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DEFINITION OF A RANGE OF IDEALIZED VALUES TO CHARACTERIZE SEATED BODY BIODYNAMIC RESPONSE UNDER VERTICAL VIBRATION

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While a considerable quantity of data has been published on driving-point mechanical impedance, apparent mass and seat-to-head transmissibility magnitude and phase characteristics of seated subjects under vertical whole-body vibration, significant variation is known to exist between various data sets. Such variations may be partly attributed to differences associated with the methodology, experimental conditions or subject population used by various investigators to determine the biodynamic response characteristcs. As part of this study, various published data sets on driving-point mechanical impedance, apparent mass and seat-to-head transmissibility are identified for which the experimental conditions are reported to fall within a prescribed range of conditions for subjects maintaining an erect seated posture without backrest support, while the feet are supported on a vibrating platform. Only those data sets are considered for which the magnitude of vertical sine and/or random excitation is reported to have been maintained below 5 m s^{-2}. A further screening of the data sets defining the magnitude and phase responses of each function is performed by eliminating all data representing outliers in the 0·5–20 Hz frequency range. On that basis, mean and envelopes of the magnitude and phase responses associated with each function are derived in the 0·5–20 Hz frequency range, representing the most probable values likely applicable under the predefined range of conditions. The resulting range of idealized values on the magnitude and phase responses are based on 8 and 7 data sets respectively for driving-point mechanical impedance and apparent mass, while only 4 and 3 data sets respectively were left to define the seat-to-head transmissibility magnitude and phase.

1. INTRODUCTION

The biodynamic response of the seated human body subjected to vibration has widely been assessed in terms of driving-point mechanical impedance or apparent mass and seat-to-head transmissibility. While the first two functions relate to the forces and motion at the point of input of vibration to the body, the last function refers specifically to the transmission of motion through the body.

Over the years, a significant quantity of data has been generated by different investigators to characterize these biodynamic response functions using widely varied

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experimental conditions involving differences in vibration excitations, postural constraints and subject populations. This has resulted in considerable discrepancies among the data reported by different investigators [1, 2], principally in view of the indications that several of the conditions associated with feet support, posture, excitation amplitude and subject mass may have a significant influence on the measured response, particularly with regard to mechanical impedance or apparent mass. Posture and backrest support have most readily been shown to influence seat-to-head transmissibility, the back support resulting in an increase in transmissibility at frequencies above 5 Hz [3], while there have been suggestions that a straight unsupported back would lower the transmissibility at low frequencies and produce more head motion at high frequencies [4]. The effect of posture and backrest support on mechanical impedance has not been well duplicated in all the studies. However, there have been indications that an erect seated posture without backrest support yields significantly higher resonant frequency and magnitude of driving-point mechanical impedance than that for a back supported posture [5]. The use of a footrest vibrating with the platform has been shown to result in lower apparent mass magnitude than when the feet are left hanging freely [6]. Subject mass has undoubtedly been shown to influence apparent mass or mechanical impedance [6], with some indications that heavier subjects would yield an increase in the magnitude of the resonant response, with a decrease in the resonant frequency [5]. Finally, the magnitude of the applied vibration has in certain cases been shown to influence the apparent mass or mechanical impedance by causing a shift in resonant frequency towards lower values with increase in excitation magnitude [6], while in some other cases involving a more restricted amplitude range, such an effect has not been observed [5].

In view of the significant influence of some of the test conditions on the biodynamic response functions, it has been suggested that any attempt to define generalized values to characterize the biodynamic magnitude and phase response functions of the body would not be appropriate unless it could be defined specifically for a particular application or over a limited and well-defined range of conditions.

In an earlier attempt to define generalized values for the biodynamic response of the body, an ISO 5982 Draft document [7] had proposed driving-point mechanical impedance and seat-to-head transmissibility magnitude and phase characteristics of the human body based on a synthesis (i.e., combination and average) of various data sets reported by different investigators for the seated and standing individuals. The proposed values, particularly with regard to mechanical impedance, were subsequently found to deviate quite considerably from those that would likely apply under conditions involving feet and postural constraints, and vibration excitation levels more typical of those likely to prevail in commonly encountered situations such as vehicle driving [1, 2]. It was thus postulated that the synthesis performed in defining the standardized values in the ISO CD 5982 perhaps included data sets, which were generated under too different and broad range of conditions, not representative of those in commonly encountered situations such as vehicle driving. In an effort to provide an understanding of the biodynamic response behaviour of the seated body under commonly encountered work vibration environments, there was a need to define a range of most probable or idealized values to characterize the magnitude and phase responses of the concerned biodynamic functions under a particular range of conditions applicable to the situation considered.

As part of this study, a range of idealized values is defined for the driving-point mechanical impedance, apparent mass and seat-to-head transmissibility of subjects maintaining an erect seated posture without backrest support, while the feet are supported and vibrated. The range of idealized values of the different biodynamic functions are determined by combining, averaging and creating envelopes of various data sets selected from within the published literature. The selected data sets, however, are limited only to those for which the reported experimental conditions include the specified posture and involve vibration excitation levels lower than or equal to $5\,\mathrm{m\,s^{-2}}$, while respecting a set of well defined selection rules. Such conditions and rules, while ensuring their correspondence with the most numerous number of data sets reported in the literature for feet supported subjects, could broadly be associated with those prevailing while driving particular types of vehicles, namely those employed in off-road applications. By extending the frequency span of interest to cover the range from 0·5–20 Hz and by incorporating the most recently available data published in the literature, this synthesis may be considered to constitute a follow-up of some previously initiated work [1].

2. IDENTIFICATION OF RELEVANT DATA SETS

The biodynamic response characteristics of the seated human body reported in the literature were thoroughly reviewed in view of the postural constraints, excitation levels, number and mass of subjects, and the frequency range. In the light of large variations in the reported data and the test conditions employed in different studies, a set of test conditions were formulated which corresponded to those applying to the largest number of data sets that could be found for feet supported subjects, while being considered likely applicable to the work vibration environment of off-road vehicle drivers. The data sets satisfying all of the following requirements were thus selected for the synthesis: (i) data sets specifying either individual or group mean body mass of the test subject population, with attempts to limit the range of individual body masses to within 49–94 kg, corresponding to the range for which the most numerous number of data sets are available; (ii) data sets on driving-point mechanical impedance and apparent mass acquired with feet of the subjects supported and vibrated, although this condition was considered irrelevant for seat-to-head transmissibility; (iii) data sets acquired under vibration excitation amplitudes below $5\,\mathrm{m\,s^{-2}}$, with the nature of the excitation specified as being either sinusoidal or random; (iv) data sets acquired under vibration excitations including spectral components within the 0·5–20 Hz frequency range; (v) data sets acquired under vibration excitations constrained to the vertical direction; (vi) data sets acquired with subject population clearly identified, with particular analysis of those sets based on single subject populations; (vii) data sets reporting the subject posture as being erect seated without backrest support, irrespective of the hands position. The data sets reporting either the magnitude, or both the magnitude and phase of the biodynamic response functions were included for the synthesis.

2.1. DRIVING-POINT MECHANICAL IMPEDANCE AND APPARENT MASS

Of a total of 22 data sets originally identified as meeting some of the defined selection rules for driving-point mechanical impedance or apparent mass, eight were rejected for not satisfying exactly all of the above stated conditions. These included the data reported by Fairley and Griffin [6, 8], Coermann [9], Mertens [10], Miwa [11], Vogt *et al*. [12], Smith [13], and Edwards and Lange [14]. The most common reasons for not considering these data were either that the feet of the subjects were left hanging freely or that the information regarding subject mass or posture was not fully reported. The unreported information relative to the total body mass of the test subjects is among the main reasons for not having considered the mean normalized apparent mass data reported by Fairley and Griffin [6], which otherwise is regarded as a very valuable data set in view of the significantly large subject population involved (60 subjects including 24 men, 24 women and 12 children).

For the purpose of defining a range of idealized values based on various published data sets, it was nevertheless considered that the mass range of the test subjects should at least lie within comparable limits amongst the studies retained for the synthesis in view of the mass dependence of mechanical impedance and apparent mass magnitude. As the mean normalized data reported by Fairley and Griffin [6] was derived by using men, women and children for which the total body mass was left unreported, it appeared very unlikely that the subject mass range could be considered to be comparable to that applying to most other data sets for which individual masses were found to lie between 49–94 kg.

The characteristics related to the subject population, excitation and response function reported for each of the remaining data sets are summarized in Table 1 as they relate to the raw data considered for the synthesis on driving-point mechanical impedance and apparent mass. While all of these data sets reported either mechanical impedance or apparent mass magnitude, only twelve provided the corresponding phase information over specific frequency ranges. The proportion of these data sets reporting mechanical impedance as opposed to apparent mass was established as being 9 to 5 for the magnitude, while 7 to 5 for the phase.

Among the data sets complying with the selection rules, a distinction is made in Table 1 for some data sets, which although reported by the same authors, were generated by using different types and/or levels of excitation. Such is the case in the study by Hinz and Seidel [16] in which mean apparent mass data is reported for two levels of sinusoidal excitation, 1·5 and 3·0 m s^{-2}, further referred to as H&S $-1{\cdot}5$ and H&S $-3{\cdot}0$, respectively. Suggs *et al*. [17] reported mean mechanical impedance data while using a constant displacement sinusoidal excitation but without exceeding an acceleration of 3·5 m s^{-2} r.m.s. within the frequency range considered. Donati and Bonthoux [18] and Boileau *et al*. [5] reported mean mechanical impedance data under both sinusoidal and random excitations of equivalent levels, 1·6 m s^{-2} in the former study while the latter included an average of data acquired at fixed amplitudes ranging from 1·0–2·0 m s^{-2}. These data sets are further identified as D&B-sine, D&B-random, Boileau *et al*.-sine and Boileau *et al*.-random in this study. Seidel *et al*. [21] reported mean mechanical impedance data grouped according to the mass range of the population of subjects involved in the experiments. These data sets, referred to as Seidel 60–70 and Seidel 70–80, represent the mean values of mechanical impedance measured under a fixed range of vibration amplitudes, by using populations of subjects with mass ranging from 60–70 kg and 70–80 kg, respectively.

The data of Holmlund *et al*. [2] represent the total group average based on mean normalized mechanical impedance values reported by using 15 female and 15 male subjects under constant excitation level of 0·5 m s^{-2}. Two apparent mass data sets, acquired under the same conditions, reported by Fairley and Griffin, are considered; one representing a single subject data (F&G-1983 [15]), while the other is obtained by averaging individual data reported for 8 subjects (F&G-1986 [20]). The data extracted from the ISO CD 5982 [7] represent a synthesis of various data sets having been reported under specific conditions. While it is not clear exactly which data sets were considered for the synthesis, the curves are said to apply to subjects for which the excitation levels are within the range of 1–2 m s^{-2}, although it is admitted that for some of the studies considered, the acceleration amplitudes were not specified by the authors. The ISO CD 5982 data considered here are based on data which are said to apply to seated subjects with an upright body position, although it is admitted that posture was often vaguely defined in the studies considered and that it generally included subjects with feet hanging freely. As for the data referred to as Sandover [19], they represent an average of six individually reported apparent mass data.

TABLE 1

Characterization of the data sets considered for mechanical impedance and apparent mass

Reference	Subjects		Excitation			Reported function
	Number	Mass (kg)	Type	Level ($m\,s^{-2}$ r.m.s.)	Freq. range (Hz)	
Fairley and Griffin [15]	1	63	Random Gaussian	1·0	0·25–20	Apparent mass magnitude and phase
Hinz and Seidel [16]	4	56–83	Sinusoidal	1·5	2–12	Mean apparent mass magnitude and phase
Hinz and Seidel [16]	4	56–83	Sinusoidal	3·0	2–12	Mean apparent mass magnitude and phase
Holmlund *et al*. [2]	30	54–93 mean 70	Sinusoidal	0·5	2–100	Mean normalized mechanical impedance magnitude and phase
Suggs *et al*. [17]	11	58–90	Sinusoidal	2·54‡	1·75–10	Mean mechanical impedance magnitude and phase
Donati & Bonthoux [18]	15	49–74	Sine sweep	1·6	1–10	Mean mechanical impedance magnitude and phase
Donati & Bonthoux [18]	15	49–74	Broad band random	1·6	1–10	Mean mechanical impedance magnitude and phase
Sandover [19]	6	52·7–87·2	Random	1·0	1–25	Individual apparent mass magnitude and phase
Fairley and Griffin [20]	8	57–85	Random	1·0	0·5–20	Individual apparent mass magnitude and phase
Seidel *et al*. [21]	11	60–70	Random (off-road machinery)	< 1·4	0·5–20	Mean mechanical impedance magnitude
Seidel *et al*. [21]	14	70–80	Random (off-road machinery)	< 1·4	0·5–20	Mean mechanical impedance magnitude
ISO CD 5982 [7]	39	51–93·8	Sinusoidal	1·0–2·0†	0·5–31·5	Mean mechanical impedance magnitude and phase
Boileau *et al*. [5]	6	69·6–80·9 mean 75·4	Sinusoidal sweep	1·0–2·0	0·5–10	Mean mechanical impedance magnitude and phase
Boileau *et al*. [5]	6	69·6–80·9 mean 75·4	Random White noise	1·0–2·0	0·5–10	Mean mechanical impedance magnitude and phase

† $m\,s^{-2}$; ‡ mm peak-to-peak.

Under harmonic excitations, the driving-point mechanical impedance magnitude can be expressed in terms of the apparent mass by using the relation

$$Z(j\omega) = j\omega M(j\omega) \tag{1}$$

where $Z(j\omega)$ represents the complex driving-point mechanical impedance function and $M(j\omega)$ the complex apparent mass function at angular frequency ω. In the above $j = \sqrt{-1}$.

Although there has been a tendency in the literature to report the apparent mass and mechanical impedance interchangeably, their relation with respect to the seat-to-head transmissibility function has been shown to be quite different [22]. In fact, it has been reported that the apparent mass is more closely related to the seat-to-head transmissibility than the mechanical impedance in yielding the primary resonant frequency of the body. In view of these differences between the apparent mass and the driving-point mechanical impedance, the analysis of the data in this study is performed separately for each of these functions by considering the data sets identified in Table 1 and by transforming them to the desired function whenever necessary.

Figure 1(a) presents a comparison of the driving-point mechanical impedance magnitude over the 0·5–20 Hz frequency range derived from the 14 reported data sets identified in Table 1. These data sets are also presented by their equivalent apparent mass magnitude in Figure 2. The corresponding phase data related to the driving-point mechanical impedance response is presented in Figure 1(b). The apparent mass phase data is not presented since, by definition, it would differ from the mechanical impedance phase only by a constant 90° phase angle. Although the conditions pertaining to these data sets are reported to lie within the common bounds established from the selection rules, significant variations, which may be more apparent over specific frequency ranges, are observed among the data. An examination of Figures 1(a) and 2 further reveals significant larger variations among the reported mechanical impedance magnitude. In contrast, the apparent mass magnitude data sets appear to be closer together, particularly towards higher frequencies, since the frequency dependence present in the mechanical impedance function is eliminated when the apparent mass function is employed.

2.2. SEAT-TO-HEAD TRANSMISSIBILITY

A total of 10 data sets on the vertical seat-to-head transmissibility of the seated human body were initially identified to satisfy some of the imposed selection rules. Two sets reported by Griffin *et al*. [23] were subsequently rejected, since the mass information of the test subjects had not been specified. The number of subjects used, and the nature and level of vibration excitations employed in each of the remaining data sets are summarized in Table 2. While all the studies reported seat-to-head transmissibility magnitude, only five provided the corresponding phase information. The majority of the data were acquired by using sinusoidal excitation with vibration levels usually much higher than those used for defining mechanical impedance or apparent mass. While the levels used for mechanical impedance or apparent mass were most often maintained below 2 m s^{-2}, the majority of seat-to-head transmissibility responses were acquired under levels ranging from 1·5–5·0 m s^{-2}.

Most of the data sets identified in Table 2 were obtained by using a considerable number of subjects, except for that reported by Coermann [9], which relates to only one subject. Hinz and Seidel [16] reported mean seat-to-head transmissibility data under two different levels of excitations, 1·5 m s^{-2} and 3·0 m s^{-2} (H&S $-$1·5 and H&S $-$3·0), using 4 subjects.

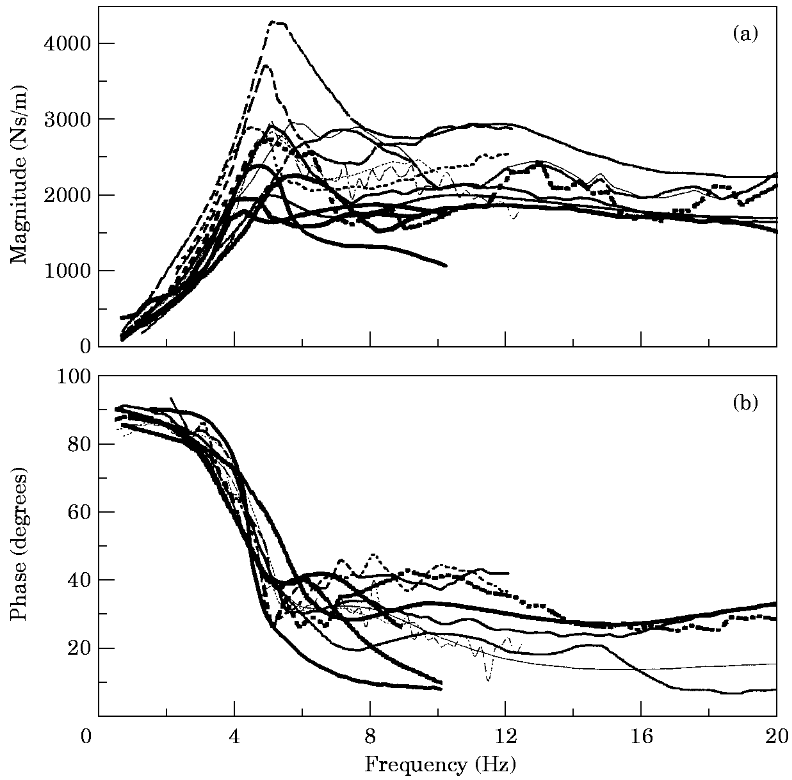

Figure 1. (a) A comparison of the magnitudes of the driving-point mechanical impedance reported under the defined conditions. ——, Suggs *et al*. [17]; — — —, Sandover [19]; ----, F&G-1983 [15]; — - —, D&B-sine [18]; — - - -, D&B-random [18]; ——, F&G-1986 [20]; – – – -, H&S-1·5 [16]; -----, H&S 3·0 [16]; –––––, ISO CD 5982 [7]; ––––––, Seidel 60–70 [21]; ——, Seidel 70–80 [21]; – – – –, Holmlund *et al*. [2]; · · · ·, Boileau *et al*.-sine [5]; ·-·-·-·-, Boileau *et al*.-random [5]. (b) A comparison of the driving-point mechanical impedance phase angles reported under the defined conditions. ——, Suggs *et al*. [17]; — — —, Sandover [19]; ----, F&G-1983 [15]; — - —, D&B-sine [18]; — - - -, D&B-random [18]; ——, F&G-1986 [20]; – – – -, H&S-1·5 [16]; -----, H&S 3·0 [16]; –––––, ISO CD 5982 [7]; – – – –, Holmlund *et al*. [2]; · · · ·, Boileau *et al*.-sine [5]; ·-·-·-·-, Boileau *et al*.-random [5].

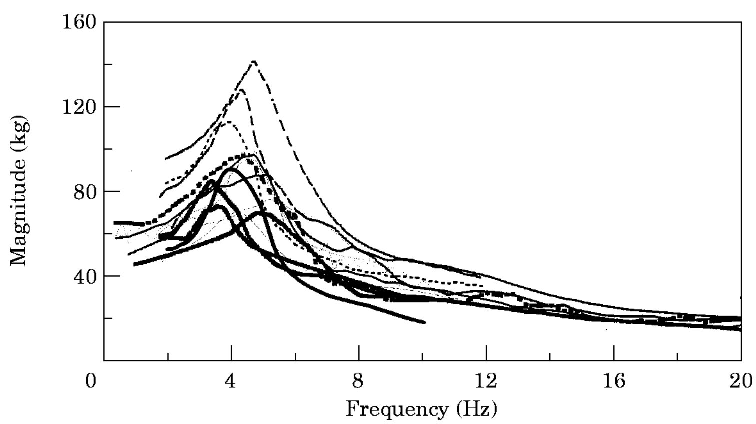

Figure 2. A comparison of the magnitudes of the apparent mass reported under the defined conditions. ——, Suggs *et al*. [17]; — — —, Sandover [19]; ----, F&G-1983 [15]; — - —, D&B-sine [18]; — - - -, D&B-random [18]; ——, F&G-1986 [20]; – – – –, H&S-1·5 [16]; ----, H&S 3·0 [16]; –––––, ISO CD 5982 [7]; ––––––, Seidel 60–70 [21]; ——, Seidel 70–80 [21]; – – – –, Holmlund *et al*. [2]; · · · ·, Boileau *et al*.-sine [5]; ·-·-·-·-, Boileau *et al*.-random [5].

TABLE 2

Characterization of the data sets considered for seat-to-head transmissibility

Reference	Subjects: Number	Subjects: Mass (kg)	Type	Excitation level ($m\ s^{-2}$ r.m.s.)	Freq. range (Hz)	Reported component
Mertens [10]	9	57–90	Sinusoidal	4·0	2–20	Mean magnitude and phase
Hinz and Seidel [16]	4	56–83	Sinusoidal	1·5	2–12	Mean magnitude and phase
Hinz and Seidel [16]	4	56–83	Sinusoidal	3·0	2–12	Mean magnitude and phase
Vogt, Coermann and Fust [12]	10	70	Sinusoidal	5†	2–15	Mean magnitude
Paddan and Griffin [3]	12	58–81 mean 70·8	Random Gaussian	1·75	<25	Individual magnitude and phase
Coermann [9]	1	84	Sinusoidal	<5	<20	Magnitude
Zimmermann and Cook [24]	30	77·6	Sinusoidal	1	4·5–16	Mean magnitude
ISO CD 5982 [7]	50	75	Sinusoidal	2·0–4·0†	0·5–31·5	Mean magnitude and phase

† $m\ s^{-2}$

The values reported by Mertens [10] and considered in this study are the means of data obtained from the superposition of a static acceleration of 1 $\boldsymbol{g}$, representing normal gravity, and of a dynamic vibration environment of 4 m s^{-2}. Vogt *et al*. [12] were amongst the earliest investigators to provide mean data complying with the selection rules, while Paddan and Griffin (P&G-1988) [3] were amongst the latest. Zimmermann and Cook [24] recently published mean data on the seat-to-head transmissibility established using 30 subjects, although the data were reported only at specific discrete frequencies between 4·5 and 16 Hz, while the corresponding phase information was not provided. Although such data, referred to as Z&C-1997, are provided for different pelvic orientations, only those defined for the neutral position are considered in this study. The data proposed in the ISO CD 5982 [7] represent a synthesis of data which are said to represent the mean transmissibility of 50 subjects with mean mass of 75 kg exposed to vibration excitation levels betwen 2 and 4 m s^{-2}. It is generally admitted that, in some of the studies considered for deriving the ISO CD 5982 curves, the vibration excitation levels were not given, nor was the body position specified, and that the synthesis did not distinguish between values pertaining to the sitting and standing body positions. Although such a distinction between standing and sitting was not considered critical for the purpose of defining seat-to-head transmissibility, the uncertainties and lack of a clear identification of the data sets involved in deriving the ISO CD 5982 data contributed in raising some doubts as to whether or

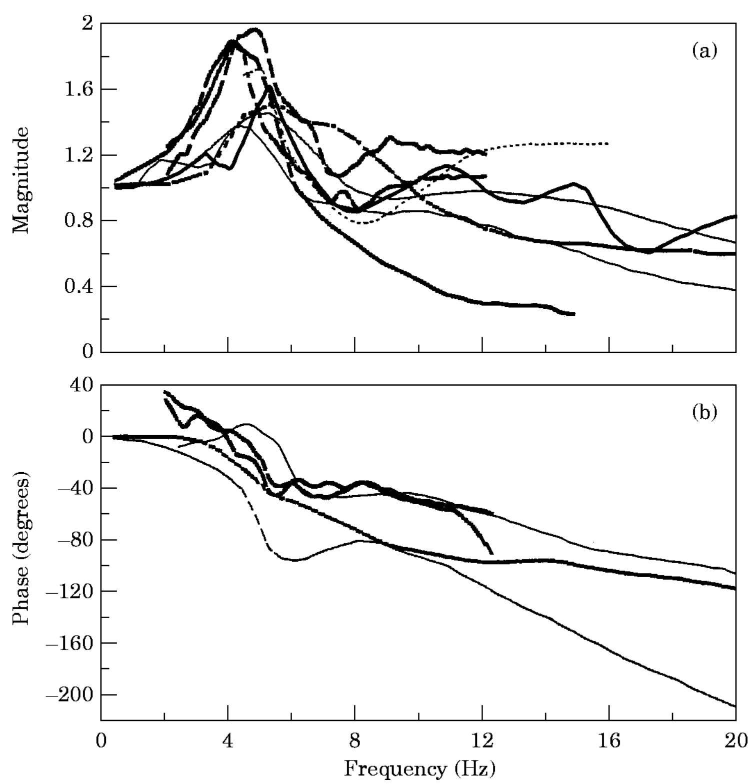

Figure 3. (a) A comparison of the magnitudes of the seat-to-head transmissibility reported under the defined conditions. ——, Coermann [9]; — — —, Vogt *et al*. [12]; ----, Mertens [10]; — - —, H&S −1·5 [16]; — - - -, H&S −3·0 [16]; ——, P&G [3]; – – – –, ISO CD 5982 [7]; ----, Z&C [24]. (b) A comparison of the seat-to-head transmissibility phase angles reported under the defined conditions. ----, Mertens [10]; — - — ·, H&S −1·5 [16]; — - - -, H&S −3·0 [16]; ——, P&G [3]; – – – -, ISO CD 5982 [7];

not such data should be incorporated as part of the final data synthesis, although satisfying the selection rules defined earlier in section 2.

Figure 3(a) presents a comparison of the seat-to-head transmissibility magnitude data derived from the various data sets identified in Table 2, while Figure 3(b) presents a comparison of the corresponding phase data, whenever available. In comparison with the data on mechanical impedance and apparent mass, significantly fewer data sets are available on seat-to-head transmissibility, while more variations are found to exist between the various data sets over most of the frequency range considered. This may be expected in view of the complexities associated with the measurement itself and owing to the fact that the function, being a transfer function through the body, is relatively more sensitive to some of the experimental conditions than the apparent mass or the mechanical impedance.

3. DATA SYNTHESIS

For each of the biodynamic response functions, such as driving-point mechanical impedance, apparent mass and seat-to-head transmissibility, the data synthesis is accomplished by simple averaging of various data sets which present similar trends and by smoothing and creating an envelope about the mean, representing the range within which the values are most likely to occur for the specific situation considered. The synthesis is performed for both magnitude and phase response functions for the driving-point mechanical impedance and the seat-to-head transmissibility, while the magnitude alone of the apparent mass is considered. From analysis of the data presented in Figures 1–3, it is seen that some isolated data sets present anomalies with respect to the trends established from the majority of the other data sets.

Although all of the identified data sets were extracted from studies in which the reported conditions matched for the most part the previously defined selection rules, it is difficult to establish the sources of variability between the various data sets. While every effort was made to restrict the range of experimental conditions to those defined by the selection rules, there most certainly remained unreported differences in experimental procedures, subject populations, postural constraints, and types and levels of vibration excitations used by the various investigators which could have contributed to the observed variations between the data sets. Although it would be impossible to eliminate completely these sources of variation when considering data originating from different studies, their relative influence may be minimized while performing the synthesis by rejecting the data presenting anomalous behaviour and retaining only those data sets for which similar trends may be observed. Such a procedure is particularly applicable to single subject data for which any deviation of trends should be viewed as a sufficient justification for its exclusion from the final synthesis.

In an effort to show the extent of the variations between the various data sets and to identify which should be excluded from the synthesis, the standard deviation on the mean values is computed as a function of frequency for different combinations of data. The combination presenting the least variation (i.e., lowest standard deviation) over the broadest frequency range is subsequently retained for the synthesis and for defining the most probable or range of idealized values applicable to the seated human body under the specified conditions.

3.1. DATA SELECTION: DRIVING-POINT MECHANICAL IMPEDANCE MAGNITUDE

In an effort to establish the range of idealized values of the driving-point mechanical impedance magnitude, which are most likely considered applicable under the specified conditions, the selected data sets are further examined to identify apparent outliers. An examination of the various mechanical impedance magnitude data sets, illustrated in Figure 1(a), reveals that the majority of the curves show certain important trends. The majority of the data sets exhibit a dominant peak in the 4–6 Hz frequency range, followed by a decline and a second weakly apparent peak within the 10–14 Hz frequency range. While the absolute magnitudes observed in various studies clearly differ, most curves show similar trends or at least have their magnitudes within close bounds except for a few isolated data sets. Such is the case for the ISO CD 5982 [7] data which definitely form an outlier over most of the frequency range. The proposed values are generally much higher than those provided by the other data sets, particularly near the primary resonant frequency. This apparent overestimation of the impedance magnitude with respect to those reported in several other studies has also been reported by Holmlund *et al*. [2], and there have been suggestions that this might be due to the fact that the ISO CD 5982 data perhaps applies more closely to subjects with feet hanging freely than to those with feet supported. The Hinz and Seidel data [16] reported under an excitation level of $1{\cdot}5\ \mathrm{m\ s^{-2}}$ (H&S $-1{\cdot}5$) are also observed to follow trends similar to those of the ISO CD 5982 data in showing magnitudes which are considerably higher than that for most of the other data sets over most of the frequency range considered. The data reported by Hinz and Seidel [16] under $3{\cdot}0\ \mathrm{m\ s^{-2}}$ (H&S $-3{\cdot}0$) present also some concerns with respect to the other data sets in constituting a potential outlier towards the lower and higher extremities of the frequency range considered. Another anomaly is observed with the Suggs *et al*. data [17] at frequencies above approximately 6 Hz, where the reported magnitude is considerably lower than that for the other data sets, while the pattern showing a continued decrease of magnitude with frequency contradicts that observed for most other data sets in a similar frequency range. The data reported by Seidel *et al*. [21] and identified as Seidel 60–70 and Seidel 70–80 may be considered to be somewhat anomalous in that both data sets show a peak magnitude occurring at a frequency ranging from 6–8 Hz, thus distinctly higher than the 4–6 Hz range established from most of the other data sets. While most data sets indicate a decrease of magnitude within the 6–8 Hz frequency range, followed by a subsequent increase at higher frequencies, these two data sets with peaks occurring in the 6–8 Hz frequency range contradict with the generally observed trend. Apart from the data sets which have just been identified as showing a peculiar behaviour, the remainder of the data sets identified in Table 1, including the single subject data of Fairley and Griffin [15], were considered to follow the generally observed trends.

The mean and standard deviations of the impedance magnitude are further computed for different combinations of the data sets in an effort to identify the definite outliers. Figure 4 presents the distribution of absolute values of the standard deviation on the mean computed as a function of frequency for different combinations of the data sets identified in Table 1 on mechanical impedance magnitude. The first case involves the combination of all 14 data sets identified in Table 1, while subsequent cases gradually excluded some of the data sets which were identified as showing anomalies with respect to the majority of data. The exclusion of data sets reported in ISO CD 5982 [7], H&S $-1{\cdot}5$ [16] and Suggs *et al*. [17] yields considerable decrease in the absolute standard deviation over most of the frequency range concerned. The results of computations involving combinations of data sets with other exclusions such as H&S $-3{\cdot}0$, Seidel 60–70 and Seidel 70–80 data sets are also shown in Figure 4. Overall, the most significant standard deviation value is observed to occur in the 4 to 6 Hz frequency range, indicating that the most important variability amongst the studies on impedance magnitude occurs at frequencies near the main body resonance. The results presented in Figure 4 suggest that the exclusion of the data sets reported in ISO CD 5982 [7], H&S $-1{\cdot}5$ [16], H&S $-3{\cdot}0$ [16], Suggs *et al*. [17], Seidel

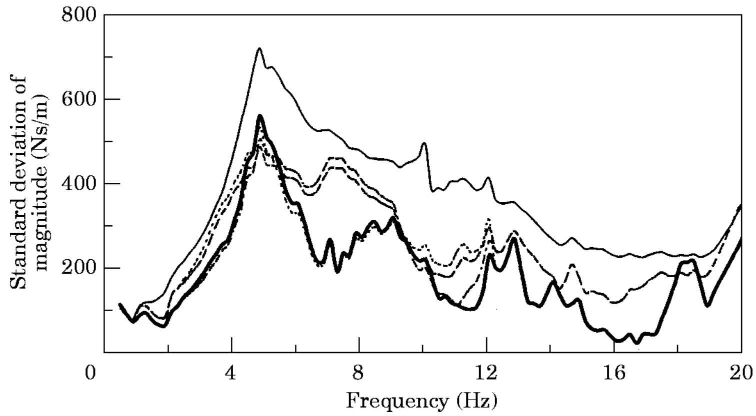

Figure 4. Absolute value of standard deviation on the mean magnitude of the driving-point mechanical impedance computed for various combinations of data. ——, All data sets; – – – –, exclusion of ISO CD 5982 [7], H&S −1·5 [16] and Suggs *et al*. [17]; - - - - ·, exclusion of ISO CD 5982 [7], H&S −1·5 [16], Suggs *et al*. [17], Seidel 60–70 [21] and Seidel 70–80 [21]; – – - – –, exclusion of ISO CD 5982 [7], H&S −1·5 [16], H&S −3·0 [16] and Suggs *et al*. [17]; ——, exclusion of ISO CD 5982 [7], H&S −1·5 [16], H&S −3·0 [16], Suggs *et al*. [17], Seidel 60–70 [21] and Seidel 70–80 [21].

60–70 [21] and Seidel 70–80 [21] leads to the combination of data sets which most likely minimizes the discrepancies existing amongst them when considered over the entire frequency range.

3.2. DATA SELECTION: APPARENT MASS MAGNITUDE

An examination of the selected data sets expressed in terms of apparent mass, and shown in Figure 2, generally reveals variations of a considerably lesser degree amongst the various data sets, when compared to the corresponding variations among the mechanical impedance data appearing in Figure 1(a). This is particularly evident towards higher frequencies, although the spread may appear broader at low frequencies.

Generally, the data sets on mechanical impedance magnitude which were identified as forming outliers or presenting anomalies are also found to present such particularities when presented in terms of the apparent mass. For three of these data sets, however, the anomaly may appear to be more or less obvious depending on whether the data is presented in terms of mechanical impedance or apparent mass. This is the case for H&S −3·0 data, which exhibits considerable deviations from the majority of the other data at lower frequencies, when presented in terms of the apparent mass. In contrast, Seidel 60–70 and Seidel 70–80 data sets are observed to follow more closely the trends prescribed by the majority of apparent mass curves than those established on the basis of mechanical impedance.

The standard deviations on the mean apparent mass magnitude established from various combinations of the data sets, identified in Table 1, are presented in Figure 5 as a function of the vibration frequencies. The results suggest that the exclusion of ISO CD 5982, H&S −1·5, Suggs *et al*., H&S −3·0, Seidel 60–70 and Seidel 70–80 data sets is most beneficial for limiting the degree of variation amongst the data, as was also the case for the mechanical impedance magnitude.

3.3. DATA SELECTION: DRIVING-POINT MECHANICAL IMPEDANCE PHASE

The comparison of the selected data sets of mechanical impedance phase, illustrated in Figure 1(b), reveals a consistent general pattern. The mechanical impedance phase is approximately 90° at very low frequencies, which asymptotically approaches 0° at higher

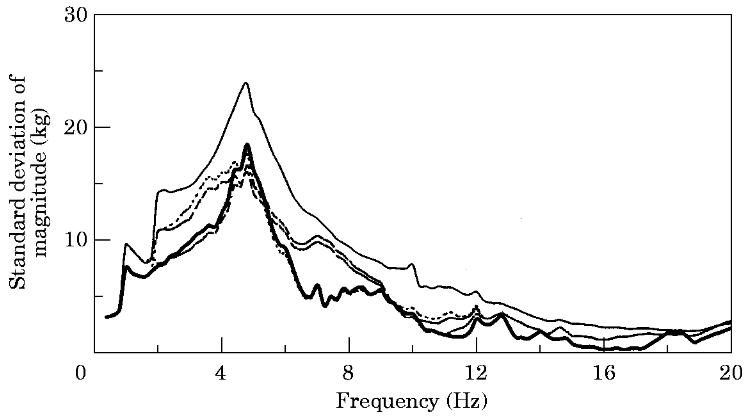

Figure 5. Absolute value of standard deviation on the mean magnitude of the apparent mass computed for various combinations of data. ——, All data sets; – – – -, exlcusion of ISO CD 5982 [7], H&S −1·5 [16] and Suggs *et al*. [17]; ----, exclusion of ISO CD 5982 [7], H&S −1·5 [16], Suggs *et al*. [17], Seidel 60–70 [21] and Seidel 70–80 [21]; –––––, exclusion of ISO CD 5982 [7], H&S −1·5 [16], H&S −3·0 [16] and Suggs *et al*. [17]; ——, exclusion of ISO CD 5982 [7], H&S −1·5 [16], H&S −3·0 [16], Suggs *et al*. [17], Seidel 60–70 [21] and Seidel 70–80 [21].

frequencies. While most data sets exhibit a generally good agreement in the phase response up to approximately 5 Hz, important differences are observed to arise amongst the data sets as the frequency is further increased. From observation of the curves shown in Figure 1(b), only two of the twelve data sets considered to characterize mechanical impedance phase are found to present important irregularities with respect to the rest of the data. These involve the data of Suggs *et al*. [17] and that proposed by Donati and Bonthoux [18] under random excitation (D&B-random), since both indicate a phase angle quickly dropping to zero at a frequency of less than 10 Hz, while the rest of the data sets indicate a more gradual decrease in phase with frequency.

Following the procedure applied for defining the most probable values of impedance and apparent mass magnitudes, the data sets presenting apparent deviations from the majority of the data are excluded to derive the most probable values of the mechanical impedance phase. Moreover, a further selection rule is introduced requesting the exclusion of the phase data whenever the associated magnitude information has itself been excluded from the synthesis. This supposes that if the magnitude information is considered inapplicable, then phase information cannot be considered either. In contrast, the inapplicability or unavailability of phase information does not imply the exclusion of corresponding magnitude information owing to the difficulties in performing proper phase measurements and to the fact that poor phase information does not impede the value of magnitude information.

Applying the above-stated selection rules to the phase data presented in Figure 1(b) results in the exclusion of the data sets referred to as ISO CD 5982, Suggs *et al*., Hinz and Seidel 1·5 and 3·0 (H&S −1·5 and H&S −3·0). Donati and Bonthoux-random (D&B-random) data is also excluded in view of irregular behaviour observed with respect to that of most other data sets. The final selection based on the remaining seven data sets is further justified by the results shown in Figure 6 which indicate that with such exclusions, the standard deviation on the mean phase values of the resulting combination is generally the lowest over most of the frequency range considered when compared with that resulting from other data set combinations.

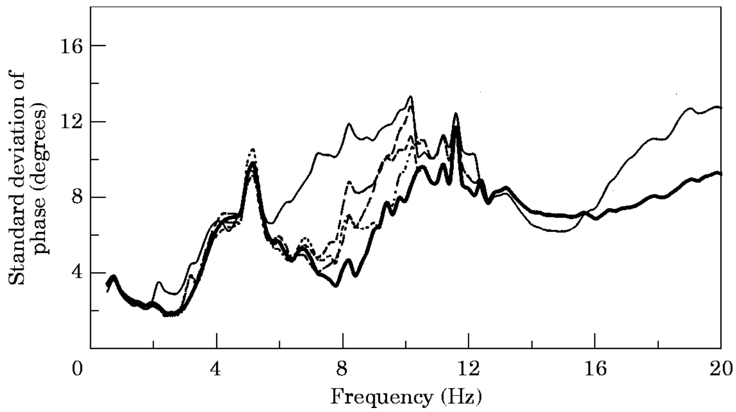

Figure 6. Absolute value of standard deviation on the mean phase angle of the driving-point mechanical impedance computed for various combinations of data. ——, All data sets; – – – –, exclusion of ISO CD 5982 [7], H&S −1·5 [16] and Suggs *et al*. [17]; ----, exclusion of ISO CD 5982 [7], H&S −1·5 [16], Suggs *et al*. [17] and D&B-random [18]; –·–·–, exclusion of ISO CD 5982 [7], H&S −1·5 [16], H&S −3·0 [16], Suggs *et al*. [17]; ——, exclusion of ISO CD 5982 [7], H&S −1·5 [16], H&S −3·0 [16], Suggs *et al*. [17], and D&B-random [18].

3.4. DATA SELECTION: SEAT-TO-HEAD TRANSMISSIBILITY MAGNITUDE

From analysis of the data shown in Figure 3(a), the pattern regarding seat-to-head transmissibility magnitude indicates a dominant peak occurring within the 4–6 Hz frequency range, corresponding to primary whole-body resonance. This is usually followed by a gradual decrease of transmissibility magnitude with frequency, although some data sets indicate potential secondary peaks at frequencies above 10 Hz. The frequency at which the peak transmissibility occurs is seen to vary amongst the data sets, as does the peak magnitude itself. In all cases, the transmissibility magnitude is larger than unity at frequencies below approximately 6 Hz, while there is a tendency for the magnitude to drop below 1·0 at most frequencies above 6 Hz. Exceptions to these trends are seen with Hinz and Seidel data sets defined at 1·5 and 3·0 m s^{-2} (H&S −1·50 and H&S −3·0). While the former indicates a transmissibility magnitude larger than 1·0 over the entire frequency range considered, the latter is seen to decrease below 1·0 only over a very limited range of frequencies. The Zimmermann and Cook data (Z&C-1997) [24] are also observed to present discrepancies at frequencies above 10 Hz by indicating a gradual amplification of vibration with frequency while most other data sets show a gradual attenuation over a similar frequency range. The Vogt *et al*. data [12] constitute a definite outlier at frequencies above 6 Hz by presenting a very pronounced drop of transmissibility magnitude with frequency as opposed to a more gradual decrease for most other data sets.

Figure 7 presents the standard deviation on the mean values of seat-to-head transmissibility magnitude computed for different combinations of the data sets. When the entire frequency range is considered, the combination of data which generally involves the lesser degree of variation at most frequencies is that based on only four data sets, which exclude those by H&S −1·5, H&S −3·0, Vogt *et al*. and Z&C-1997. The remaining four data sets include the single subject data of Coermann [9] and that proposed in the ISO CD 5982 [7] for which the reasons motivating their inclusion as part of the final data synthesis could be questioned, upon considering that the former is based on only one subject while the origin of the latter is not well known. However, as both data sets were observed to follow the trends established from other more traceable studies and in view

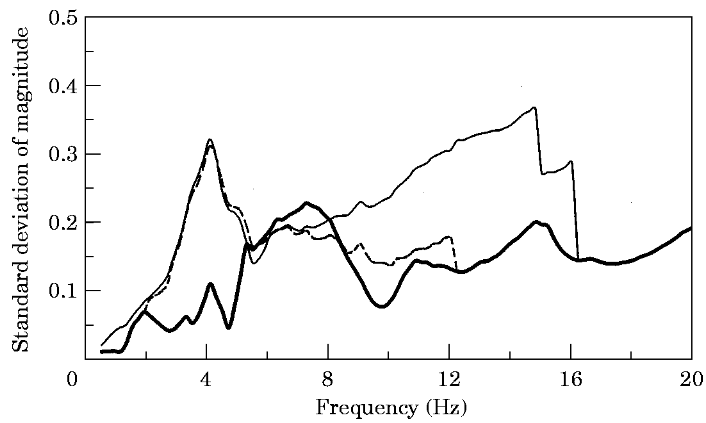

Figure 7. Absolute value of standard deviation on the mean magnitude of the seat-to-head transmissibility computed for various combinations of data ——, All data sets; - - - -, exclusion of Vogt *et al*. [12] and Z&C [24]; **——**, exclusion of Vogt *et al*. [12], Z&C [24], H&S −1·5 [16] and H&S −3·0 [16].

of the difficulties associated with identifying other additional data sets that could be shown to satisfy the selection rules, both these data sets were judged suitable for inclusion as part of the synthesis.

3.5. DATA SELECTION: SEAT-TO-HEAD TRANSMISSIBILITY PHASE

The five data sets on the seat-to-head transmissibility phase response, shown in Figure 3(b), indicate a general pattern with most curves showing a 0° phase angle at low frequency followed by a gradual decrease of phase angle as the frequency is increased. Applying the data synthesis selection rule defined in section 3.3 to the effect that phase data should be excluded whenever magnitude data is rejected results in the exclusion of H&S −1·5 and H&S −3·0 data sets. Consequently, only three data sets are made available to define the seat-to-head transmissibility phase information. These are the data reported by Mertens [10], Paddan and Griffin [3] and that proposed in ISO CD 5982 [7].

4. DEFINITION OF IDEALIZED VALUES

The unexplained differences in biodynamic response characteristics emerging from studies conducted by different investigators serve to justify the exclusion of outliers or of data sets which present peculiar behaviour with respect to the generally observed trends established from a majority of other studies. Since the aim of this study is to define a range of idealized values applicable under a very specific range of conditions, the exclusion of any particular data set should not be interpreted as a value judgment on the quality of the reported data, but more as an indication that the particular conditions under which the data was acquired perhaps did not comply with the intended prescribed range of conditions. While every effort was made to consider only the data for which the reported conditions would closely match with those established by the selection rules, the possibility of particular conditions, either unreported or misinterpreted, could have led to the observed discrepancies.

The range of idealized or most probable values characterizing the biodynamic response of the seated body under the particular conditions considered is derived in the 0·5–20 Hz frequency range from the smoothened envelope of the values of data reported in selected studies, upon removal of the outliers or odd-behaved data sets. Smoothing is accomplished from successive piecewise approximations using a fixed number of points while creating an overlap. The smoothened contours of magnitude and phase responses of the driving-point mechanical impedance, apparent mass and seat-to-head transmissibility thus derived may be considered to characterize the range of idealized values in the sense that they encompass the characteristics reported in all the investigations judged suitable for the synthesis under the specified conditions. Thus any data that fall within the range of idealized values defined by the envelope curves may be considered to be acceptable representation of the biodynamic response functions of the seated human body under the specific conditions defined.

The range of most probable values in the 0·5–20 Hz frequency range are shown by the continuous curves in Figures 8–10, for driving-point mechanical impedance magnitude and phase, apparent mass magnitude, and seat-to-head transmissibility magnitude and phase, respectively. These express the smoothened envelopes of maximum and minimum values from within the data reported in the various studies as a function of the vibration frequency. The mean values of the data sets considered, indicated in the figures as central bold solid lines, relate to the target values which may be considered for biodynamic modelling or other applications. For completion, the smoothened envelopes formed from the computations of the standard deviation on the mean values are also included in the figures as dotted lines. The mean, upper and lower bounds, and the standard error corresponding to the most probable values of each of the smoothened biodynamic response functions are also summarized in Tables 3–5 at central frequencies of one-third octave bands between 0·5 and 20 Hz.

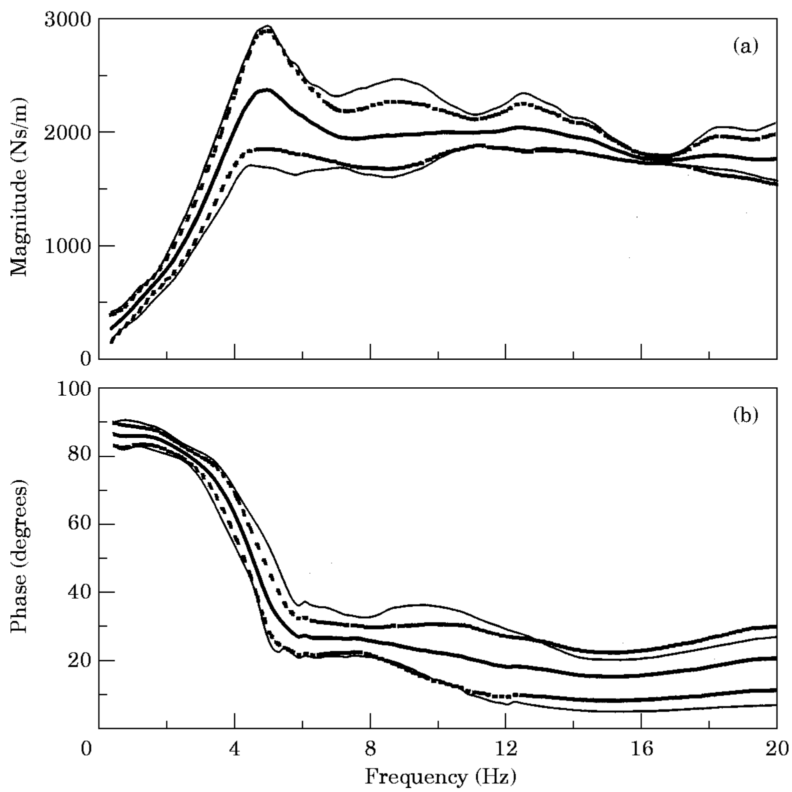

Figure 8. Driving-point mechanical impedance data envelope contours of (a) idealized magnitude and (b) phase values under the defined conditions. ——, Mean (target) values; ——, envelope of maximum and minimum values; ---·, envelope of mean ± standard deviation.

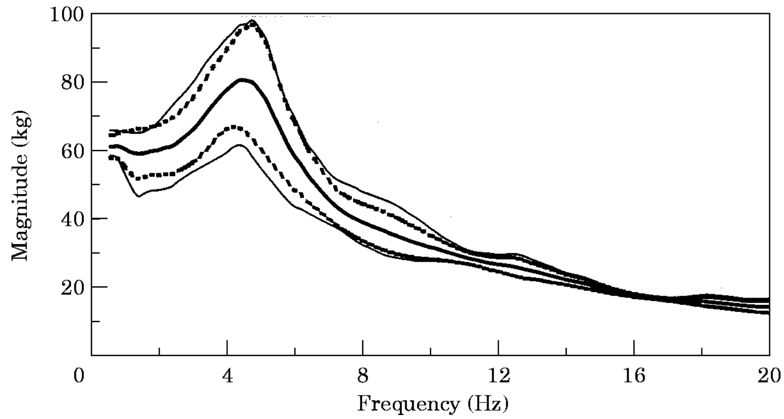

Figure 9. Apparent mass data envelope contours of idealized magnitude values under the defined conditions. ——, Mean (target) values; ——, envelope of maximum and minimum values; ----, envelope of mean ± standard deviation.

Upon exclusion of the data sets identified in sections 3.1 and 3.2 for driving-point mechanical impedance and apparent mass magnitudes, the synthesis of the data shown, respectively in Figures 8 and 9, is based on 8 data sets identified as Sandover [19], F&G-1983 [15], D&B-sine [18], D&B-random [18], F&G-1986 [20], Holmlund *et al*. [2],

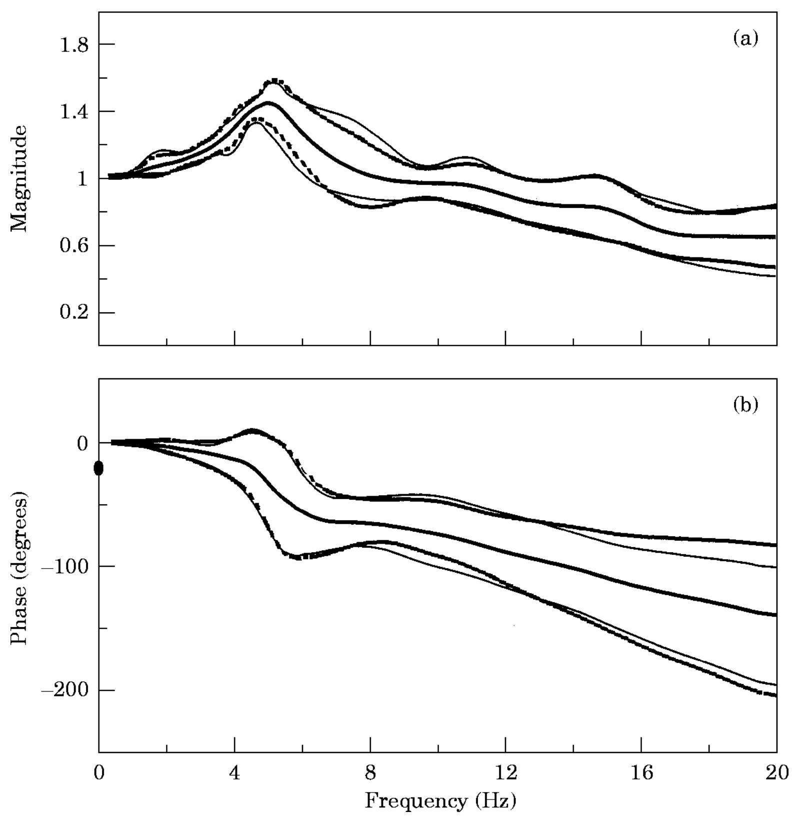

Figure 10. Seat-to-head transmissibility data envelope contours of idealized (a) magnitude and (b) phase values under the defined conditions. ——, Mean (target) values; ——, envelope of maximum and minimum values; ----, envelope of mean ± standard deviation.

TABLE 3

Target and range of idealized driving-point mechanical impedance of the seated human body under the defined conditions

Frequency (Hz)	Magnitude (N s/m) Lower limit	Mean (target)	Standard error	Upper limit	Phase (degrees) Lower limit	Mean (target)	Standard error	Upper limit
0·5	148	254	116	400	83	86	3	90
0·63	218	304	95	425	82	86	3	90
0·8	266	359	86	471	82	86	3	91
1	310	424	87	539	83	86	3	90
1·25	356	493	88	607	83	86	2	90
1·6	490	627	71	703	82	85	2	89
2	614	768	93	893	80	84	2	87
2·5	758	947	132	1141	79	81	2	84
3·15	1131	1429	212	1732	69	75	3	80
4	1541	2002	316	2389	52	61	7	69
5	1663	2346	522	2908	24	36	9	52
6·3	1635	2065	298	2404	20	26	5	36
8	1605	1939	274	2392	20	25	4	32
10·0	1756	1981	196	2273	14	22	8	35
12·5	1828	2023	211	2327	7	18	8	27
16·0	1710	1750	37	1791	4	15	7	20
20·0	1552	1755	239	2099	6	20	9	26

Boileau *et al*.-sine [5] and Boileau *et al*.-random [5]. Overall, these represent mean data acquired with 65 different subjects whose mass ranges from 49–93 kg, with a mean close to 70 kg. The excitation levels used for generating these data are observed to vary between

TABLE 4

Target and range of idealized apparent mass of the seated human body under the defined conditions

Frequency (Hz)	Magnitude (kg) Lower limit	Mean (target)	Standard error	Upper limit	Phase (degrees) Lower limit	Mean (target)	Standard error	Upper limit
0·5	58·7	61·2	3·2	65·9	−7	−4	3	0
0·63	58·0	61·4	3·5	65·8	−8	−4	3	0
0·8	53·8	60·6	5·0	65·6	−8	−4	3	1
1	49·8	59·6	6·2	65·2	−7	−4	3	0
1·25	46·9	59·2	7·2	65·2	−7	−4	2	0
1·6	48·5	60·0	7·0	66·7	−8	−5	2	−1
2	49·0	60·8	7·6	70·6	−10	−6	2	−3
2·5	51·2	62·6	8·5	75·2	−11	−9	2	−6
3·15	56·0	70·7	10·4	85·6	−21	−15	3	−10
4	61·0	79·3	12·4	94·6	−38	−28	7	−21
5	52·8	74·5	16·6	92·3	−66	−54	9	−38
6·3	41·9	53·2	7·7	61·9	−69	−64	5	−54
8	31·9	38·5	5·4	47·4	−69	−65	4	−58
10·0	27·8	31·5	3·1	36·1	−76	−68	8	−55
12·5	23·4	25·9	2·7	29·8	−83	−72	8	−63
16·0	17·0	17·4	0·4	17·8	−85	−75	7	−70
20·0	12·5	14·1	1·9	16·9	−84	−70	9	−64

TABLE 5

Target and range of idealized seat-to-head transmissibility of the seated human body under the defined conditions

Frequency (Hz)	Magnitude Lower limit	Magnitude Mean (target)	Magnitude Standard error	Magnitude Upper limit	Phase (degrees) Lower limit	Phase (degrees) Mean (target)	Phase (degrees) Standard error	Phase (degrees) Upper limit
0·5	1·00	1·01	0·01	1·02	−1·2	−0·6	0·8	0·0
0·63	1·00	1·01	0·01	1·02	−1·9	−1·0	1·3	0·0
0·8	1·00	1·01	0·01	1·02	−2·4	−1·2	1·7	0·0
1	1·01	1·02	0·01	1·03	−2·8	−1·5	1·9	−0·1
1·25	1·02	1·03	0·02	1·06	−3·4	−1·8	2·3	−0·1
1·6	1·02	1·06	0·05	1·14	−5·6	−2·9	3·8	−0·2
2	1·03	1·08	0·06	1·16	−8·4	−4·3	5·8	−0·2
2·5	1·04	1·10	0·05	1·15	−11·8	−6·3	6·3	−0·6
3·15	1·11	1·16	0·05	1·22	−20·5	−9·7	9·4	−3·4
4	1·16	1·29	0·09	1·36	−32·5	−15·0	18·5	4·2
5	1·28	1·45	0·12	1·56	−72·9	−35·6	38·4	3·8
6·3	0·99	1·23	0·19	1·44	−93·0	−59·8	30·3	−34·1
8	0·87	1·01	0·19	1·28	−81·5	−66·3	19·0	−45·3
10·0	0·86	0·96	0·09	1·08	−93·1	−75·6	26·5	−45·1
12·5	0·74	0·86	0·13	0·99	−121·2	−93·2	29·8	−62·1
16·0	0·55	0·71	0·15	0·89	−166·1	−119·5	41·0	−89·0
20·0	0·40	0·63	0·18	0·84	−206·3	−142·2	55·8	−104·3

0·5 and 2·0 m s^{-2} r.m.s., with a slightly higher proportion of subjects submitted to sinusoidal than to random excitations. While the mean smoothened mechanical impedance magnitude curve shows a peak occurring at 4·8 Hz, that for apparent mass is more towards 4·4 Hz. In both cases, the envelopes formed from the standard deviation on the mean follow very closely those formed from maximum and minimum values. The coefficient of variation (i.e., ratio of standard deviation to the mean) is relatively the same between mechanical impedance and apparent mass magnitude, except at lower frequencies ($<1·5$ Hz), where the variation is considerably larger when the data is treated in terms of mechanical impedance rather than of apparent mass.

With regard to the driving-point mechanical impedance phase, the exclusion of the data sets identified in section 3.3, resulted in a synthesis based on 7 data sets including Sandover [19], F&G-1983 [15], D&B-sine [18], F&G-1986 [20], Holmlund *et al*. [2], Boileau *et al*.-sine [5] and Boileau *et al*.-random [5]. The results, shown in Figure 8, indicate a significant broadening of the error or coefficient of variation at frequencies above 8 Hz owing to the considerable discrepancies between the data sets. Overall, these data are established with the same subject population and excitation levels used for defining mechanical impedance and apparent mass magnitude, with the exception that a considerably higher proportion of subjects were subjected to sinusoidal than to random excitations.

Finally the synthesis of the data on seat-to-head transmissibility presented in Figure 10 for magnitude and phase is based on four and three data sets, respectively, including those of Mertens (1978) [10], P&G-1988 [3] and ISO CD 5982 (1993) [7]. The data of Coermann (1962) [9] is the fourth data set considered for seat-to-head transmissibility magnitude. Overall, 72 subjects are reported to have been involved in generating the data reported in these studies, their mass ranging from 59–90 kg. The largest population of subjects is that reported in the ISO CD 5982, which involves 50 out of the 72 subjects. The excitation levels used in these studies is observed to vary between 1·75 and 5 ms^{-2}, with a considerably higher

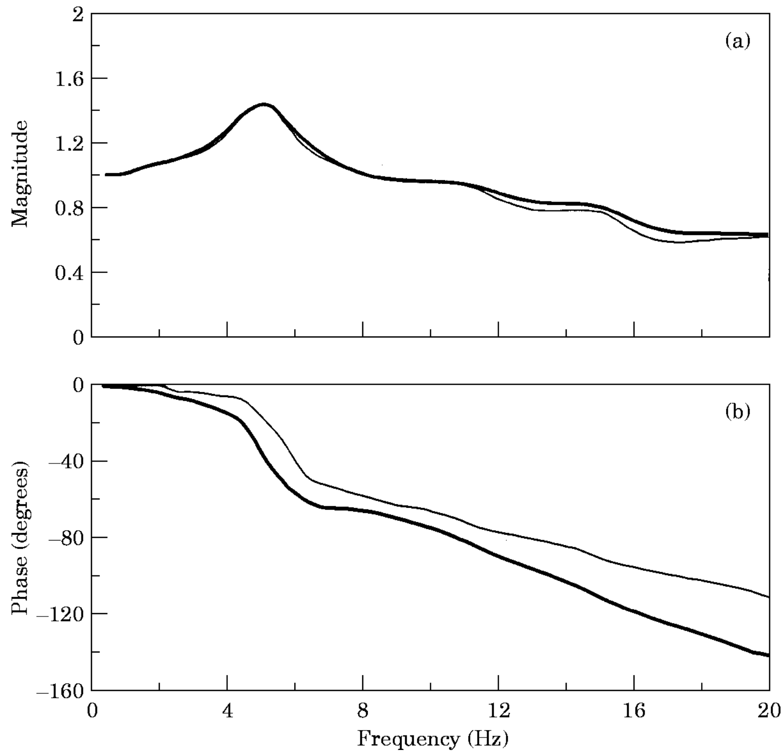

Figure 11. Comparison of proposed mean (target) values of seat-to-head transmissibility with those excluding ISO CD 5982 [7]. ——, Target values; ——, excluding ISO CD 5982. (a) Magnitude, (b) Phase.

proportion of subjects reported to have been submitted to sinusoidal than to random excitations. The data sets which are included as part of the final synthesis are the same as those which are integrated as part of a previous study [1] in which the analysis had been limited to an upper frequency of 10 Hz. From Figure 10, peak transmissibility magnitude would be expected to occur at a frequency of 5·1 Hz, thus slightly different from the resonance frequencies of 4·8 and 4·4 Hz, estimated from the mechanical impedance and apparent mass target values, respectively. For magnitude, but even more so for the phase, the large error reported is just an indication of the wide spread of values amongst the data sets considered.

In view of the uncertainties associated with the inclusion of the ISO CD 5982 data as part of the final data synthesis on seat-to-head transmissibility, a comparison was further made of the mean synthesized values reported in Figure 10 with those which would have resulted by not considering the ISO CD 5982 data. The results, shown in Figure 11, indicate that the effect of not including the ISO CD 5982 data while computing the mean seat-to-head transmissibility magnitude is almost negligible; while the effect appears to be considerably more important on phase. Furthermore, the exclusion of the ISO CD 5982 data from the synthesis does not prevent the resulting mean phase information from falling within the envelope of values previously defined while retaining this data set (see Figure 10). On that basis, it is concluded that the range of idealized seat-to-head transmissibility values computed while retaining the ISO CD 5982 data (see Figure 10) would not be altered in any significant manner by not considering this data set.

5. CONCLUSIONS

The driving-point mechanical impedance, apparent mass and seat-to-head transmissibility data reported in the literature for the seated body differ considerably in magnitude and phase response. Even when limiting the selection of the data to those studies reporting similar experimental conditions performed under a prescribed range involving specific posture, feet support and vibration excitation level, considerable differences amongst the data sets may still remain, although perhaps to a lesser degree than when no control is placed on the test conditions. By excluding outliers and odd-behaved data sets, biodynamic response data acquired under similar test conditions can be grouped within reasonable envelopes of magnitude and phase angle responses, though the discrepancies generally remain unexplained.

A synthesis of the selected data was performed and smoothened envelope contours encompassing the mean values of the selected data were constructed in the 0·5–20 Hz frequency range to characterize the driving-point mechanical impedance, apparent mass and seat-to-head transmissibility of the seated subjects with feet supported, and exposed to vibration excitation levels lower than $5\ \mathrm{m\ s^{-2}}$. It was suggested that such conditions would match more closely those encountered in many work environments, including those involving driving particular types of vehicles. The final curves encompass the response characteristics reported in all the investigations judged suitable for synthesis and including the most recent data. They are based on 8 data sets for mechanical impedance and apparent mass magnitude, and on 7 for the phase response. The idealized curves on seat-to-head transmissibility are based on considerably fewer data sets; four for the magnitude and three for the phase. The data that fall within the proposed range of idealized values are considered to provide acceptable representation of the seated human body's biodynamic response behaviour under the specific range of conditions. For some alternative conditions involving quite different postures, feet support, subject mass range and excitation levels, it is suggested that perhaps different sets of idealized values would have to be defined.

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