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SIX AXES OF HEAD ACCELERATION DURING AMBULATION

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SUMMARY - Acceleration at the heads of 12 subjects has been measured in three translational and three rotational axes during walking at six speeds (1 to 2.25 steps per second). The effect of wearing a 1.3 kg helmet on the acceleration of the head was also investigated. Power spectral densities of the acceleration at the head showed that increases in walking speed increased the magnitude of the dominant vertical and pitch head acceleration which occurred at the stepping frequency. Acceleration measured in the fore-and-aft axis of the head was influenced by the pitch displacement of the head and was greatest at the lowest walking speeds. Wearing the helmet tended to reduce head accelerations over the range 2 to 5 Hz.

1. INTRODUCTION

There have been many studies of the effects of whole-body vibration caused by machines and vehicles, but few studies of the vibration caused by walking and running. The previous investigations conducted in laboratory and field environments allow estimates of the vibration transmitted through the body and predictions of the effects of this vibration on human comfort, performance and health [1]. Although some studies have been conducted to measure the motions of the body during ambulation [2-4], there is no comprehensive description of the motions in the body during ambulation and little consideration of human responses to these motions.

It has been reported that the magnitude of the vertical acceleration and displacement at the head increases with increased walking speed [3,4]. People wear helmets while walking in many environments. Laboratory studies with subjects seated on motion simulators have shown that the motion of the head is influenced by the presence of a helmet, in particular during vertical seat vibration the peak in head pitch motion at 5 Hz reduces when wearing a helmet [5].

This study was conducted to determine the motions occurring in six axes at the head during walking and how these motions are affected by walking speed and the wearing of a helmet.

2. APPARATUS

Accelerometers were mounted on a bite-bar to measure head motion. The bite-bar consisted of six translational accelerometers to measure six axes of motion of the head. Rotational accelerations were determined from signals provided by pairs of translational accelerometers. The mass of the bite-bar including the accelerometers was 80g and was low in comparison to the mass of the head (about 5 kg) and helmet (1.3 kg).

3. EXPERIMENTAL PROCEDURE

Twelve male subjects (median age 23.5 yrs, weight 66 kg and height 1.72 m) completed the experiment in one visit to the laboratory. Measurements were made in two conditions: with and without a helmet. The helmet was a Medium Sized Mark 6 Combat Helmet (mass 1.3 kg) and was fitted to each subject with the chinstrap and webbing secured.

All subjects walked 8.75m barefoot on a level floor (concrete floor with a 2 mm thick linoleum floor cover). The gait was controlled by placing markers across the walkway at a separation distance of 0.75 m. The walking pace was controlled using a digital metronome with a cadence of 1, 1.25, 1.5, 1.75, 2.0 and 2.25 steps/s.

Data acquisition and analysis were conducted with a *HVLab* Techfilter system. The data acquisition sample rate was 128 samples/s and the data were filtered at 31.5 Hz with an elliptical filter having a cut-off rate of 72 dB/octave at 63 Hz. The accelerations at the head were acquired for 15 seconds. Power spectra were determined with a resolution of 0.50 Hz, giving 32 degrees of freedom.

4. RESULTS AND DISCUSSION

Fig. 1 shows the characteristic acceleration time histories of motion at the head for a single subject walking at the slowest speed (1 step/s). The motions in the fore-and-aft, vertical and pitch axes of the head were dominated by peaks in the time histories at the stepping frequency.

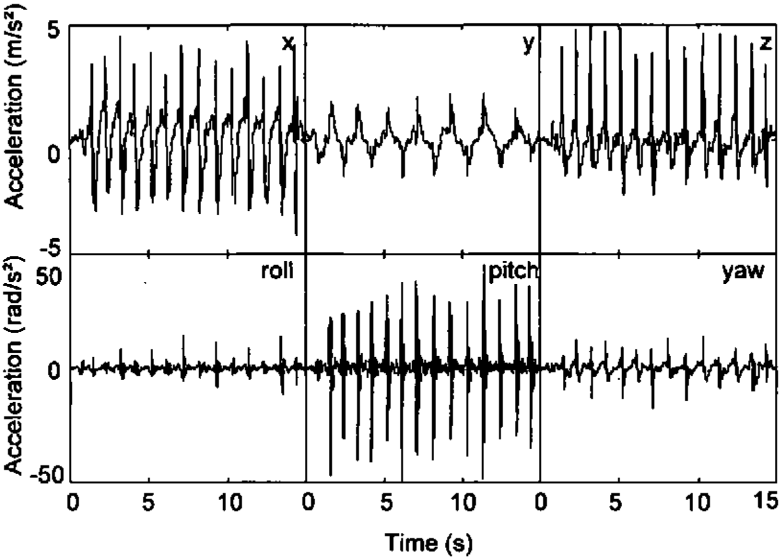

Fig. 1 Acceleration time histories at the head in six axes for a single subject walking at 1 step/s.

Power spectral densities of the acceleration at the head were calculated for each of the 12 subjects walking at the six speeds. Median power spectral densities were then calculated for the 12 subjects for each walking speed. Fig. 2 shows the median acceleration power spectral densities of fore-and-aft and vertical head motion with varying walking speed for subjects not wearing a helmet. The magnitude of the acceleration measured in the fore-and-aft axis of the head decreased significantly as the walking speed increased (Wilcoxon, $p<0.05$). Part of the acceleration measured in the fore-and-aft axis of the head is caused by pitch motion of the head producing a component of fore-and-aft acceleration proportional to gravitational acceleration and the pitch displacement of the head. There was a significant increase in the magnitude of the vertical head acceleration with each increase in walking speed ($p<0.05$).

Figs. 3 and 4 show the median power spectral densities of the pitch and yaw head acceleration with varying walking speed for subjects not wearing a helmet. In the frequency range 0.5 to 5.5 Hz, walking speed had a significant effect on the power spectral density of pitch head acceleration ($p<0.05$). There were also significant differences in the power spectral density of yaw head acceleration in the frequency range 0.5 to 3.5 Hz ($p<0.05$).

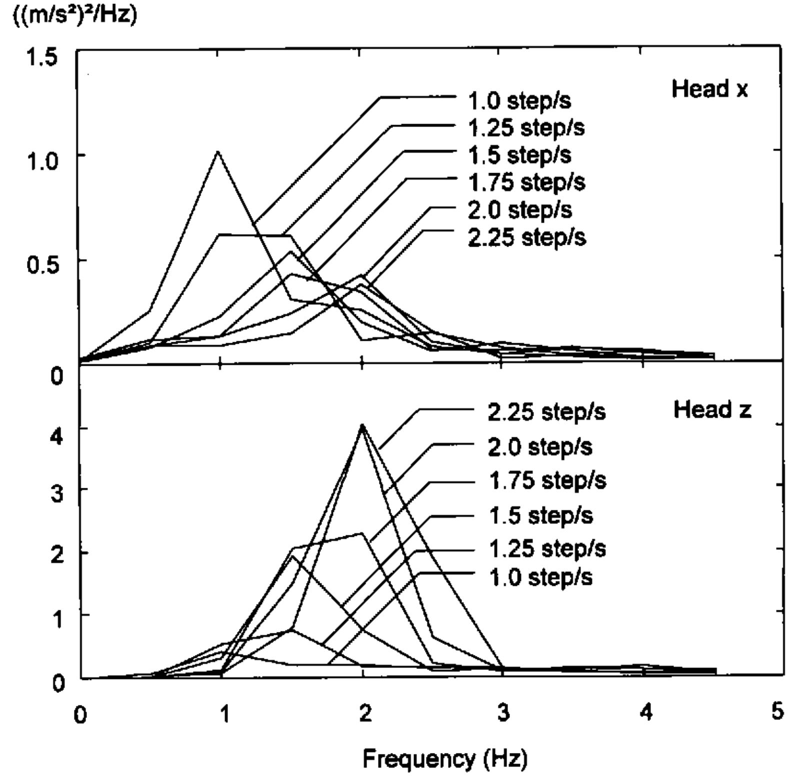

Fig. 2 Median power spectral densities of fore-and-aft and vertical head acceleration for 12 subjects walking at 6 speeds, without a helmet (0.5 Hz resolution).

Median power spectral densities of head motion calculated for the 12 subjects walking at 1 step/s with and without a helmet are shown in Fig. 5. The helmet caused a small but statistically significant increase in fore-and-aft head motion in the frequency range 1 to 1.5 Hz (Wilcoxon, $p<0.05$). The presence of the helmet significantly reduced lateral head motion in the frequency range from 1 to 2 Hz ($p<0.05$), vertical head motion at 3 Hz ($p<0.1$), roll head motion in the frequency range from 2.5 to 7.5 Hz ($p<0.05$), pitch head motion in the frequency range from 2.5 to 4 Hz ($p<0.05$) and yaw head motion in the frequency range from 2 to 7 Hz ($p<0.05$).

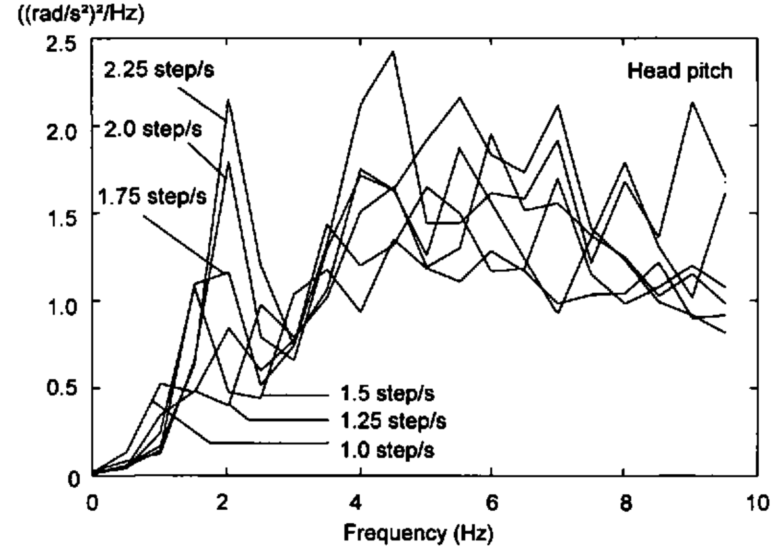

Fig. 3 Median power spectral densities of pitch head acceleration for 12 subjects walking at 6 speeds, without a helmet (0.5 Hz resolution).

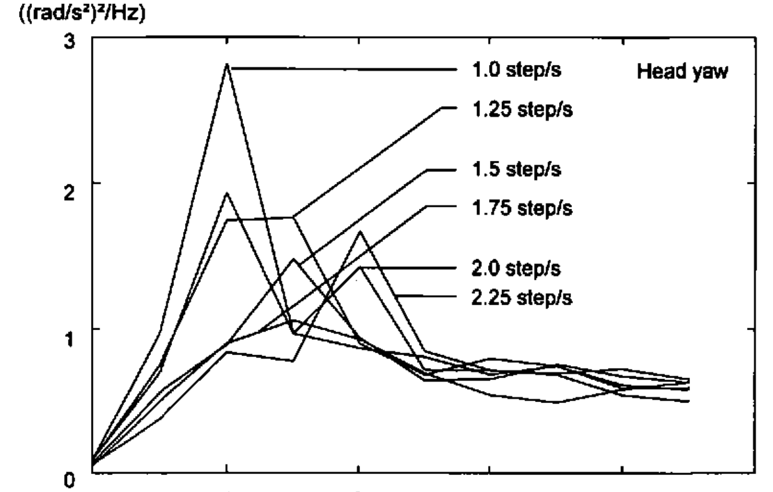

Fig. 4 Median power spectral densities of yaw head acceleration for 12 subjects walking at 6 speeds, without a helmet (0.5 Hz resolution).

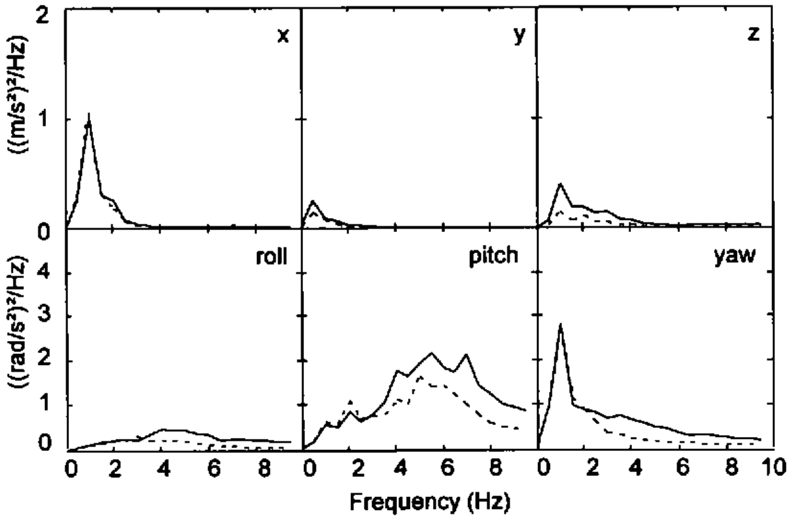

Fig. 5 Median power spectral densities for six axes of head acceleration for 12 subjects walking 1 step/s without helmet (__) and with helmet (_ _).

5. CONCLUSIONS

During walking, acceleration of the head in the fore-and-aft, vertical and pitch axes is dominated by peaks in the time histories at the stepping frequency. As walking speed increases, the magnitude of the dominant vertical and pitch head acceleration increases but the magnitude of the dominant acceleration in the fore-and-aft and yaw axes of the head reduces. Wearing a helmet tended to reduce head motion in the frequency range 2 to 5 Hz.

6. ACKNOWLEDGEMENTS

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