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Sound Level Within Transport Incubator During Use of Ambulance Siren

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Abstract— **During medical transport, neonates may be exposed to high levels of sound and vibration. A ground ambulance test had been performed in collaboration with the Children's Hospital of Eastern Ontario and the Ottawa Paramedic Service to quantify sound and vibration at the transport incubator location. Ambulance sirens were not utilized during this test, although in emergency transport they are activated for short periods when required. There is an interest in quantifying the sound levels due to the ambulance siren to fill this gap. This paper presents the findings from a stationary siren test, which has been completed to assess the sound level within the ambulance cabin, inside the transport incubator, and at the driver location. The vehicle's two siren tones were run over 30-second durations, and the A-weighted sound pressure levels at the three locations were evaluated, as well as the frequency response in the form of power spectral density. The sound levels within the incubator averaged 65 dBA and 67 dBA during the two tones, both exceeding the recommended level of 60 dBA. The findings support a recommended practice of limiting siren use when transporting neonatal patients.**

Keywords— **Neonatal transport, transport incubator, ground ambulance, noise exposure, sound pressure level.**

I. Introduction

Neonatal transport exposes patients to elevated levels of sound and vibration. In Ontario, Canada, a collaborative study between the Carleton University Applied Dynamics Laboratory (ADL) and the Children's Hospital of Easten Ontario (CHEO) has been investigating the extent of physical stressors in the standard Neonatal Patient Transport System (NPTS). The NPTS is used across the province, and includes a transport incubator and supportive medical equipment that is transported along with the patient [1]. In ground ambulances, the NPTS mounts atop a stretcher which is then secured to the vehicle floor, as shown in Figure 1.

In 2021, the Carleton research team, alongside CHEO, the Ottawa Paramedic Service (OPS), and National Research Council Canada (NRC), performed a study measuring sound and vibration levels across the NPTS and vehicle [2]. The test aimed to replicate realistic transport conditions. A baby manikin was used to simulate the mass of a patient, and various

Fig. 1 NPTS loaded inside of ground ambulance.

road types and vehicle speeds were included in the study. The ambulance sirens that are used during emergency transport were not activated in this testing. To fill this gap and form a more complete understanding of the transport environment noise exposure, there is a desire to quantify the sound levels within the incubator during its usage. This paper reports on a dedicated siren test conducted using the same ambulance model used by OPS for CHEO's neonatal transport (Demers MX-164 Type III with Ford E-450 chassis), and the NPTS, to determine sound level thresholds and compare against the sound exposure typically experienced during transport.

II. Background

To evaluate the sound pressure level (SPL), A-weighting is often applied in accordance with IEC 61672-1 standards to scale perceived loudness based on the sensitivity of the human ear. It is often recommended that sound levels during neonatal transport should not exceed 60 dBA [3], while in the neonatal intensive care unit (NICU), less than 45 dBA for continuous exposure has also been recommended [4]. During real transport, patients routinely wear earmuffs to assist in mitigating this noise.

During this project's previous road testing, average sound levels across all road trips were found to be 64 dBA within the incubator, and 69 dBA in the cabin, exceeding recommended levels [5]. This testing was performed without using the vehicle's siren. External studies have investigated sound levels within an ambulance or transport incubator during ground transport. However, most do not explicitly report whether the siren was included or excluded in the testing. These studies have reported sound levels reaching well above 60 dBA [3,6], and often upwards of 80 dBA [4,7-9]. Campbell et al. recorded levels between 91-101 dBA, and identified peak values in the range of 40-250 Hz [10]. Macnab et al. compared sound inside and outside the incubator [3]. At frequencies 160 Hz – 1.2 kHz, the noise inside the incubator was significantly lower than that outside. However, around 100 Hz, the sound level within the incubator exceeded that of the cabin by about 5 dB. Bouchut et al. acknowledged the effect of the ambulance siren during road testing. It was found to be a more significant contribution in the medium and high frequency ranges, with an average of 67 +/- 3 dBA in the incubator [11]. This test aims to supplement the current knowledge in this area by identifying the sound levels due to sirens, within an ambulance-loaded neonatal incubator.

III. Objective

The objectives of this test were to quantify the A-weighted sound pressure level within a transport incubator, outside the incubator in the rear of the ambulance cabin, and at the driver location while the siren is activated. These levels are then compared to those recorded during ground vehicle testing, without use of the sirens, as well as the recommended exposure levels. The difference between measurements taken inside and outside the incubator will be considered, alongside the frequency response at the two locations, to establish the attenuation and amplification of noise by the incubator.

IV. Methods

The sensor setup for this siren test was intended to replicate that which was used in previous testing. The same ICP microphones (Model 378B02, PCB Piezotronics, Depew, NY, USA) were used for data collection; one within the incubator near the position of a patient's head, and the other in the cabin, pointed towards the incubator. Figure 2 presents the two microphone locations relative to the transport incubator. Data were also collected near the driver position, as shown in Figure 3. A CCLD Signal Conditioner (Model 1704-A-002, Bruel & Kjaer, Virum, Denmark) and DAQ (USB-6259, National Instruments, Austin, TX, USA) were used to log measurements to a laptop computer.

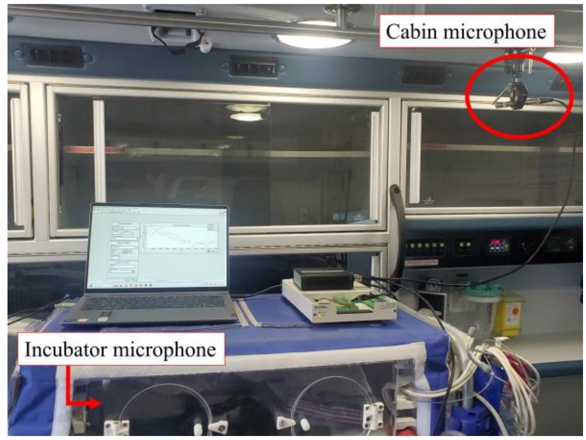

Fig. 2 Cabin and incubator microphone locations.

Fig. 3 Driver microphone location.

Samples were taken at a rate of 50 kHz, and later filtered between 20 Hz to 20 kHz as this is the frequency range of human hearing. The signals were scaled with the A-weighting curve, using the sound pressure level metering tool in the MATLAB Audio Toolbox (MathWorks, Natick, MA, USA). The time-weighted SPL for each test was found by averaging over the standard fast-weighting time segment of 125 ms. To determine the responses in the frequency domain, the power spectral density (PSD) of each microphone signal was found using MATLAB's *pwelch* function.

Testing occurred November 7, 2023, on the CHEO campus in a far, empty parking lot to avoid disturbances to staff or visitors. Given the historical weather data from the nearest weather station, Ottawa CDA RCS (79.20 m elevation), the temperature around the time of testing was 5.5 °C, and the atmospheric pressure was 99.63 kPa.

Two siren tones were run for 30-second durations. Tone 1 is a more gradually repeating alarm used while travelling along a road, while Tone 2 has a more rapid pattern and is used when approaching intersections to capture the attention of other drivers. Measurements were taken within the incubator and cabin simultaneously, and the sirens were run again after repositioning a microphone by the driver's seat. In addition to the siren tones, measurements were taken of ambient noise, and while playing audio files of frequency sweeps using speakers inside of the cabin. These measurements are intended to be used to characterize the frequency response of the incubator and assess linearity with respect to increasing audio volume. However, these additional data are not examined in this paper and will be explored in future work.

V. Results

The A-weighted SPLs for each siren tone were found within the vehicle cabin and incubator. The time histories of each of these approximately 30-second siren runs are presented in Figures 4. Tone 1, which uses a more gradual siren pattern, reaches 74.3 dBA within the incubator and 68.2 dBA in the cabin. Tone 2, the more rapid siren pattern, produced levels reaching 68.5 dBA in the incubator and 68.1 dBA in the cabin. During Tones 1 and 2, the average levels in the cabin are 65.2 dBA and 68.3 dBA, and within the incubator are 65.0 dBA and 67.0 dBA. The SPL recorded by the driver seat during Tones 1 and 2 are presented in Figure 5, with averages of 71.9 dBA and 72.4 dBA, respectively.

The power spectral density of each microphone signal has also been computed, as shown in Figures 6 and 7. A similar response is found for both tones; around 40-150 Hz, the exterior values noticeably exceed those within the incubator. The levels inside the incubator and at the driver are generally greater across the rest of the spectrum.

VI. Discussion

For both siren tone tests, the sound level within the incubator exceeds the recommended 60 dBA for the entire duration. Once the sirens were turned off, the SPL within the incubator decreased to approximately 58-60 dBA, while the ambient cabin noise remained well above 60 dBA. Repeating both siren runs and recording at the driver's location revealed that the levels were greatest here. This is reasonable given this position is closest to the siren located within the vehicle grill. Reaching nearly 82 dBA during Tone 1, these findings indicate that the siren exposes the driver to higher sound levels than a patient within the incubator.

In both tone tests, the sound level within the cabin did not change significantly once the siren was activated. The orientation of the microphones may have contributed to an often lower SPL in the cabin than in the incubator. The ambulance siren is located at the front, exterior of the vehicle. Given the cabin microphone was directed towards the rear of the vehicle, and the incubator microphone was oriented forward, this could be a factor causing the cabin results to be lower than expected. Additionally, other sources of noise such as the heating and cooling fan and hum from the on-board electronics were also present.

Considering the frequency response, the greatest amplitudes occurred around 100 Hz for all three locations. At higher frequencies, and at a low frequency peak near 25 Hz, the incubator level is greater than the surrounding cabin, indicating amplification. Within the 40-150 Hz range, the cabin response is greater than that of the incubator. This differs from the findings of Macnab et al. This may be due to the stationary nature of this test. Reviewing the frequency response from our previous ground vehicle test showed amplification consistent to that of Macnab, and it may be a product of much higher energy input due to the vehicle motion [12].

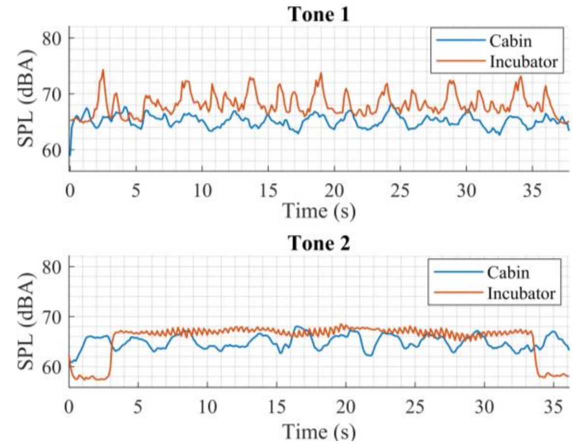

Fig. 4 SPL of siren Tones 1 and 2 at cabin and incubator locations.

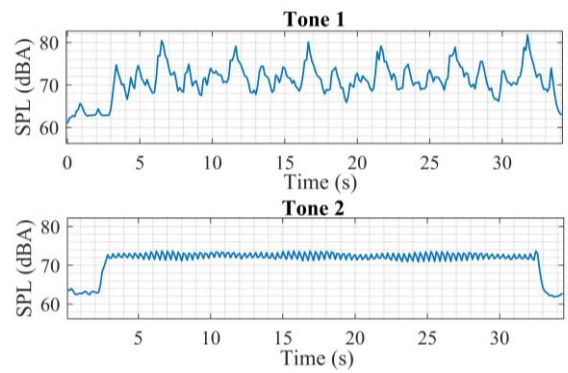

Fig. 5 SPL of siren Tones 1 and 2 at driver location.

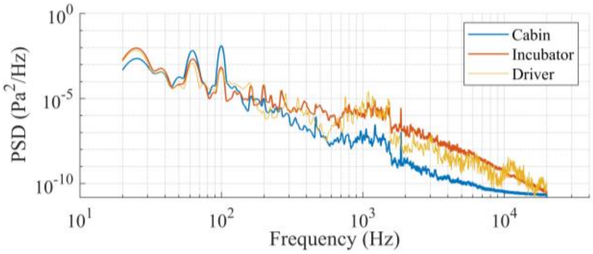

Fig. 6 PSD of siren Tone 1.

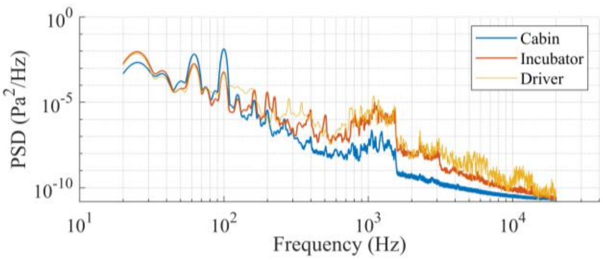

Fig. 7 PSD of siren Tone 2.

The stationary siren test is thought to explore too narrow of an input condition to expect the response of a full road test. Further investigation of noise amplified by the incubator will be performed by assessing the measured sound levels when exposed to a controlled, continuous frequency sweep input.

The SPL within the incubator exceeded recommended levels during both siren tones, which supports OPS's practice of only using the siren when necessary.

VII. Conclusions

Previous ground ambulance testing in collaboration with CHEO and OPS investigated sound levels inside the cabin and incubator, over various road conditions [5]. To supplement these tests, which did not involve running the ambulance siren, a stationary siren test was performed at the CHEO campus. The sound of the ambulance siren was found to not only exceed the recommended level of exposure for the incubator, but occasionally is greater than sound produced during the typical transport conditions explored in ground testing. In the case of both siren tones, the SPL measured within the incubator was often higher than that within the cabin of the vehicle. Further investigation into the frequency response at the three locations will provide additional insight into the incubator properties and frequency ranges of greatest concern. Additionally, evaluating the attenuation provided by the earmuffs routinely worn by neonates will assist with quantifying exposure at the patient level. Ultimately, this short siren test supports a recommended practice of limiting the use of ambulance sirens during the transport of neonates whenever possible, and the need to implement appropriate hearing protection.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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