Journal of Sound and Vibration (1998) **215**(4), 977–988
Article No. sv981603

LABORATORY TESTING OF OPERATOR SEAT VIBRATION WITH 37 SUBJECTS—CRITICAL COMMENT ON ISO/DIS 7096

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(*Accepted* 18 *March* 1998)

The operators of earth moving machinery are often exposed to a low frequency vibration environment caused by the movement of vehicles over uneven ground and the task carried out. The seat constitutes the last state of suspension before the driver. The efficiency of attenuation under consideration of the best design practice today is the basis for the revision of ISO 7096 for the testing seats for earth moving machinery. This standard requires the participation of two subjects with different body masses (52–55 kg; 98–103 kg). The aim of the study was to investigate (1) the extent and the influence of individual variability and posture change on the result of seat tests, and (2) the possibility of deducing representative results for the user population. 37 male subjects took part in the experimental investigations. They were exposed in three postures for 67 s to three acceleration signals in a vertical direction corresponding to the spectral classes (EM2, EM5, EM6) in ISO/DIS 7096 on two commercial suspension seats. The vertical accelerations were measured at the seat basis and at the interface between seat cushion and subject. The results of the analysis of variance show a significant influence of exposure, type of seat, and interactions exposure-by-posture, exposure-by-type of seat, and posture-by-type of seat on the SEAT factor. Simple and multiple regression analyses were applied in order to test the predictability of the seat factor (SEAT) by anthropometric variables. The conclusions were drawn that the seat testing could be improved by (1) selecting subjects according to the 5th and 95th percentile masses of the population of vehicle or machinery users for which the seat is intended (ISO 10326), instead of fixed masses (ISO 7096), (2) considering other anthropometric parameters for the selection like the body height and body mass supported by the seat, and (3) the inclusion of several subjects near the 50th percentile in order to assess the variability of the SEAT factor.

1. INTRODUCTION

Several studies have shown a qualitative relationship between low-back problems and exposure to seated whole-body vibration [1]. Drivers of vehicles such as tractors, earth moving machinery or other construction vehicles have all been found to be at an increased risk to develop pathological spinal changes [2, 3]. A seat adapted to the vehicle is one of the most important technical measures to reduce vibration. The aims of the study were (1) to elucidate the significance of the between-subject variability and posture for the results of seat testing and (2) to examine, if laboratory testing with only two subjects with extreme body masses is valid for the total user population.

In order to test the performance of seats, the ISO 10326 [4] specifies the basic requirements for the laboratory testing of vibration transmission through a vehicle seat to the occupant. The requirements of the masses of two test persons are described in clause 7.2: "These masses will normally be based on the 5th and the 95th percentile masses of

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the population of vehicle or machinery users for which the seat is intended. The tolerance shall be low, preferably 0 to -5% of the required mass for the low-mass test person. For the heavy test person, a greater tolerance is permissible, up $+5$ to 0% of the required mass." In clause 10 the conditions for the acceptance of seats are described. Application standards shall state the acceptance values relevant for the specific seat test. The acceptance value for the simulated input vibration test shall be given either as the maximum value of the Seat Effective Amplitude Transmissibility (SEAT) factor, described for the first time by Griffin [5], or as the maximum frequency weighted r.m.s. value measured at the seat pan/driver interface. To pass the test, lower values than this maximum shall be obtained for each test person. The ISO 7096 [6] and its revision [7]–an application standard–specify a laboratory method for vibration testing of operator seats for earth-moving machinery at frequencies between 1 and 20 Hz with two persons: one with a body mass of 55 (-3 to 0) kg and another of 98 (0 to $+5$) kg.

2. METHOD

2.1. SUBJECTS

37 male subjects (body mass 49 to 103 kg, body height 163 to 191 cm, 3 groups of somatotypes with a frail, intermediate or robust skeleton [8]) were selected as paid volunteers on the basis of a detailed anamnesis including a comprehensive assessment of the clinical state (see Figure 1). An anthropometric examination (63 parameters) was performed for a sufficient quantitative characterization of the subjects [9]. Two subjects with extreme body masses of 49 and 103 kg were selected in order to test, if the method of ISO/DIS 7096 [7] would enable a prediction for all seat users from two seat users with body masses between these extremes.

The percentile data of body mass and body height are listed in Table 1 in comparison with the data by Greil [10] and of Kinghorn and Bittner [11]. The results of Greil [10] are based on a representative sample of the German male population, the results of Kinghorn and Bittner [11] describe a representative group of male truck drivers in the United States. In these two studies the percentile values of the body mass were higher than in our group of subjects. Reasons for these higher values may be the consideration of higher age groups by Greil [10] and the selection of a special user population, the truck drivers, by Kinghorn and Bittner [11].

2.2. EXPERIMENTAL DESIGN

The subjects were exposed to simulated input vibrations similar to the three spectral classes EM2, EM5 and EM6 defined in ISO/DIS 7096 [7]. Figure 2 shows the mean values of power spectral densities of the accelerations in the *z* direction measured at the seat basis. The simulation had a duration of 67·58 s.

Two types of suspension seats were used: seat 1 which had the spring system under the seat and seat 2 with the spring system behind the backrest. Both seats had a suspension manually adjustable for the body mass. The seats were placed directly on the electrohydraulic vibration simulator and adjusted individually for the body mass of each subject. Rare bottoming occurred only during EM2 with the heaviest subject on seat 1. The steering wheel and foot plate moved with the platform; seat belts were not used. Three driving postures were chosen and tested on each of the two seats: posture S, according to ISO-DIS 7096, each person shall adopt a natural position on the seat and maintain this throughout the test with recommended angles of knees of $100^\circ \pm 10^\circ$ and ankles $90^\circ \pm 10^\circ$, hands resting on the thighs near the knees (cf, Figure 1 of ISO/DIS 7096 [7]); posture D, two hands on the side of the wheel while seated relaxed back against the backrest in the lumbar region; posture B, each hand on an operator lever while seated bending forward with the upper trunk and the lumbar region was in contact with the backrest. For each subject, two of the 9 exposure conditions (3 classes, 3 postures) were randomly selected and additionally repeated to test the reproducibility.

Two accelerometers were used to measure the transmission of acceleration: one uniaxial accelerometer was placed on the platform (z direction, BWH 101/Metra)), one triaxial seat accelerometer housed in a rubber pad which is shaped for comfortable seating (z- and x-directions, Type 4322, B&K/Denmark) was placed at the seat pan/driver interface (z, x directions) midway between the ischial tuberosities of the seat occupant according to sub-clause 4.2.2 of ISO 10326 [4].

2.3. DATA RECORDING

The signals of the accelerometers were digitised with a sampling rate of 1 ms by means of a multichannel frontend SCADAS II (DIFA, The Netherlands). The SEAT factors were calculated for the measured acceleration time series,

$$\text{SEAT factor} = (P_{xx}(f)S^2(f)\,\mathrm{d}f)^{1/2}/(P_{yy}(f)S^2(f)\,\mathrm{d}f)^{1/2}, \tag{1}$$

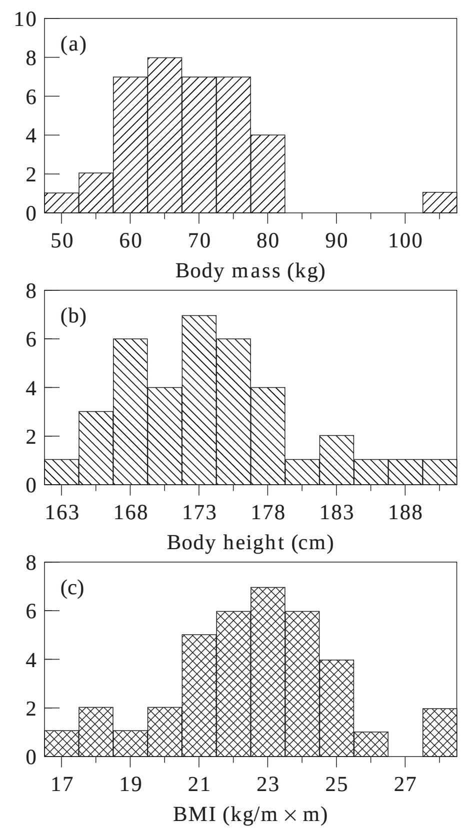

Figure 1. Histograms for the anthropometrical characterization of the 37 male subjects for the (a) body mass (top); (b) body height (middle); (c) *BMI* (bottom). (a) mean value 68 kg ($SD = 9{\cdot}7$ kg, $N = 37$); (b) mean value 174 cm ($SD = 6{\cdot}5$ cm, $N = 37$); (c) mean value 23 kg/m × m ($SD = 2{\cdot}4$ kg m × m, $N = 37$).

TABLE 1

Percentiles for the body mass and body height in the representative studies of GREIL [10] *for the population in east Germany and Kinghorn and Bittner* [11] *for a population of truck drivers in the USA in comparison with the percentiles of the group of subjects selected by Hinz et al.* [9]

Percentile	Body mass (kg) [10]	Body mass (kg) [11]	Body mass (kg) [9]
1	53	—	49
5	59	69·1	57
50	75	90·4	67·6
95	96	118·7	82
99	106	—	103
	Body height (cm) [10]	Body height (cm) [11]	Body height (cm) [9]
1	157·6	—	163·3
5	162·6	165·0	164·3
50	174·3	176·2	173·5
95	185·6	186·0	186·3
99	191·1	—	191·0

where $P_{xx}(f)$ is the power spectral density of the acceleration measured at the interface between seat and subject in the z direction, $P_{yy}(f)$ is the power spectral density of the acceleration measured at the seat base in the z direction, and $S^2(f)$ is the evaluation function of ISO 2631 [12] for the z direction.

3. RESULTS

The SEAT factors ranged from 0·3–1·4. For the conditions examined, the following factors had a significant influence on the SEAT factors (ANOVA-648 cases): exposure, type of seat and the exposure by posture interaction, the exposure-by-type of seat interaction, the posture-by-type of seat interaction (cf. Figure 3). The factor posture had no systematic significant effect on the SEAT factor.

During exposure EM2, both seats reached their maximum SEAT factors; the SEAT factors of seat 1 were bigger than those of seat 2 and had the largest ranges. The SEAT factors exceeded 1: i.e., both seats amplified the vibration input. During exposure EM5, the SEAT factors of both types of seats reached values between 0·5 and 0·7, with higher values at seat 1. During exposure EM6, the results of the SEAT factor calculation were between 0·3 and 0·5, with lower values at seat 1.

The relations between the SEAT factors at different postures varied with the kind of exposure, as indicated by the significant interactions (ANOVA). With exposure EM2, e.g., seat 1 exhibited the lowest SEAT factors at posture B, with the exposure EM6 the same posture was accompanied by the highest SEAT factor. Minor effects of the posture were observed with the seat 2, except high SEAT factors with the exposures EM5 and EM6 at posture B.

The relationships between body mass and the SEAT factor as well as between body height and the SEAT factor were tested with a correlation analysis. Table 2 shows the Pearson's correlation coefficients with the actual significance level. The body mass and body height correlated highly significantly with the SEAT factor during the majority of exposure conditions. Linear regression analysis can be used to test if the SEAT factor can be predicted simply from the body mass or body height. The coefficient of determination coincides for a simple linear regression with the squared correlation coefficient and shows the goodness of fit. For the exposure conditions tested the coefficients of determination varied with the exposure condition. Figure 4 demonstrates the exposure conditions with the lowest (on the top) and highest (on the bottom) coefficients of determination for the prediction of the SEAT factor from body mass of all exposure conditions, Figure 5 for one exposure (EM6) during the posture S according to ISO/DIS 7096 [7].

The possibility of predicting the SEAT factor from the selected anthropometric results was further examined by the method of multiple linear regression analysis (stepwise selection out of all independent variables listed in the Appendix, with searching for violations of assumptions by an analysis of the residuals, program SPSS-PC for Windows). By this method of regression analysis, significant variables were successively selected for the regression equation (see Table 3) based on the extent of partial correlation. The stepwise selection of variables was indicated by the increased values of the coefficients of determination, for each exposure condition in Table 3. Six independent anthropometric variables were not selected by the procedure "stepwise". *BKB*, *BKU*, *FZ*, *GKL*, *HB*, *TU* (cf., the Appendix). The multiple linear regression analysis (method stepwise (SPSS)) for the prediction of the SEAT factor by numerous anthropometric parameters has shown that the coefficient of determination could reach sufficiently high values by an inclusion of additional anthropometrical values in the regression equation. A systematic selection of the parameter *KPH* was obvious during the exposure EM2 for both seats and during the exposure EM5 for seat 1, postures S and D. For the other experimental conditions different anthropometric parameters were included with various testing conditions, and a systematic selection of certain parameters was not obvious. During the exposure EM6 using seat 2, the *MSI* was the primarily selected parameter. The comparison of SEAT factor means of repeated measurements (paired samples t-test) did not exhibit significant differences. The

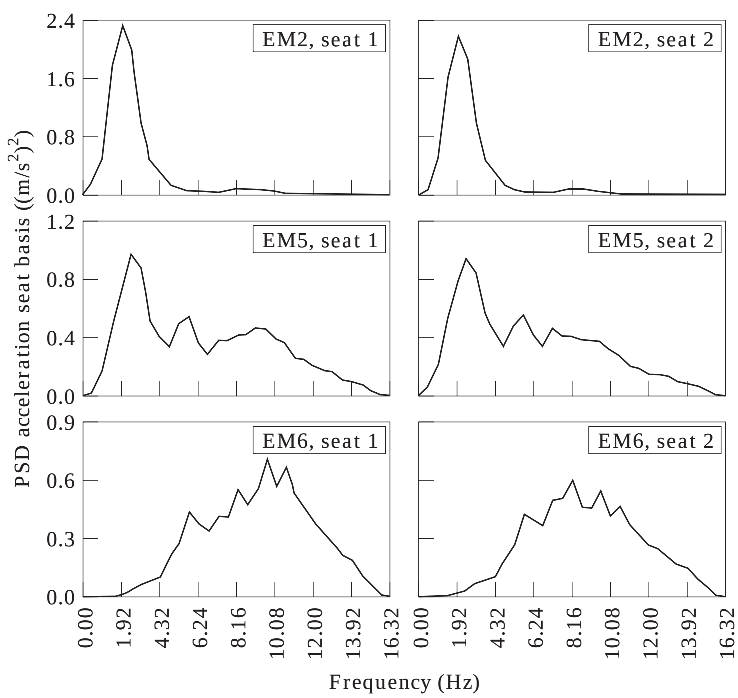

Figure 2. Mean values ($N = 37$) of power spectral densities EM2 (top), EM5 (middle), EM6 (bottom) of the accelerations in the z direction measured at the seat basis (posture S)—for seat 1 (left side), and for seat 2 (right side).

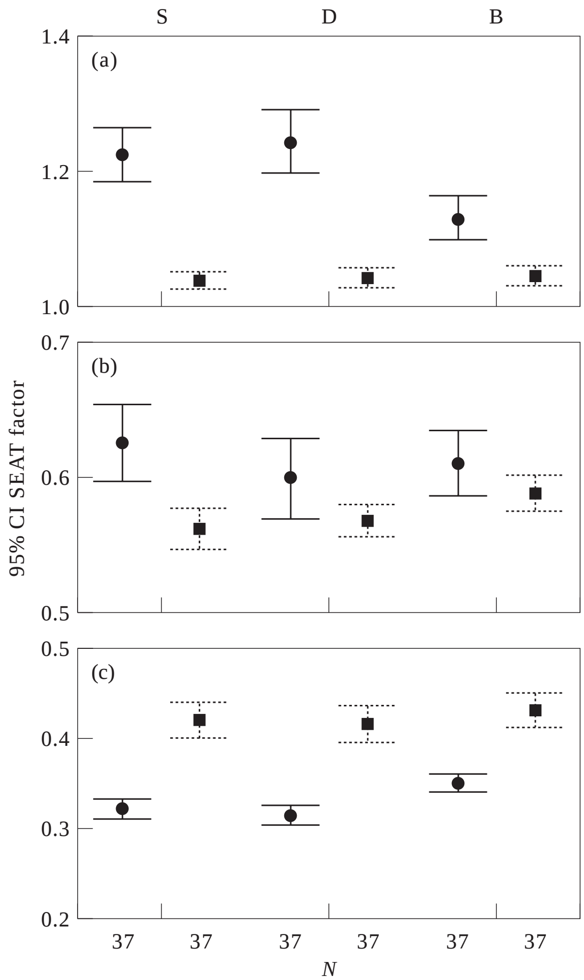

Figure 3. SEAT factors; (a), during exposure with the input spectral class EM2 using seats 1 and 2 in postures S, D, and B; (b), during exposure with the input spectral class EM5 using seats 1 and 2 in postures S, D, and B; (c), during exposure with the input spectral class EM6 using seats 1 and 2 in postures S, D, and B. Key: ●, seat 1; ■, seat 2.

correlation coefficient of 0·997 for repeated measurements indicated a good reproducibility.

4. DISCUSSION

A permanent physical activity has an effect on the body-build or "somatotype" [10]. Greil [10] tested the effect of professions with different physical loads and found a smaller height of workers with a heavy physical load compared with workers in professions which are characterized by frequent walking or prolonged standing and sitting. These differences were significant. The results of Kinghorn and Bittner [11] suggest that the average body mass of truck drivers in the USA is considerably bigger than that of a representative sample of the German male population examined by Greil [10]. The mean body weights reported by Magnusson *et al*. [13] for small groups of bus drivers (83 kg for $N = 40$ in the USA, 78·4 kg for $N = 71$ in Sweden) and truck drivers (84·9 kg for $N = 40$ in the USA, 83·5 kg for $N = 77$ in Sweden) exhibited clearly higher values than the 50th percentile estimated for the total German population [10].

The mass of the light and heavy subjects to be selected for seat testing of earth moving machinery according to ISO/DIS 7096 [7] correspond to the 1st percentile ($55 - 3, +0$ kg) and 99th percentile ($98 - 0, +5$ kg), respectively, of the results obtained by Greil [10]. Both values are considerably smaller than the percentiles reported by Kinghorn and Bittner [11] for the user population. Therefore, a selection of subjects according to reference [4] would be more appropriate and may help to overcome the practical difficulty to find volunteer subjects with the respective body masses. For this purpose, more reliable data on the user populations in different territories are urgently needed.

Another objective of a suitable selection of subjects may be directed towards an assessment of the variability of the SEAT factor that can be expected under practical conditions, when persons with the same body mass use the seat. Our results suggest a minor effect of the body mass on this variability, when two groups of subjects with a mass from 57–60 kg (8 subjects) and from 61–64 kg (8 subjects) were compared. The ranges of the SEAT factors varied in the first group from 4·7 percent (EM6, seat 1) up to 23·3 percent (EM4, seat 1) and from 5·9 percent (EM6, seat 2) up to 20·9 percent (EM2, seat 1) in the second group. The large variation with EM2 may be an unexpected result with regard to the dynamic behaviour like a rigid mass at very low frequencies [14]. A calculation for a single-degree-of-freedom model with a natural frequency of 3·9 Hz and damping ratio of 0·4 shows, however, that the difference between the impedance of the model and a rigid mass equals about 30 percent at 2 Hz; i.e., near the dominant frequency of EM2 (see Figure 2). Hence, the considerable, mass-independent variability of the SEAT factor with EM2 could well be related to the between-subject variability of human biodynamics. In order

TABLE 2

Results of the correlation analysis (Pearson's correlation coefficient with the actual significance level) between SEAT *factor and body mass and* SEAT *factor and body height for the exposure conditions tested*

Exposure condition	Correlation coefficient SEAT factor (body mass)	Actual significance level	Correlation coefficient SEAT factor (body height)	Actual significance level
EM2 S s1	−0·4858	0·002	−0·5901	0·000
EM2 D s1	−0·2833	0·089	−0·5781	0·000
EM2 B s1	−0·1594	0·346	−0·4324	0·008
EM2 S s2	−0·3224	0·052	−0·6081	0·000
EM2 D s2	−0·2362	0·159	−0·4730	0·003
EM2 B s2	−0·3826	0·019	−0·5490	0·000
EM5 S s1	−0·5404	0·001	−0·6309	0·000
EM5 D s1	−0·6052	0·000	−0·6097	0·000
EM5 B s1	−0·6202	0·000	−0·5945	0·000
EM5 S s2	−0·6179	0·000	−0·3783	0·021
EM5 D s2	−0·8849	0·000	−0·6146	0·000
EM5 B s2	−0·6376	0·000	−0·4972	0·002
EM6 S s1	−0·3983	0·015	−0·0594	0·727
EM6 D s1	−0·5330	0·001	−0·0204	0·905
EM6 B s1	−0·4325	0·008	−0·0701	0·680
EM6 S s2	−0·8276	0·000	−0·4491	0·005
EM6 D s2	−0·8086	0·000	−0·4700	0·003
EM6 B s2	−0·7741	0·000	−0·4147	0·011

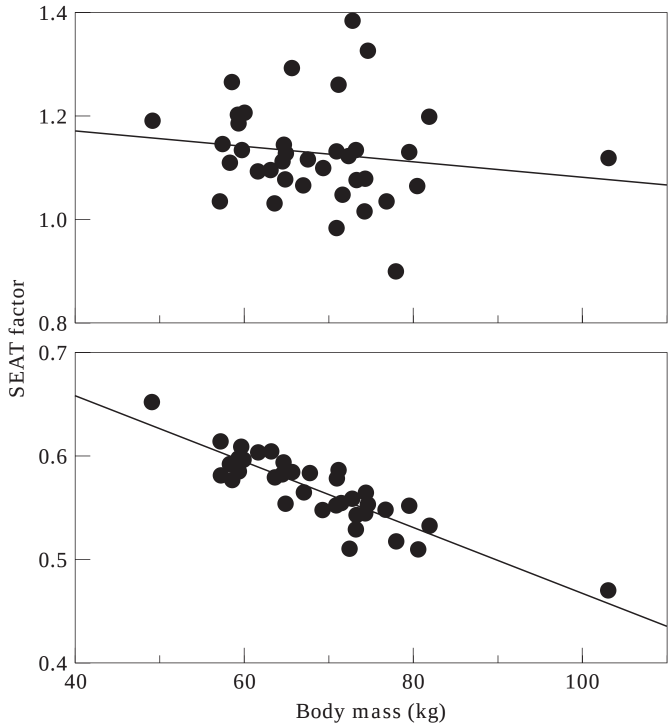

Figure 4. Scatter plots and linear regression lines of the SEAT factors and the body mass, top: for input spectral class EM2 using seat 1 in posture *B* ($N = 37$, $R = 0{\cdot}02$). Bottom: for the input spectral class EM5 using seat 2 in posture D ($N = 37$, $R = 0{\cdot}78$). *R* is coefficient of determination.

to assess the variability of the SEAT factor, testing of several subjects with an average body mass may be recommended.

Only a few publications have dealt with the relations between anthropometric parameters and biodynamics or seat transmissibility. Griffin and Whitham [15] examined the relationship between the seat-to-head transmissibility and three anthropometric parameters of 56 males during sinusoidal exposures with 4 and 16 Hz. They found a significant correlation with the body mass only at 16 Hz, but did not report relations with the SEAT factor. Corbridge [16] examined 15 males exposed to two random vibrations in five postures and reported a significant effect of the posture on the seat transmissibility. Significant relations between the magnitude of peak seat transmissibility and subject's physical characteristics (height and mass) were not observed. Corbridge [16] recommended to test seats with different postures as observed in the vehicles under normal operating conditions. The present data, especially those of the SEAT factor at posture B (see Figure 3), exhibited tendencies similar to those in reference [16].

The significant correlation coefficients between $-0{\cdot}40$ and $-0{\cdot}88$ suggest a functional relationship, but they must not be interpreted as a relation with the body mass as the only causative factor. Formally, they could be an expression of an effect of a third unknown variable or of an interaction between body mass and SEAT factor, too. Also with regard to the sometimes low or missing significance of the correlation (see Table 2), further evidence is required to verify a causal relationship [17]. The visualisation of the present results as scatter plots and linear regression lines (see Figures 4 and 5) demonstrate in several cases a variable effect of the body mass on the SEAT factor and/or considerable

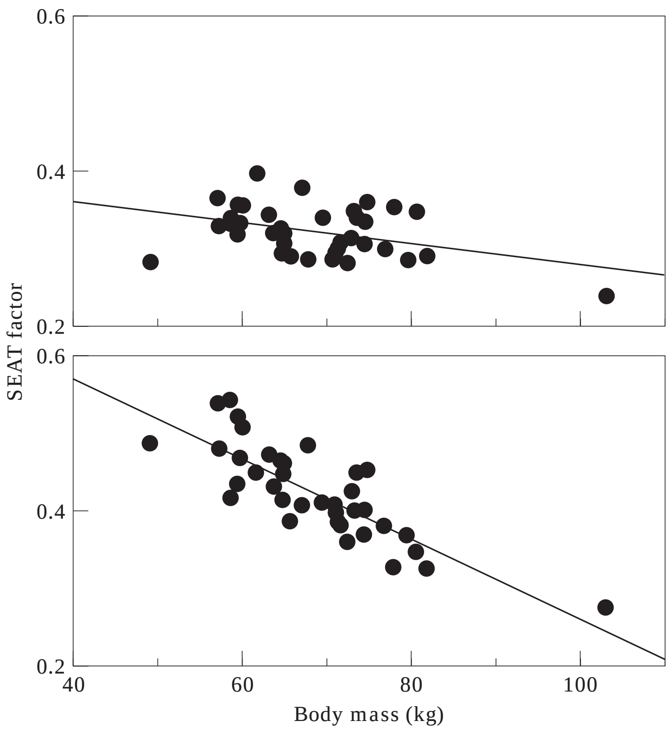

Figure 5. Scatter plots and linear regression lines of the SEAT factors and the body mass during exposure EM6 in posture S, top: using seat 1 ($N = 37$, $R = 0{\cdot}16$). Bottom: using seat 2. ($N = 37$, $R = 0{\cdot}69$). R is coefficient of determination.

ranges of SEAT factors for persons with the same body mass. These results contradict a systematic, general, linear relation between the body mass and SEAT factor that apparently served as main hypothesis for the guidance how to select subjects for seat testing in order to achieve valid test results for a user population.

The multiple linear regression analysis provided hints to anthropometric characteristics that could be significant for the prediction of SEAT factors, with the variable explained by regression considerably varying from 18–80% (cf., Table 3). The total body mass was included in the stepwise multiple regression only for three experimental conditions, in two cases together with the height above the seat. The estimated body mass supported by the seat was included for the exposure with a low magnitude similar to EM6 using seat 2. For eight exposure conditions, mainly those with the highest magnitude, the body height (*KPH*) proved to be the most important characteristic. Altogether, the low accuracy of the prediction may be caused by a deficient selection of anthropometric characteristics. The results also suggest a dependence of the SEAT factors on the inseparably mixed magnitude and frequency content of the input vibration as well as on the combination of the seat type with posture. They could not corroborate the significance of the total body mass of persons as the specific parameter for the selection of test persons in a standard for seat testing.

5. CONCLUSIONS

The ISO/DIS 7096/ [7], uses the SEAT factor as acceptance level. Because only two subjects are recommended for seat testing, one can conclude that the basis for the selection

TABLE 3

Coefficients of determination of the multiple regression analysis (stepwise selection of independent variables with searching for violations of assumptions by an analysis of the residuals (K-S Lilliefors)—prediction of the SEAT factor from selected anthropometric results (cf. the Appendix)

Exposure condition	*ADS*	*BKBT*	*BMI*	*BRI*	*DEB*	*HBS*	*HI*	*KPH*	*KPHS*	*KPM*	*MSI*	*OSU*	K-S (Lilliefors)
EM2 S s1	—	—	—	—	—	—	—	0·348	—	—	—	—	>0·2000
EM2 D s1	—	—	0·658	—	0·704	0·467	—	0·334	—	—	—	—	>0·2000
EM2 B s1	0·278	—	—	—	—	—	—	0·187	—	—	—	—	>0·2000
EM2 D s2	—	—	—	—	—	—	—	0·370	—	—	—	—	>0·2000
EM2 D s2	—	—	—	—	—	—	—	0·224	—	—	—	—	0·1812
EM2 B s2	—	—	—	—	—	—	—	0·301	—	—	—	—	>0·2000
EM5 S s1	—	—	—	—	—	—	—	0·398	—	—	—	—	0·1147
EM5 D s1	—	—	—	—	—	—	—	0·372	—	—	—	0·460	0·0647
EM5 B s1	—	—	—	—	—	0·512	—	—	—	0·385	—	—	>0·2000
EM5 S s2	—	—	—	—	—	—	—	—	—	—	0·382	—	>0·0299
EM5 D s2	—	—	—	—	—	—	—	—	0·812	0·783	—	—	>0·2000
EM5 B s2	—	—	—	—	—	—	—	—	0·472	0·406	—	—	>0·2000
EM6 S s1	—	—	—	0·328	—	0·222	—	—	—	—	—	—	>0·2000
EM6 D s1	—	—	0·397	0·534	0·654	—	—	—	—	—	—	0·594	>0·2000
EM6 B s1	—	0·357	—	—	—	—	—	—	—	—	—	0·272	>0·2000
EM6 S s2	—	—	—	—	—	—	—	—	—	—	0·691	—	>0·2000
EM6 D s2	—	—	—	—	—	—	—	—	—	—	0·656	—	0·1952
EM6 B s2	—	—	—	—	—	—	0·690	—	—	—	0·605	—	0·1487

of subjects was the hypothesis about a strong functional relationship between body mass and SEAT factor, independently of the exposure, seat type and posture. The present results for a large group of subjects contradict this hypothesis. The SEAT factor obtained for one subject does not justify the assumption of the same SEAT factors for the other seat users with the same body mass, since the range of the SEAT factor varied for nearly identical body masses considerably. More than one posture and "a posture appropriate to the application" [4] might be integrated in the seat tests in order to enhance the validity of test results for real working conditions. It is recommended changing the selection of subjects. More investigations are needed in order to characterize anthropometrically the population of vehicle or machinery users for which the seat is intended [4]. Seat testing could further be improved by considering other anthropometric parameters for the selection of subjects like the body height and body mass supported by the seat, and the inclusion of several subjects near the 50th percentile in order to assess the variability of the SEAT factor.

Further research is required on the relations between the biodynamics and the anthropometric parameters of the subjects in order to improve the selection criterion for subjects involved in seat evaluation tests. Future guidelines of seat evaluations should provide evidence for the validity of a representative selection of subjects.

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APPENDIX: DEFINITION OF ANTHROPOMETRIC PARAMETERS [10, 18]

Abbreviation	Anthropometric parameter and equipment for its measurement
ADS	Greatest sagittal diameter of the abdomen when seated Projected linear horizontal distance from the furthest dorsally projecting point in the area of the buttocks to the furthest ventrally forward curved point of the abdomen. Bar compasses
BKB	Pelvic breadth (cristal breadth, bi-cristal diameter) Linear distance between the two lliocristalia (lliac crest point, corresponds to the most lateral point of the lliac crest). Large calipers
BKBT	Chest breadth (thoracic breadth, transverse diameter of the thorax plan) Greatest transverse diameter of the torso at the height of the mesosternum (median breastbone point: corresponds to the middle point of the breast bone at the height of the joints of the fourth rib pair) when breathing softly. Large calipers

TABLE—*continued on next page*

TABLE—*continued*

Abbreviation	
BKU	Chest circumference (normal thoracic circumference) Horizontal circumference of the upper body at the height of the mesosternum (see *BKBT*). Tape measure
BMI	Body mass index—relative body weight, Quotient: KPM/KPH^2 [kg/m^2]
BRI	Quotient: leg length/trunk length [%]
DEB	Bi-deltoidal shoulder width (bi-deltoid breadth, bi-deltoid diameter) Greatest transverse diameter at the head of the musculus deltoidus. The largest sideways projection which determines this dimension occurs in the transition region between the upper arm and the shoulder. Large calipers
GKL	Buttocks–knee length Projected linear horizontal distance from the furthest dorsally projecting point in the area of the buttocks to the furthest distally projecting point on the kneecap of the right knee. Anthropometer
HB	Hip breadth Greatest transverse diameter of the torso in the region of the hips; distance between the coxale (most lateral point of the hip and thigh region). Large calipers
HBS	Greatest width across the hips when seated Greatest linear horizontal distance between the furthest laterally projecting points in the area the thighs and the hips. Beam compasses
HI	Humeral index—Quotient: Elbow breadth/upper arm length
	Anthropometric measurements
KPH	Body height, stature Linear distance of the vertex (highest point of the top of the head in the median plane with the head orientated in the plane of the ear and eyes) from the reference surface. Anthropometer
KPHS	Difference *SFH–SH* *SFH*; Height of seat surface, linear distance of the surface of the seat from the seat reference surface; for each test person, with the upper and lower legs so positioned that they formed an angle of 90°. Anthropometer *SH*; Seated height, linear distance of the vertex from the seat reference surface for an upright seated posture and orientation of the head in the plane of the eyes and ears. Anthropometer
KPM	Body weight, body mass Weighting of ligthly clad body; Soehnle bathroom scale with precision 0·15 kg
OSU	Circumference of the thigh (greatest thigh girth) Greatest horizontal circumference of the thigh for balanced weight distribution between feet and a relaxed muscular system. Tape measure
MSI	Body mass supported by the seat, calculated on the basis of regression analysis [19]
TU	Minimum circumference of waist Smallest horizontal circumference of the torso between the chest and hips when breathing softly. Tape measure