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The vertical, fore-and-aft, and lateral seat-to-head transmissibility on an elastic seat: influences of the cross-axis coupling, the vibration magnitude and the backrest

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Vibration transmitted from the cushion to the human head can affect riding comfort and even induce motion sickness during the vertical excitation. Although seat-to-head transmissibility has been investigated using a rigid seat, only biodynamic properties of seated occupant were considered and influence of the seating dynamics was neglected. In this study, the in-line and cross-axis seat-to-head transmissibilities of 14 seated occupants were investigated on an elastic seat with the vertical excitation (1–15 Hz) of three different excitation magnitudes (0.2, 0.4, 0.8 m/s^2 r.m.s.). The influence of contacting with or without the backrest on the transmissibilities was also analysed. The primary peak frequencies approximately at 4 Hz of the seat-to-head transmissibilities significantly decreased when increasing the excitation magnitude. When contacting with a backrest, the higher primary peak frequencies were observed in seat-to-head transmissibilities for both the vertical in-line and the fore-and-aft cross-axis directions, compared to the measurements without contacting to the backrest. Seat-to-head transmissibilities measured with an elastic seat in this study differs markedly from those tested on a rigid seat in previous studies. This highlights the necessity of further investigation of the influences of dynamic body-seat interactions on seat-to-head transmissibilities, in order to enhance the insight into riding comfort.

Key words: *seat-to-head transmissibilities, occupant-seat system, cross-axis response, vibration*

1. Introduction

The seat-to-head transmissibility (STHT) has been studied for occupants on the rigid seat with the aim of characterize the biodynamic responses of the seatedoccupants and serve as a basis for the standardized values established in ISO 5982 [1], [14]. Models of the seated occupant were established using the standardized ranges of biodynamic responses to predict the effective magnitude transmissibility of the seat (SEAT) for assessment of riding discomfort. However predicted SEAT values were often found to exceed the experimental results [15], [33]. These discrepancies were believed to be due to limitations in the body models developed based on "sitting-on-the-rigid-seat" conditions, as the measured STHT data used for the model validation did not account for dynamics of the elastic seat and dynamic interactions within the occupant-seat systems in real world [11], [29], [32].

Systematic investigations of the STHT measured on the elastic seat have remained limited, primarily due to the difficulty in accurately measuring the interaction forces at occupant-seat interfaces. The relationship between STHT and ride comfort when exposed to the vertical excitation was analyzed with the elastic seat, but the influence of the seating dynamics on STHT has not been reported yet [34]. Furthermore, biodynamic

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responses of whole-body excitation with the elastic seat have been characterized using other response functions, including the apparent mass (APMS) [19]. For example, lower APMS were obtained at the seat cushion with the elastic seat than those measured with the rigid one, and these differences were attributed to a more even distribution of the occupant mass at the contact interfaces [6], [18], [31]. However, these APMS studies have primarily focused on the motion-force interactions at the occupant-seat interfaces and did not provide comprehensive information about how the vibration is transmitted to various occupant segments. As the head vibration is proved to be a predominant cause of the visual disturbance and motion sickness [17], [22], [30], STHT should be systematically investigated with the occupant seated on the elastic seat.

The cross-axis influence was clearly observed when measured the STHT on the rigid seat with varying magnitudes of vertical excitation, regardless of the sitting posture. Head movements were detected not only in the excitation (i.e., vertical) direction but also along fore-and-aft and lateral directions [2], [12]. A primary peak frequency within 4–6 Hz was identified in both vertical in-line STHT and fore-and-aft cross-axis STHT, while no clear primary peak was observed in the lateral direction [2], [12]. More pronounced pelvic rotation has been reported during the measurement on elastic seats compared with measurements on rigid seats when exposed to the vertical vibration [33]. Increased motion magnitudes in the upper body and head may be induced by this enhanced pelvic rotation [23]. Therefore, the cross-axis response of STHT measured on the elastic seat may differ from that observed with the rigid seat, and a distinct primary peak may emerge in the lateral cross-axis STHT. The comprehensive measurement of both in-line and cross-axis STHT on elastic seats is necessary to advanced the understanding of how the seating dynamics affect the vibration transmitted to the head.

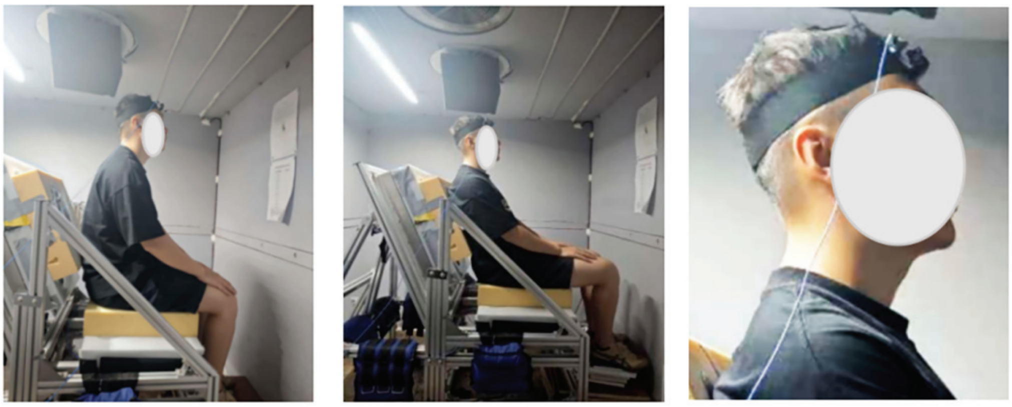
The influence of the vertical excitation magnitude on STHT was investigated with a rigid seat. A decrease in the primary peak frequencies of the STHT was observed when increasing the vertical excitation magnitude [2], [10], [12]. A similar trend was later reported when testing on the rigid seat with backrest support [3], [4]. This "softening tendency" has also been found in measurements of APMS either on an elastic or a rigid seat, although it was less pronounced when tested on an elastic seat relative to on a rigid one [5]. Given the differences in APMS between measurements on the rigid and elastic seats, further investigation is necessary to determine this "softening tendency" of STHT when the occupant is seated on an elastic seat in the real world.

Backrest support can affect STHT by altering the spine curvature, which changes sitting posture and thereby modifies both the geometry and the contact conditions of the occupant-seat system [8], [21]. Significant reductions in the peak transmissibilities of both vertical in-line and fore-and-aft cross-axis STHT when testing on the rigid seat have been observed when the upright backrest support was introduced [3]. A significant increase in the primary peak frequency of fore-and-aft cross-axis STHT when testing on the rigid seat, and reduced inter-subject variability at the primary peak frequency, was reported with the inclined backrest relative to the unsupported case [26]. The vibration experienced by the seated occupant may be altered by the backrest of an elastic seat, thereby affecting the STHT [33]. Given that the inclined backrest postures more accurately represent typical sitting behavior than the upright one, the present research is aimed to explore the influence of backrest support on STHT with two backrest conditions: contacting with or without the inclined backrest.

In this study, various STHT (i.e., the in-line and cross-axis STHT) of 14 seated occupants was investigated on an elastic seat during the vertical vibration (1–15 Hz) with three different excitation magnitudes (0.2, 0.4, 0.8 m/s^2 r.m.s.) both with backrest contact and without it. It is hypothesized that the cross-axis response of the STHT when testing on the elastic seat would differ from observed on the rigid seat, and that the influence of backrest support on the STHT may also deviate from the results obtained with the rigid seat. Furthermore, it is expected primary peak frequencies of STHT measured on the elastic seat would decrease when increasing the vertical excitation magnitude.

2. Materials and methods

The experimental setup and apparatus are shown in Fig. 1. To simulate the elastic seat in the real world, a pair of open-cell polyurethane foam blocks, each sized 450 mm × 450 mm × 90 mm and weighing 500 g, were mounted on the inclined backrest and the seat pan of a steel seat. The foam blocks were selected with identical material properties, namely 14 800 Pa in Young's modulus, 18% in hysteresis loss factor and a 48 kg/m^3 in density. Equipped with a sensitivity of 100 mV/g, the PCB356A15 piezoelectric accelerometer was used to capture the vertical excitation at the cushion. Equipped with a sensitivity of 100 mV/g, the PCB356A15 piezoelectric accelerometer was employed to record the vibration of the head, attached to the subject's fore-



(a) (b) (c)

Fig. 1. Schematic illustration of the test set-up: (a) no backrest contact, (b) with an inclined backrest, (c) an accelerometer fixed to the forehead

head with the medical tape which was held in position by the sports headband (Fig. 1). The piezoelectric accelerometer was aligned parallel to the biodynamic axis by adjusting the headband. The tension of the headband was adjusted to ensure a tight and comfortable fit.

Fourteen healthy adult subjects (Table 1) participated in this study. The subjects were chosen with the GB 10000-88 Chinese Adult Body Size Standard. Exposed to the random vertical excitation, the subject with experienced an acceleration power spectrum that was flat and maintained a constant bandwidth over 1–15 Hz. Used in this study, the vertical excitation magnitudes (0.2, 0.4 and 0.8 m/s^2 r.m.s.) were within established safety limits and did not pose any risk to health. Two backrest contact conditions were investigated: no contact with the seat backrest and leaning naturally against the inclined elastic seat backrest. During the test, the subjects remained comfortably seated, with the head oriented forward in a natural upright forward posture. The head position of each subject was visually monitored, with the experimenter ensuring the date reliability. Each test lasted 60 s and was performed in a randomized order to minimize potential influence of order.

Table 1. Characteristics parameters of subjects

Characteristics parameters	Minimum	Maximum	Mean	Standard deviation
Age [years]	19	31	25.70	3.84
Weight [kg]	51.7	90	67.94	9.78
Stature [cm]	158	180	171.14	6.54

The STHT was determined via cross spectral density (CSD) function method:

$$\mathrm{STHT}(f) = G_{io}(f)/G_{ii}(f), \quad (1)$$

$$\gamma^2(f) = |G_{io}(f)|^2 / G_{ii}(f)G_{oo}(f). \quad (2)$$

The vertical in-line STHT (STHT_{ZZ}) was calculated by the vertical excitation of the head (a_{zh}) and vertical excitation on cushion (a_{zf}). The fore-and-aft cross-axis STHT (STHT_{ZX}) was calculated by the fore-and-aft excitation of the head (a_{xh}) and vertical excitation on cushion (a_{zf}). The lateral cross-axis STHT (STHT_{ZY}) was calculated by the lateral excitation of the head (a_{yh}) and vertical excitation on cushion (a_{zf}). The $r^2(f)$ was the coherence function; The $G_{ii}(f)$ and the $G_{oo}(f)$ were the power spectral density (PSD) function of the floor and the head, respectively; The $G_{io}(f)$ was the CSD between the excitation at the floor and the head.

3. Results

3.1. The cross-axis coupling and inter-subject variability in seat-to-head transmissibility

The excitation obtained in this study were used to determine the in-line and cross-axis STHT of 14 subjects sitting on the elastic seat either with or without an inclined backrest when excited with three vertical excitation magnitudes (0.2, 0.4 and 0.8 m/s^2 r.m.s.). All three measured STHT exhibited significant inter-subject variability, particularly within the frequency range of 2–6 Hz. The coefficient of variation (CoV) of the magnitude varied between 10% and 35% within this frequency range. In Figure 2, the mean STHT (STHT_{ZZ}, STHT$_{ZX}$, and STHT$_{ZY}$) of the 14 subjects are depicted, and the standard deviations of the mean are represented by the error bars.

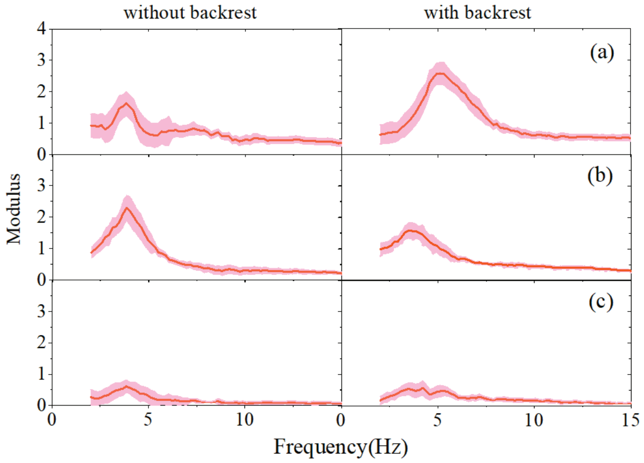


Fig. 2. Inter-subject variability of the 14 subjects (0.8 m/s^2 r.m.s.): (a) STHT$_{ZZ}$, (b) STHT$_{ZX}$, (c) STHT$_{ZY}$

The single-axis vertical vibration resulted in both the in-line and the cross-axis motion of the head, regardless of the backrest conditions or the excitation magnitudes. The primary peak frequency of the STHT$_{ZZ}$ varied from 3.5 to 4.9 Hz for the "No backrest contact" condition, and frequencies within the 4.1 to 5.8 Hz were obtained for the "Contact with the backrest" condition. The primary peak frequency of the STHT$_{ZX}$ varied from 3.7 to 4.9 Hz for the "No backrest contact" condition, and frequencies within the 3.9 to 5.4 Hz were obtained when testing with the contact to the backrest. For the STHT$_{ZY}$, the primary peak frequency ranged from 3.6 to 5.2 Hz under the "No backrest contact" condition, and from 3.8 to 5.3 Hz when testing with the contact to the backrest.

3.2. Influence of the excitation magnitude on various seat-to-head transmissibilities

The influence of vertical excitation magnitudes (0.2, 0.4, and 0.8m/s^2 r.m.s.) on STHT measured on the elastic seat were analysed. A significant decrease in the primary peak frequency of the STHT$_{ZZ}$ from 5.1 Hz to 3.5 Hz was identified when the vertical excitation magnitude was increased from 0.2 to 0.8 m/s^2 r.m.s. (Fig. 3, $p < 0.05$, Wilcoxon). The primary peak frequency of the STHT$_{ZX}$ significantly decreased from 4.8 Hz to 3.6 Hz (Fig. 4, $p < 0.05$, Wilcoxon). The primary peak frequency of the STHT$_{ZY}$ significantly decreased from 4.9 Hz to 3.5 Hz (Fig. 5, $p < 0.05$, Wilcoxon). The change of the primary peak frequency was more evident for the "No backrest contact" condition relative to the "Contact with the backrest" condition (Table 2). Some subjects revealed a peak in 7–9 Hz of the STHT$_{ZZ}$ when testing with the contact to the backrest, and this secondary peak frequency also significantly decreased when the vertical excitation magnitude was increased.

Table 2. Influence of the excitation magnitudes (0.2, 0.4, and 0.8 m/s^2 r.m.s.) on the STHT: Wilcoxon matched-pairs signed rank test for the primary peak frequency (f_r), the peak transmissibility (TR_f), and the secondary peak frequency (Tf_r) between pairs of the vertical excitation magnitudes

Backrest conditions	STHT		For f_r		For TR_f		For Tf_r	
		excitation [m/s^2 r.m.s.]	0.4	0.8	0.4	0.8	0.4	0.8
No backrest contact	STHT$_{ZZ}$	0.2	↓*	↓**	–	–	↓*	↓*
		0.4		↓*		–		↓*
	STHT$_{ZX}$	0.2	↓**	↓***	–	↓*		
		0.4		↓**		↓*		
	STHT$_{ZY}$	0.2	–	↓**	–	–		
		0.4		↓*		–		
Contact with the backrest	STHT$_{ZZ}$	0.2	↓*	↓*	↓*	–		
		0.4		↓*		–		
	STHT$_{ZX}$	0.2	↓*	↓**	↓*	↓*		
		0.4		↓**		–		
	STHT$_{ZY}$	0.2	↓*	↓*	↓*	↓*		
		0.4		↓*		–		

– $p > 0.05$; * $p < 0.05$; ** $p < 0.01$;*** $p < 0.001$.
↓: Mean value decreased as the vertical excitation magnitude increased.

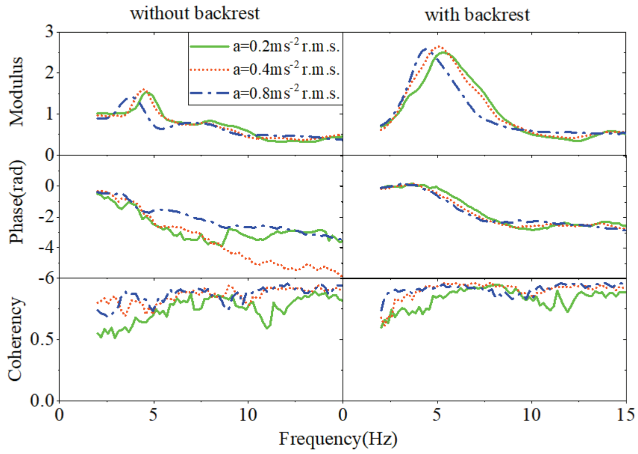


Fig. 3. Mean $STHT_{ZZ}$ of the 14 subjects seated with and without the backrest contact

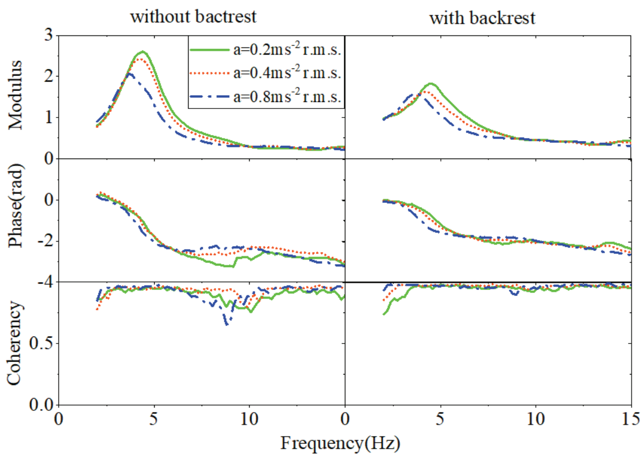


Fig. 4. Mean $STHT_{ZX}$ of the 14 subjects seated with and without the backrest contact

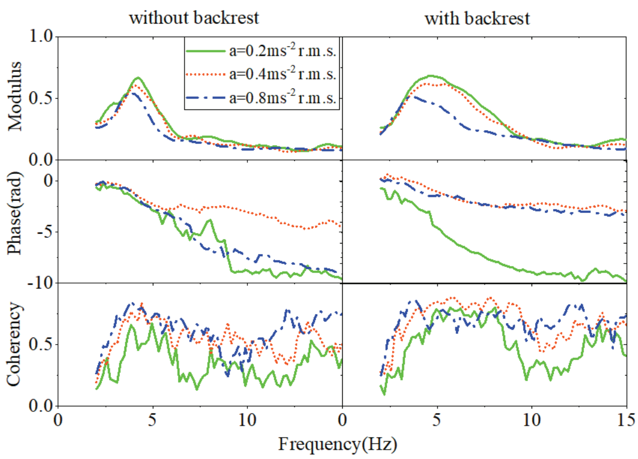


Fig. 5. Mean $STHT_{ZY}$ of the 14 subjects seated with and without the backrest contact

3.3. Influence of the backrest on various seat-to-head transmissibilities

For the STHTzz, both the primary peak frequency and the peak transmissibility measured with the backrest contact were significantly higher relative to those measured without the backrest, irrespective of the vertical excitation magnitudes (Fig. 6a, Table 3). magnitudes were lager for the “Contact with the backrest” condition comparing to the “No backrest contact” condition in the 3–7 Hz frequency range (Fig. 6a, $p < 0.05$, Wilcoxon).

The primary peak frequency of the $STHT_{ZX}$ was significantly higher for the “Contact with the backrest” condition relative to that for the “No backrest contact” condition (Fig. 6b, Table 3). The peak transmissibility measured with the backrest contact was significantly smaller relative to that measured without the backrest (Fig. 6b, Table 3). Larger magnitudes were observed for the “No backrest contact” condition in the 3–5 Hz range (Fig. 6b, $p < 0.05$, Wilcoxon). Larger magnitudes were observed for the “Contact with the backrest” condition in the 8–15 Hz range (Fig. 6b, $p < 0.05$, Wilcoxon).

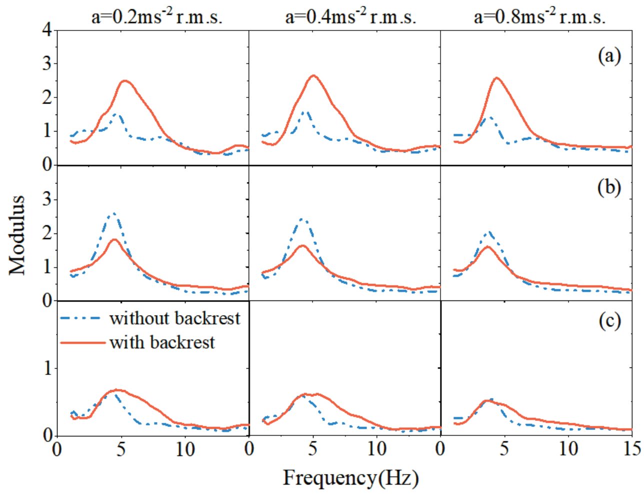


Fig. 6. Influence of the backrest contact on STHT of the 14 subjects: (a) $STHT_{ZZ}$, (b) $STHT_{ZX}$, (c) $STHT_{ZY}$

Both the primary peak frequency and the peak transmissibility of the $STHT_{ZY}$ were no significant difference between the two backrest contact conditions (Fig. 6c, Table 3). However, larger magnitudes were observed for the with backrest contact condition in the 5–15 Hz frequency range (Fig. 6c, $p < 0.05$, Wilcoxon).

Table 3. Influence of the backrest contact (without the backrest, with the inclined backrest) on the STHT: Wilcoxon matched-pairs signed rank test for the primary peak frequency (f_r) and the peak transmissibility (TR_f) between pairs of the backrest contact

	STHT	Excitation [m/s^2 r.m.s.]	Significance *p*-value
f_r	$STHT_{ZX}$	0.2	0.042*
		0.4	0.036*
		0.8	0.031*
	$STHT_{ZY}$	0.2	–0.052
		0.4	–0.068
		0.8	–0.059
	$STHT_{ZZ}$	0.2	0.038*
		0.4	0.026*
		0.8	0.024*
TR_f	$STHT_{ZX}$	0.2	0.031*
		0.4	0.026*
		0.8	0.015*
	$STHT_{ZY}$	0.2	–0.183
		0.4	–0.064
		0.8	–0.067
	$STHT_{ZZ}$	0.2	0.011*
		0.4	0.003*
		0.8	0.026*

– $p > 0.05$, * $p < 0.05$.

4. Discussions

4.1. The in-line and cross-axis seat-to-head transmissibilities on the elastic seat

4.1.1. Influence of the vertical excitation magnitude

The columns in Fig. 7 represent the range of the peak frequency in the STHT, and the lines represent the medians of the peak frequency. The primary peak frequencies evident in the $STHT_{ZZ}$ and the $STHT_{ZX}$ when measured on the elastic seat decreased with increasing the vertical excitation magnitude, irrespective of the backrest contact conditions (Fig. 7), exhibiting a "softening tendency" which is similar to the previous report for the $STHT_{ZZ}$ and the $STHT_{ZX}$ measured on the rigid seat [3], [12]. None of the previous studies on $STHT_{ZY}$ measured on the rigid seat has reported such a "softening tendency", whereas it was also observed for the $STHT_{ZY}$ measured on the elastic seat in this study. This phenomenon was also identified when measuring the vertical in-line and fore-and-aft cross-axis APMS on the rigid cushion [9], [16]. Moreover, previous studies of the vertical in-line and fore-and-aft cross-axis transmissibilities at the neck (C7) and the spine (L5, L3, T12, and T5) from the seat base exhibited primary peak frequencies in the range of 4–6 Hz, and the primary peak frequencies decreased as the vertical excitation magnitude increased [23], [24], [35]. This indicates the head motion during the vertical excitation could be highly correlated to the biodynamic response of the upper body.

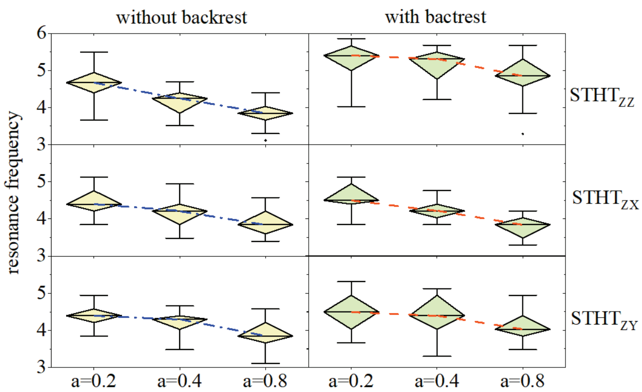


Fig. 7. The peak frequency in the STHT of the 14 subjects with vertical excitation

This "softening tendency" was observed in all three measured STHT may be attributed to the muscular stiffness of the seated occupants caused by increased vertical excitation magnitude. And this could be approved by studies of the biodynamics. For example, significant reductions in the vertical stiffness were found at the viscera, the ischial tuberosities, and the front thighs when increasing the vertical excitation magnitude [20]. And the fore-and-aft stiffness at the front and middle thighs were also reported to decrease when increasing the vertical excitation magnitude [20]. In addition, this "softening tendency" may be also associated with the dynamic stiffness of the seat. Other studies [33] have found the dynamic stiffness of the seat decreased with increasing foam thickness in the range of 60–100 mm. And the dynamic stiffness has also been found to decrease with increasing magnitude of vibration excitation in the range of 0.25–1.0 ms^{-2} r.m.s.

4.1.2. Influence of the backrest contact

Significant increases in the primary peak frequencies of the $STHT_{ZZ}$ were observed with a change in posture from "No backrest contact" to "Contact with the backrest" (Fig. 6). This "stiffening effect" was also observed when measuring the vertical in-line APMS on a rigid seat [28]. The columns in Fig. 8 represent the range of the peak transmissibility in the STHT. Significant increases in the peak transmissibilities of the $STHT_{ZZ}$ were observed with a change in posture from "No backrest contact" to "Contact with the backrest" (Fig. 8). This phenomenon was also observed when measuring the vertical in-line APMS on an elastic seat [6]. This indicates the trend of the head motion has a strong correlation with the whole-body biodynamic responses. In contrast, significant decreases in the primary peak frequencies of the $STHT_{ZZ}$ were observed with a change in posture from "No backrest contact" to "Contact with the backrest" in previous studies on elastic seat cushions with a rigid backrest [7]. This difference may be attributed to the influences of rigid and elastic backrests on the occupant-seat system interaction.

Significant increases in the primary peak frequencies of the $STHT_{ZX}$ were observed with a change in posture from "No backrest contact" to "Contact with the backrest" (Fig. 6). This phenomenon is consistent with the test of the $STHT_{ZX}$ measured on a rigid seat [6]. And this phenomenon was also observed when measuring the fore-and-aft cross-axis APMS on a rigid seat [19]. Moreover, Significant reductions in the peak transmissibilities of the $STHT_{ZX}$ were observed with a change in posture from "No backrest contact" to "Contact with the backrest" (Fig. 8). This could be due to the restriction of upper-body pitch motion by the backrest contact. And this phenomenon was also observed during measurements of the $STHT_{ZX}$ on a rigid seat [26].

The $STHT_{ZY}$ associated with backrest contact has not been reported yet, and this study is an attempt to address this research gap. Significant increases in the magnitude of the $STHT_{ZY}$ were found in the 5–15 Hz frequency range with a change in posture from "No backrest contact" to "Contact with the backrest" (Fig. 6), because the backrest serves as contributes an additional excitation input and also alters the tension in the supporting muscles.

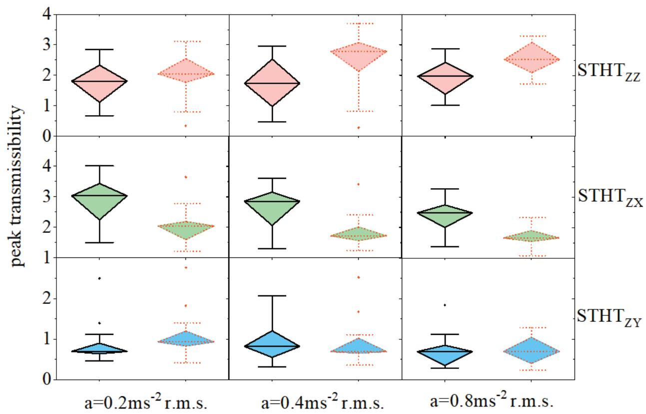


Fig. 8. The peak transmissibility in STHT of the 14 subjects with the vertical excitation (— without backrest, --- with backrest)

More evident inter-subject variations were observed in all three measured STHT for the "No backrest contact" condition relative to the "Contact with the backrest" condition (Fig. 2). For the "No backrest contact" condition, the coefficient of variation at the primary peak frequency is approximately 24% ($STHT_{ZZ}$), 20% ($STHT_{ZX}$) and 32% ($STHT_{ZY}$), which reduces to around 17% ($STHT_{ZZ}$), 12% ($STHT_{ZX}$) and 25% ($STHT_{ZY}$), when testing with the contact to the backrest. This is due to differences in the extent of contact between the occupant and the backrest, consistent with the measurement of the vertical in-line STHT on the rigid seat [27].

4.2. Differences between STHT measured on an elastic and on a rigid seat

Although similarities exist between the cross-axis response of the STHT measured on the elastic seat in this study and the STHT measured on a rigid seat in previous studies [3], [12], certain differences could be observed and warrant attentions.

The primary peak frequencies of the $STHT_{ZZ}$ was found near 4.1 Hz when testing on the elastic seat without the backrest contact, which was lower than the report from the previous study (i.e., 4.93 Hz) measured on a rigid seat [3]. And this difference was also observed in the vertical in-line APMS between measurements conducted on the elastic rigid seating conditions [5], [6]. This may be attributed to the variation of the vertical stiffness within the occupant-seat contact area. On the rigid seat, the vertical stiffness is governed exclusively by the compressive behavior of the buttocks and thigh tissues, while the vertical stiffness testing on the elastic seat involves the combined serial stiffness of these soft tissues and the polyurethane foam, yielding a lower stiffness than either component alone.

The primary peak frequencies of the $STHT_{ZX}$ was approximately 4Hz on the elastic seat without the backrest contact, which was lower than the previous study (i.e., 5 Hz) measured on a rigid seat [3]. This may be due to the pressure distribution on the rigid seat being concentrated over the ischial tuberosities, while a more uniform pressure distribution could be observed within the occupant-seat contact area on the elastic seat [25], which may alter the mechanical properties and thereby affect the $STHT_{ZX}$.

The primary peak frequency of the $STHT_{ZY}$ measured on the elastic seat was found near 4.2 Hz (Fig. 7), whereas no apparent primary peak frequency was found when measuring on a rigid seat [12]. The peak transmissibilities of the $STHT_{ZY}$ were greater than 1 when measured on the elastic seat (Fig. 8). However, the peak transmissibilities of the $STHT_{ZY}$ measured on the rigid seat in previous studies were consistently below 0.3 [3]. This may be due to the pelvic rotation resulting from the deformation in the polyurethane foam of the seat cushion [3], [13], indicating the polyurethane foam either at the backrest or the seat cushion should be regarded as the predominant factor when investigating the excitation transmitted through the seat to the body.

5. Conclusions

In the present study, the seat-to-head transmissibilities measured on an elastic seat indicated that vertical excitation on the cushion could result in head motions in the vertical, the fore-and-aft and the lateral axis, regardless of the excitation magnitude or the backrest support condition. The primary peak frequencies in both the in-line and the cross-axis seat-to-head transmissibilities decrease when increasing the vertical excitation magnitude. This decrease was more evident for the "No backrest contact" condition relative to the "Contact with the backrest" condition. The primary peak frequencies of the vertical in-line and the fore-and-aft cross-axis seat-to-head transmissibilities were significantly higher for the "Contact with the backrest" condition relative to "No backrest contact" condition. More evident inter-subject variations were observed in all three measured STHT for the "No backrest contact" condition relative to the "Contact with the backrest" condition. A primary peak frequency of 4.2 Hz was observed for the lateral cross-axis seat-to-head transmissibilities on the elastic seat was 4.2 Hz, whereas no apparent primary peak was observed when measuring the lateral cross-axis seat-to-head transmissibilities on a rigid seat in previous studies. Lower primary peak frequencies were observed for the elastic seat in this study than for the rigid seat in previous studies in both the vertical and fore-and-aft cross-axis directions under the "No backrest contact" condition. There are limitations in the present study that deserve attentions. Further work is necessary to check if these observations are also applicable to other ethnic groups and different sitting postures.

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