REDUCING WHOLE-BODY VIBRATIONS IN NEONATAL TRANSPORT

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Abstract and 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 have been linked to an increase in the odds of severe brain injury. In particular, intraventricular hemorrhaging (IVH), can lead to neurodevelopmental impairment or death [2], [3]. To resolve this issue, a metal and gel composite damper has been proposed to help mitigate the harsh vibrations. The damper consists of four layers: silicone gel, aluminum, foam, and stainless steel. This design was inspired by the anatomy of a woodpecker, which can naturally reduce the vibrations its head experiences during pecking. A total of four dampers were placed between the inner and outer trays of the transport isolette. Two configurations of dampers were produced: one to be inserted along the side of the inner tray and one to be inserted in the front corners of the tray. Accelerometer and gyroscope data were collected from various locations in the ambulance with and without the dampers during a test route to quantify the effect of the 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, mechanical forces, and excessive sound has the potential to significantly improve the outcomes of neonatal transport.
- There is no standardized vibration-reducing device used in neonatal transport.

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

Background

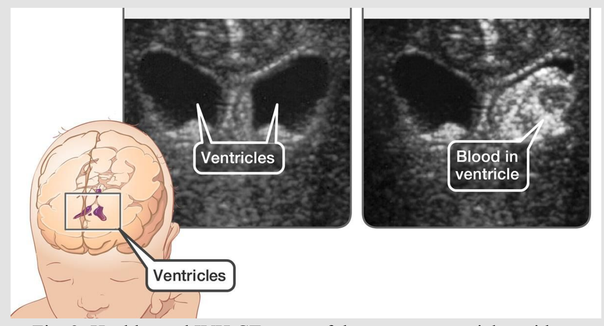

Fig. 2: Healthy and IVH CT scans of the neonate ventricles with an anatomical reference on the left [8].

- 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].

Fig. 3: The incubator assembly [9].

- 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.

Design Criteria

- Minimizes vibrational, translational, and rotational forces to **prevent injury of the neonate**.
- Installation of the device **dampens vibrational forces to below 0.87 m/s^2** for the entire transport [5].
- 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

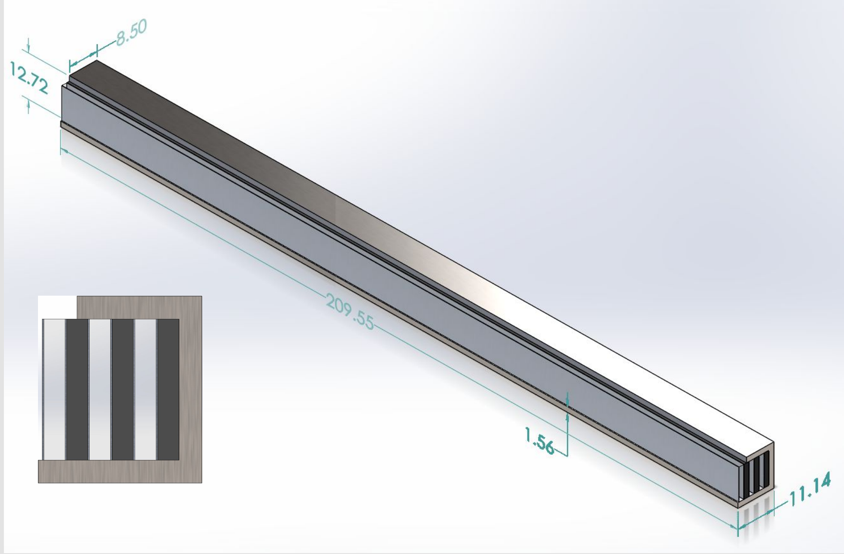

Fig. 4: A SolidWorks model of side damper. Inset view shows cross-section of damper. Dimensions are in mm.

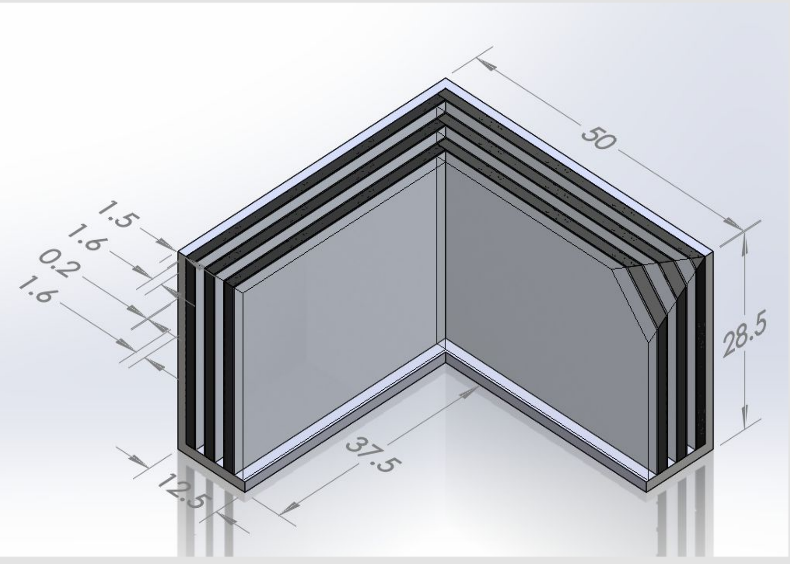

Fig. 5: A SolidWorks model of the corner damper. Dimensions are in mm.

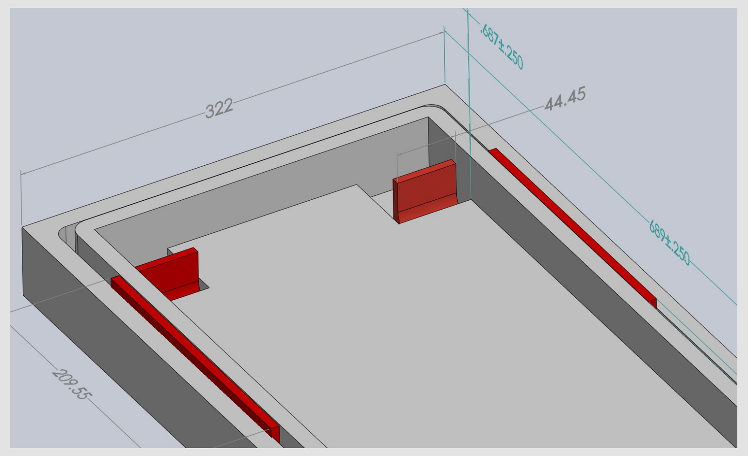

Fig. 6: The damper system placement in the isolette. Dampers are highlighted in red. Dimensions are in mm.

Fabrication

Steel modification:

- Rectangular tube stock was cut to length for side dampers using a drop saw and the top opening was formed using a mill.
- The corner damper housing was cut to dimension using a water jet and bent using a sheet metal bending break.

Layer preparation:

- Layers were cut using a breaker, scissors, and an X-acto knife.

Assembly:

- Layers were arranged in the order of foam, aluminum, gel, aluminum, repeated three times for each damper.
- Between layer placement, spray adhesive was applied.
- Any exposed edges of the layers were wrapped in aluminum.

Installation:

- The side dampers were placed such that the steel outer layer was flush with the outer tray's bottom and exposed sides.
- The corner dampers were rotated with the steel layer against the outer tray and the outermost layer of silicon gel resting against the bottom of the inner tray.

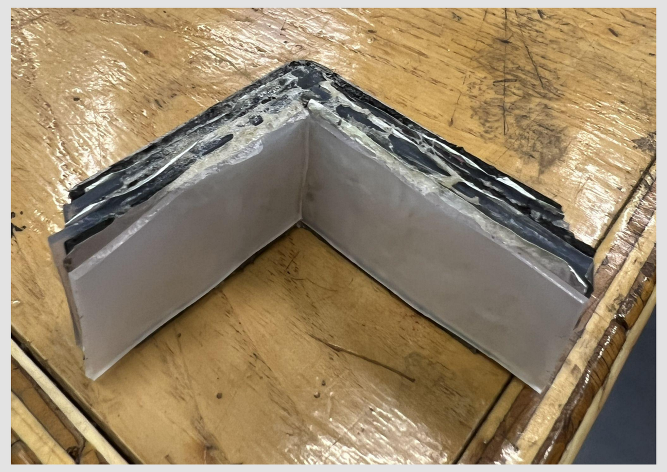

Fig. 7: The layers of the corner damper, organized in the order of foam, foil, gel, foil, repeated three times. The layers were secured using a spray adhesive.

Fig. 8: The final prototype wrapped in the foil outer layer.

Testing

- Vibrations were recorded in the current transport setup during an ambulance ride with the UW Hospital Medlife Team
  - Control run without the Metal/Gel Dampers on 10/21/2022
  - Testing of prototype with the Metal/Gel Dampers on 12/2/2022
- The team designed a route for the ambulance consisting of a variety of terrains:
  - Local roads (20-30mph), highways (50-70mph), and freeways (70-80mph)
  - Low and high traffic areas
  - Bumps, hills, sharp turns, stop signs, and stop lights
- The MATLAB sensor app was used to collect accelerometer and gyroscope data throughout the route at six locations as pictured in Figure 9.
- An event log was made during the trip with exact timings of events such as accelerations, bumps, hills, hard stops, and turns.

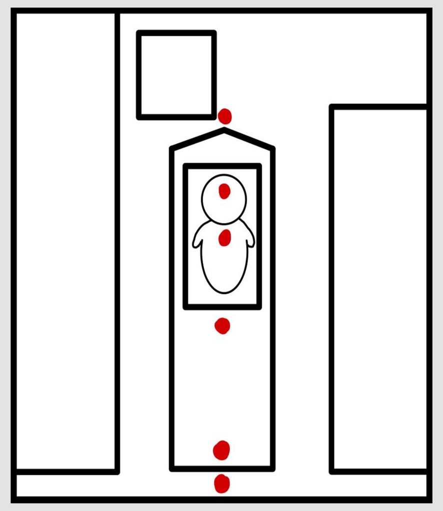

Fig. 9: An aerial drawing of the MATLAB sensor placements for data collection.

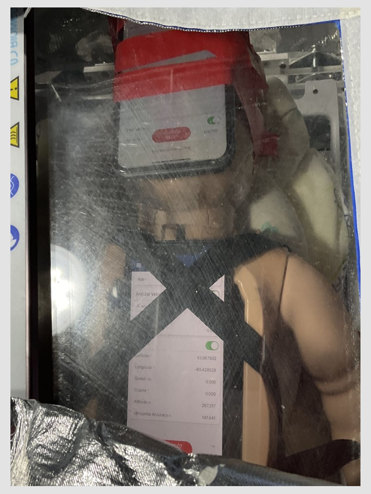

Fig. 10 (above): Top view of phone placement on mannequin during data collection.

Fig. 11 (left): The testing setup inside the incubator which, including a mannequin*, body position pillows, a 5-point restraint system, and two phones placed on the chest and on the forehead.

*Mannequin is much larger than typical neonates transported in this isolette.

Results and Analysis

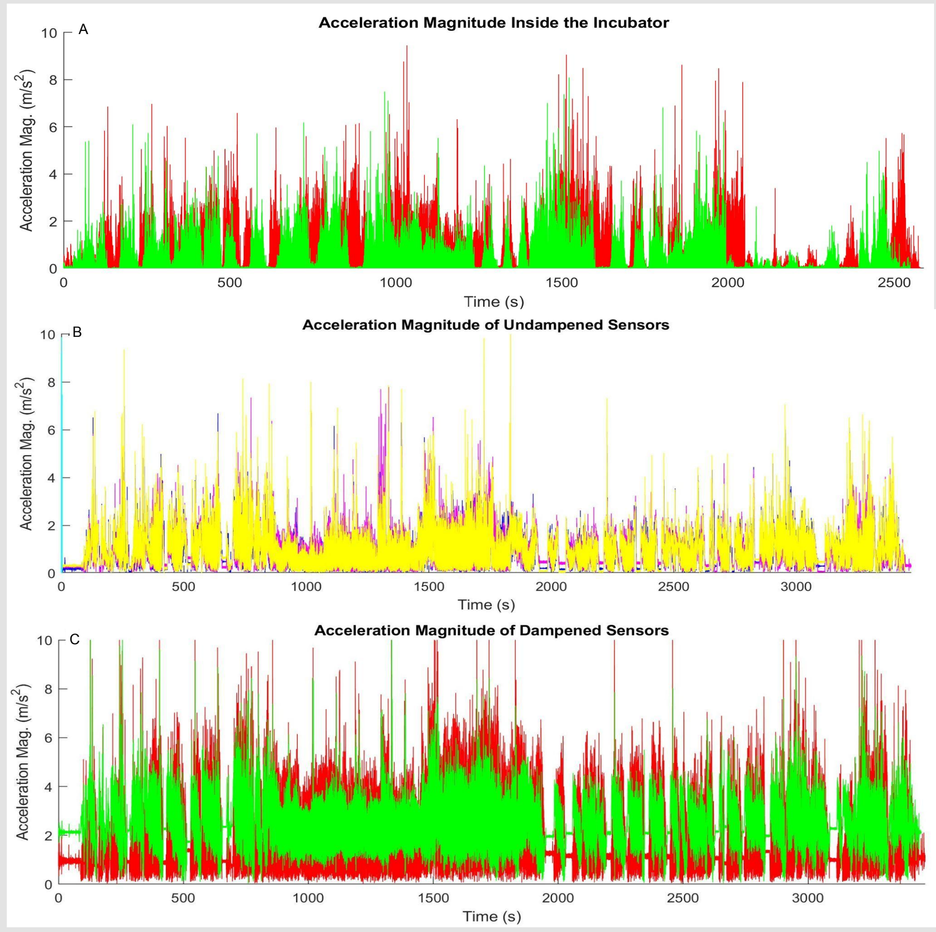

Fig. 12: Acceleration vs. Time graphs for measurements (A) inside the incubator without the dampening prototype, (B) outside the incubator, and (C) inside the incubator with the dampening prototype.

Analysis of Data:

1. The data collected from the MATLAB sensors was separated into time and acceleration components in the x, y, and z directions.
2. A fast fourier transform function was applied to the data in order to gather the frequency components.
3. The data was cleaned using the "detrend" function in MATLAB in order to remove the best straight-fit line from the data [10].
4. The data was plotted as separate signals for Acceleration vs. Time and as a one-sided Amplitude vs. Frequency spectrum.
5. The 6 different sensors will be denoted as Back Floor (BF), Chest, Front Floor (FF), Middle Sled (MS), Head, and Back Sled (BS).

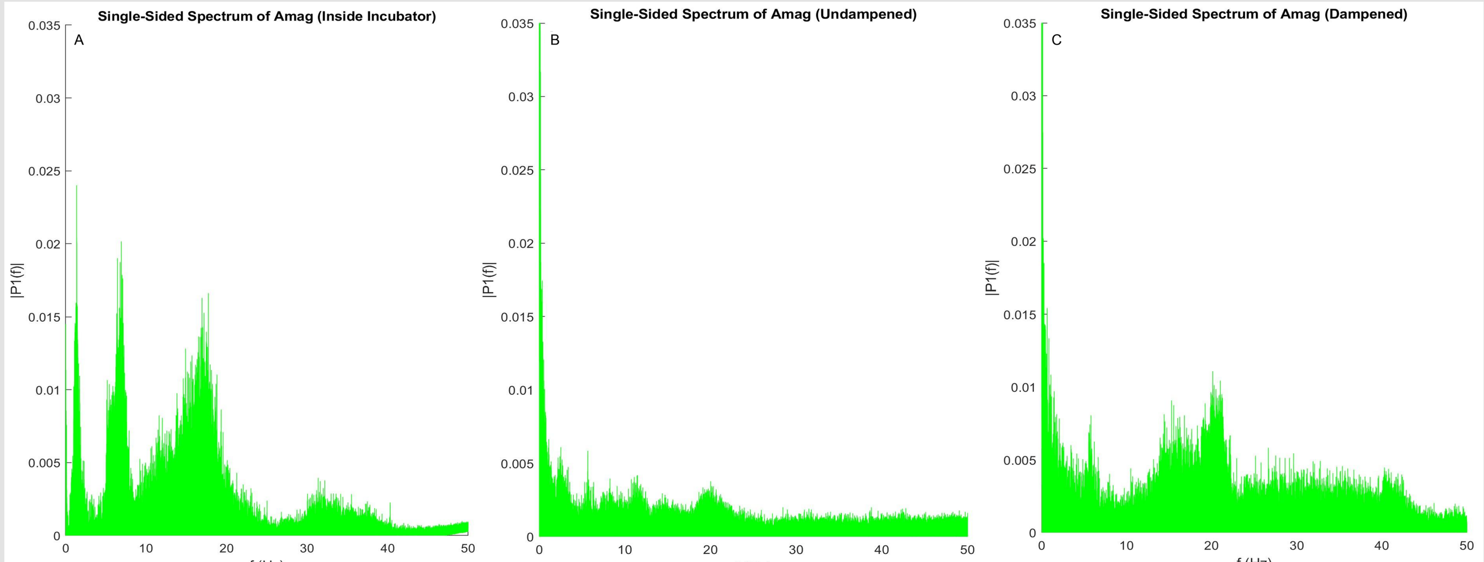

Fig. 13: Power spectral density graphs for measurements (A) inside the incubator without the dampening prototype, (B) outside the incubator, and (C) inside the incubator with the dampening prototype.

Statistical Significance:

1. In order to increase the number of trials, the acceleration magnitude data was grouped into bins of 1-minute lengths containing 6,000 samples per trial.
2. Each acceleration magnitude bin was binned again by the frequency in order to create step sizes of 1Hz from 1-50Hz.
3. An alpha for the test statistic was determined using the Bonferroni correction and a multiple comparison two-sample t-test was run to determine whether the data appears to have come from the same or different populations.
4. Based on the p-value, we reject the null hypothesis that the data came from the same population.
5. The data provides strong evidence that the population means are different.
6. The prototype was unsuccessful at reducing the acceleration to be below the literature threshold of 0.87 m/s^2.

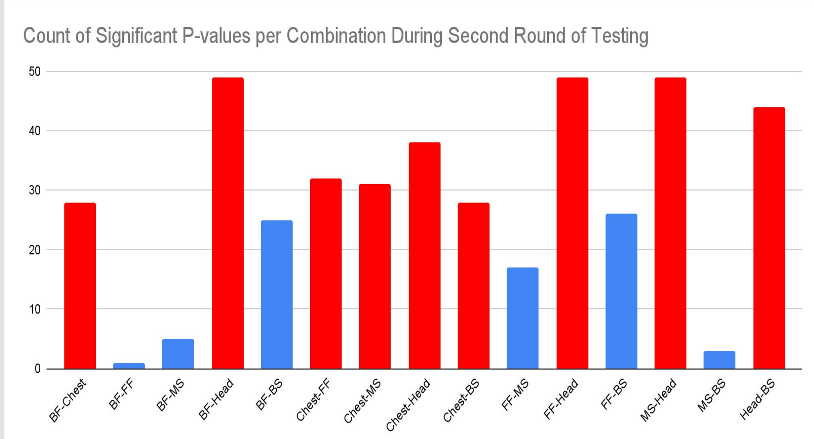

Fig. 14: The number of significant p-values calculated per comparison for dampened sensors inside the incubator and undampened sensors outside the incubator. Comparisons using at least 1 dampened sensor are filled in red.

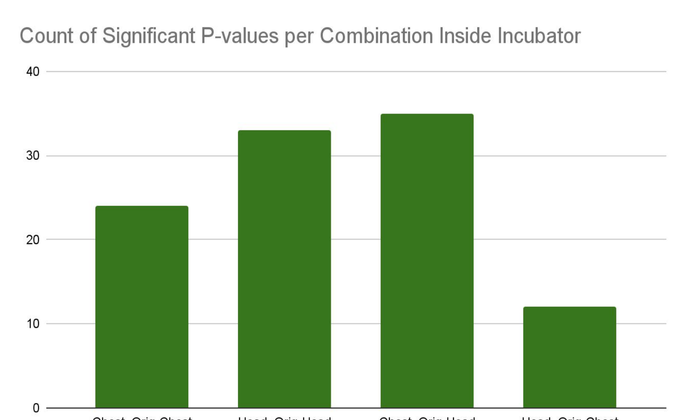

Fig. 15: The number of significant p-values calculated per comparison for dampened and undampened sensors inside the incubator.

Future Work

- Improve the method of encasing the layers within the device
- Modify method of securing the dampers to the incubator
- Change the shape of the corner dampers to fit into the holes in the inner tray.
- Explore a head restraint to add a sound reduction component

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