SURFACE MEASUREMENT OF VIBRATION TRANSMISSIBILITY OF THE HUMAN SPINE DURING DAILY LIFE ACTIVITIES

Dafne Z. Morgado R., Siobhan Strike, Raymond Lee
Roehampton University, London; email: d.morgado-ramirez@roehampton.ac.uk

INTRODUCTION

Previous studies have suggested that the spinal column has shock absorbing properties when subjected to simple biomechanical movements, mechanical shocks and whole body vibration devices [1,2]. However, the spine may have a different response when exposed to intricate and random stimuli such as daily life activities. Simple biomechanical movements during which the dynamic response of the human spine has been investigated are mainly walking [2], running [2] and heel strike [3]. However, activities such as ascending and descending stairs and turning have not yet been investigated.

Having a reliable method to measure the biomechanical response of the human spine during daily life activities may assist understanding the conditions under which it is effectively and safely stimulated.

The purpose of this study is to validate the surface measurement of vertical vibration transmissibility over the human spine during some physical activities that would resemble daily life.

METHODS

Three healthy male participants were recruited (25-30 years old). After obtaining written informed consent three inertial sensors (Wireless InertiaCube3™, InterSense Inc.) were used to measure acceleration over their spine. To validate, two inertial sensors were put side by side over the first thoracic spinous process (T1) allowing for each to move in their vertical direction without touching each other. One more accelerometer was put over the first sacral vertebra (S1).

To correct for skin movement, all skin-sensor interfaces were subjected to four nudge tests which induce a free vibration response by displacing the sensor with the finger approximately one centimetre in the vertical direction and then quickly releasing it. During these tests and five seconds before each physical activity, participants were asked to stand still, looking forward with arms on their sides and in a relaxed and comfortable way. Volunteers were asked to perform three activities (three times) at a self selected and comfortable speed: walk in a straight line (33m), ascend and descend standard stairs consisting of 17 steps.

All data was analyzed using Matlab (R2010a, Mathworks Inc.). Raw sensor-local acceleration measured during the skin-sensor interface tests was re-sampled to 110 Hz and low pass filtered at 6.5 Hz. To estimate the free vibration response the damping ratio (ζ) and natural frequency (*fn*) were calculated for each skin-sensor interface [4]. Acceleration measured during physical activity was coordinate transformed to the global-earth system (global) in order to correct for the inclination of the sensor to the vertical throughout the measurements. Accelerometers were used as inclinometers (first five seconds before each physical activity) in order to calculate the mean angle to the vertical for each sensor. Local and global acceleration was corrected for skin movement in the frequency spectrum by employing the free vibration response of each skin-sensor interface. Power spectral density (PSD) of global acceleration corrected for skin movement and low pass filtered at 20Hz was calculated. Transmissibility of vertical vibration along the spine was estimated as the ratio of the PSD of the output (T1) over the PSD of the input (S1) and over the frequency range of 0 – 20 Hz.

To assess the validation of the methods presented, cross correlation coefficients were determined for the acceleration between trials for each sensor and between the pair of sensors over T1, for all subjects and for both the uncorrected and corrected (low pass filtered, transformed to the global frame and skin corrected) conditions. Similarly, cross correlation coefficients were calculated between left and right mean transmissibility over T1 for all subjects and activities. In order to determine the frequencies at which the spine transmits vibrations produced by daily life activities, mean transmissibility over T1 is presented.

RESULTS AND DISCUSSION

Values of ζ and *fn* are within the range of previously published data employing this technique (see Table 1).

Table 1: Free vibration response elements.

Subject	T1 Left		T1 Right		S1	
	ζ	***fn***	ζ	***fn***	ζ	***fn***
1	0.192	5.516	0.175	5.410	0.187	5.511
2	0.149	5.964	0.232	5.964	0.172	5.780
3	0.169	5.154	0.159	5.225	0.203	4.958

The technique showed to be reliable by improving cross correlations from uncorrected (U) to corrected (C) acceleration. A summary of these can be seen in Table 2. Cross correlations of transmissibility measured at T1 (Table 3) did not show a significant change after correction for skin movement yet both correlated above 0.95 (see Table 3).

Table 3: Cross correlation of transmissibility before and after correction for skin deformation.

Subject	Walk		Ascending		Descending	
	U	**C**	**U**	**C**	**U**	**C**
1	0.997	0.997	0.996	0.997	0.999	0.998
2	0.989	0.959	0.996	0.966	0.997	0.984
3	0.986	0.986	0.991	0.989	0.989	0.986

Figure 1 presents uncorrected (grey) and corrected (black) mean transmissibility for ascending stairs, for subject 2 and for the right measurement over T1. Maximum transmissibility between 6.5-12 Hz decreased by 15% after skin correction, transmitting a maximum of 1.243 times the input within the frequency range mentioned.

Mean transmissibility for walking (figure 2), ascending (figure 3) and descending (figure 4) stairs was calculated for three trials of each sensor over T1 and for each subject.

Mean transmissibility of trials (black) is presented with each trial (grey). Transmissibilities were dissimilar for different activities regarding amplification and attenuation characteristics at different frequencies. While ascending stairs the input was amplified only between 7-10 Hz reaching a maximum of 115%. For walking, transmissibility reached 115% at 1 Hz and an average maximum of 117% between 12.5-18 Hz. Attenuation of vibration was evident while descending stairs for all subjects, while at 14.6 Hz a maximum of 98% of the input was transmitted. Single transmissibility trials show a large variability between subjects for the same activity.

CONCLUSION

The results of this study show that we are able to successfully correct vibration signals for errors due to skin deformation. It is concluded that surface measurement of vertical vibration transmissibility over the spine and during daily life activities is possible with the correction method presented. The small sample size might not be representative of the population but has confirmed that changes in posture during daily life activities have a significant influence on the degree of transmissibility. More subjects will be recruited and further research conducted to identify movements and frequencies that could have clinically beneficial anabolic potentials.

REFERENCES

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Table 2: Cross correlation for each location over the spine between trials and between left and right side over T1.

		Acceleration between trials						**Acceleration between sensors over T1**	
		Left T1		**Right T1**		**S1**		**Left and Right**	
Activity	**Subject**	U	C	U	C	U	C	U	C
Walking in a straight line	1	0.944	0.974	0.940	0.972	0.938	0.969	0.923	0.965
	2	0.958	0.973	0.946	0.971	0.940	0.943	0.962	0.977
	3	0.986	0.988	0.975	0.988	0.961	0.968	0.998	0.998
Ascending Stairs	1	0.968	0.976	0.969	0.975	0.974	0.973	0.997	0.998
	2	0.959	0.969	0.950	0.970	0.952	0.969	0.993	0.993
	3	0.951	0.968	0.949	0.965	0.926	0.947	0.999	0.999
Descending Stairs	1	0.939	0.954	0.928	0.941	0.901	0.902	0.986	0.989
	2	0.943	0.968	0.949	0.972	0.911	0.943	0.994	0.996
	3	0.962	0.974	0.927	0.951	0.928	0.931	0.972	0.982

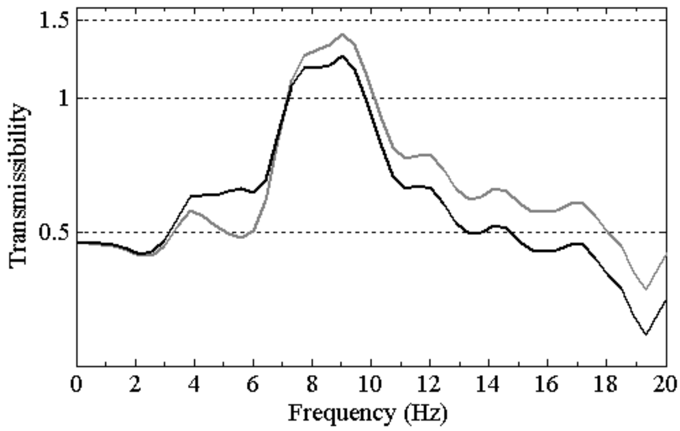

Figure 1: Ascending stairs, transmissibility from S1 to T1, before and after correction.

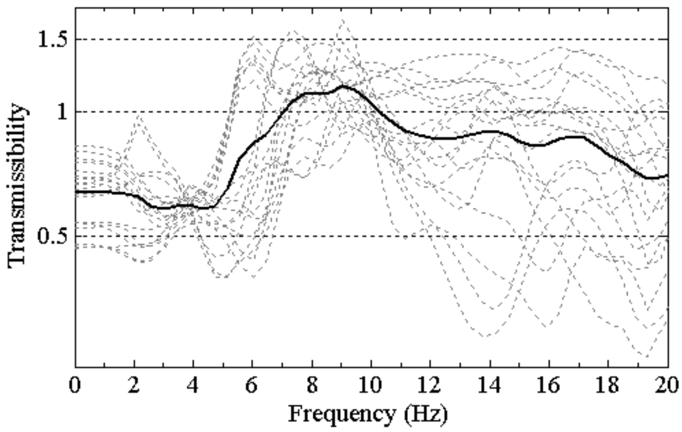

Figure 3: Ascending stairs, transmissibility from S1 to T1.

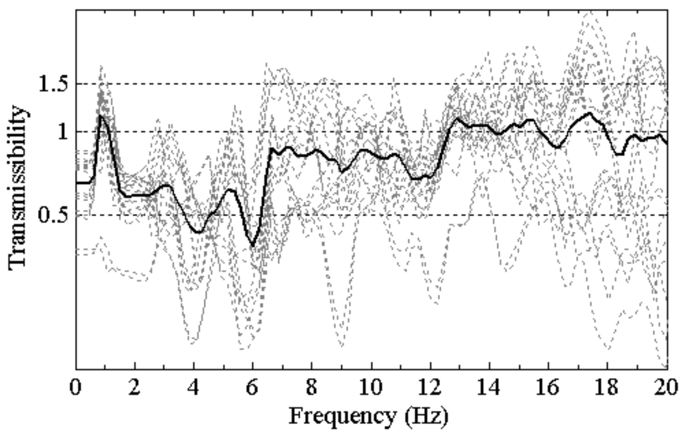

Figure 2: Walking, transmissibility from S1 to T1.

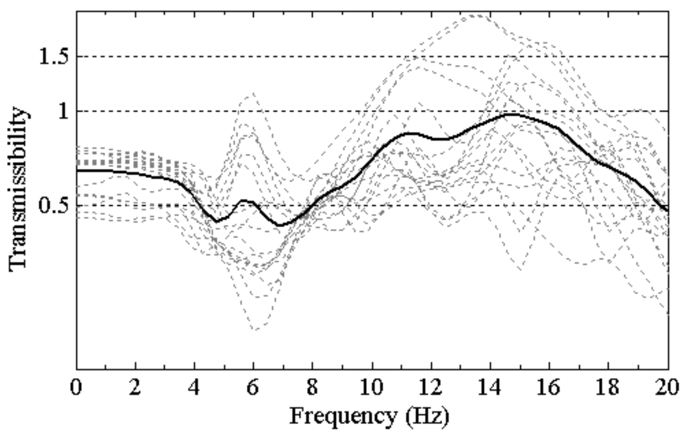

Figure 4: Descending stairs, transmissibility from S1 to T1.