The Effect of Backrest Angles on Discomfort Caused by Fore-and-Aft Back Vibration

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Abstract: The effect on discomfort of the frequency and the backrest angle of x-axis (fore-and-aft) vibration of backrest have been studied. The method of adjustment was employed to obtain contours of equivalent comfort for three types of rigid backrests, whose surface were vertical, inclined 20 degrees and 40 degrees from vertical. Eighteen subjects were required to adjust test vibration over the frequency range 2-80 Hz to produce discomfort equivalent to that caused by 10 Hz 0.25 m/s² r.m.s. sinusoidal reference vibration for each backrest. The direction of vibration was perpendicular to backrest surface. Results shows that the sensitivity at 20 and 40 Hz on inclined backrests is significantly about 1.4 to 1.5 times greater than that on a vertical backrest (p<0.01) but there is no significant difference between the two contours for inclined backrests. The contour for a ‘vertical’ backrest obtained in this experiment agrees with the contour calculated from the frequency weighting factors for x-axis back vibration, Wc, in ISO2631-1, but the contours for inclined backrests do not agree with the contour well.

Key words: Vibration, Discomfort, Backrest, Angle

Introduction

The vibration which a human body is exposed to is transmitted to various parts of body may cause discomfort. If a subject’s posture is changed, the part or degree of discomfort by vibration which a subject feels may also changes because of the change of the vibration transmissibility characteristics. Therefore there is a possibility that vibration sensation of back depends of the backrest angle. Parsons et al. investigated the effect on discomfort of back vibration and the frequency weightings for back vibration are proposed in ISO2631-1, but the effect of the backrest angle is not mentioned.

The purpose of the experiment was to investigate the effect of the frequency and the backrest angles on discomfort caused by x-axis (fore-and-aft) back vibration.

Apparatus

Figure 1 shows Vibration and Signal generation system. An aluminum rigid backrest was attached to a vibration table of a Shinken 3-axis electrodynamic vibration generator and wooden surfaced rigid non-vibrating seat-squab was attached on the floor. Vibrator acceleration distortion on a vibration table is 4.5% at 2 Hz and less 1% at the other frequencies which were used in this study. Surfaces of the rigid seats were covered by 1 mm thick rubber to provide a high friction contact with subjects’ clothing. And a button to stop the vibrator in case of emergency and a control box which had a switch and a 10 turn potentiometer to enable subjects to select reference vibration or test vibration and to adjust the acceleration level of test vibration, were attached beside the rigid seat. Another flat, horizontal surfaced rigid seat without a backrest was also attached on a vibration table in order that discomfort by seat vibration could be compared with that by backrest vibration.

There were no cue marks on the knob of potentiometer...
to avoid bias errors. The signals from digital signal generators were controlled by digital vibration controller or phase-shifter and gain controller to generate perpendicular vibration to the inclined backrest, and drove the vibration generator through power amplifiers.

Three sets of rigid seats with backrests were used in this experiment, whose backrest-surfaces were inclined by 0, 20 and 40 degrees from vertical (see Fig. 2). In order that subjects could sit with natural posture, the angles between rigid seat-squab surface and rigid backrest surface were 90 degrees for a vertical backrest and 100 degrees for the others.

Translational vibration of backrests was measured with piezoelectric accelerometers which were attached to the point of backrest surface in the rear about 350 mm from seat-squab surface and to the surface of the rigid seat without backrest and found that the cross-axis coupling was less than 10% for all experimental conditions with the exception of 10 Hz on the rigid backrests (22% for lateral (y) direction with a vertical backrest and 16% for lateral direction with a 20 degree-inclined backrest).

Subjects

18 healthy adults (13 males and 5 females) aged 24 to 50 participated in the experiment (see Table 1). All subjects had a practice session to experience vibrations on vibrator and to be able to match pairs of stimuli.

Procedure

The method of adjustment was employed to obtain...
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A subject was exposed to 'reference' vibration and 'test' vibration and asked to adjust the knob of 10 turn potentiometer to control the magnitude of test vibration so that overall discomfort caused by test vibration was equivalent to that caused by reference vibration. The exposure time for vibration was not limited and a subject was allowed to switch between reference and test vibration as many times as they needed.

Reference vibration was 10 Hz 0.25 m/s² r.m.s. sinusoidal vibration and test vibration was 2, 5, 20, 40 and 80 Hz sinusoidal vibration. 20 Hz 0.25 m/s² r.m.s. sinusoidal reference vibration and 10 Hz sinusoidal test vibration were also compared to cancel bias errors because of the method of adjustment, which the subjects tends to under-adjust the magnitude of test vibration. The level of each reference vibration was checked and the output level of a signal generator was adjusted manually, if necessary, before the magnitude matching was started. The direction of vibration was perpendicular to backrest. These all pairs of reference and test vibration were compared in random order.

The bias errors were removed as follows. If there were bias errors that subjects tended to under-adjust the magnitude of test vibration, the ratio that acceleration at 20 Hz divided by acceleration at 10 Hz would be changed by frequency of reference vibration.

The 'sensational' magnitude of the reference vibration without bias errors for each backrest, a'(10)ref.=10°, was obtained by next equation;

\[ a'(10)_{\text{ref}=10°} = \left( \frac{0.25}{a(20)_{\text{ref}=10°}} + \frac{a(10)_{\text{ref}=20°}}{0.25} \right) \frac{a(20)_{\text{ref}=10°}}{2} \]

where \( a(i)_{\text{ref}=j°} \) is the equivalent comfort acceleration at \( i \) Hz against the reference vibration at \( j \) Hz.

Next, the accelerations at all frequencies except 10 Hz were multiplied by the acceleration of the 'real' reference vibration at 10 Hz divided by that of the 'sensational' reference vibration at 10 Hz, \( a'(10)_{\text{ref}=10°} \) for each backrest, to adjust the difference of degrees of bias errors among three backrests.

At the end of each session, each subject had a vibration magnitude matching between the rigid seats with and without backrest. In this case, 'reference' vibration was 10 Hz 0.25 m/s² r.m.s. sinusoidal vertical (z-axis) vibration on the rigid seat without backrest. A subject on this rigid seat was asked to put his or her feet on vibration table without shoes and to estimate discomfort by not only vibration on the rigid seat but also that on vibration table. 'Test' vibration was 10 Hz sinusoidal perpendicular backrest vibration on the rigid seats with backrests, and a subject sat both rigid seats alternately and was asked to adjust the magnitude of test vibration in order that overall discomfort caused by test vibration was equivalent to that caused by reference vibration.

Each subject was required to match these 7 pairs for one backrest angle in one session. Each session took 30 min or less. The matching was conducted twice for each rigid seat, so each subject attended six sessions in random order.

### Results

Figure 3 shows the individual contours of levels of backrest vibration. Table 2 shows the mean accelerations at 10 Hz in each backrest equivalent to 10 Hz 0.25 m/s² r.m.s. sinusoidal vertical vibration on the rigid seat without backrest. Each mean equivalent comfort acceleration for 18 subjects was multiplied by the acceleration ratio, that the mean acceleration at 10 Hz in each backrest divided by that in the
vertical backrest, for the calibration of relative sensitivity among the contours obtained by three kind of backrests (see Fig. 4).

Discussion

The equivalent comfort contour, which was calculated from reciprocals of the frequency weighting factors for x-axis back vibration in ISO2631-1, $W_c$, was also shown in Figure 4. The equivalent comfort contour for the ‘vertical’ backrest obtained in this experiment indicates a good similarity to the contour calculated from the frequency weighting factors, $W_c$, in ISO2631-1.

The shapes of two contours for backrests inclined 20 and 40 degrees are very similar and but there is no significant difference between them ($p>0.05$). The sensitivity for vibration on inclined backrests may be seen to be smaller below 5 Hz and greater above 10 Hz than that on a vertical backrest. Results of the analysis of variance shows that there are significant differences between a vertical backrest and inclined backrests at 20 and 40 Hz ($p<0.01$) and the sensitivity at 20 and 40 Hz on inclined backrests is about
1.4 to 1.5 times greater than that on a vertical backrest.

The findings suggest that the weighting contour for x-axis backrest vibration, Wc, in ISO2631-1 can be applied to Japanese people too for x-axis vibration on the vertical backrest, but the contours for inclined backrests do not agree with the contour well. Therefore there seems to be a possibility that discomfort at frequency range from 20 to 40 Hz may be underestimated for that on inclined backrests.

One reason of the sensitivity differences between backrest angles may be the difference of contact conditions between subjects' back and backrests. As subjects' bodies are pressed more strongly against inclined backrests than against a vertical backrest by the effect of the gravity, the vibration of backrests will be easily transmitted to human bodies. It is assumed that the result that there is a significant difference between the sensitivity on a vertical backrest and inclined backrests but no difference between two inclined backrests indicates that the difference of the contact condition between a vertical backrest and inclined backrests is larger than that between two inclined backrests. In general the influence on the contact conditions may be large for relatively high frequency vibration whose displacement is smaller than vibration at low frequency with the same acceleration. Since vibration transmitted to subjects' bodies were not measured in this experiment, a conclusion can not be drawn but future research may show the relation between the angles of backrests and the vibration levels transmitted to human bodies.

Conclusions

The equivalent comfort contours of levels of x-axis (fore-and-aft or perpendicular to backrest surface) backrest vibration for three backrest angles (vertical, 20 degrees and 40 degrees from vertical) were measured. Results of the analysis of variance shows that there are significant differences between a vertical backrest and inclined backrests at 20 and 40 Hz (p<0.01) and the sensitivity at 20 and 40 Hz on inclined backrests is about 1.4 to 1.5 times greater than that on a vertical backrest, but there is no significant difference between the two contours for inclined backrests.

The contour for a 'vertical' backrest agrees with the contour calculated from the frequency weighting factors for x-axis back vibration, Wc, in ISO2631-1, but the contours for inclined backrests do not agree with the contour well.

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