CHEST TRANSMISSIBILITY CHARACTERISTICS DURING EXPOSURE TO SINGLE- AND COMBINED-AXIS VIBRATION

Suzanne D. Smith,[1] Stephen E. Mosher[2]
[1]Air Force Research Laboratory, [2]General Dynamics AIS
Wright-Patterson AFB, Ohio, U.S.A.

Introduction

Ground, air, and water vehicles can expose humans to substantial multi-axis vibration. Multiple input/multiple output relationships or models exist for estimating frequency response functions of linear systems[1, 2]. These relationships have been applied by some investigators to evaluate the effects of occupied seat vibration[3, 4]. Using a multiple input/single output model, this study investigated the effects of single- and combined-axis vibration in the fore-and-aft (X), lateral (Y), and vertical (Z) directions on vibration transmission to the human chest. Frequency response functions (transmissibilities) were estimated and compared for the back-on and back-off postures.

Methods

A rigid seat with seat back was mounted onto the Six Degree-of-Freedom Motion Simulator (SIXMODE). A flat acceleration vibration signal was generated between 2 and 40 Hz at 1.0 ms^{-2} rms in the single and combined X, Y, Z, XY, XZ, YZ, and XYZ axes. The signals were shifted in time so that the combined inputs were not fully correlated. Lightweight triaxial accelerometers were used to measure accelerations at the seat base (input) and at the bony manubrium of the chest (output). The maximum of nine frequency response functions ($H(\omega)$) or transmissibilities were estimated from the auto- and cross-spectra. The system transfer matrix for the XYZ inputs and chest Z output is

$$\begin{bmatrix} H_{xZ} \\ H_{yZ} \\ H_{zZ} \end{bmatrix} = \begin{bmatrix} P_{xx} & P_{xy} & P_{xz} \\ P_{yx} & P_{yy} & P_{yz} \\ P_{zx} & P_{zy} & P_{zz} \end{bmatrix}^{-1} \begin{bmatrix} P_{xZ} \\ P_{yZ} \\ P_{zZ} \end{bmatrix} \quad (1)$$

where P_{xZ}, P_{yZ}, and P_{zZ} are the cross-spectra between the three inputs at the seat base and the Z output at the chest, respectively, and P_{xx}, P_{xy},…$_{zz}$ are the auto- and cross-spectra between the input signals (ω not shown in Eq. 1). Equation 1 can be similarly written for the chest X and Y outputs. Matlab® was used to estimate the auto- and cross-spectral densities for calculating the transmissibilities, ordinary coherences (for single inputs), partial coherences, and multiple coherences.

Results

Figure 1 illustrates the major chest transmissibilities observed for the two postures. Vertical vibration showed a consistent influence on the chest X response (Chest X/Z), most likely causing chest pitch. Some chest Z responses were observed with X-axis inputs, but the results were variable and difficult to interpret. In general, other factors besides the known inputs did not affect the transmissibilities shown in Figure 1 (Repeated Measures ANOVA, $P<0.05$). This was

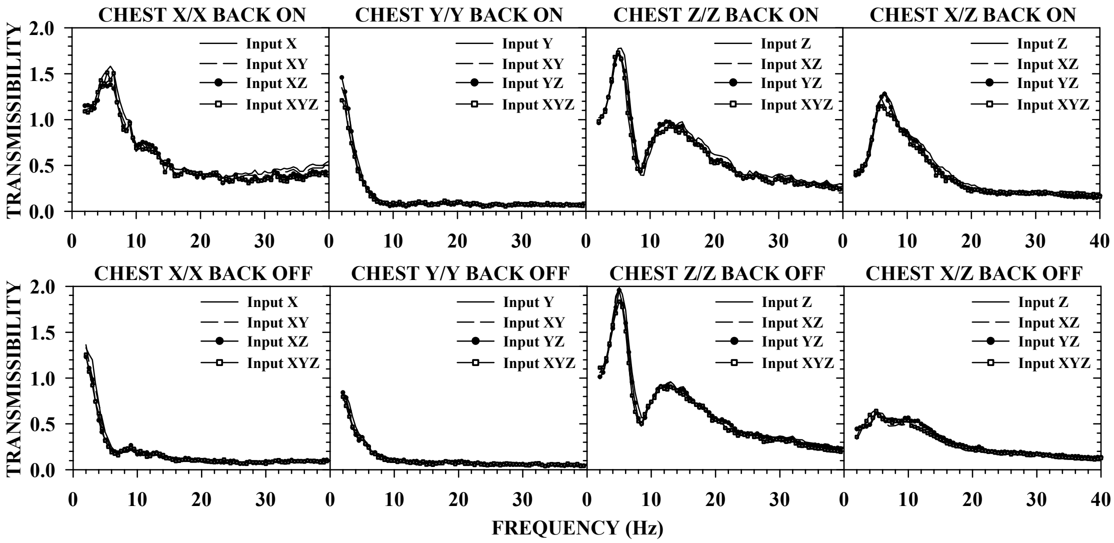

Figure 1 Mean Chest Transmissibilities from Nine Subjects (4 Females, 5 Males)

reflected by the relatively high partial coherences, particularly associated with the primary peak responses (majority PCoh>0.85). More variable coherences were noted among the subjects for Chest X/Z for the XZ and XYZ inputs, the lowest mean value being 0.75±0.14. Regardless of the input, the back-off posture showed the elimination of the 4-6 Hz peak in Chest X/X, the significant reduction in the peak frequency for Chest X/Z, and the significant reductions in the Chest Y/Y and Chest X/Z transmissibilities (Fig. 1, Paired t-test, $P<0.05$).

Discussion

Lower partial coherences would suggest that the chest responses were not fully accounted for by a linear relationship to the known inputs. This could occur due to chest pitch, which was expected to some extent with both the X and Z inputs. Except for a few cases, the partial coherences were relatively high. The seating posture was found to have a significant effect on the chest multi-axis biodynamics. Specifically, coupling with the seat back promoted the influence of vertical vibration on the chest X response, causing higher upper torso motion in the X direction at a peak coincident with whole-body resonance (~4-6 Hz, as observed in Chest Z/Z). When contact with the seat back was removed, these effects were reduced and the peak chest X motions appeared dampened at higher frequencies. The chest X motion with the back off appeared to be more influenced by lower frequency vibration associated with relatively higher seat displacement (~2 Hz).

References

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