2):129-34.

HOWARTH HVC, GRIFFIN MJ. Subjective response to combined noise and vibration: summation and interaction effects. J Sound & Vibr 1990b;143(3):443-54.

HOWARTH HVC, GRIFFIN MJ. The annoyance caused by simultaneous noise and vibration from railways. J Acoust Soc Am 1991;89(5):2317-23.

HULSHOF CTJ, VELDHUYZEN van ZANTEN OBA. Gezondheidseffecten van langdurige blootstelling aan lichaamstrillingen tijdens arbeid. Voorburg: Ministerie SoZa, 1986. ICG-rapport LA-DR-10-02.

ISO (International Organization for Standardization). Evaluation of human exposure to whole-body vibration - Part 1: General requirements. 1st ed. Geneve, ISO, 1985. ISO 2631/1-1985(E). Eveneens verschenen als Nederlandse Norm NEN-ISO 2631/1.

ISO. Evaluation of human exposure to whole-body vibration - Part 2: Continuous and shock-induced vibration in buildings (1 to 80 Hz). 1st. ed. Geneve: ISO, 1989. ISO 2631/2-1989 (E) Eveneens verschenen als Nederlandse Norm NEN-ISO 2631/2.

ISO. Evaluation of human exposure to whole-body vibration - Part 3: Evaluation of exposure to whole-body z-axis vertical vibration in the frequency range 0,1 to 0,63 Hz. 1st ed. Geneve: ISO, 1985. ISO 2631/3-1985(E). Eveneens verschenen als Nederlandse Norm NEN-ISO 2631/3.

ISO. Mechanical vibration and shock - Vibration of buildings - Guidelines for the measurement of vibrations and evaluation of their effects on buildings. 1st ed. Geneve, ISO, 1990. ISO 4866-1990(-E). Eveneens verschenen als Nederlandse Norm NEN-ISO 4866.

JEANS MJF. Environmental effects of lorries. J Inst Highway Engineers 1983;(3):14-9.

JONES AJ, SAUNDERS DJ. Equal comfort contours for whole-body vertical, pulsed sinusoidal vibration. J Sound Vibr 1972;23(1):1-14.

JONES AJ, SAUNDERS DJ. A scale of human reaction to whole-body, vertical, sinusoidal vibration. J Sound & Vibr 1974;35(4):503-20.

JONES RRK, WATERS DM. Traffic noise annoyance near light controlled intersections. Appl Acoustics 1981;14:7-13.

JONG RG de. Psychomedische effecten van trillingen in de woning. Lezing ten behoeve van de Stichting Bouwresearch, gehouden op 3 maart 1993 te Rotterdam.

JONG GR de, OPMEER CHJM, MIEDEMA HME. Hinder door milieuverontreiniging in Nederland. Effecten van geluid, geur, trillingen, stof, verlichting en onveiligheid, peiling 1993. Leiden: TNO-PG, 1994. TNO-PG Publ.nr. 94.056.

JUTULSTAD H. Challenges on the issues of noise and vibrations during realisation of a new railway connection. Paper presented at the fifth international workshop on railway and transit system noise. Voss, 1995:6.4.1-6.

KJELLBERG A, WIKSTRöM B-O. Whole-body vibration: exposure time and acute effects: a review. Ergonomics 1985a;28(3):535-44.

KJELLBERG A, WIKSTRöM B-O. Subjective reactions to whole-body vibration of short duration. Ergonomics 1985b;28(3):415-424.

KJELLBERG A, WIKSTRöM B-O, DIMBERG U. Whole-body vibration: exposure time and acute effects: experimental assessment of discomfort. Ergonomics 1985;28(3):545-54.

KLEIN W, GRAAF de W. Inventarisatie van het optreden van trillinghinder veroorzaakt door inrichtingen: een verkennende enquete onder gemeenten. Leidschendam: Ministerie VROM, 1981. ICG Rapport IL-HR-05-01.

KNALL V. Railway noise and vibration. Fifth International workshop on railway and tracked transit system noise, Voss: June 1995.

KUPPELWIESER H. Tool for predicting vibration and structure borne noise immissions caused by railways. Fifth International Workshop on railway and tracked transit system noise. Voss: June 1995, 4.3.1-9.

LANGDON FJ. Noise nuisance caused by road traffic in residential areas: part I. J of Sound and Vibration 1976a;47(2):243-63.

LANGDON FJ. Noise nuisance caused by road traffic in residential areas: part II. J of Sound and Vibration 1976b;47(2):265-82.

LANGDON FJ. Noise nuisance caused by road traffic in residential areas: part III. J of Sound and Vibration 1976c;49(2):241-56.

LEATHERWOOD JD. Human discomfort response to noise combined with vertical vibration. ...., 1979: NASA Technical paper 1374.

LEVENTHALL HG. Annoyance caused by low frequency/low level noise. In: Mϕller H, Rubak P, eds. Conference on Low Frequency Noise and Hearing, Aalborg, May 1980:113-20.

LEWIS CH. Frequency weighting procedures for the evaluation of human response to vibration. Paper presented at the United Kingdom Informal Group Meeting on Human Response to Vibration, 17-19 September 1985 in Derby.

LOUDA L. Perception and effect of the mixture of two vertical sinusoidal vibrations on sitting man. Work Env Health 1970;7(1):62-6.

MANNINEN O. Further studies on changes in subjective stressfulness under various combinations of noise, vibration, temperature and work tasks. Arch Complex Env Studies 1990;2(2):31-39.

MELONI T, KRUEGER H. Wahrnehmung und Empfindung von kombinierten Belastungen durch Lärm und Vibration. Z Lärmbekämpfung 1990;37:170-5.

MIEDEMA HME. Response functions for environmental noise in residential areas. Leiden: NIPG-TNO, 1992. Publ.nr. 92.021.

MIEDEMA HME. Geluidmaten voor vliegverkeer. Leiden: NIPG-TNO, 1993. Publ.nr.93.085.

MIEDEMA HME, JONG RG de. Het aandeel van goederentransport in het treinverkeer en effecten van geluid en trillingen op omwonenden. Leiden: NIPG-TNO, 1993. Publ.nr.93.013.

MIWA T. Evaluation methods for vibration effect. Part 1: Measurements of threshold and equal sensation contours of whole body for vertical and horizontal vibrations. Ind Health 1967a;5:183-205.

MIWA T. Evaluation methods for vibration effect. Part 2: Measurement of equal sensation level for whole body between vertical and horizontal sinusoidal vibrations. Ind Health 1967b;5:206-12.

MIWA T. Evaluation methods for vibration effect. Part 4: Measurement of vibration greatness for whole body and hand in vertical and horizontal vibrations. Ind Health 1968a;6:1-10.

MIWA T. Evaluation methods for vibration effect. Part 5: Calculation method of vibration greatness level on compound vibrations. Ind Health 1968b;6:11-7.

MIWA T. Evaluation methods for vibration effect. Part 6: Measurements of unpleasant and tolerance limits for sinusoidal vibrations. Ind Health 1968c;6:18-27.

MIWA T. Evaluation methods for vibration effect. Part 7: The vibration greatness of the pulses. Ind Health 1968d;6:143-64.

MIWA T. Evaluation methods for vibration effect. Part 8: The vibration greatness of random waves. Ind Health 1969a;7:89-115.

MIWA T. Evaluation methods for vibration effect. Part 9: Response to sinusoidal vibration at lying posture. Ind Health 1969b;7:116-26.

MUSSON Y, BURDORF A, DRIMMELEN D van. Trillen en schokken tijdens het werk "gezondheidsklachtenonderzoek". Lichaamstrillingen. Voorburg: DGA, 1989. Studiereeks S 58-4.

NAKAMURA H, NOHARA S, NAKAMURA H, et al.. Field study on subjective responses to noise and vibration. Arch Complex Env Studies 1990;2(3):25-32.

NELSON CM. Measurement and analysis techniques for the evaluation of human exposure to vibration. Proceedings of the Institute of Acoustics, 1989 Spring Conference, 1989;11(5):167-74.

NELSON PM. Transportation noise reference book. London (etc): Butterworth & Co, 1987.

OBORNE DJ. Whole-body vibration and International Standard ISO 2631: a critique. Human Factors 1983;25(1):55-69.

OBORNE DJ, BOARER P, HEATH TO. Variations in response to whole-body vibration intensity dependent effects. Ergonomics 1981;24(7):523-30.

OBORNE DJ, CLARKE MJ. The determination of equal comfort zones for whole-body vibration. Ergonomics 1974;17(6):769-82.

OBORNE DJ, HUMPHREYS DA. Individual variability in human response to whole-body vibration. Ergonomics 1976;19(6):719-26.

OHRSTRöM E, SKANBERG A-B. The effect of exposure to noise and vibrations from trains: field surveys in areas exposed to different number of trains and different levels of vibrations. In: Vallet M, ed. Proceedings 6th international congress on noise as a public health problem. Volume 2. Nice:INRETS, 1993:403-6.

OHRSTRöM E, SKANBERG A-B. A field survey on effects of exposure to noise and vibrations from railway traffic. Fifth International Workshop on railway and tracked transit system noise. Voss: June 1995.

OKADA A, YAMASHITA T, FUKUDA K. City vibration and its threshold limits. Env Research 1971;4:471-7.

OORTMAN GERLINGS P, DRIMMELEN D van, MUSSON Y. Trillingen en schokken op de arbeidsplaats. Inventarisatie van buitenlandse, internationale en bedrijfnormen. Voorburg: Ministerie SoZa, 1986. ICG-rapport LA-DR-10-01.

ORE Question D 151. Vibrations transmitted through the ground. Report no 4. Effect of vibration on buildings and their occupants: analysis of the literature and commentary. Utrecht: Office for Research and Experiments of the International Union of Railways, 1982. Report D 151/RP 4.

ORE Question D 151. Vibrations transmitted through the ground. Report no 5. Vibrationsproduced in buildings by train operations. Evaluation of test reports of various railways. Utrecht: Office for Research and Experiments of the International Union of Railways, 1983. Report D 151/RP 5.

PARSONS KC. Whole-body vibration perception thresholds of sitting, standing and lying subjects. Paper presented at the United Kingdom Informal Group Meeting, held at NIAE, Silsoe, September, 1983.

PARSONS KC, GRIFFIN MJ. Whole-body vibration perception thresholds. J Sound & Vibr 1988;-121(2):237-58.

PASSCHIER-VERMEER W. Geluid en gezondheid. Den Haag: Gezondheidsraad, 1993. Publikatie nr. A93/02 (in Dutch).

PASSCHIER-VERMEER W. Noise and Health. Den Haag: Gezondheidsraad, 1993. Publikatie nr. A93/02E.

PAULSEN R, KASTKA J. Effects of combined noise and vibration on annoyance. J Sound & Vibr 1995;181(2):295-314.

PERSSON K, RYLANDER R. Disturbance from low-frequency noise in the environment: a survey among the local environmental health authorities in Sweden. J of Sound and Vibration 1988: 121(-2):339-45.

PERSSON K, BJÖRKMAN M, RYLANDER R. An experimental evaluation of annoyance due to low frequency noise. J of Low Frequency Noise and Vibration 1985;4(4):145-153

RAMALINGESWARA P, VENKATESWARA K, SCINIVAS K, et al.. Subjective reaction to road traffic noise in the city of Visa-khapatnam. Indian J Environmental Protection 1990;10(11):852-5.

PERNICA G. Dynamic live loads at a rock concert. Can J Civl Eng 1983;10(2):185-91.

RONGEN E van. Hinder door trillingen. Den Haag: Gezondheidsraad, 1994. Rapport A94/03.

RUBLACK H. Wirkungen mechanischer Schwingungen auf den Organismus. Z ges Hyg 1978; 24(9):649-65.

SANDO FD, BATTY V. Road traffic and the environment. Central Stat Office Soc Trends 1974;5-:64-9.

SANDOVER J. Modelling human responses to vibration. Aviation, Space Env Med 1978;49:335-9.

SANDOVER J, PORTER CS, VLACHONIKOLIS IG. The effects of combinations of heat, noise and vibration on task performance. Arch Complex Env Studies 1990;2(1):1-9.

SATO T. The effect of vibration on noise annoyance: a survey on traffic noise and vibration in Sapporo. Env International 1990;16:561-6.

SCHOMER PD, AVERBUCH A. Indoor human response to blast sounds that generate rattles. J Acoust Soc Am 1989;86(2):665-73.

SCHOMER PD, NEATHAMMER RD. The role of helicopter noise-induced vibration and rattle in human response. J Acoust Soc Am 1987;81(4):966-76.

SCHÜMER-KOHRS A, SCHÜMER R, KNALL V, KASUBEK W. Interdisziplinäre Feldstudie über die Besonderheiten des Schienverkehrlärms gegenüber dem Strassenverkehrslärm. Vol I and II, München: Planningsburo Obermeyer, 1983.

SEIDEL H, BASTEK R, BRAUER CH et al.. On human response to prolonged repeated whole-body vibration. Ergonomics 1980;23(3):191-211.

SEIDEL H, ERDMANN U, BLüTHNER B et al.. Evaluation of simultaneous exposures to noise and whole-body vibration by magnitude estimation and cross-modality matching: an experimental study with professional drivers. Arch Complex Env Studies 1990;2(3):17-24.

SEIDEL H, HEIDE R. Long-term effects of whole-body vibration: a critical survey of the literature. Int Arch Occup Environ Health 1986;58:1-26.

SHOENBERGER RW. Intensity judgements of non-sinusoidal vibrations: support for the ISO weighting method. Aviation Space Env Med 1978:1327-30.

STAALDUINEN PC van, JONG RG de. Hinder ten gevolge van trillingen voor mensen in gebouwen. Delft: TNO-BOUW, 1991.rev 1993. Rapport B-91-0151.

STAALDUINEN PC van, VECHT J van der. Schade aan bouwwerken door trillingen. Meet- en beoordelingsrichtlijn. Rotterdam: Stichting Bouw Research, 1993a. Richtlijn 1.

STAALDUINEN PC van, VECHT J van der. Hinder voor personen in gebouwen door trillingen. Meet- en beoordelingsrichtlijn. Rotterdam: Stichting Bouw Research, 1993b. Richtlijn 2.

STAALDUINEN PC van, VECHT J van der. Storing aan apparatuur door trillingen. Meet- en beoordelingsrichtlijn. Rotterdam: Stichting Bouw Research, 1993c. Richtlijn 3.

STANWORTH CG. Literature references on ground vibration. Utrecht: Office for Research and Experiments of the International Union of Railways, 1984.

STEINHAUSER P. Qualitätskriterien für Schienenverkehrslärm und Erschütterungen bei Vollbahnen. Teil 2: Qualitätskriterien für Erschütterungs- und Körperschallimmissionen bei Vollbahnen. Wien: Bundesministerium für öffentliche Wirtschaft und Verkehr. Forschungsarbeiten aus dem Verkehrswesen, 1992. Band 36/2.

STEPHENS DG, LEATHERWOOD JD, CLEVENSON SA. The development of interior noise and vibration criteria. Arch Complex Env Studies 1990;2(3):9-16.

TöPFER K, FüRST P. Lärm- und Schwingungsbeeinflussung der Anwohner von Bahnanlagen. Z gesamte Hyg 1986;32(2):75-8.

TUKKER JC, WOLDE T ten. Voorlopige methode voor het meten van trillingsimmissie ten gevolge van railverkeer. ICG-rapport RL-HR-14-02. Den Haag: ICG, 1977a.

TUKKER JC, WOLDE T ten. Voorschrift voor het meten van de trillingemmissie door railvoertuigen. ICG-rapport RL-HR-14-01. Den Haag: ICG, 1977b.

VDI (Verein Deutscher Ingeniere). Einwirkungen mechanischer Schwingungen auf den Menschen. Blatt 1: Grundlagen, Gliederung, Begriffe. Blatt 2: Bewertung. Blatt 3: Beurteilung. Düsseldorf, VDI, 1987. VDI-Richtlinie 2057, 1987.

VREESWIJK A. Het beoordelen van trillingen vanwege milieuvergunningplichtige inrichtingen. Geluid 1993;(3):101-5.

WALKER JG, CHAN MKF. Human response to structurally radiated noise due to underground railway operations. Fifth International Workshop on railway and tracked transit system noise. Voss: June 1995, 1.6.1-9.

WATTS GR. Vibration nuisance from road traffic - results of a 50 site survey. Crowthorne, Transport and Road Research Laboratory, 1984. Laboratory Report 1119.

WATTS GR. Groundborne vibrations generated by HVGs: effect of vehicle, road and ground parameters. Proceedings of the Institute of Acoustics, 1989 Spring Conference, 1989;11(5):99-109.

WOODROOF HJ. Annoyance caused by railway-induced building vibration to residents living within 100 metres of railway lines in Scotland. Paper presented at the United Kingdom Informal Group Meeting on Human Response to Vibration, held in Derby, 1985.

WOODROOF HJ. Comparative annoyance from railway and building vibration. Proceedings of the Institute of Acoustics, 1989 Spring Conference, 1989;11(5):129-34.

WOODROOF HJ, GRIFFIN MJ. A survey of the effect of railway-induced building vibration on the community. Southampton: Institute Sound and Vibration Research, 1987. ISVR Technical Report 160.

WOODROOF HJ, STUART HVC. A description and evaluation of railway-induced building vibration. Paper presented at the United Kingdom Informal Group Meeting on Human Response to Vibration, held at Heriot-Watt University, Edinburgh, September 1984.

WOODROOF HJ, LEWIS CH, GRIFFIN MJ. Vibrations transmitted through the ground. Experimental studies of subject response to railway-induced building vibration. Utrecht: Office for Research and experiments of the International Union of Railways, 1983. Report DT 159 (D 151).

YAMANAKA K, NAGAWAKA T, KOBAYASHI F, et al.. Criteria for acceptable levels of the Shinkansen Super Express Train noise and vibration in residential areas. J sound & Vibr 1982;84(-4):573-91.

YEOWART NS, WILCOX DJ, ROSSALL AW. Community reactions to noise from freely flowing traffic, motorway and congested traffic flow. J of Sound and Vibration 1977;53:127-45.

ZEICHART K, SINZ A, SCHUEMER R, SCHUEMER-KOHRS A. Erschütterunswirkungen aus dem Schienenverkehr. München: Obermeyer Planen und Beraten, 1993. Kurzfassung.

ZEICHART K, SINZ A, SCHUEMER R, SCHUEMER-KOHRS A. Erschütterunswirkungen aus dem Schienenverkehr. München: Obermeyer Planen und Beraten, 1993. Hauptbericht.

Annex A

ERSCHÜTTERUNGSWIRKUNGEN AUS DEM SCHIENENVERKEHR (ZEICHART, SINZ, SCHÜMER AND SCHÜMER-KOHRS, 1993)

A.1 Introduction

This Annex gives a summary of the field investigation carried out by Zeichart et al. in Germany from 1889 to 1991. The investigation is presently the largest one dealing with adverse effects from exposure to environmental vibrations. This Annex aims at presenting the main conclusions of the investigation, together with information relevant for the present report.
In the Zeichart-report several measures of the vibration exposure magnitude and of the noise exposure magnitude have been used. Also, several effect parameters have been used to describe the subjective response to both vibrations and noise from railway traffic. These vibration, noise and effect parameters are set forth in paragraph A8 of this Annex, if they have not been defined in the main report.

A.2 Outline of the investigation

The investigation is an interdisciplinary survey, in which vibration and noise measurements have been carried out in conjunction with a social survey in which respondents were questioned verbally. The investigation deals with adverse effects from intercity trains ('Fernbahn', in this Annex denoted by F-trains) and from overground suburban rapid transit systems ('S-bahn: S-trains). Study areas have been selected according to specified combinations of vibration exposure magnitudes (for z-vibrations between 0.02 and 2.66 KB_{Fmax} for F-trains and between 0.02 and 0.91 for S-trains), numbers of trains per 24 hours (between 60 to up to more than 240) and noise exposure magnitudes (between 40 and 73 dB(A) (L_{AFmax}, measured indoors) for F-trains and between 36 and 61 dB(A) (L_{AFmax}, measured indoors) for S-trains). The distances from the railway tracks to the dwellings appeared to be 5 to 60 meters in the case of F-trains and 10 to 45 meters in the case of S-trains.

Noise and vibration has been measured have been carried out in 284 dwellings in the F-train areas and in 102 dwellings in the S-train areas. In each of these dwellings vibration measurements have been carried out in the living room and in one of the bedrooms. The total number of respondents

that took part in the social survey and who had also measurements taken in their home were 417 and 148 for F- and S-train areas respectively. In all, the total number of respondents that took part in the social survey were 765 in the F-train areas and 261 in the S-train areas. The distributions of the respondents according to age, gender, professional class and education correspond to those of the German population (1990).
A large part of the Zeichart-report is devoted to the results for the F-train areas. Results for S-trains are only given in comparison to those for F-trains. This Annex follows the same course.

In table A1 the number of respondents in whose dwellings noise and vibration measurements have been carried out are specified with respect to vibration magnitude, noise exposure class and number of F-trains passing the dwelling in 24 hours. The results in the Zeichart report have been limited to vibration magnitudes in the z-direction, since the vibration magnitudes in other directions surpassed those in the vertical direction in a few situations only.

Table A1 Number of respondents in the F-train areas (Source: Zeichart et al., 1993).

Number of trains per 24 hours	Noise level*	Vibration magnitude (KB_WZ)				
		< 0.1	0.1 - 0.3	0.3 - 0.5	> 0.5	total
> 240	L+	5	25	34	21	85
> 240	L-	29	34	13	7	83
160-239	L+	4	62	23	21	110
160-239	L-	14	21	8	2	45
60-159	L+	6	23	14	15	58
60-159	L-	4	21	8	3	36
total		62	186	100	69	417

L+: LMAX_W > 55 dB(A) (measured indoors)
L-: LMAX_W < 55 dB(A) (measured indoors)

A.3 Vibration and noise magnitude measures for F-train areas

From the vibration measurements in the living and bedrooms various vibration magnitude measures have been derived, such as various KB-values as specified in German regulations and standards and VDV-values, in analogy to the vibration dose value specified in the British Standard BS 6841 (1987). (It is not quite clear from the Zeichart report which frequency weighting has been applied to determine the VDV-values. Anyway, differences between the VDV-value as specified in the

British Standard and the VDV-values used in the Zeichart report most probably exist, since the latter value does take into account goods transport trains in a specific way, and such a specification has not been given in the British Standard).

The various vibration magnitude measures have been related to each other and correlation coefficients have been determined. Some results for F-trains are given in Table A2.

Table A2 Correlation coefficients of the correlation between the vibration magnitude measures KB_WZ, KB_SZ and other vibration magnitude measures (Source: Zeichart et al., 1993).

Vibration measure	Vibration measure KB_WZ	Vibration measure	Vibration measure KB_SZ
KB_WZ*	1.000	KB_SZ**	1.000
KB_PK_WZ	0.954	KB_PK_SZ	0.951
KB_WZ3	0.997	KB_SZ3	0.998
KB_WZ3T***	0.998	KB_SZ3T	0.999
KB_WZ3N****	0.988	KB_SZ3N	0.988
KBR-WT	0.950	KBT_ST	0.960
KBR_WN	0.898	KBR_SN	0.922
VDV_WT	0.966	VDV_ST	0.972
VDV_WN	0.918	VDV_SN	0.929
KBEQ_WT	0.884	KBEQQ_ST	0.911
KBEQ_WN	0.791	KBEQ_SN	0.823
KBMAX_W	0.939	KBMAX_S	0.938

* WZ: Wohnzimmer (living room)
** SZ: Schlafzimmer (bedroom)
*** T: tags (day-time : 06-22 hours)
**** N: nachts (night-time : 22-06 hours)

Table A2 shows high correlation coefficients of the correlation between the vibration exposure measures determined at the same location in the house (living room or bedroom). Therefore, the Zeichart-report usually specifies the results of the social survey only in one vibration measure derived from measurements in the living room (usually KB_WZ) and in one vibration measure representative for the bedroom (usually KB_SZ).

In Table A3 the correlation coefficients of the correlation between vibration measures determined in the living room and some determined in the bedroom are given.

Table A3 Correlation coefficients of the correlation between vibration measures determined in the living room and those determined in the bedroom (Source: Zeichart et al., 1993).

	Vibration measure in the living room						
Vibration measure in the bedroom	KB_WZ	KBR_WT	KBR_WN	VDV_WT	VDV_WN	KBEQ_WT	KBEQ_WN
KB_SZ	0.52						
KBR_ST	0.51	0.57					
KBR_SN	0.48		0.59				
VDV_SN	0.49			0.56			
VDV_SN	0.47				0.60		
KBEQ_ST	0.48					0.60	
KBEQ_ST	0.43						0.66

Apparently, the correlation between vibration magnitude measures determined in different rooms in a dwelling is much lower that the correlation between vibration magnitude measures determined in the same room. Considering the lower correlation coefficients, the Zeichart-report concludes that it is not possible to describe the magnitude of vibration exposure in a dwelling by only one vibration magnitude measure.

In the Zeichart-report also the correlations between various vibration exposure measures and various noise exposure measures are considered. On average, the correlation coefficients appeared to be in the order of 0.2 to 0.4. This observation seems quite relevant with respect to the analysis of the social survey in relation to vibration and noise, since a high correlation between noise and vibration might have obscured a possible interaction effect of noise and vibration during simultaneous exposures.

A.4 The social survey

The questionnaire dealt with the following five aspects:

(1) reactions to vibrations. Perception of and disturbances due to vibrations;

(2) reactions to noise. Perception of and disturbances due to noise;

(3) questions to compare the effects of noise and those of vibration;

(4) a-specific effects: total disturbance by railway traffic without specification of the cause (noise and/or vibration);

(5) other items, such as satisfaction with the environment, general susceptibility to noise, vibration and other environmental factors and socio-demographic features.

Apart from the verbal scaling of the responses to most of the questions, respondents were also asked to measure their annoyance due to vibrations, noise and their overall annoyance due to railway traffic on an 'annoyance thermometer'. The scale of this thermometer ranged from 0 to 11.

A.5 Results for F-trains

Some of the results in the Zeichart-report on the annoyance/disturbance from the exposures to vibration and noise from F-trains are presented here in the sequence given in the Zeichart-report.

Figure A1 gives the result on the question whether respondents considered the railway-induced vibrations or the railway-induced noise more annoying in their own situation. Only eight percent of the 761 respondents considered vibrations more and much more annoying than noise. On the other hand 76% of the respondents considered railway-induced noise (much) more annoying than railway-induced vibrations.

Figure A2 gives a comparison of the mean values and the standard deviations of the adverse reaction score for vibration and for noise exposure related to some questions in the questionnaire and to responses on the annoyance thermometer.

Figure A1 Result of a comparison by the 761 respondents of their annoyance due to railway-induced vibrations and their annoyance due to railway-induced noise in their homes (Source: Zeichart et al., 1993).

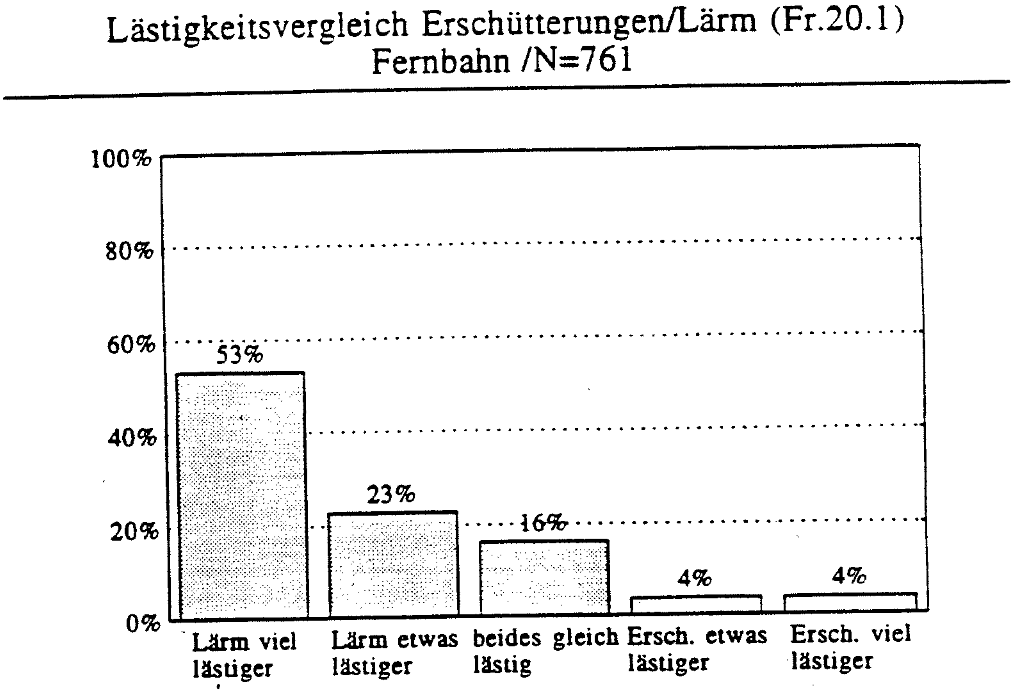
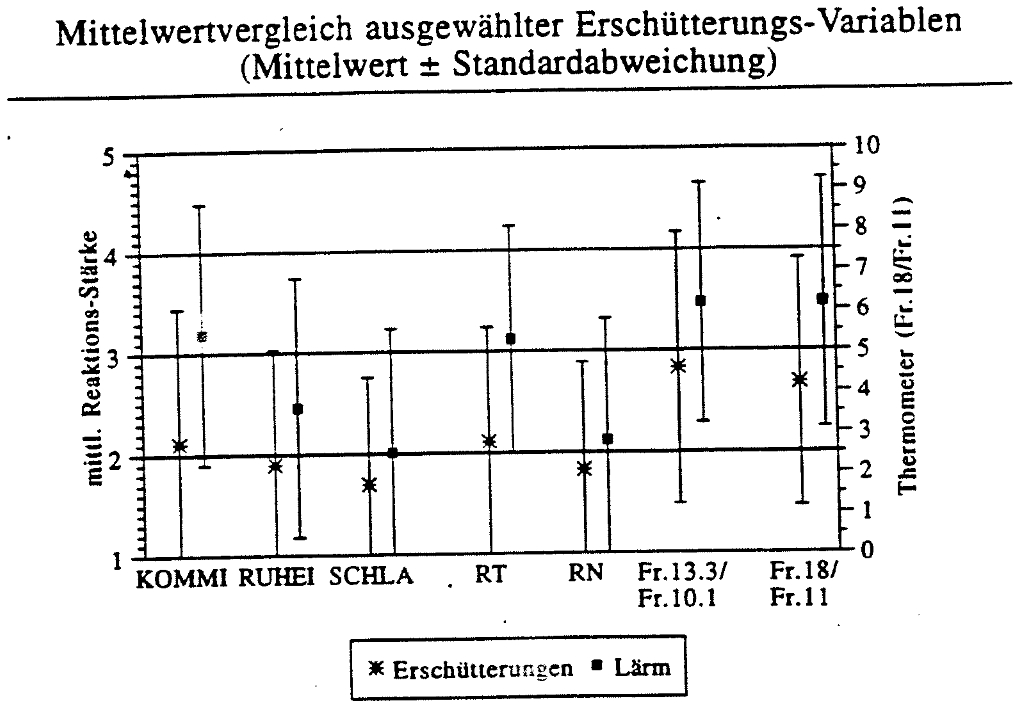
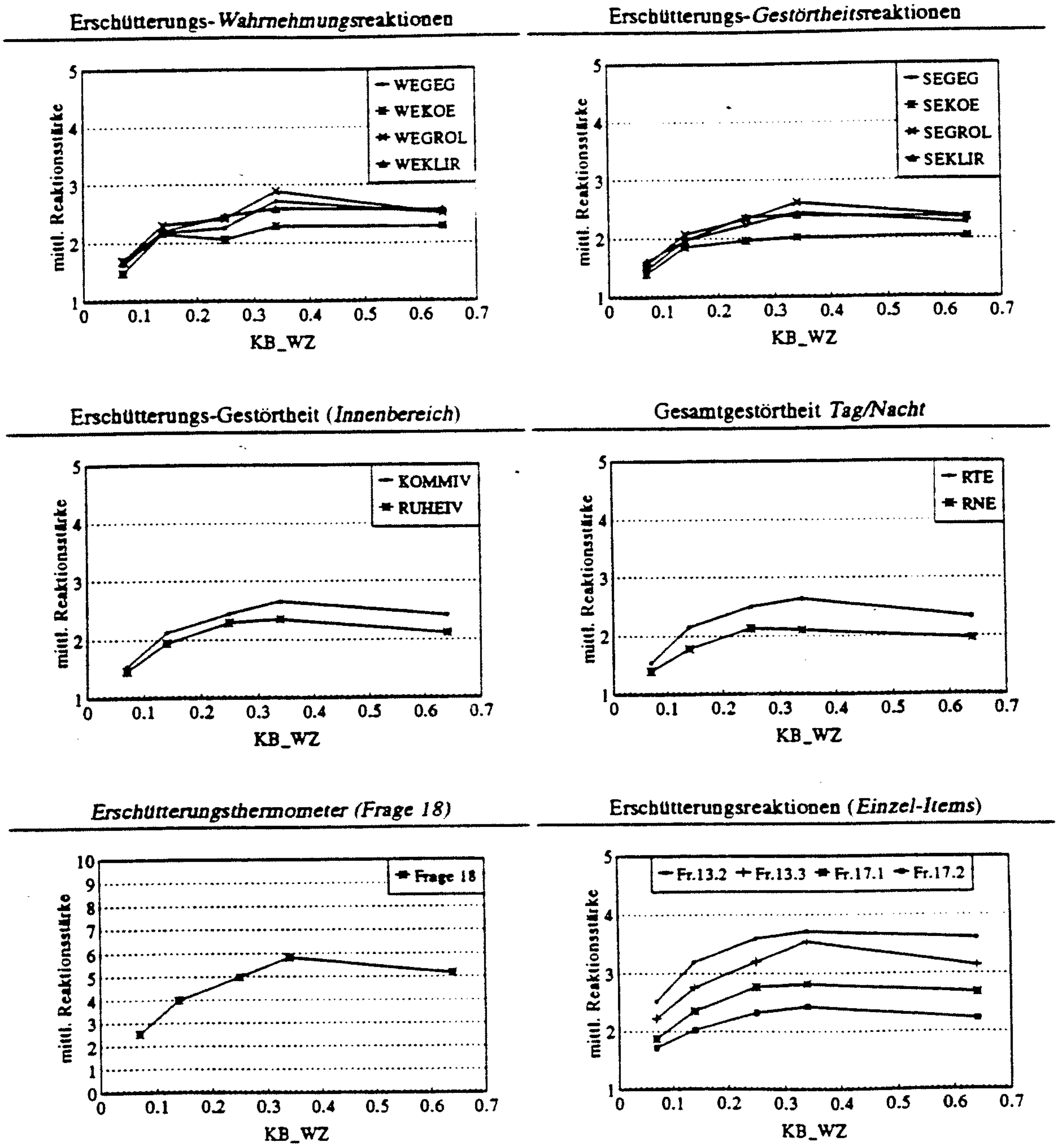


Figure A2 Mean values and standard deviations of the scores of the adverse reaction to vibration and to noise with respect to communication, rest, sleep, annoyance during day- and night-time, disturbance during day- and night-time and the mean scores on the annoyance thermometer (Source: Zeichart et al., 1993).



In figure A3 the mean score of the subjective response to vibrations experienced in the dwelling is given as a function of the vibration magnitude, specified in five classes of KB_WZ for several aspects of annoyance (disturbance of communication and rest, annoyance due to day- and night-time vibration exposures, effect on the annoyance thermometer and answers to specific questions about vibration-induced annoyance). All curves show the same trend: an increase in the lowest three vibration magnitude classes and a constant level or even a decrease in the two highest vibration magnitude classes.

Figure A3 Mean scores of the subjective response to vibration-exposures as a function of KB_WZ of the vibrations (Source: Zeichart et al., 1993).



The Zeichart report also gives data on the relations between individual responses to vibrations and vibration magnitude. These data are relevant with respect to the question which vibration magnitude allows the best estimate of individual subjective response to vibration. The measure with the highest correlation between vibration magnitude and subjective response is usually the measure which is most desirable in that respect. In Table A4 the correlation coefficients are given of a selection of the coefficients presented in the Zeichart-report of various vibration magnitude measures related to various subjective responses. The table shows that all vibration magnitude measures have about the same correlation with the subjective response measures. Therefore, table A4 suggests that a preference for any vibration magnitude measure cannot be based on the results presented in this table.

Table A4 Correlation coefficients* of linear relation between subjective effects from vibrations and vibration magnitudes (Source: Zeichart et al., 1993)

Vibration effect measure**	Vibration magnitude measure					
	KB_WZ	KB_SZ	KBEQ_WT	KBEQ_SN	VDV_WT	VDV_SN
RTE	0.09	0.12	0.12	(0.11)	0.11	(0.12)
RNE	0.04	0.08	(0.09)	0.09	(0.06)	0.08
question 13.2	0.22	0.15	0.23	0.12	0.23	0.14
question 13.3	0.14	0.19	0.17	0.15	0.15	0.17
question 17.1	0.08	(0.12)	0.12	(0.07)	0.11	(0.09)
question 17.2	(0.03)	0.08	(0.06)	0.06	(0.04)	0.07
question 18	0.17	0.20	0.20	0.15	0.19	0.15
question 9.1	0.13	0.19	0.18	0.19	0.16	0.19
question 11	0.14	0.18	0.20	0.19	0.18	0.19

* Values within brackets are related to a combination of a vibration magnitude measure for the living room and subjective response for the night or a combination of a vibration magnitude measure for the bedroom and subjective response for the day-time.

** Explanation of variables:
RTE: day-time disturbance by vibrations
RNE: night-time disturbance by vibrations
question 13.2: perception of vibrations
question 13.3: annoyance due to vibrations
question 17.1: overall annoyance due to day-time vibrations
question 17.2: overall annoyance due to night-time vibrations
question 18: vibration annoyance using the annoyance 'thermometer'
question 9.1: railway-induced annoyance using the annoyance 'thermometer'
question 11: noise annoyance using the annoyance 'thermometer'.

As figure A3 shows, the relations between the vibration magnitude measures and subjective responses are not linear. Therefore, in the Zeichart report also the correlation has been determined between log KB_WZ and subjective responses and between log KB_SZ and a selected number of subjective responses. Unfortunately, no correlation coefficients have been determined between the logarithm of other vibration magnitude measures and subjective response. Results are given in table A5. Correlation coefficients are presented for all respondents together and for the subgroups exposed to lower or higher railway noise levels.

Table A5 shows two clearly observable results. First, the correlation coefficients increase considerable when the log of KB_WZ is taken as independent variable instead of KB_WZ. The second observation is that correlation coefficients are quite different for the low and for the high noise exposure class. Apparently, in the low noise exposure subgroup the subjective response is related to the vibration magnitude, whereas in the high noise exposure subgroup there is obviously no relation between vibration magnitude and subjective response.

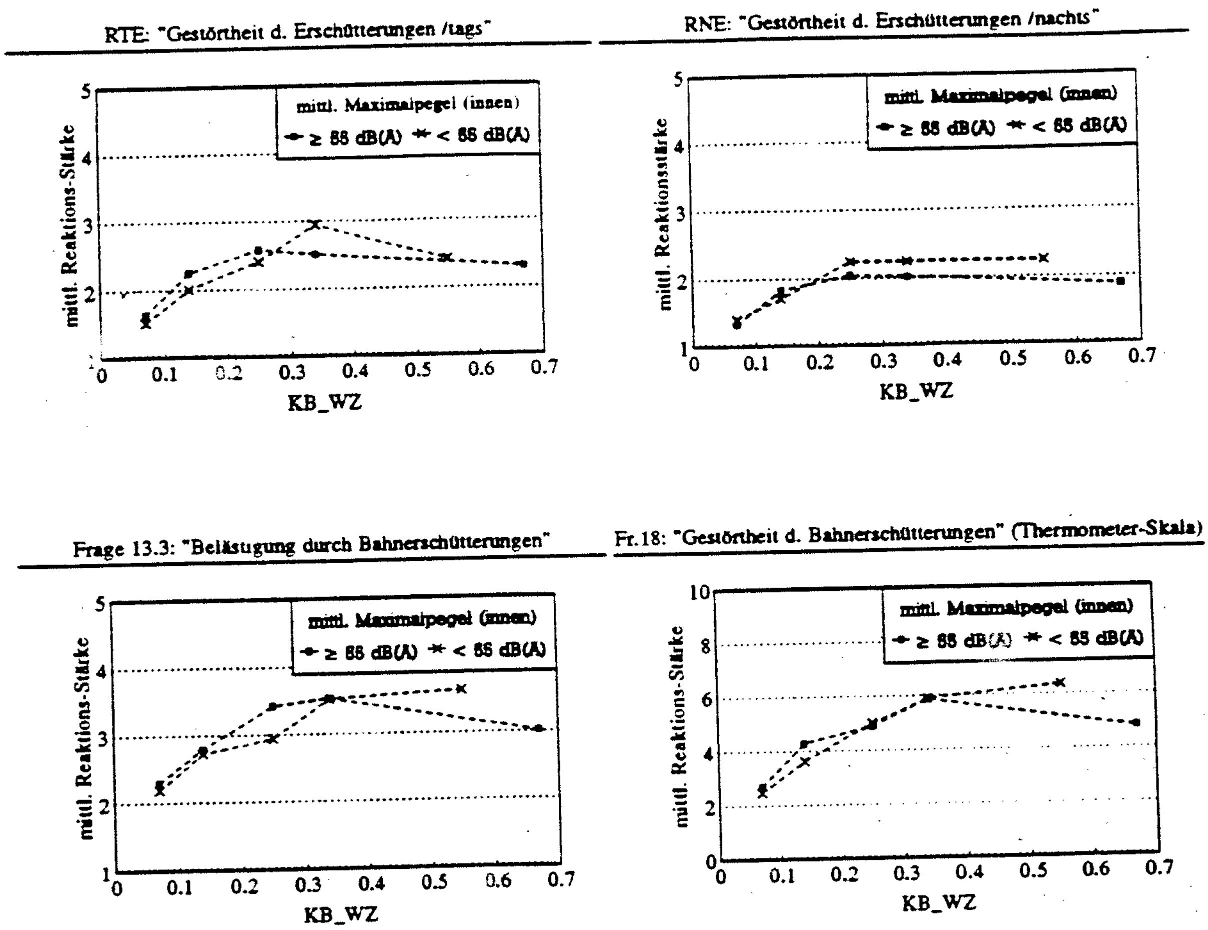
Table A5 Correlation coefficients of the relations between KB_WZ and KB_SZ and several subjective response measures. Upper rows: all respondents; middle rows: respondents with low noise levels; lower rows: respondents with high noise levels (Source: Zeichart et al., 1993).

respondents	vibration effect measure	KB_WZ	KB_SZ	log KB_WZ	log KB_SZ
all	RET	0.09		0.22	
	RNE	0.04	0.08	0.16	0.11
	Thermometer response	0.17	-	0.31	
L-	RTE	0.28		0.38	
	RTN	0.26	0.21	0.32	0.22
	Thermometer response	0.41		0.48	
L+	RTE	-0.02		0.05	
	RTN	-0.05	0.01	0.03	0.03
	Thermometer response	0.06		0.13	

The Zeichart report deals extensively with a possible interaction between vibration and noise exposure. A statistical analysis resulted in a chance of 0.07 of such an interaction, which means that the hypothesis that such an interaction does exist should be rejected. However, as the Zeichart report states, an analysis in which the nightly disturbance was not taken into account, showed a statistical significant interaction effect ($p= 0.03$).

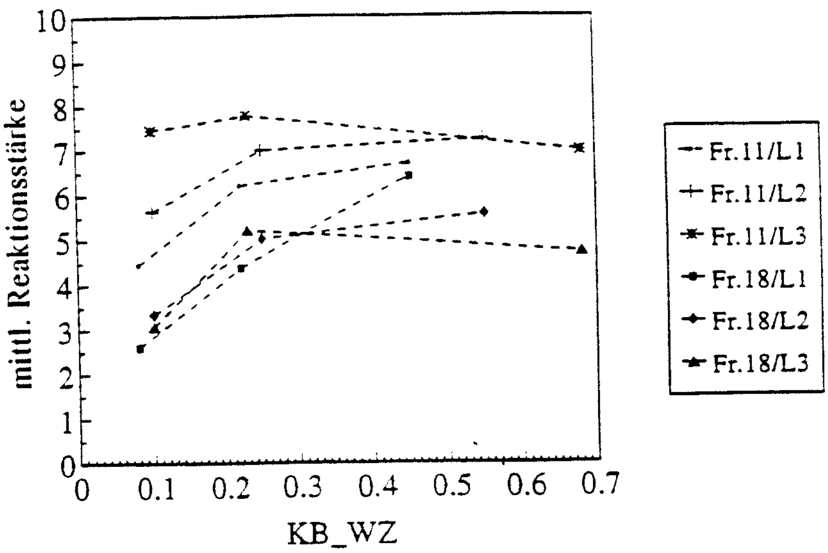
An interaction effect might also be observable when subjective vibration response is plotted as a function of vibration magnitude for subgroups having different noise exposures. Figure A4 shows four of such graphs. The figure shows that an interaction effect, if it does exist, is obscured by the variation in the data and apparently does not have much of an effect on the shape and the relative position of the curves.

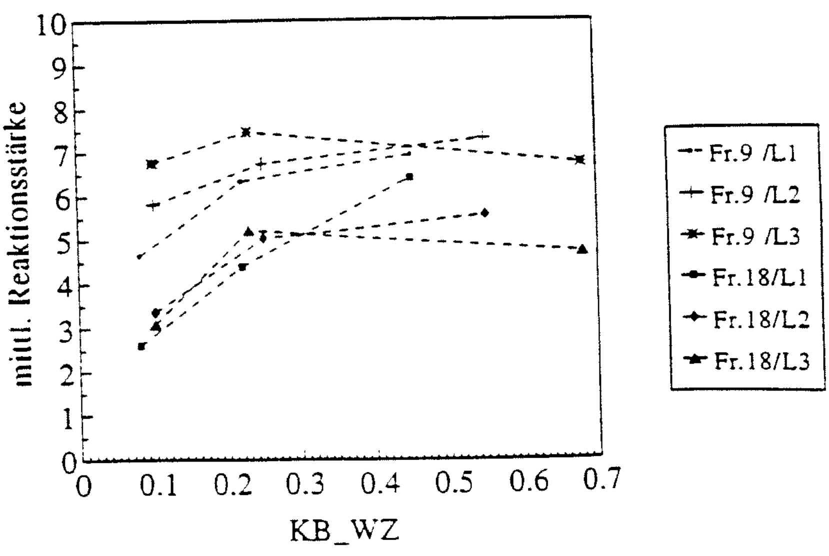
Figure A4 Mean subjective response to vibrations as a function of vibration magnitude KB_WZ (Source: Zeichart et al., 1993).



Hardly any information is given in the Zeichart report on the overall subjective response to railway traffic, irrespective of the type of intrusion (vibration or noise). Figure A5 gives some information. Question 9 concerns the overall judgement of the simultaneous exposure to railway-induced vibration and noise. The shape and relative positions of the curves representing the overall subjective response clearly resembles those representing the subjective response to noise only. At the lower vibration values, vibration-induced annoyance is independent of noise exposure, since the mean score to question 18 (vibration-induced subjective response) is about the same for the three subgroups classified according to noise exposure class. Differences seem to exist at the highest vibration exposures. For the two higher noise exposure classes mean vibration annoyance score is independent of vibration magnitude, whereas for the lowest noise exposure class mean annoyance score increases with vibration magnitude. This implies the same effect observed in table A5. The results suggest that only at the highest vibration magnitude an interaction between vibrations and noise occurs. The interaction would then have a negative effect on the overall response to a combined exposure.

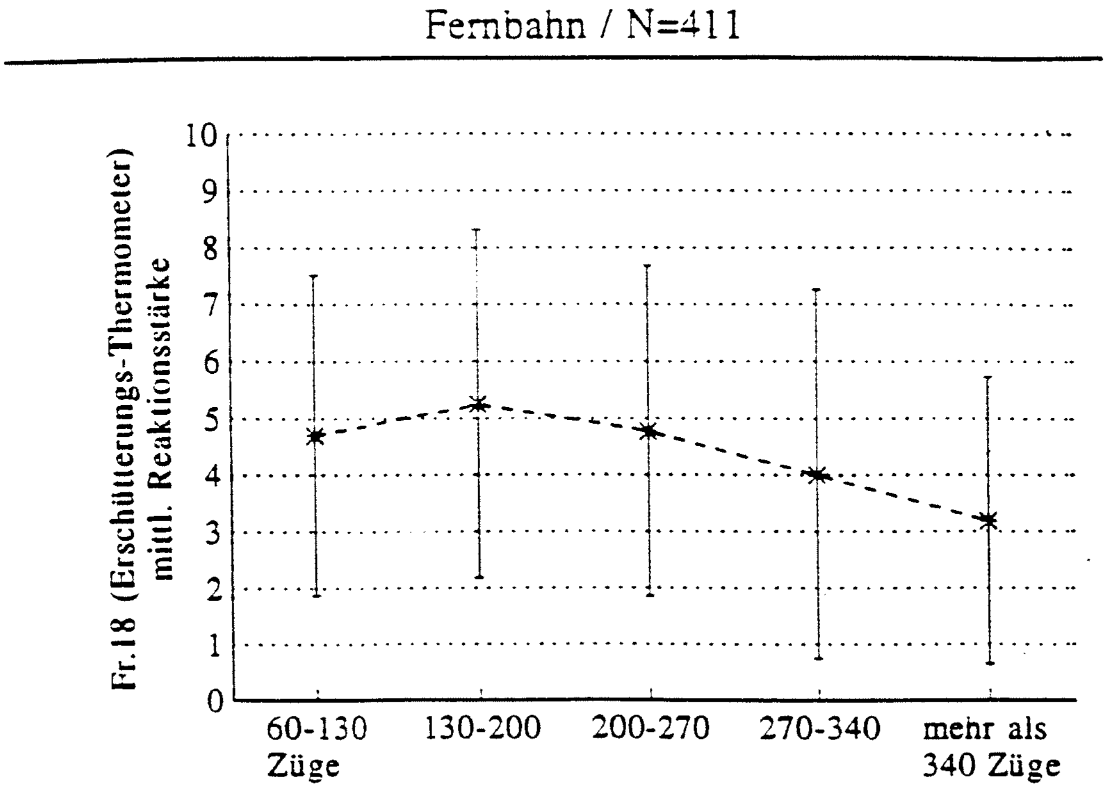
Figure A5 Mean subjective reaction scores as a function of KB_WZ for three subgroups with different noise exposure characteristics (L_1 highest noise exposure category; L_2 middle noise exposure category; L_3 lowest noise exposure category).
Upper figure: question 11 concerns subjective response to noise, question 18 concerns subjective response to vibrations.
Lower figure: question 9 concerns overall response to simultaneous exposure, question 18 concerns subjective response to vibrations (Source: Zeichart et al., 1993).





In the investigation, the number of F-trains varied by a factor of more than 6 (from 60 to more than 340 trains per 24 hours). In figure A6 the mean subjective response to the vibrations of the F-trains is given as a function of the number of trains. Contrary to expectations, the subjective response decreases as the number of trains per 24 hours increases. Zeichart et al. (1993) suggest two intervening factors. The first factor is related to the perceptibility of train vibrations. In the situations with 240 or more trains per 24 hours the mean percentage of perceptible train vibrations is 73%, for 160-240 trains per hour it is 75% and for less than 160 trains per 24 hours it is 80%. However, the small differences in these mean percentages do not seem to account for the observed effect. The second factor may be due to differences in the noise exposure magnitudes. Even if these differences are taken into account, the subjective response to railway-induced vibrations decreases with increasing number of trains per 24 hours in a way quite comparable to that in figure A6.

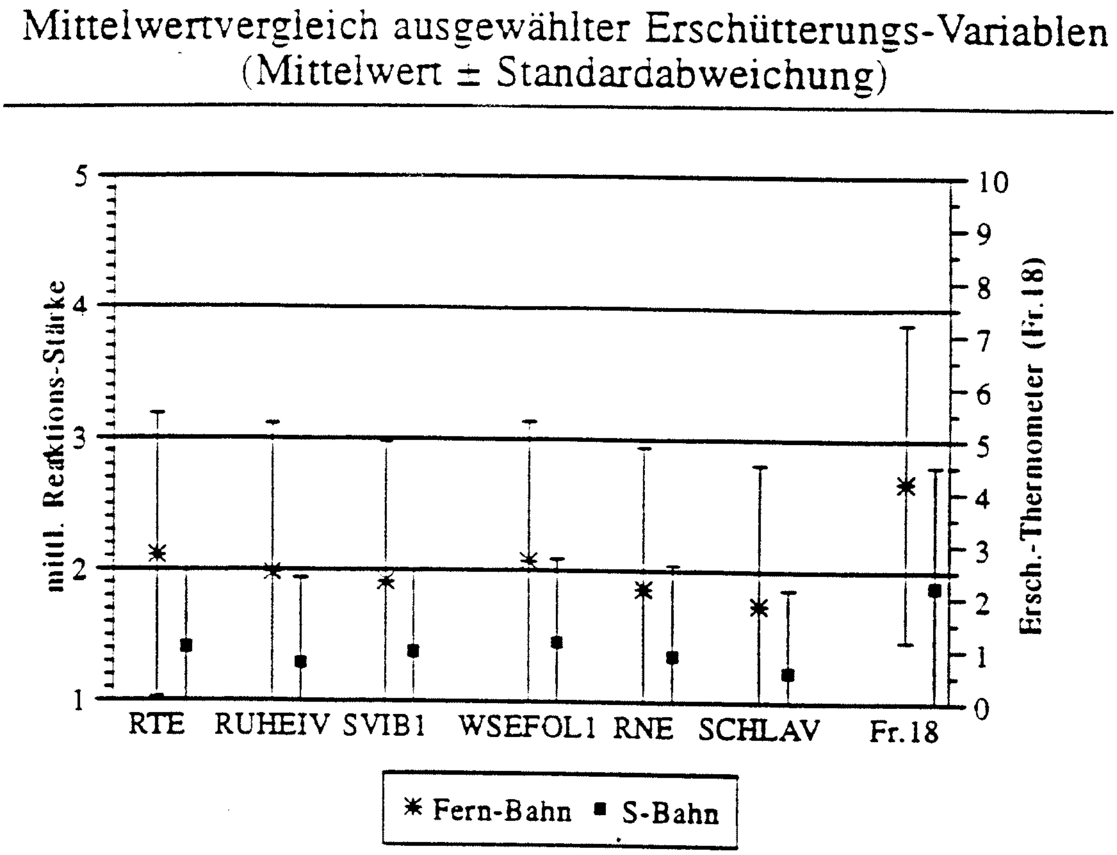
Figure A6 Mean subjective response (plus standard deviation) to railway-induced vibrations as a function of the number of trains per 24 hours (Source: Zeichart et al., 1993).



A.6 Comparison of results for F- and S-trains

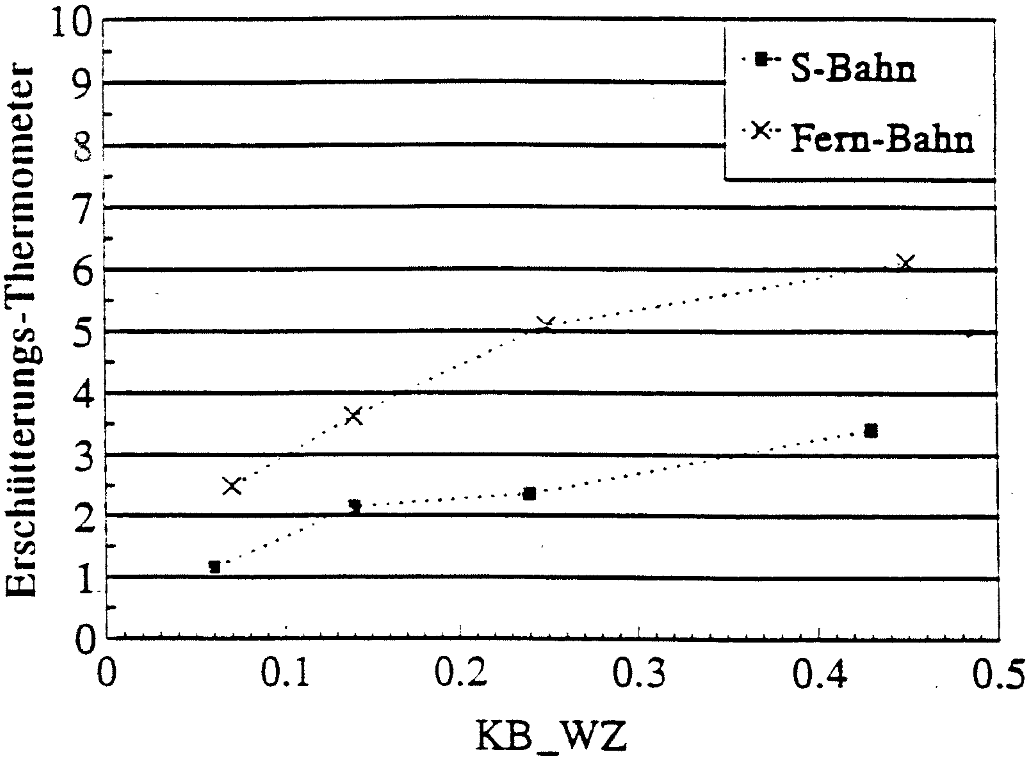
In the Zeichart-report some results obtained for F-trains have been compared to those for S-trains. In figure A7 various subjective responses to vibrations of S-trains have been compared to those from F-trains. For all these and other subjective responses the mean value of the subjective response for S-trains appears to be smaller than that for F-trains, although the vibration magnitudes are quite comparable. There is, however, an obvious difference between the respondents exposed to F-trains and those exposed to S-trains: noise exposure of the respondents exposed to vibrations from S-trains is in 87% (129 out of 148) cases limited to the lower noise exposure class with LMAX_W < 55 dBA).

Figure A7 Comparison of the mean adverse reaction scores with respect to vibrations from S-trains and those from F-trains (Source: Zeichart et al., 1993).



Since in the S-train subgroup of respondents, exposure to railway noise was almost exclusively in the lower noise exposure class, in figure A8 the responses on the annoyance thermometer plotted as a function of KB_WZ have been restricted to the two subgroups of respondents exposed to railway noise in the lower noise class. Obviously the mean reaction score of the respondents exposed to vibrations from S-trains is about half as the mean reaction score of the respondents exposed to the F-train vibrations.

Figure A8 Mean annoyance score on the annoyance thermometer with respect to vibrations from S- and F-trains as a function of vibration magnitude KB_WZ for respondents in the lower noise exposure class (Source: Zeichart et al., 1993).



The difference between the magnitude of the subjective response to vibrations from S- and F-trains essentially remains the same, if also the number of trains per 24 hours is taken into account. Zeichart et al. did not perform a systematic analysis on intervening factors to account for the difference in subjective response to vibrations from F- and S-trains. In their explanation of the difference they mention the difference in the use by the respondents of the F- and S-trains: 67% of the respondents in the F-train areas never or hardly ever use an F-train, whereas only 30% of the respondents in the S-train areas never or hardly ever use an S-train. Other possible explanations might, according to Zeichart, be related to differences in indoors and outdoors noise exposures, to differences in day/night noise exposure patterns and to differences in the lengths of the trains, having an impact on the durations of the passages of the trains.

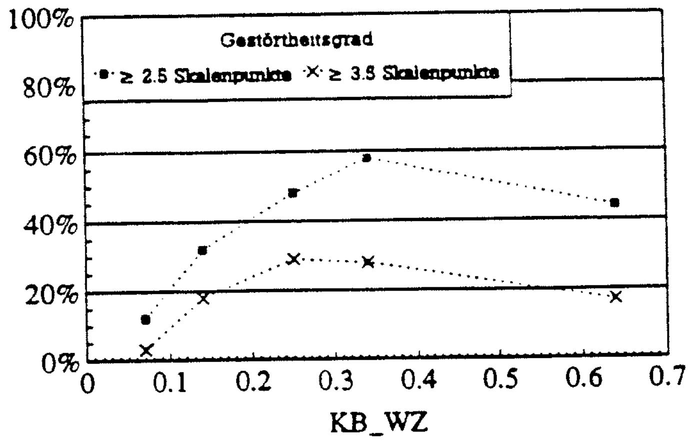
A.7 Exposure-effect relations for vibrations from F-trains

Exposure-effect relations have already been presented in the foregoing sections in which the format of an average subjective reaction score as a function of a vibration magnitude measure was used. Zeichart also presents some of the results in the format in which percentage (very) much annoyed respondents are given as a function of the vibration magnitude measure KB_WZ. For subjective responses of at least 2.5 on a 5-points scale he introduces the term 'erheblich gestört' (much annoyed). Respondents with a subjective response of at least 3.5 on a 5-points scale will be indicated by very much annoyed. The annoyance thermometer concerns an 11-points scale; Zeichart considers respondents with a response of more than 4 much annoyed.

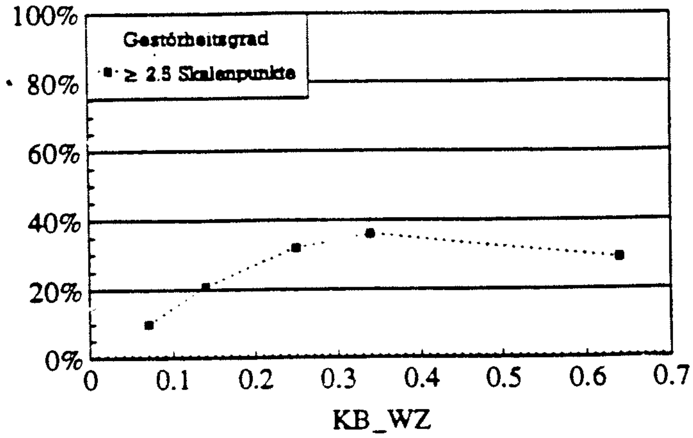
The two upper parts of figure A9 shows the percentages respondents that are very much annoyed and much annoyed due to day-time vibrations from F-trains and the percentage respondents that are much annoyed by those vibrations during night-time. Unfortunately Zeichart does not present the percentage respondents very much annoyed by night-time vibrations. The percentage respondents (very) much annoyed due to vibrations apparently increases from KB_WZ values of 0.07 to about 0.2 à 0.3 and remains constant, or even decreases somewhat, with increasing vibration magnitude. The lower part of figure A9 gives the percentage respondents much annoyed by vibrations from F-trains derived from the annoyance thermometer results. The percentages much annoyed are given for all respondents and for the two subgroups of respondents, splitted up according to railway-induced noise exposure. For the low noise exposure subgroup the percentage much annoyed respondents is an increasing function of KB_WZ over the whole vibration magnitude range considered.

Figure A9 Percentage respondents in the F-train areas much and very much annoyed by railway-induced vibrations as a function of vibration magnitude measure KB_WZ. Upper figure: day-time vibrations, middle figure: night-time vibrations, lower figure: results based on annoyance thermometer scores for all respondents, and for two subgroups classified according to railway-induced noise exposure (Source: Zeichart et al., 1993).

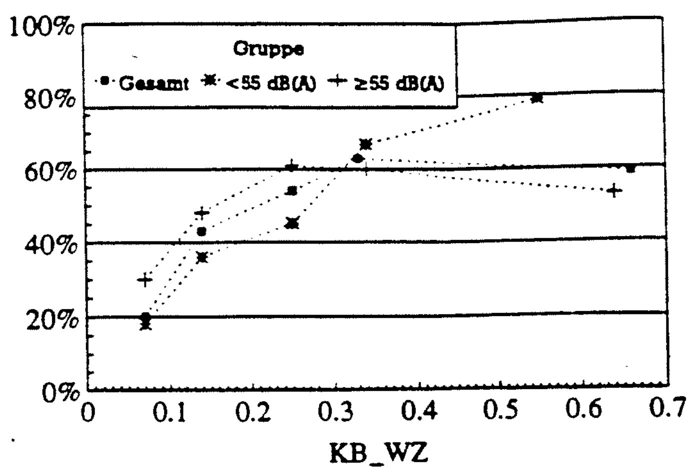
Gesamt-Gestörtheit d. Erschütterungen tags
(Variable RTE)



Gesamt-Gestörtheit d. Erschütterungen nachts
(Variable RNE)



Fr.18: "Gestörtheit d. Bahnerschütterungen" (Thermometer-Skala)



Although the analysis failed to show a statistical significant interaction effect on overall annoyance due to a combined exposure to noise and vibration, the results in figure A10 could be explained to some extent by a negative interaction. Taking the model presented in Howarth and Griffin (1990b) an interaction term would increase with increasing vibration and noise magnitudes. Therefore an interaction would become obvious only at higher vibration and noise exposures. At higher exposures, a negative interaction term would counterbalance the increase in annoyance due to an increase in exposure magnitudes. Such an effect is observable in the figures A4, A5, and A10.

A.8 Specific terms and definitions

In the Zeichart report several specific terms and definitions have been used. Most of these terms are based on German Standardization Reports, such as DIN 4150-2 and VDI 2057. The specific terms used in this Annex are specified below (see also the definitions given in chapter 8 of the main report).

$$KB_{Fmax,i}\text{:}KB_{Fmax} \text{ of train passage } i$$

$$KB\_x = [\frac{1}{n} \sum_{i=1}^{n} KB_{Fmax,i}^{2}]^{1/2}$$

where:

x measurement location (WZ: living room, SZ: bedroom);

n number of train passages.

$$KB_{G,X} = [\frac{1}{N_G} \sum_{i=1}^{N_G} KB_{Fmax,G,i}]^{1/2}$$

where:

N_G number of passing goods trains;

$KB_{Fmax,G,i}$ KB_{Fmax} of the i-th goods train.

$$KB_{R,X} = [\frac{1}{N_R} \sum_{i=1}^{N_R} KB_{Fmax,R,i}]^{½}$$

where:

N_R number of passing passenger trains

$KB_{Fmax,R,i}$ KB_{Fmax} of the i-th passenger train.

$$KB\_x3z= [\frac{N_G}{N_G+N_R} KB^2_{G,X} + \frac{N_R}{N_G+N_R} KB^2_{R,X}]^{½}$$

where:

x measurement location (WZ: living room, SZ: bedroom);

z observation time (T: day-time, N: night-time).

$$KBR\_xz = [\frac{N_G}{T(z)} KB^2_{G,X} + \frac{N_R}{T(z)} KB^2_{R,X}]^{½}$$

where:

T(z) the number of 30-second periods during the observation time (day-time (16 hours) equals 1920 30-s periods; night-time (8 hours) equals 960 30-s periods).

$$KB_{eq,i} = [\frac{1}{T_0} \int_0^{T_r} KB^2_{F,i}(t)\ dt]^{½}$$

where:

$KB_{F,i}(t)$ the value of KB_F at time t of the i-th train passage;

T_e the duration of the train passage in seconds;

T_0 taken equal to 30 s in the Zeichart et al. report.

$$KB_{eq-G-x} = [\frac{1}{N_G} \sum_{i=1}^{N_G} KB^2_{eq,G,i}]^{½}$$

where:

$KB_{eq,G,i}$ $KB_{eq,i}$ of the i-th goods train.

$$KB_{eq-R-x} = [\frac{1}{R} \sum_{i=1}^{N_R} KB^2_{eq,R,i}]^{½}$$

where:

$KB_{eq,R,i}$ $KB_{eq,i}$ of the i-th passenger train.

$$KBEQ\_xz = [\frac{1}{T(z)} (KB^2_{eq-R-x} N_R + KB^2_{eq-G-x} N_G)]^{½}$$

KBMAX_x: the maximum of the $KB_{Fmax,i}$ values determined at location x.

$$VDV\_xz = [\frac{1}{T(z)}(VDV^4_{R-x} N_R + VDV^4_{G-x} N_G)]^{¼}$$

where:

VDV_{R-x} VDV value of passenger trains determined at location x;

VDV_{G-x} VDV value of goods trains determined at location x.

$L_{Afmax,i}$: the maximum of the sound level measured with the sound level meter with time constant 0.125 s (F) during the passage of a train.