REDUCING WHOLE-BODY VIBRATIONS IN NEONATAL TRANSPORT

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Problem Statement

Transport puts extreme stress on neonates who are often in critical condition, lowering their chance of survival [1]. Vibrational forces experienced by neonates during transport are linked to an increased chance of severe brain injury. In particular, intraventricular hemorrhaging (IVH), can lead to neurodevelopmental impairment or death [2], [3]. To resolve this issue, a spring and damper system has been proposed to help mitigate the harsh vibrations. This design is comprised of four sets of oscillating and damping components in parallel, inserted between the inner and outer trays of the transport isolette.

Vibrational data was collected with an accelerometer inside the isolette, both with and without the design. Results were analyzed to quantify the effect of the springs and dampers on the magnitude and direction of vibrations.

Motivation

- The quality of transport for critically-ill neonates to a Neonatal Intensive Care Unit (NICU) directly influences chances of survival [4].
- The current methods of transport expose a neonate to whole-body vibrations (WBV), translational and rotational motion, and excessive sound [5].
- Transportation of a neonate significantly increases the odds of severe brain injury (odds ratio of 2.32) and significantly lowers odds of survival without brain injury (odds ratio of 0.60) [5, 6].
- Reducing vibrations has the potential to significantly improve the outcomes of neonatal transport.
- There is no standardized vibration-reducing device used in neonatal transport.

Figure 1: A preterm neonate in the NICU [7].

Background & Competing Designs

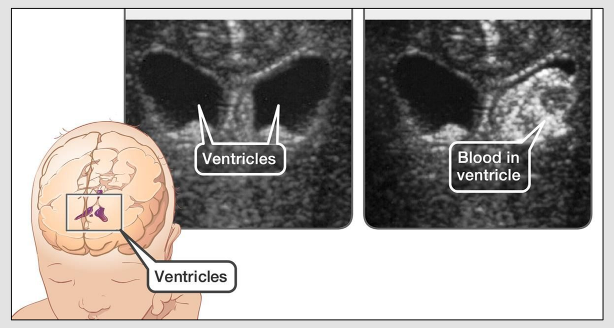

Figure 2: Healthy and IVH CT scans of the neonate ventricles with an anatomical reference on the left [8].

Figure 3: The incubator assembly [9].

Background:

- WBV can cause the fragile capillaries surrounding the neonate's ventricles to rupture, leading to a pooling of blood in the ventricular space (IVH) [8].
- During transport, the neonate is placed in an incubator which sits on the deck of an adult-sized patient gurney. The deck of the gurney also carries supporting equipment such as oxygen tanks.
- A removable inner tray supports a mattress and attaches to a permanent outer tray on the bottom of the incubator. Below the incubator is metal housing for the temperature and other control systems.

Competing Designs:

- Isolation device for shock reduction [10]
  - Utilizes gas springs
  - Adjustable pressure for attenuating different frequencies
- Quasi-Zero-Stiffness Isolator [11]
  - Utilizes pair of repelling magnets and a coil spring.

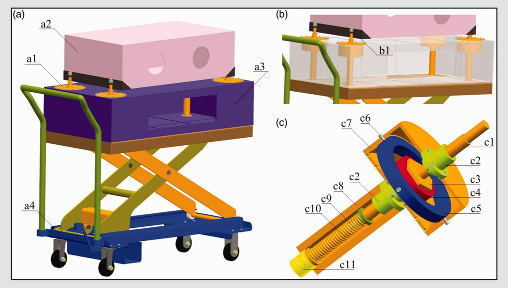

Figure 4: QZS Schematic [11]

Design Criteria

- Minimizes vibrational, translational, and rotational forces to **prevent injury of the neonate**.
- Installation of the device **dampens vibrational forces to below 0.315 m/s²** for the entire transport [12].
- The device must either **attach to the current incubator setup** OR include all the associated functions including ventilators, monitoring equipment, and temperature control mechanisms.
- The device **must not interfere** with any medical interventions or life-sustaining equipment, nor should it interfere with the transport process.
- The dimensions of the device must allow it to **fit within a standard ambulance**.
- All exposed materials must be **easily sterilized and safe** for a hospital environment.

Final Design

Spring Calculations:

- Normalized Frequency: 3.6
  - Damping Ratio = 0.3
  - Displacement (Y/X) = 0.2
- Excitation Frequency (f): 17 Hz
- Mass (m): 6 kg
  - Includes hypothetical mass of baby, gel mattress, pads, and trays

$$\frac{\omega}{\omega_n} = \frac{2\Pi f}{\sqrt{k/m}}$$

Figure 5: Equation used to calculate the spring constant

- Using the equation in Figure 4, the spring constant was calculated to be 31,692.4 N/m, which is approximately 7,923.10 N/m for each of the 4 springs.

The team selected Smalley® C037-L1 crest-to-crest springs with k = 7880.70 N/m for a combined spring constant of 31,522.80 N/m.

Damping Calculations:

- The damper was selected using the equation in Figure 5 to calculate $C_{critical}$, which is the minimum amount of damping required to prevent oscillation.

$$C_c = 2\sqrt{k \times m}$$

Figure 6: Equation used to calculate the damping coefficient

- Using the previously defined mass of 6 kg and a combined spring constant of 31,522.80 N/m, each damping component should have a C_c of 218 N•s/m, or 1.25 lbf•sec/in.

The team selected Sorbothane® 40-Durometer sheet stock with a damping coefficient of 1.10-1.68 and 10% compression.

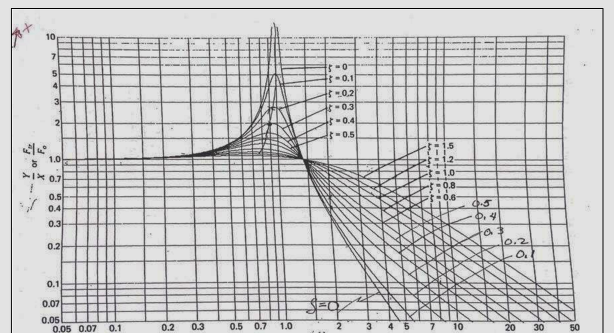

Figure 7: Displacement transmissibility plot used to determine the required spring constant for the springs selected in the final prototype [13].

Fabrication:

- **Base:** 4" x 4" squares of HDPE
- **Fixation Mechanism:** Three small holes were drilled in a corner of each base piece, which line up with the three points of contact that the bottom of the spring has.

Assembly:

- Three pieces of thread were looped and tied around the bottom layer of the spring, then thread through each of the three holes and tied in a single knot under that piece of HDPE to hold the springs in place.
- Super glue was used to secure the knot underneath the HDPE to ensure it didn't unravel or move during use.
- The Sorbothane already had an adhesive layer which was stuck onto the HDPE on the same side as the spring.

Installation:

- One of the spring and damper combinations was placed on each of the four corners of the outer tray of the transport isolette.
- The four prototypes were secured to the inner tray by the adhesive layer of the Sorbothane that was not stuck on the HDPE to minimize movement during transport.

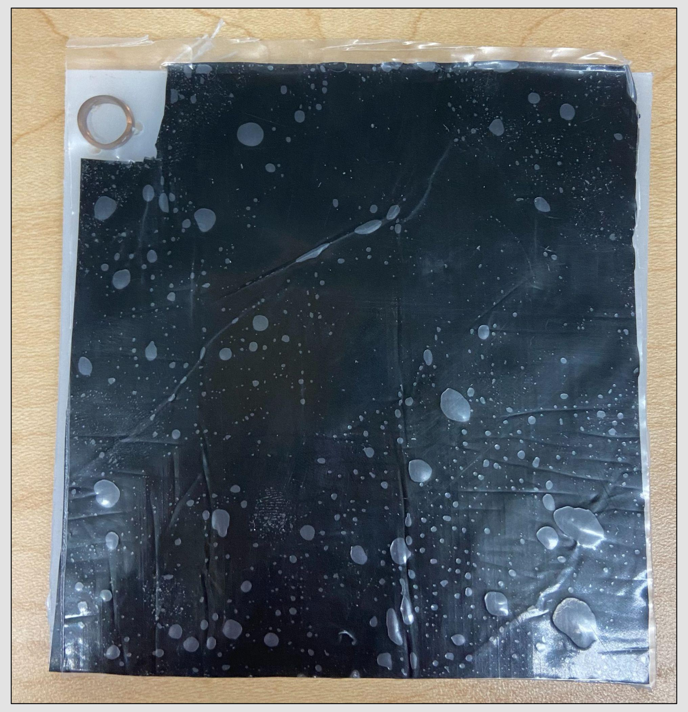

Figure 8: 4" x 4" HDPE with Sorbothane damping material and spring placed in upper left corner.

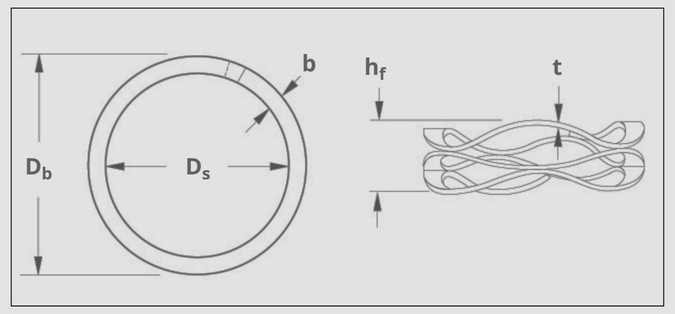

Figure 9: Technical drawing of the C037-L1 spring used in the final prototype [14].

Results and Analysis

Analysis of Data:

1. The text files of acceleration data in the z-direction from the accelerometer were analyzed in MATLAB.
2. The FFT function (Fast Fourier Transform) is used to compute power spectral density of the input signal in the frequency domain.
3. The first half of the power spectral density, up to the Nyquist frequency, is maintained while the second half is replaced with its positive complex conjugates.
4. The frequency vector f is also defined based on the length of the signal and the sampling frequency.
5. The above process is repeated for each set of acceleration components and the resulting power spectral density is then plotted as a function of frequency.

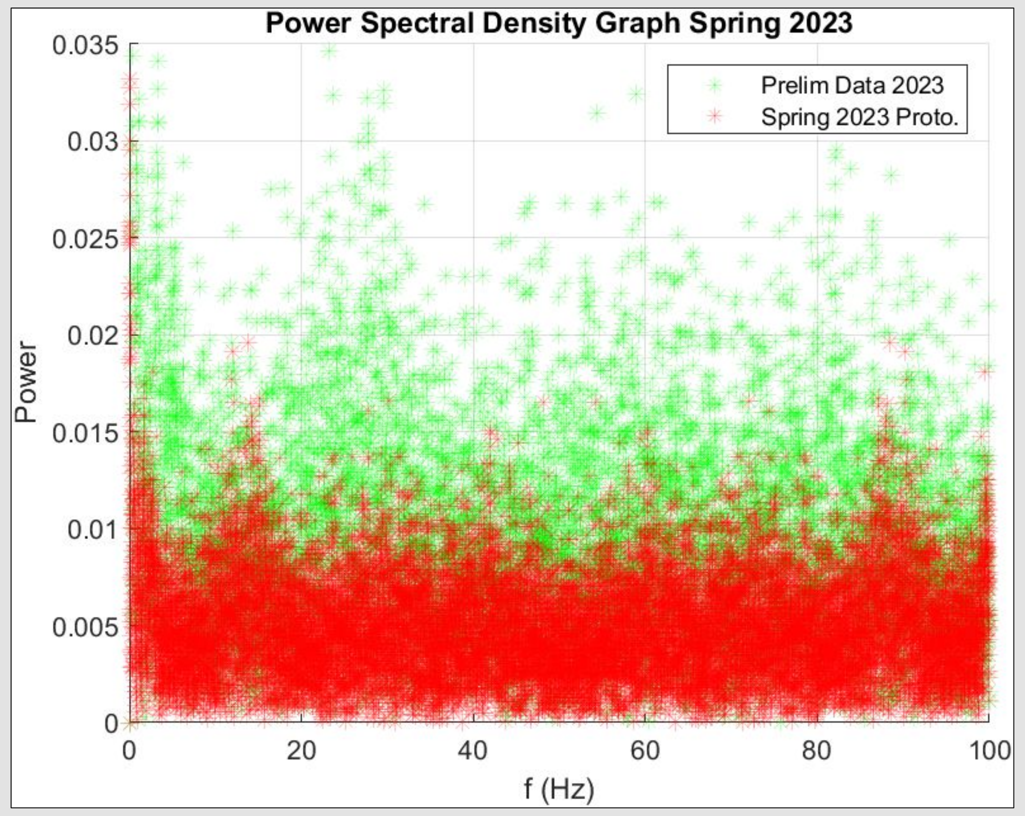

Figure 12: Power Spectral Density curve for the data collected during preliminary and final testing in Spring 2023.

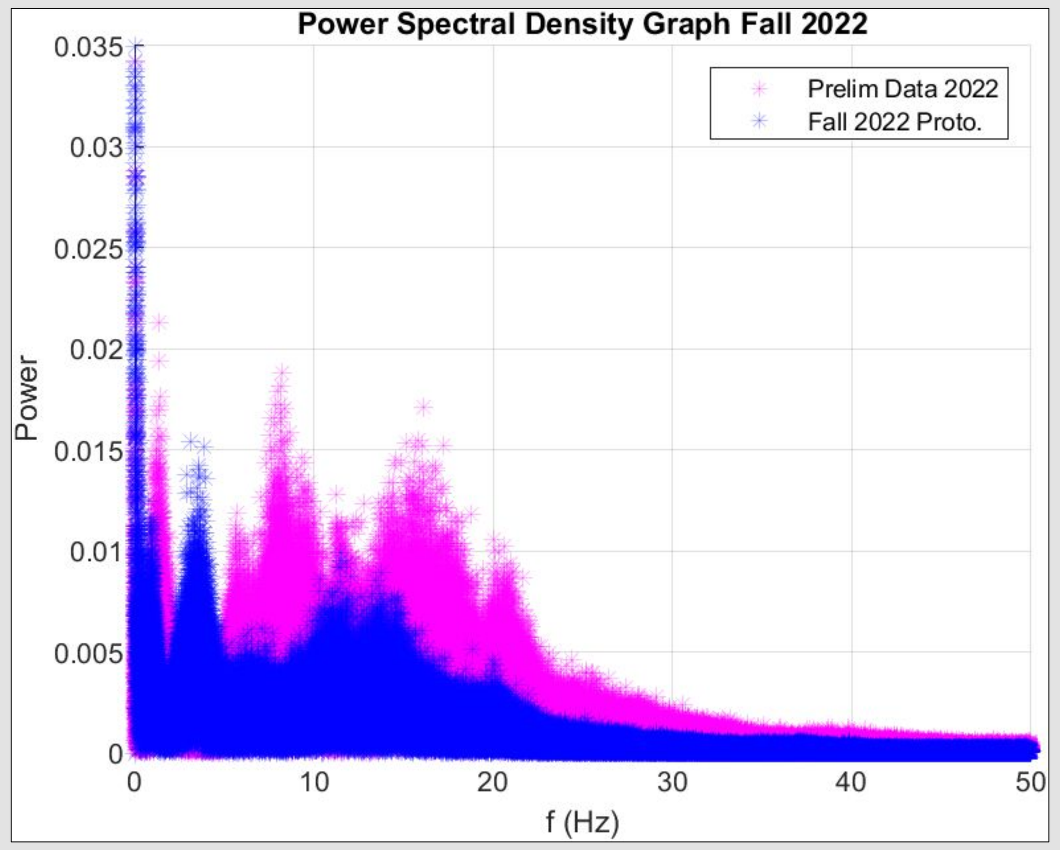

Figure 13: Power Spectral Density curve for the data collected during preliminary and final testing in Fall 2022.

Determination of Statistical Significance:

1. The data was separated into 250 bins for each of the sets of PSD components.
2. Iterates over each bin and performs Welch's t-test on the corresponding data points from the two inputted PSDs.
3. The number of bins that have a p-value less than the significance threshold of 0.05, indicating statistical significance was counted and reported.

	# of Number of Significant Bins	% Significant
Fall 2022 Prototype	163	65.2%
Spring 2023 Prototype	106	42.4%

Table 1: Count of significant p-values for Fall and Spring Prototypes.

Testing

- Vibration data was collected in the current transport setup during two ambulance rides with the UW Hospital Medlife team.
  - Control run with no spring & damper prototype on 4/14/2023
  - Testing with spring & damper prototype on 4/21/2023
- Each ambulance ride followed the same route and was approximately 50 minutes long, enduring various terrain such as freeway travel and stop-and-go travel to understand the vibration response.
- Acceleration was measured with the WitMotion WT901SDCL Accelerometer at a sampling frequency of 200 Hz.
  - Placed inside the inner tray around where the head of the neonate would typically go, but beneath the gel mattress to stay secure.

Figure 10: Prototype placed in the corners of the outer tray.

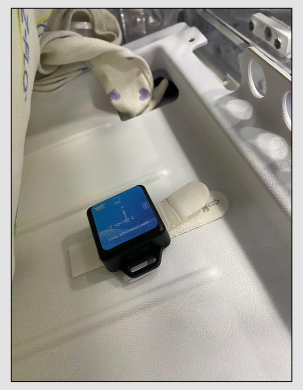

Figure 11: Placement of WitMotion accelerometer inside the inner tray. Secured with two command strips.

Discussion & Future Work

There were minor improvements in vibration reduction seen with the use of the device compared to baseline data. Compared to the previous semester's work, which shows a frequency response shifted to a lower frequency, this prototype shows a reduction in the amplitude of the vibrations. Therefore, the team plans to continue to revise this prototype to better mitigate this effect.

1. Continue to optimize spring constant & damping coefficients to further reduce vibrations
2. Replace current springs with a larger effective length to prevent complications with the spring mounting process
3. Connect all four pieces under one plate to minimize impact of ribbed surface of the outer tray
4. Hone testing protocol to better imitate true transport conditions
5. Investigate vibration reduction in x & y planes

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