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SEATED OCCUPANT APPARENT MASS CHARACTERISTICS UNDER AUTOMOTIVE POSTURES AND VERTICAL VIBRATION

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The biodynamic apparent mass response characteristics of 24 human subjects (12 males and 12 females) seated under representative automotive postures with hands-in-lap (passengers) and hands-on-steering wheel (drivers) are reported. The measurements were carried out under white noise vertical excitations of 0·25, 0·5 and 1·0 m/s^2 r.m.s. acceleration magnitudes in the 0·5–40 Hz frequency range and a track measured input (1·07 m/s^2). The measured data have been analyzed to study the effects of hands position, body mass, magnitude and type of vibration excitation, and feet position, on the biodynamic response expressed in terms of apparent mass. A comparison of the measured response of subjects assuming typical automotive postures involving inclined cushion, inclined backrest and full use of backrest support with data determined under different postural conditions and excitation levels revealed considerable differences. The biodynamic response of automobile occupants seated with hands in lap, peaks in the 6·5–8·6 Hz frequency range, which is considerably higher than the reported range of fundamental frequencies (4·5–5 Hz) in most other studies involving different experimental conditions. The peak magnitude tends to decrease considerably for the driving posture with hands-on-steering wheel, while a second peak in the 8–12 Hz range becomes more apparent for this posture. The results suggest that biodynamic response of occupants seated in automotive seats and subject to vertical vibration need to be characterized, as a minimum, by two distinct functions for passenger and driving postures. A higher body mass, in general, yields higher peak magnitude response and lower corresponding frequency for both postures. The strong dependence of the response on the body mass is further demonstrated by grouping the measured data into four different mass ranges: less than 60 kg, between 60·5 and 70 kg, between 70·5 and 80 kg, and above 80 kg. From the results, it is concluded that hands position and body mass have the most significant influence on the apparent mass response under automotive posture and vibration.

1. INTRODUCTION

The biodynamic response characteristics of seated human subjects have been extensively reported in terms of apparent mass (APMS), driving-point mechanical impedance (DPMI) and seat-to-head vibration transmissibility (STHT) [1–4]. These studies have contributed

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greatly to the understanding of seated occupant response to whole-body vertical vibration. The biodynamic response characteristics have been applied for development of mechanical equivalent models of seated occupants and anthropodynamic dummies for vibration assessment of seat–occupant system [5–8]. Considerable differences among the reported datasets, however, have been observed due to wide range of test conditions used in different studies, such as sitting posture, frequency and amplitude of vibration excitation, number and physical characteristics of subjects [3]. The ranges of idealized values of apparent mass (APMS), driving-point mechanical impedance (DPMI), and seat-to-head transmissibility (STHT) of seated body biodynamic response under vertical vibration have also been proposed in ISO/DIS-5982 [9] on the basis of a synthesis of various datasets reported under comparable test conditions.

The ranges of idealized values presented in ISO/DIS-5982 [9] are not intended to characterize the biodynamic response of seated human occupants under automotive postures and vibration conditions, since they are based upon data acquired with no back support and under relatively high magnitudes of vertical vibration. The application of the vast majority of reported data to automotive seating postures also raises many concerns due to considerably different posture and vibration conditions of automobiles. The reported studies, with only few exceptions, have considered the subjects seated with either no back support or support with a vertical backrest, hands-in-lap and high levels of input vibration, which do not represent the postures and vibration environment of automobiles [10]. The sitting postures in automotive seats are known to be considerably different from those employed in these studies. These differences mostly arise from inclined cushion, inclined backrest, relatively low-seated height, and occupants making full use of the back support. The sitting postures may be further influenced by the hands position. Vast majority of biodynamic response data have been acquired for sitting posture with hands-in-lap, which could be representative of a posture assumed by a passenger in an automobile. The driver posture mostly involves hands located on the steering wheel. The influence of hands position on the biodynamic response behaviour, however, has not been quantified.

Furthermore, the reported studies, with only few exceptions, have invariably used high levels of input vibration, ranging from 1 to 3 $\mathrm{m/s^2}$ r.m.s. acceleration, to characterize the biodynamic response of seated occupants. Such levels of vibration are considered to be considerably higher than those likely to occur in automobiles. The exceptions to this include the data reported by Holmlund *et al.* [2] under sinusoidal vibration of 0·5 $\mathrm{m/s^2}$ r.m.s. acceleration, Mansfield and Griffin [11] under 0·25–2·5 $\mathrm{m/s^2}$ r.m.s. vertical random vibration and Fairly and Griffin [1] under 0·25 and 0·5 $\mathrm{m/s^2}$ r.m.s. acceleration. These studies, however, were performed with no back support and vertical back support, respectively, and thus do not represent the automotive postural conditions. Moreover, most of the studies have reported mean values of a biodynamic response measure (APMS or DPMI or STHT) derived from data acquired with subjects of considerably different body masses, while the influence of body mass on the biodynamic response has not been clearly identified. The ensuing mechanical models and test dummies are thus derived to characterize the mean biodynamic response, which is perhaps most representative of subjects with body mass in the vicinity of mean mass of the test subject population considered in a study. For automotive seating applications, the knowledge of body mass dependence of the biodynamic response is perhaps important due to strong dependency of energy restoring and dissipative properties of polyurethane foam cushions upon seated body mass [12].

In this study, the apparent mass response characteristics of 24 individuals (12 females and 12 males) are characterized under postural and vibration conditions representative of those

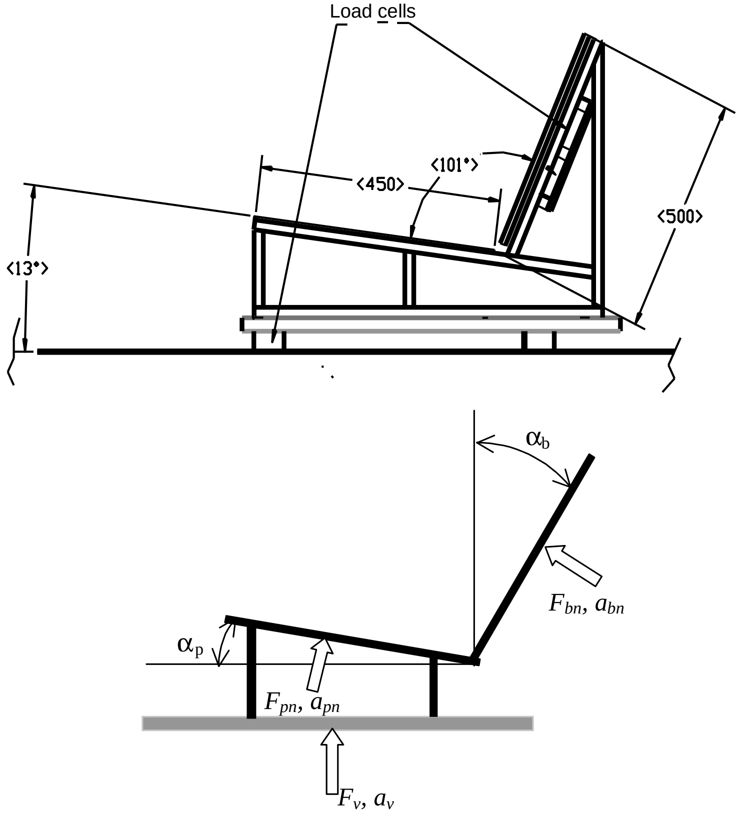

Figure 1. A schematic of the rigid test seat.

applicable to automobile drivers and passengers. The measurements are performed to establish the influence of hands position, body weight, seat-to-pedal distance and vibration excitation level on the seated body apparent mass response. On the basis of these results, the mean apparent mass characteristics of seated automobile occupants are derived for different mass groups.

2. TEST METHODOLOGY

2.1. AUTOMOTIVE SEAT DESCRIPTION

The experiments were conducted using a specially designed rigid seat considered to provide a typical automotive seat geometry, and representative seated postures for automobile drivers and passengers. The seat was designed using a truss structure of hollow square-section steel bars to reduce its total weight and to achieve its natural frequency above 40 Hz. The 450 mm × 450 mm seat pan was installed at an angle of 13° with respect to horizontal, while the angle between the pan and the backrest was fixed at 101°. Figure 1 illustrates a schematic of the test seat used in this study. The seat pan is rigidly fixed on the truss structure, while the backrest is mounted through two identical 222 N force sensors (Sensotec, Model 41), which are installed to measure the total force exerted by the occupant to the backrest. The backrest provided a support surface of 450 mm × 500 mm.

2.2. EXPERIMENTAL SET-UP

The seat assembly was installed on a vertical axis whole-body vehicular vibration simulator (WBVVS) through a force platform consisting of four identical force sensors (Sensotec, Model 41, each rated at 444 N) and a summing junction to measure the total vertical force. The seat with the force platform resulted in seated height of 220 mm, measured from the base of the backrest to the WBVVS platform. The seat and the force platform were positioned to achieve the overall centre of gravity of the seat–occupant system near the geometric centre of force sensors. The weight of the entire assembly including base plate, seat structure and two backrest force sensors was measured as 36 kg. A steering column was also installed on the vibration simulator to realize a driver posture with hands placed on the steering wheel. The steering column formed an angle of 23° with the horizontal surface of the vibration platform (Figure 2). The primary resonance frequency of the seat and its support structure was measured as 45 Hz.

The rigid seat was instrumented to measure the total body force acting on the seat pan and the backrest using six force sensors (four beneath the base plate to measure the vertical force transmitted to the pan, and two in the backrest to measure the back force transmitted normal to the backrest). One accelerometer (Crossbow, Model CXL04) was installed on the seat base to measure the acceleration due to input vertical vibration at the driving point. It should be noted that under pure vertical vibration of the rigid seat, the magnitudes of normal components of accelerations encountered at the backrest and the seat pan are related to the vertical acceleration by the seat geometry:

$$a_{bn} = a_V \sin(\alpha_b) \quad \text{and} \quad a_{pn} = a_V \cos(\alpha_p), \tag{1}$$

where a_V is the magnitude of vertical acceleration measured at the seat base, a_{bn} and a_{pn} are the magnitudes of acceleration components normal to the inclined backrest and pan, respectively, as shown in Figure 1. α_b and α_p are their respective inclination angles with respect to vertical and horizontal axes. For the test seat designed in this study, $\alpha_b = 24°$ and $\alpha_p = 13°$.

In view of the close agreement observed between normalized APMS and STHT functions in terms of magnitudes and primary resonance frequency of the seated body [13], the biodynamic response in this study is characterized by the APMS. The APMS response of an occupant seated on an inclined pan may be defined as the ratio of dynamic force at the occupant–pan interface to the acceleration at the driving point, both being measured along

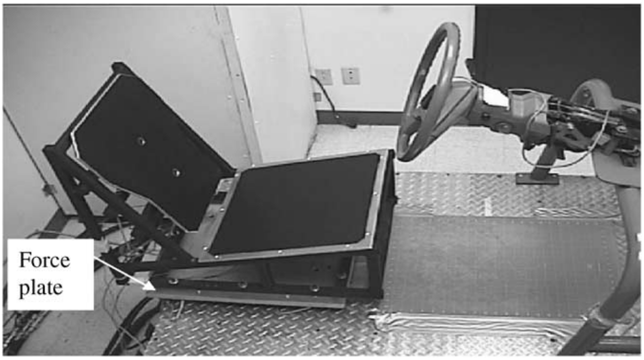

Figure 2. A pictorial view of the test seat and the steering column.

an axis normal to the pan, such that

$$M(\mathrm{j}\omega) = \frac{F_{pn}(\mathrm{j}\omega)}{a_{pn}(\mathrm{j}\omega)}, \tag{2}$$

where $M(\mathrm{j}\omega)$ is complex apparent mass corresponding to angular frequency of excitation ω. $F_{pn}(\mathrm{j}\omega)$ is normal component of force acting on the seat pan, which is related to vertical force F_V measured by the force platform, $F_{pn} = F_V \cos(\alpha_p)$. Considering the geometric relationships between vertical and normal forces and accelerations, the vertical apparent mass of the seated body can be expressed in terms of measured vertical variables:

$$M(\mathrm{j}\omega) = \frac{F_V(\mathrm{j}\omega)}{a_V(\mathrm{j}\omega)}. \tag{3}$$

The measurements were thus performed to measure the vertical force (F_V) and vertical acceleration (a_V) at the seat base.

2.3. TEST SUBJECTS

A total of 24 (12 male and 12 female) subjects were considered for the study. All subjects were considered to be healthy with no signs of musculo-skeletal system disorders. Prior to the test, each subject was given written information about the experiment and was requested to sign a consent form previously approved by a *Human Research Ethics Committee*. The mean, standard deviation, minimum and maximum values of subjects age, body mass and height are summarized in Table 1. The body mass of the test subjects ranged from 48 to 111·4 kg, with mean body mass of 71·2 kg. The age of test subjects ranged from 21 to 53 years with mean age of 39·3 years. While the mean mass of female subject population (63·9 kg) is considerably less than that of the male subject population, relatively wide variations in body mass of female subjects were observed.

2.4. TEST MATRIX

The measurements were performed for each subject assuming two different sitting postures, three different feet positions, and two different types of vertical vibration excitations. Two different postures were realized by placing the hands-in-lap (passenger posture) and hands-on-steering wheel (driving posture), while maintaining the back in contact with the inclined backrest and the feet resting flat on the base platform. The subjects

TABLE 1

Age, body mass and height of male and female participants

Gender	Male	Female	All
Variable	Mean (std. dev., min, max)	Mean (std. dev., min, max)	Mean (std. dev., min, max)
Number	12	12	24
Body mass (kg)	78·5 (13·45, 58, 100)	63·9 (17·14, 48, 111·4)	71·2 (16·81, 48, 111·4)
Height (cm)	176·3 (3·92, 169, 181)	165·4 (5·9, 153, 175)	170·9 (7·42, 153, 181)
Age (yr)	38·2 (8·8, 21, 53)	40·4 (9·3, 26, 52)	39·3 (8·9, 21, 53)

were asked to assume a comfortable but stable posture with respect to the back support and feet position. The subject-selected feet position was considered as the nominal position. The influence of seat-to-pedal distance on the biodynamic response was investigated by considering three different feet positions: the nominal position, referred to as 'M'; 7·5 cm ahead of the 'M' position (referred to as 'L'); and 7·5 cm behind the 'M' position (referred to as 'S'). The biodynamic response characteristics of participants were measured under different types and levels of excitations: white-noise random excitations in the 0·5–40 Hz range with levels of 0·25, 0·5 and 1·0 m/s^2 r.m.s. acceleration, and random vibration measured at the seat base of an automobile on a relatively rough track (1·07 m/s^2 r.m.s. acceleration). The resulting test matrix thus included a total of 24 tests which were performed on each subject in order to characterize the influence of nature and magnitudes of vibration, hands position and feet position on the vertical apparent mass response.

2.5. APPARENT MASS DETERMINATION

The measurements were initially performed on the seat alone under selected excitations. The vertical APMS response of the seat obtained from measured force and acceleration revealed nearly constant magnitude and negligible phase response in the 0·5–40 Hz frequency range. These data were used to perform inertial correction of the APMS response of the human subjects. For each subject assuming a posture with specified hands and feet position, the body weight supported by the seat pan and the backrest were recorded from the static force signals displayed to the experimenter. The static force signals representing the portions of body weight supported by the seat and the backrest were also recorded after each test. These static force signals were compared with those recorded prior to the test to examine the consistency in the subject posture. The test was repeated when difference in static forces acquired before and after a test exceeded 10%.

The whole-body vehicular vibration simulator was operated to produce the motion signals corresponding to a selected excitation and the resulting force and acceleration signals were acquired using a 2-channel B&K 2635 signal analyzer. These signals were subsequently used to compute the apparent mass response function as the ratio of cross-spectral density of force and acceleration (S_{FA}) to the auto spectral density of the acceleration (S_A). The analyses were performed in the 0·1–100 Hz frequency band with resolution of 0·125 Hz. The vertical APMS responses of seated occupants were derived upon performing inertia correction of the measured force data. The corrected real and imaginary components were analyzed to compute magnitude and phase responses corresponding to each test condition. The smoothing of the corrected APMS response data was then performed using moving average technique.

3. RESULTS AND DISCUSSIONS

Figures 3 and 4 illustrate the individual vertical APMS responses of 24 subjects seated assuming passenger (hands-in-lap) and driving (hands-on-steering wheel) postures with nominal feet position (M), respectively, under vertical white-noise vibration of 0·25 m/s^2 r.m.s. acceleration magnitude. The results show considerable scatter in the magnitude and phase responses for both postures, while the scatter is wider for hands-on-steering wheel posture. This scatter in magnitude, however, diminishes at frequencies above 15 Hz for both postures, while the corresponding scatter in the phase response increases. The scatter in magnitude response at lower frequencies can be partly attributed to variations in body

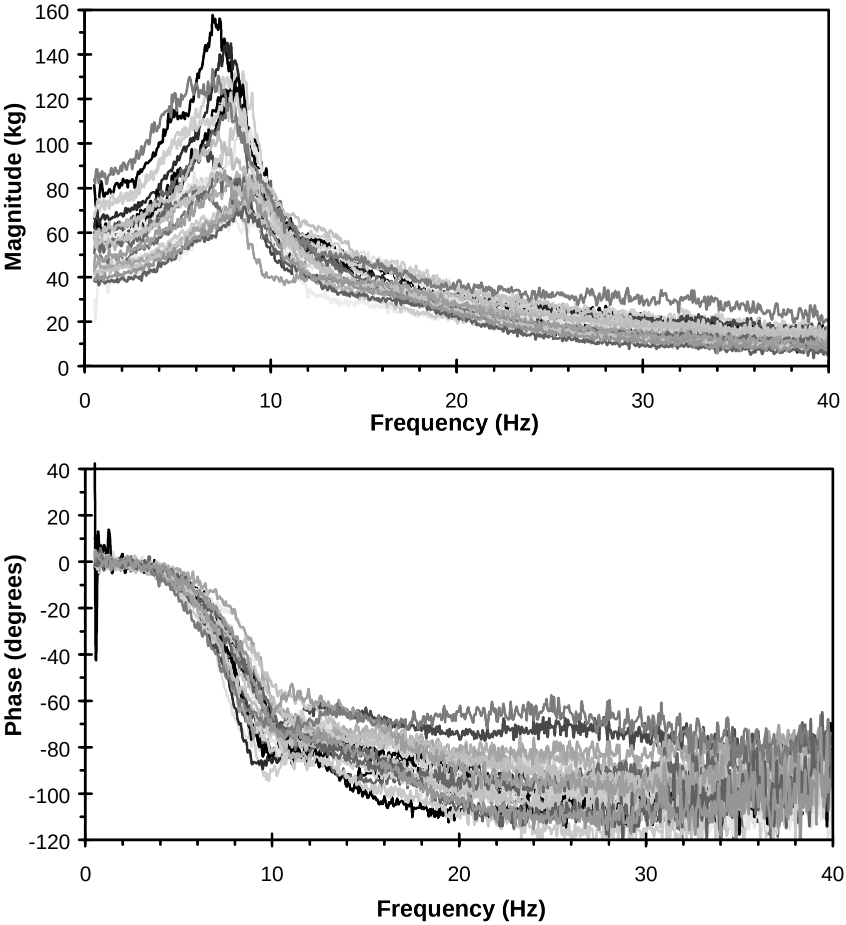

Figure 3. APMS response characteristics of 24 male and female subjects (posture: hands-in-lap; excitation: 0·25 m/s^2 r.m.s. acceleration).

masses, and it could be reduced considerably by normalizing the magnitude data with respect to the body mass supported by the pan. The peak standard deviation of the normalized magnitude data was observed to be in the order of 16% for the hands-in-lap posture and 18% for the hands-on-steering wheel posture, which occurred near the primary resonance frequency. The phase responses under both postures revealed peak standard deviations in the order of 22% occurring at frequencies above 30 Hz.

All the magnitude curves attained for passenger posture exhibit a single peak in the 6·5–8·6 Hz frequency range, while majority of the curves attained for driving posture exhibit two peaks in the 5·1–8·25 and 8–12 Hz ranges. The frequencies corresponding to peak magnitudes of responses due to individual subjects are observed to be considerably higher than those reported in the literature (in the 4·5–5 Hz range) [1, 3, 4]. These frequencies corresponding to the magnitude peaks are considered as the resonance frequencies of the body. The results further show that peak magnitudes attained with a driving posture are considerably smaller than those obtained with a passenger posture. The data acquired under different magnitudes and types of vertical vibration, and feet positions also revealed identical trends, namely lower primary frequency and peak magnitude under a driving posture, and existence of an identifiable secondary peak in the 8–12 Hz frequency range.

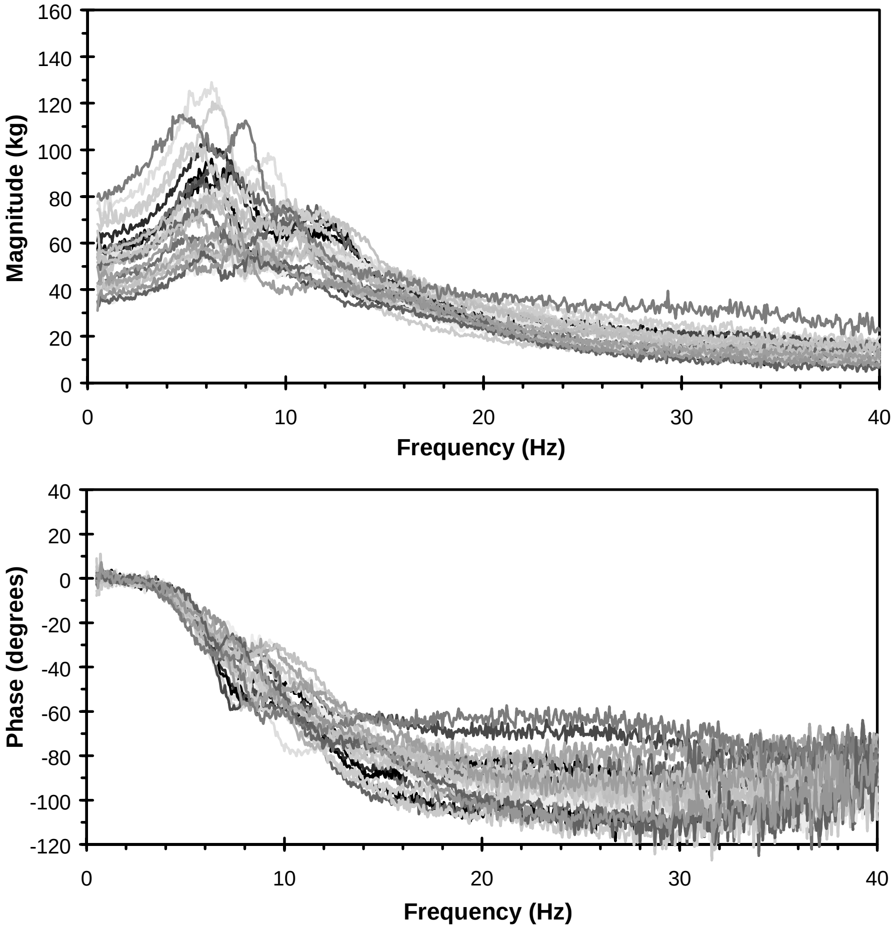

Figure 4. APMS response characteristics of 24 male and female subjects (posture: hands-on-steering wheel; excitation: 0·25 m/s^2 r.m.s. acceleration).

The individual subjects data measured under vertical white-noise vibration of 0·5 m/s^2 r.m.s. acceleration magnitude and feet position M are further analyzed to derive means and ranges of APMS response under different test conditions. The mean values are computed from means of both the real and imaginary components of the 24 datasets. The mean and range of APMS response characteristics derived for a passenger posture are shown in Figure 5 where they are compared with the range of idealized values proposed in ISO/DIS-5982 [9]. As could be expected, considerable differences between the measured and ISO/DIS-5982 proposed responses are observed, owing to the differences in experimental conditions considered in this study, namely, back support, seat geometry, posture, and level of vertical vibration. The peak APMS magnitude obtained in this study is considerably higher than those reported in various studies [1, 3, 4, 8] and in ISO/DIS-5982. The corresponding frequency lies in the vicinity of 7·8 Hz, which is also considerably higher than the reported values (in 4·5–5 Hz range) in most other studies. These differences are most likely attributed to postural differences caused by automotive seat geometry associated with inclined pan, backrest and lower seated height.

Figure 6 illustrates the mean and range of vertical APMS response of 24 subjects measured for a driving posture (hands-on-steering wheel) with nominal feet position (M)

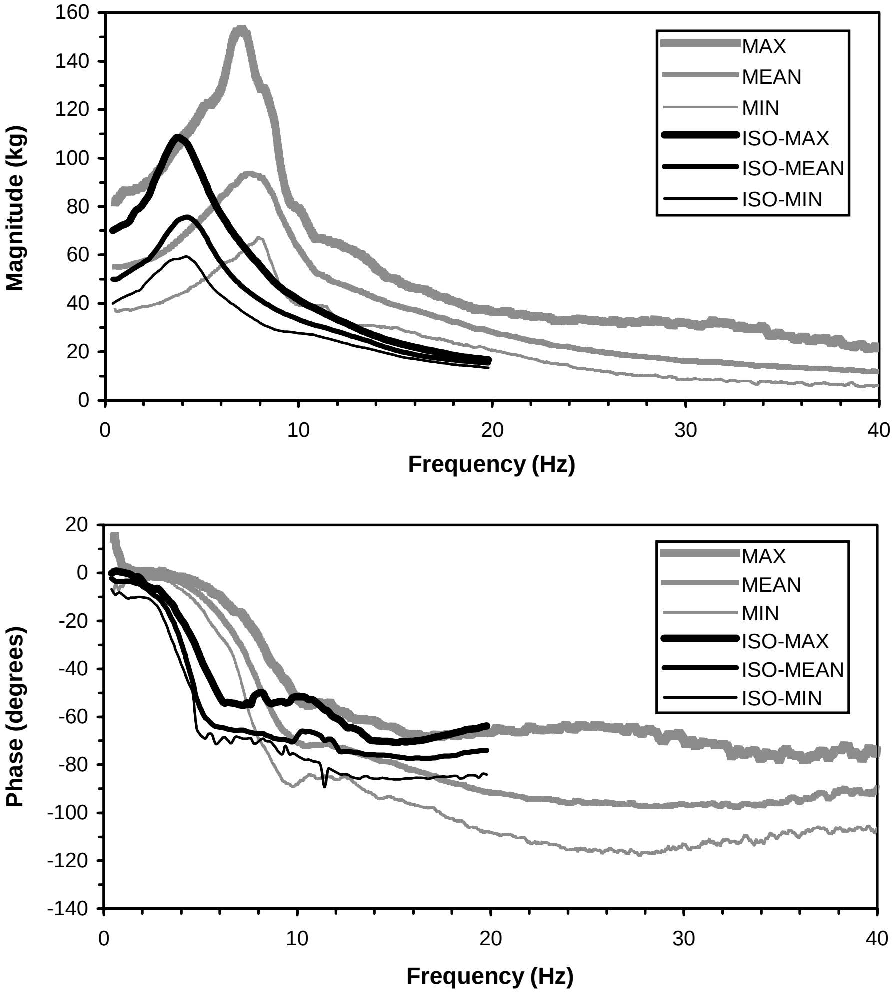

Figure 5. Comparison of mean and range of measured APMS phase and magnitude response with range of idealized values presented in ISO/DIS-5982 (posture: hands-in-lap; excitation: 0·5 m/s^2 r.m.s. acceleration).

and 0·5 m/s^2 r.m.s. vertical acceleration excitation. The mean and range of measured response is also compared with the range of idealized values proposed in ISO/DIS-5982. As expected, the mean and range of measured data applicable to automobile drivers differs considerably from the range of idealized values in view of the differences in experimental conditions involved. The mean measured response obtained for automobile drivers under a vibration excitation level of 0·5 m/s^2 reveals existence of two peaks occurring near 6·1 Hz and in the 10–12 Hz range. The fundamental natural frequency, as evident from the mean measured response is closer to the reported values, although postural conditions considered in this study are considerably different. A comparison of mean curves shown in Figures 5 and 6 suggests that a driving posture yields considerably lower peak apparent mass magnitude and corresponding frequency than a passenger posture. The phase responses under both postures, however, are somewhat comparable. These trends were also observed from the data acquired under different magnitudes and types of vertical excitations, and feet positions. The results are further analyzed to study the effect of automotive postural and

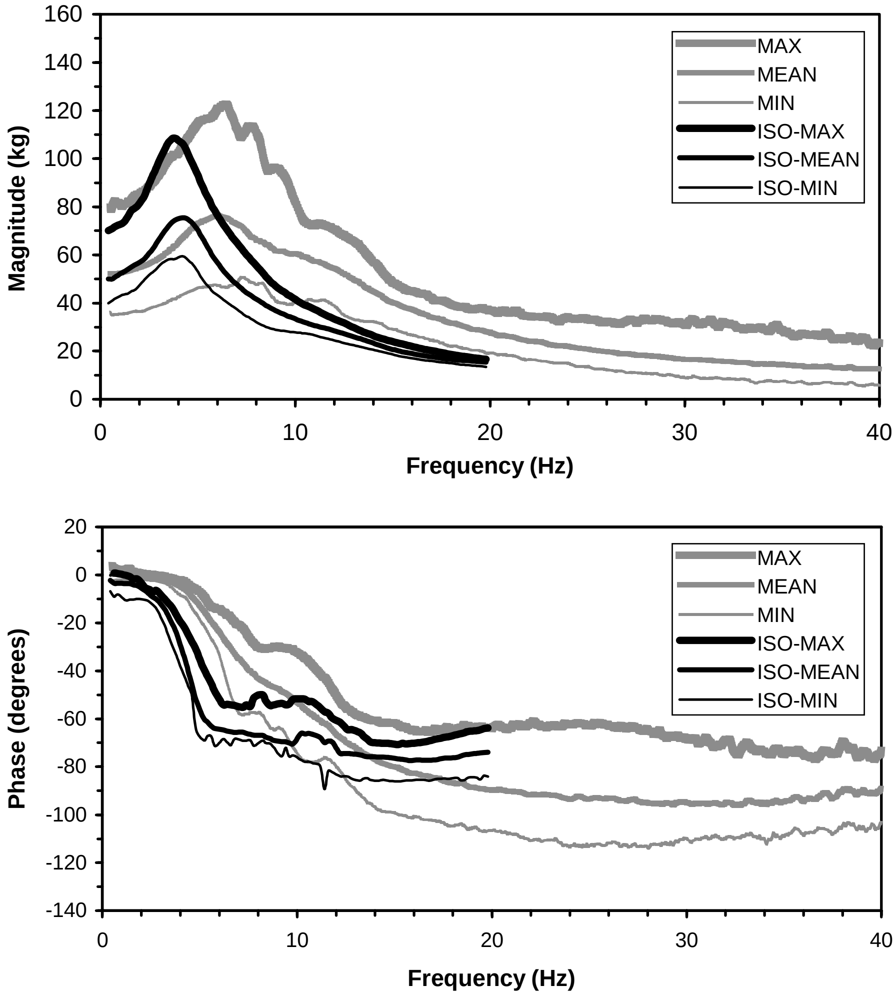

Figure 6. Comparison of mean and range of measured APMS phase and magnitude response with range of idealized values presented in ISO/DIS-5982 (posture: hands on steering wheel; excitation: 0·5 m/s^2 r.m.s. acceleration).

vibration environment, and body mass on the APMS response of subjects under vertical vibration.

3.1. INFLUENCE OF MAGNITUDE AND TYPE OF VIBRATION EXCITATION

The measured data attained under different levels of broadband white-noise and road-measured excitations are examined to identify the influence of magnitude and type of excitation. The mean vertical APMS magnitude responses of the 24 subjects obtained under 0·25, 0·5 and 1·0 m/s^2 r.m.s. broadband, and track-measured excitations, are compared in Figure 7, for both postures. The results show that peak magnitude and corresponding frequency decrease slightly as the magnitude of broadband random excitation increases. Similar trends, attributed to ‘softening’ of human body under higher levels of vibration, have also been reported in many studies [1–3]. The variations in magnitude response due to

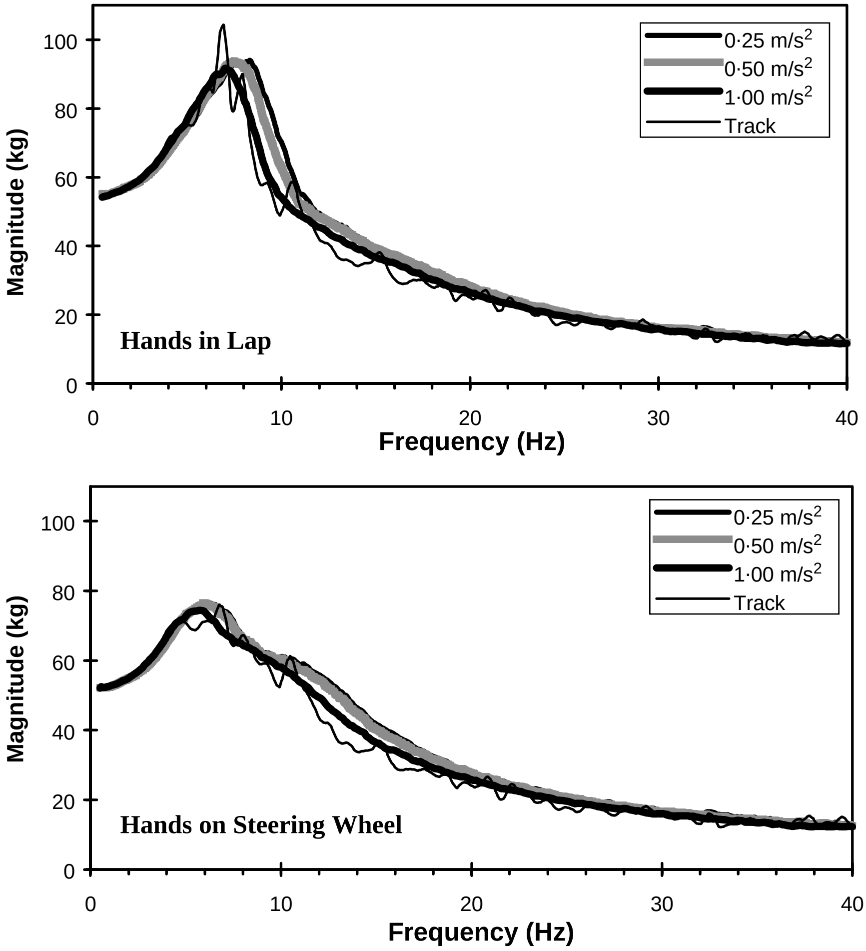

Figure 7. Mean APMS magnitude response attained for different magnitudes and types of vibration excitations.

different magnitudes of vibration are observed to be slightly more important for the passenger posture (hands-in-lap) than for the driving posture (hands-on-steering wheel). The mean magnitude response under track-measured excitation is close to the response under 1·0 m/s^2 white-noise excitation. Since the overall r.m.s. acceleration due to track-measured excitation is 1·07 m/s^2, the effect of types of vibration considered in this study can be considered negligible. Although not reported here, the influence of variations in magnitude and type of vibration on the phase response was also observed to be negligible.

3.2. INFLUENCE OF FEET POSITION

Figure 8 illustrates a comparison of mean APMS magnitude response of 24 subjects corresponding to three different feet positions (L, M and S) and two different sitting postures. Although the results are presented for a white-noise excitation of 0·5 m/s^2 r.m.s. acceleration magnitude, identical trends were observed under different excitations. The

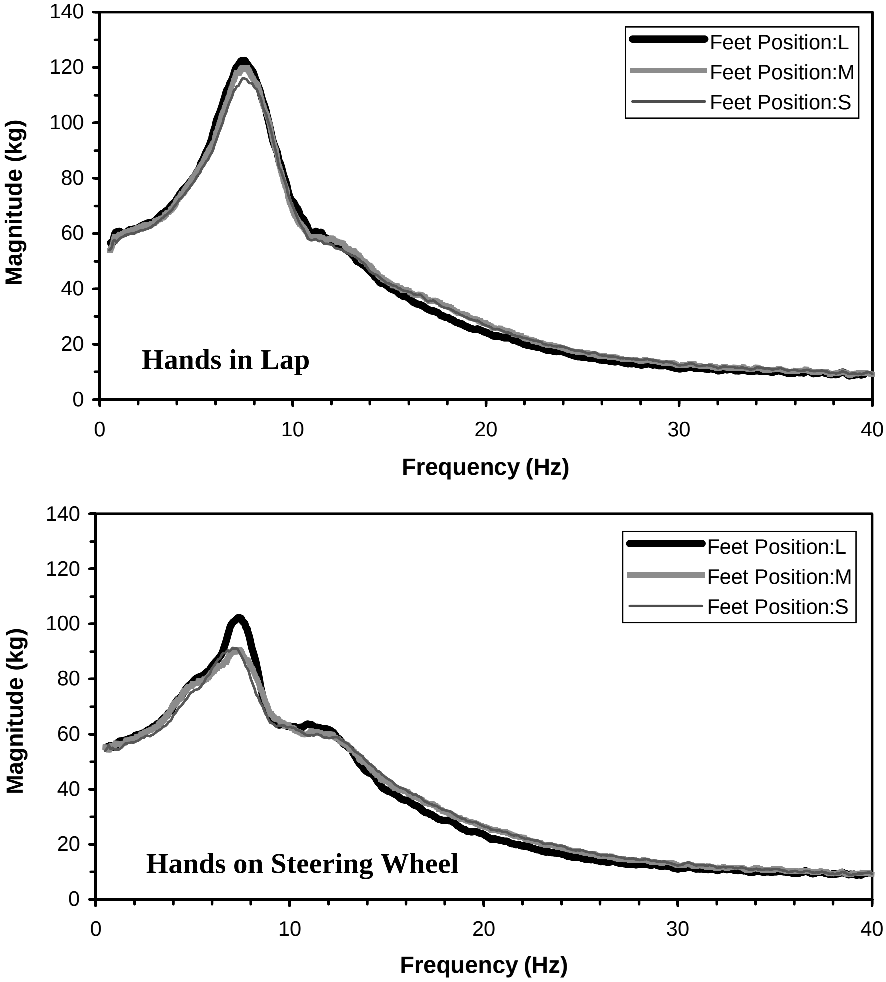

Figure 8. Influence of feet position on the magnitude response for two sitting postures.

results show that for hands-in-lap posture the peak magnitude increases only slightly as the feet are positioned farther away from the seat (L position). The corresponding frequency, however, does not vary with variations in the feet position. The nominal (M) and short (S) feet positions yield similar magnitude response, irrespective of the hands position. The farther location of the feet (L position), however, yields higher peak magnitude under hands-on-steering wheel posture. With the exception of the peak value, the influence of feet position on the magnitude response in the entire frequency range is negligible. The influence of variations in the feet position on the phase response was also observed to be negligible (results not shown).

3.3. INFLUENCE OF SITTING POSTURE

Human occupants in an automobile may assume many different postures. While a driver assumes a sitting posture with hands on the steering wheel, a passenger may assume

TABLE 2

Mean and standard deviations of per cent body mass supported by seat pan and backrest (Feet Position: M)

	Per cent body mass supported			
	Pan		Backrest	
High position (posture)	Mean	Std. Dev.	Mean	Std. Dev.
Lap	76·6	2·31	30·4	4·67
Steering wheel	73·5	2·37	28·1	5·49

a posture with hands-in-lap. The body weight supported by the seat pan and the backrest also varies with hands position. The per cent body mass supported by inclined pan and backrest were evaluated for all subjects as a function of the sitting posture using mean values of static forces measured before and after each test. The results, summarized in Table 2 for subjects with feet position M, show that mean body mass supported by the seat pan is 76·6% with hands-in-lap posture for the automotive seat geometry considered. The mean body mass supported by the pan with hands-on-steering wheel is approximately 3% lower than that with the hands-in-lap posture. The inclined backrest, considered in this study, supports 30·4 and 28·1% of body mass under passenger and driving postures respectively. Larger variations in per cent body mass supported by the backrest were observed, as evident from the standard deviations. These variations were clearly evident for shorter subjects and hands-on-steering wheel posture; these subjects tended to shift their torso to maintain adequate contact with the steering wheel.

The influence of the hands position on the apparent mass response of seated individuals has not been clearly reported in the literature. Although some studies have considered different postures involving variations in hand and arm positions, such as crossed in front of chest, resting in lap or resting on a steering wheel, the distinct influence of hands position has not been clearly identified [14]. A comparison of the overall mean apparent mass magnitude response is shown in Figure 9 for the two different hands positions considered in the study. The overall mean curves were obtained by averaging the mean data corresponding to the different magnitudes of broadband random excitations for feet position M in view of negligible influence of excitation magnitude and feet position observed on the apparent mass response. The mean of means response curves were derived upon consideration of real and imaginary components of APMS response data attained for each individual subject. Figure 9 clearly shows important differences in the mean APMS response due to different hand positions or postures. The differences in static values of APMS are due to differences in body masses supported by the pan under two postures. The peak magnitude of mean vertical APMS response of occupants sitting with hands-in-lap is significantly larger than that obtained with hands-on-steering wheel. These trends were observed for all the excitations considered in the study, as described earlier, and reported in Figures 3 and 4. The mean magnitude response with hands-in-lap appears to be similar to that of a underdamped single-degree-of-freedom system. The resonance frequency of the occupants, as observed from the mean apparent mass response for hands-in-lap, occurs near 7·8 Hz, which was observed to vary in the 6·5–8·6 Hz range depending upon magnitude of excitation and individual subject characteristics. The corresponding mean phase response decreases rapidly to approximately -70° at 10 Hz, and gradually approaches near -90° at higher frequencies.

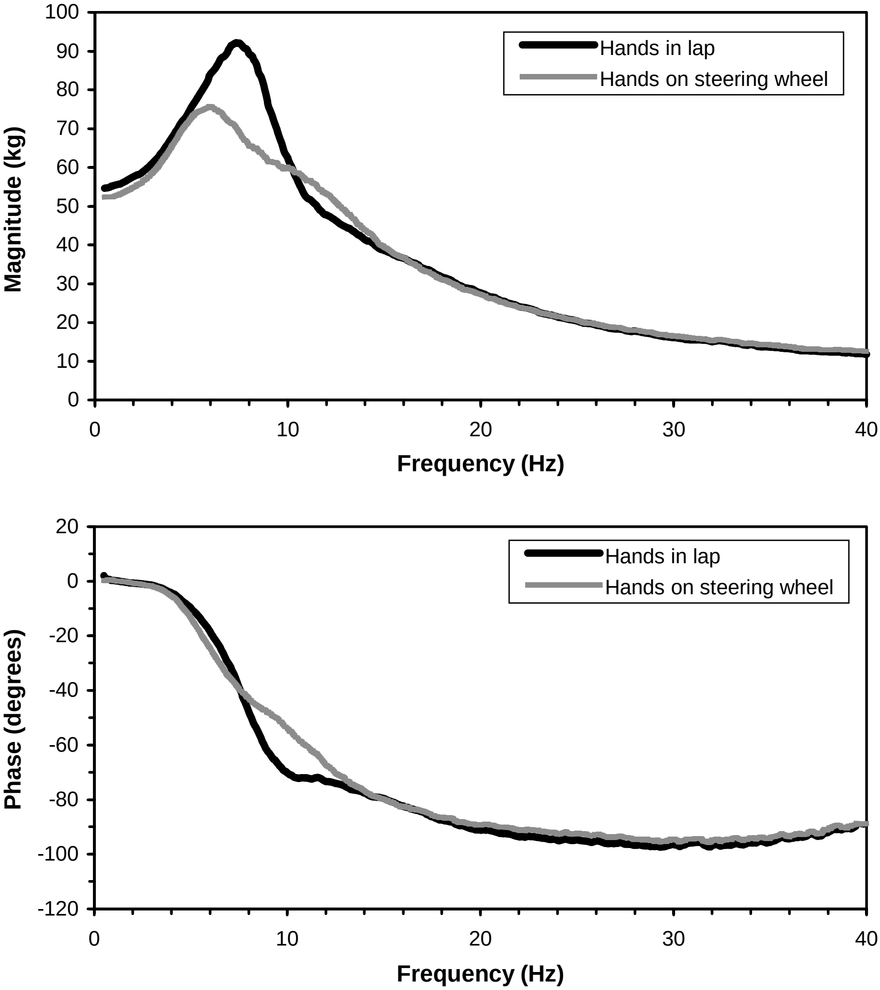

Figure 9. Comparison of mean APMS responses attained for different hands positions or postures.

Having the hands-on-steering wheel yields two peaks in the mean apparent mass magnitude response, irrespective of the excitation level. The primary resonance frequency is considerably lower than that for hands-in-lap and lies near 6·1 Hz (varies in the 5·1–8·25 Hz range under different excitations and individual subject characteristics). The low magnitude of the primary peak suggests well-damped behaviour of the body for the hands-on-steering wheel position. The second resonance frequency appears to occur in the vicinity of 11 Hz. The corresponding mean phase response decreases rapidly to approximately − 45 near 8 Hz and remains considerably less than that attained with hands-in-lap up to approximately 14 Hz. At frequencies above 14 Hz, both postures involving the two hand positions yield almost identical mean magnitude and phase response.

3.4. INFLUENCE OF BODY MASS

The APMS of seated body under vertical vibration is strongly affected by the body weight, as evident from the wide spread of data shown in Figures 3 and 4. The trends

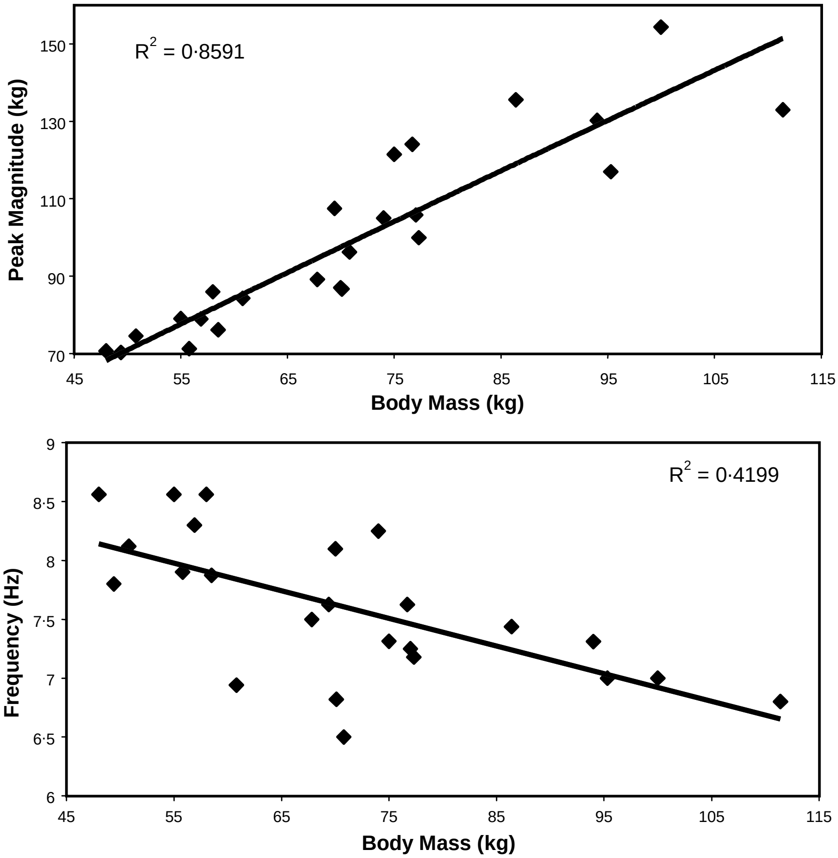

Figure 10. Dependence of peak APMS magnitude and corresponding frequency on the body mass (hands-in-lap posture).

observed in magnitude data suggest that peak values increase with increasing body mass, while the corresponding frequency tends to decrease. This trend in peak magnitude variation, however, is not evident when magnitude data is normalized with respect to body mass supported by the inclined pan. Figure 10 illustrates these trends in peak magnitude and corresponding frequency with the body mass under a passenger posture (hands-in-lap) and 0·5 m/s^2 r.m.s. acceleration excitation. Although considerable dispersion in the data is evident, the trendlines shown in the figure suggest that peak apparent mass magnitude could be positively correlated with increasing body mass while the correlation with frequency is considerably lower. The data acquired under driving posture also reveal a similar trend in peak magnitude, but the trend in the fundamental frequency is very poor, as shown in Figure 11. These results confirm that body mass effectively has some important influence on the apparent mass response of seated automobile occupants.

In this study, the influence of the body mass on APMS response is analyzed by grouping the measured datasets in four mass ranges: below 60 kg; 60·5–70 kg; 70·5–80 kg; and above 80 kg. These mass groups included 8, 5, 6 and 5 subjects, respectively, with mean body masses of 53·4, 67·8, 75·1 and 97·4 kg. Considering negligible effects of magnitude of vibration excitations, the data acquired under three different magnitudes of broadband vibration are combined to derive mean of mean responses for the four mass groups. The

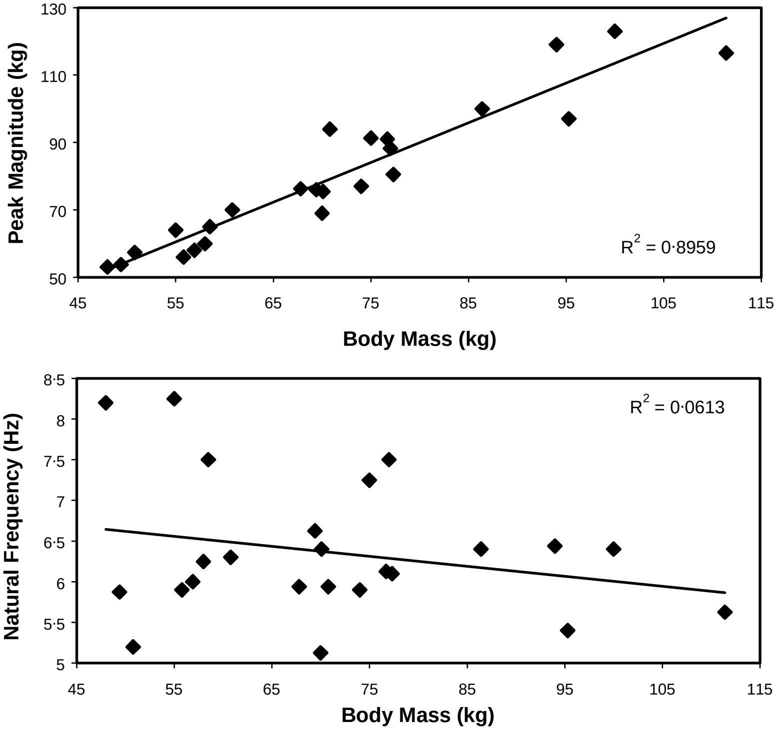

Figure 11. Dependence of peak APMS magnitude and corresponding frequency on the body mass (hands-on-steering wheel posture).

mean of means response curves are derived upon consideration of real and imaginary components of APMS response of individuals within each mass group.

Figure 12 illustrates the mean magnitude response characteristics of seated occupants within the four mass ranges for both sitting postures involving hands-in-lap and hands-on-steering wheel. The results show that the magnitude of the responses for both postures due to heavier occupants is considerably larger than that due to the light-weight occupants, specifically at frequencies below 10 Hz. The body weight dependence of magnitude response, however, is relatively small at excitation frequencies above 10 Hz. The results further show that the primary resonance frequency of light-weight occupants is considerably larger than that of the heavier occupants. There is a tendency for the resonance frequency (frequency corresponding to the peak apparent mass magnitude) to shift to a lower value and for the peak magnitude to increase as the group mean mass increases. The mean curves, shown in Figure 11, are considered to represent the body weight-dependent biodynamic behaviour of seated occupants assuming postures representative of passenger and driving in automobiles, and exposed to vertical vibration in the 0·25–1·0 m/s^2 r.m.s. acceleration range. These mean curves could thus serve as the target curves for development of mechanical equivalent models or anthropodynamic dummies for assessment of vibration performance of automotive seats.

4. CONCLUSIONS

The biodynamic response characteristics of 24 seated human subjects (12 males and 12 females) were established under representative automotive postures applicable to drivers

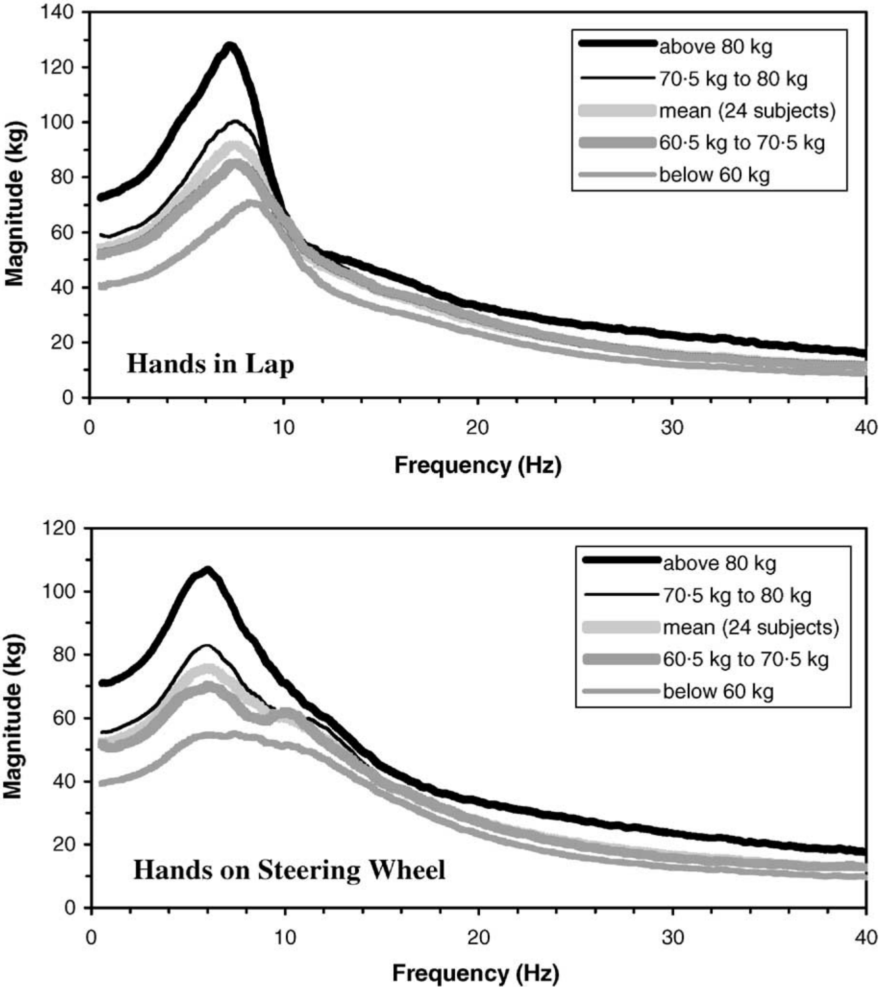

Figure 12. Mean APMS magnitude response as a function of body mass.

and passengers and vertical vibration of different magnitudes in the 0·5–40 Hz frequency range. The results have shown that the vertical APMS responses of occupants seated with an automotive posture differ considerably from those reported in most other studies, which considered significantly different postures and vibration excitation levels. The peak magnitudes of APMS applicable to automobile passengers with hands in lap posture were observed to occur in 6·5–8·6 Hz frequency range, with mean at 7·8 Hz, which is considerably higher than that usually reported (4·5–5 Hz) in the literature. The higher resonance frequency is most likely attributed to different sitting posture caused by inclinations of the pan and backrest, lower seated height and lower vibration excitation levels considered for automobile occupants. Moreover, hands position was observed to have the most influential effect on APMS response, the peak magnitude and corresponding frequency decreasing considerably when hands are moved from lap to the steering wheel (driver posture). A secondary resonance peak in the 10–12 Hz range (mean of 11 Hz) becomes more apparent with hands-on-steering wheel (driver posture), while the dominant frequency is observed to occur in the 5·1–8·25 Hz range, with a mean at 6·1 Hz. At frequencies above 14 Hz, the difference in apparent mass response for the two postures becomes negligible.

The body mass forms another most significant factor that affects the vertical apparent mass response of seated automobile occupants. A higher body mass in general yields higher peak magnitude response and lower corresponding frequency for both passenger and driver postures. The magnitude is also observed to be higher over the entire frequency range when the mean body mass is increased, although the influence is relatively small at frequencies above 10 Hz. While a positive correlation could be established between peak apparent mass magnitude and total body mass, the trend in decreasing fundamental frequency with increasing body mass showed a poor correlation. The results also suggest a relatively negligible influence of feet position, and types and magnitude of vibration excitation considered. From the results, it is concluded that the biodynamic response of occupants seated with automotive postures and subject to vertical vibration need to be characterized, as a minimum, by two distinct functions for two postures: hands-in-lap and hands-on-steering wheel. The application of biodynamic response for studies on automotive seating dynamics also necessitates appropriate considerations of strong influence of the body mass.

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