A System for Measuring Sound Transmission Through Joints

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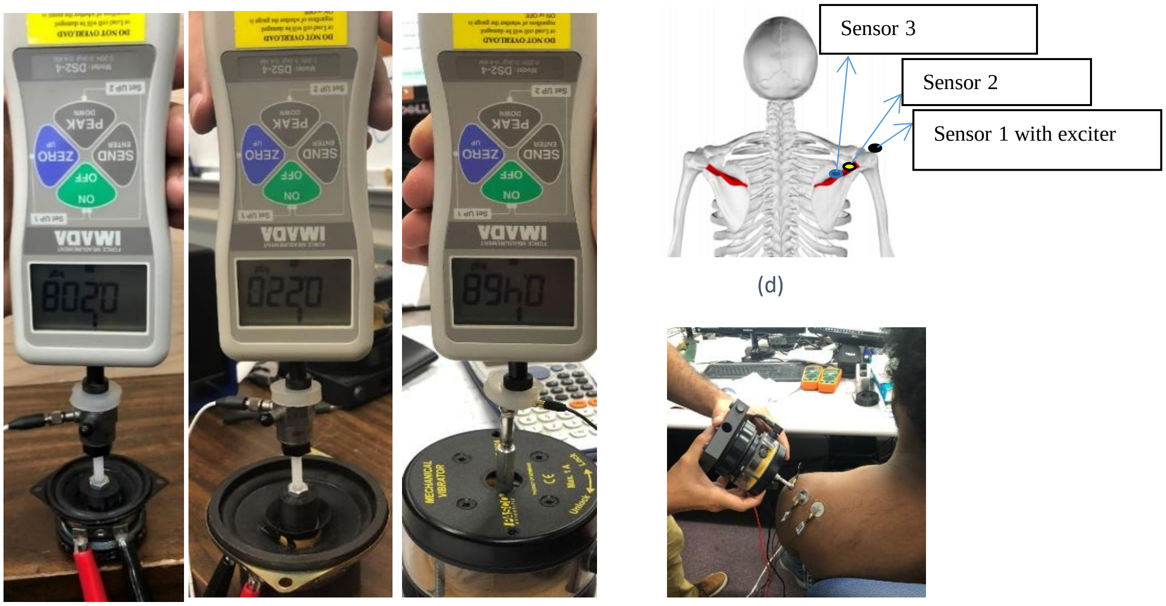
Sound transmission in the human body can be affected by the tissue composition along the sound path and surrounding structures. Therefore, acoustic transmission may correlate with pathologies involving structural changes. Previous studies utilized sound transmission to detect a variety of pulmonary, gastrointestinal, vascular, cardiac conditions, and developmental dysplasia of the hip (DDH) [1] [2] [3] [4] [5] [6]. The objective of this study is to design and test a reliable system capable of providing adequate acoustic stimulus, and simultaneously measure transmitted signals at multiple skin surface locations. The study objectives include determining: (1) the static load needed to reach a target SNR (>20 dB) at the measurement points and a target coherence (>0.8) between excitation and measurement points; (2) the exciter sensitivity to static load changes; and (3) the exciter input maximum power and corresponding acceleration. These results will help guide the choice of optimal exciter that: (1) can withstand sufficient static load (~500g), which would provide coupling to the bone to reach a target SNR and coherence; (2) has low sensitivity to load (low variability for a load change ~100 gm); (3) can provide sufficient acoustic excitation energy to maintain the target SNR and coherence; (4) be available at a reasonable cost (~<$500); (5) ensures patient comfort (with no subject discomfort reported for a contact area of ~ 2 cm^2).

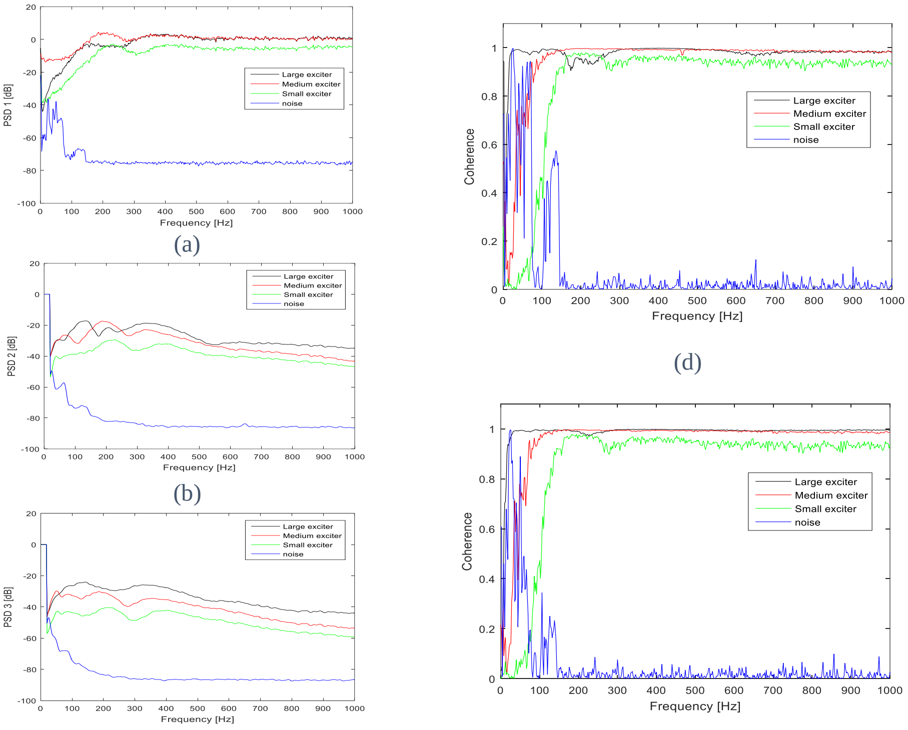
In the current study, a system for measuring sound transmission through joints was built and tested. The system is composed of an electromagnetic vibrational exciter capable of generating a band-limited stimulus signal (10-2500 Hz) and three accelerometers that simultaneously measure the stimulus and transmitted sounds. Three different exciters (small, medium, and large exciters) were tested for this purpose. To effectively input the acoustic signal into the body, a static load between the sound source and skin was must be applied. The Signal to Noise Ratio (SNR) of transmitted sounds was quantified under different static loads. Tests were performed in a bench top model, and in a human subject as shown in Figure 1. The power spectrum spectral density [7], SNR of all signals, and the coherence [8] between stimulus and transmitted signals were calculated.

Results suggested that the large exciter has the disadvantages of being heavier (900 gm vs 400 and 120 gm for other exciters), and more expensive ($300, vs <$20 for the other 2 exciters). On the other hand, its advantages include: low sensitivity to static load (up to 1000g), maximum SNR at measurement points, and higher efficiency (requires 0.5 W vs 2.5 and 5W for other exciters to attain the desirable S/N ratio) as shown in Figure 2. The chosen design can apply a static load of up to 500g, which would provide sufficient coupling to the bone to maintain a target SNR and coherence of > 20 dB and > 0.8, respectively (for frequencies between 50-1000Hz). These results suggest that the proposed system may be useful for measuring sound transmission through joints. In future studies, this system will be used to detect DDH (developmental dysplasia of hip) in animal models and in humans.



(a) (b) (c) (d) (e)

Figure 1: Experimental set up to study the effect of static load using the benchtop model of soft tissue on (a) small exciter, (b) medium exciter, (c) large exciter, (d) location of sensor on human subject, and (e) human tests



(a) (b) (c) (d) (e)

Figure 2: PSD for the 3 exciters with and without the excitation signal for (a) sensor 1, (b) sensor 2, (c) sensor 3, (d) coherence between sensor 1 and 2, and (e) Coherence between sensor 1 and 3

REFERENCES

[1] H. Mansy, T. Royston and R. Sandler, "Use of abdominal percussion for pneumoperitoneum detection," *Medical and Biological Engineering and Computing,* vol. 40 (4), pp. 439-446.

[2] H. Mansy, R. Balk, W. Warren, T. Royston and Z. Dai, "Pneumothorax effects on pulmonary acoustic transmission," *Journal of applied Physiology,* 2015.

[3] H. Mansy, S. Hoxie, N. Patel and R. Sandler, "Computerised analysis of auscultatory sounds associated with vascular patency of haemodialysis access," *Medical and Biological Engineering and Computing,* 2005.

[4] F. Khalili, P. Gamage, R. Sandler and H. Mansy, "Adverse hemodynamic conditions associated with mechanical heart valve leaflet immobility," *Bioengineering,* 2018.

[5] A. Taebi and H. Mansy, "Effect of Noise on Time-frequency Analysis of Vibrocardiographic Signals," *Journal of bioengineering & biomedical science,* 2016.

[6] T. Hassan, L. Mckinney, R. H. Sandler, A. Kassab, C. Price, F. Moslehy and H. A. Mansy, "An Acoustic Approach for Detection of Developmental Dysplasia of Hip," in *IEEE Signal Processing in Medicine and Biology Symposium (SPMB),* Philadelphia, 2018.

[7] P. Stoica and R. Moses, *Spectral Analysis of Signals*. Prentice Hall, 2005.

[8] J. S. Bendat and A. G. Piersol, *Random Data: Analysis and Measurement Procedures*. Wiley-Interscience, 1986.

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Abstract

- **Background:** Sound Transmission through the human body can be affected by the tissue composition along the sound path and surrounding structures. Hence, acoustic transmission may correlate with pathologies involving structural changes.
- **Methods**: A system for measuring sound transmission through joints was built and tested. The system is composed of an electromagnetic vibrational exciter capable of generating a band-limited stimulus signal (10-2500 Hz) and accelerometers simultaneously measuring stimulus and transmitted sounds. To effectively input the acoustic signal into the body, a static load between the sound source and skin is needed. The signal to noise ratio (SNR) of transmitted sounds was quantified under different static loads. Benchtop and human subject testing were performed. The SNR of all signals, and the coherence between stimulus and transmitted signals were calculated.
- **Results:** Benchtop and human model results showed that different exciters can withstand varying levels of static loads with minimal performance degradation. The chosen design can apply a static load of up to 500g, which delivers sufficient coupling to the bone to maintain a target SNR and coherence of > 20 dB and >0.8, respectively (50<f<1000Hz).
- **Conclusion:** The proposed system has low sensitivity for load changes of ~100 gm. This suggests that the proposed system may be useful for measuring sound transmission through joints.

Methods: Available Exciters

- Three exciters were considered.

Small exciter

Medium exciter

Large exciter

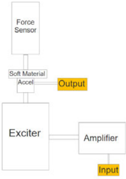
Methods: Hardware and Analysis

- A computer-controlled system was constructed to generate band-limited white acoustic noise (50-2500 Hz) and measure acoustic signals.
- Power spectrum density (PSD) is a measure of the strength of the incident and transmitted vibrations as a function of frequency. PSDs were calculated using Fast Fourier Transform (FFT).
- Coherence quantifies the association between two signals as a function of frequency. It is bound by 0 and 1, with a higher value indicating a stronger association. The following function is used to calculate coherence ($\gamma_{ab}(f)$) between signals *a* and *b*:

$$\gamma_{ab}(f) = \frac{(|P_{ab}(f)|)^2}{(P_{aa}(f))(P_{bb}(f))}$$

Methods: Benchtop Models

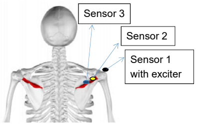
- A soft cylinder was placed on top of exciters. A static load was applied to the soft cylinder by a force gauge. An accelerometer was rigidly connect to the exciter.



- The applied static loads for each exciter were: Small exciter: 0, 50, 100, 150 and 200g; Medium exciter: 0, 50, 100, 150, 200, 300, 400 and 500g; Large exciter: 0, 100, 200, 500, 800, and 1000g.
- The maximum loads were chosen such that the maximum static displacement remains within a few mm. The stimulus signal (electrical input to amplifier) was acquired by Channel 1. The accelerometer output signal was acquired by Channel 2.

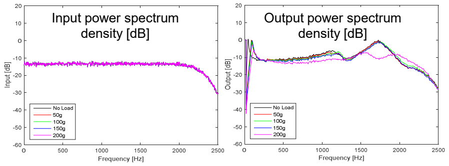
Methods: Human Subject

- Sensor 2 and 3 were placed on the spine of scapula. Sensor 1 (with exciter) was placed on the greater tubercle.
- Sensor 1, 2, 3 data were acquired by channel 1, 2 and 3, respectively.



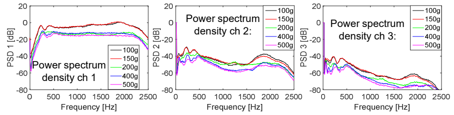
Results: Effect of Applied Static Load

➢ Small exciter – benchtop model:



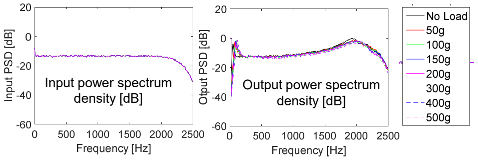
- Similarities in the PSD signals were observed for frequencies > ~200 Hz and loads between 0 and 150g.
- For a load < 200 gm, little PSD differences were noticed. For a load of 200g, the PSD difference was larger, (~10 dB near 1750 Hz).

➢ Small exciter - human subject:



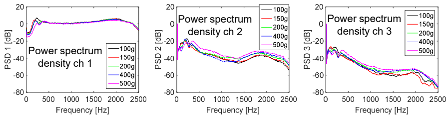
- The small exciter was less sensitive to loading changes in the 50-150g static load range.

➢ Medium exciter-benchtop model:



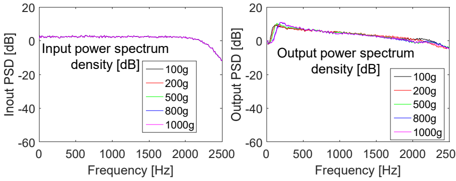
- The medium exciter was less sensitive to loading changes in the 0-500g range (200<f<1750Hz).

➢ Medium exciter- human subject:



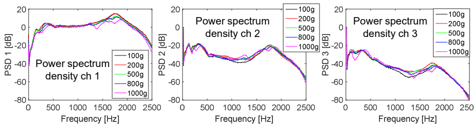
- Similarities in the PSD signals were observed for sensor 1 at frequencies > about 300 Hz and loads between 100 and 400g.

➢ Large exciter-benchtop model:



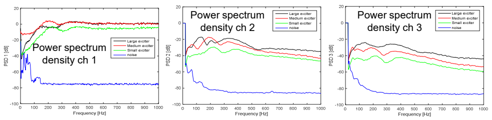
- Similarities in the PSD signals were observed for loads between 100g and 1000g, except in the 50-150Hz where PSD was lower for a load > 500g.

➢ Large exciter- human subject:



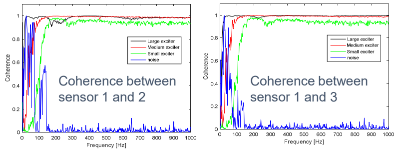
- For sensor 3, at a load of 1000g, the PSD showed a small drop, suggesting that the large exciter is less sensitive to loading changes in the 100-800g range.

Results: Signal-to-noise-ratio for Different Exciters



- Here, the input power was 5, 2.5, and 0.5 W and the static load was 150, 400 and 500g for the small, medium and large exciter, respectively. These conditions were chosen such that the load effects were small and power is close to maximum without noticeable signal distortions.
- SNR was highest for the large exciter.

Results: Coherence



- The large exciter appeared to have higher coherence values (>0.8) at low frequencies (50-200 Hz) than the medium and small exciters.

Summary

- The study aims include determining:
  (1) the static load needed to reach a target SNR (>20 dB) at the measurement points and a coherence (>0.8) between excitation and measurement points;
  (2) the exciter sensitivity to static load changes;
  (3) the exciter input maximum power and corresponding acceleration.
- These results will help guide the choice of optimal exciter that: (1) can withstand sufficient static load (~500g), which would provide coupling to the bone to reach a target SNR and coherence; (2) has low sensitivity to load changes (e.g., low variability for a load change ~100 gm); (3) can provide sufficient acoustic excitation energy to maintain the target SNR and coherence; (4) be available at a reasonable cost (~<$100); (5) ensures patient comfort (with no subject discomfort reported for a contact area of ~ 1 cm2).
- Results suggested that the large exciter has the disadvantages of being heavier (900 gm vs 400 and 120 gm for other exciters), and more expensive ($300, vs <$20 for the other 2 exciters). On the other hand, its advantages include: low sensitivity to static load (up to 1000g), high SNR at measurement points, and high efficiency (e.g., requires 0.5 W vs. 2.5 and 5W for other exciters to attain the desirable S/N ratio.
- In future studies, this system will be used to detect DDH (developmental dysplasia of hip) in animal models and in humans.