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Development of a Digital Noise Exposure System for Research on Noise Induced Hearing Loss

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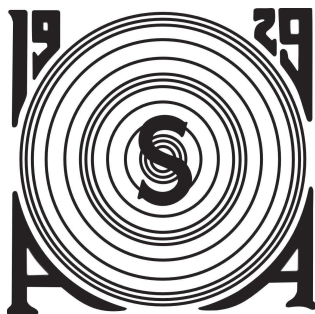
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5aNS12.   Development of a digital noise exposure system for research on noise induced hearing loss

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  Over thirty million Americans suffer from noise induced hearing loss (NIHL). Previous research demonstrated that different types of noises, even with equal sound energies, could produce different amounts of hearing loss. In this project, a novel digital noise exposure system has been developed for generating various noise signals (e.g. pure-tone, Gaussian, impulsive, and complex noise). The developed system can be used to study NIHL in animal models. The system could produce impulse noise with peak sound pressure level (SPL) up to 160 dB, which effectively mimics the noise generated by a military weapon (e.g., M-16 rifle). The preliminary results of in an animal study showed significant permanent threshold shift (PTS) produced by 90 shocks impulse noise with peak SPL = 155 dB generated by the system. In summary, the digital noise exposure system replicates environmental noise allowing researchers to study impulse noise induced hearing loss in a controlled situation.

Introduction

Noise induced hearing loss (NIHL) is a serious health related problem that affects many people worldwide. It was estimated that about 29 million Americans have some type of hearing loss within the speech frequency range [1]. This number seems to be on the rise since about 30 million Americans are currently exposed to noise every day in their jobs [2]. Hearing loss has been shown to lower the quality of life, impair social interactions, cause isolation, and can cause loss of cognitive function [2]. NIHL can be developed from gradual developing hearing loss (GDHL) and acoustic trauma [3]. GDHL is the damage to the cochlea from prolonged, excessive sound pressures [4, 5]. The threshold of GDHL is considered to be no more than eight hours of exposure to a sound pressure level at 85 decibels (dB) or more [5]. Acoustic trauma is the permanent damage to the cochlea due to short-time exposure to a high sound pressure at or above 120 dB. It is most often referred to as impulsive noise induced hearing loss [3, 4].

Noise can be classified into Gaussian continuous noise (i.e., stead state noise), high-level transient noise (i.e., impulsive noise including impulse noise and impact noise), and complex noise (i.e., a non-Gaussian noise consisting of high-level transients noise mixed in a Gaussian noise) [6-8]. All types of noises could cause hearing loss at high noise level[4].

In this paper, impulse noise refers to the nonreverberant A-duration wave, and it is a type of highly transient noise widely experienced in military field (e.g., an intense blast wave) [9]. Impulse noises can be produced by firearms, rockets, hammering, etc. [10]. Impulse noise typically causes acoustic trauma to the ear as the sharp fast pressure change can do traumatic damage in a very short period of time. Animal studies demonstrated the impulse noise could cause more hearing loss than continuous noise (i.e., Gaussian noise) with same amount of acoustic energy [11].

Although significant progress has been made on the investigation of impulse noise and its prevention, impulse noise induced hearing loss still remains as a severe problem in military and industrial fields. Research on experimental simulation and characterization of impulse noise is still needed. In this study, a novel digital noise exposure system has been developed for generating various noise exposures. The system can successfully produce impulse noise with peak sound pressure level (SPL) up to 160 dB, which effectively mimics the noise generated by a military weapon (e.g., M-16 rifle). The results of animal experiments show a significant permanent threshold shift (PTS) produced by 90 shocks impulse noise with peak SPL = 155 dB generated by the developed system.

Methods and Materials

1. Digital noise exposure system

A digital noise exposure system has been developed for generating different noise signals [12]. As shown in Figure 1, the noise exposure system consists of a data acquisition device (NI DAQUSB-6251), an audio power amplifier (Yamaha P2500S), an

acoustic compression driver (JBL 2446J), a shock tube extension (3' length and 2" diameter), an exponential horn (JBL 2380), and a computer. A user interface is created using LabVIEW software to generate digital noise signals and control the system. The system is installed in a reverberant chamber.

To simulate the A-duration impulse noise, the waveform of the digital signal can be described by the Friedlander equation.

$$p(t) = P_s e^{-t/t^*} (1 - \frac{t}{t^*}) \tag{1}$$

where P_s is the peak sound pressure, and the t^* is the time at which the pressure crosses the x-axis and goes from positive to negative. The digital signals of impulse noise were generated using the Friedlander equation in LabVIEW, and then converted into analog signals through the data acquisition device with 62.5 kHz sampling rate. The analog signals were amplified by the audio power amplifier, and fed into the compression driver to create impulse noise.
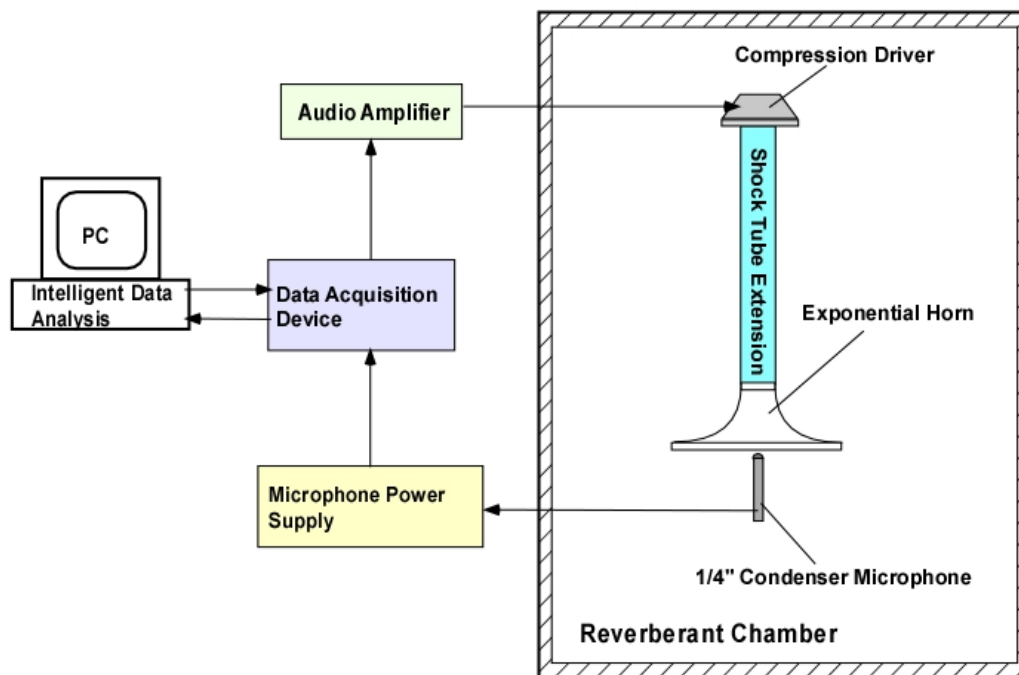

Figure 1: Schematic diagram of the digital noise exposure system and the ¼" condenser microphone set for the measurement of impulse noise.

2. Measurement and characterization of impulse noise

To measure the impulse noise generated by the developed system, a ¼" high sensitivity condenser microphone set (GRAS 46BF) was used. The measured noise signals were converted into digital signals through the data acquisition device with 125 KHz sampling rate and saved in the computer (as shown in Figure 1). The microphone

was aligned at the center of the horn. The impulse noise was generated at different output voltages (from 0.3 V to 8 V). Ten waveforms of impulse noise were recorded at each output voltage.

The key parameters of the impulse noise were defined according the international standard of Acoustic Determination ISO 1999 -1990 [13]. The peak positive pressure P^+, time duration of positive pressure t^+ (i.e., A-duration), were determined from the waveforms of impulse noise. The A-weighted equivalent sound pressure level, L_{Aeq} is defined as:

$$L_{Aeq} = 10\log_{10}[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2}\frac{p_A^2(t)}{p_0^2}dt] \qquad (1)$$

where $p_A(t)$ refers to the instantaneous A-weighted sound pressure of impulse noise signal, p_0 is the reference pressure at 20 µPa, and t_2-t_1 is the period T over which the average is taken starting from t_1 and ending in t_2.

The spectral distribution in the frequency domain of the impulse noise signal was obtained by applying the fast Fourier transform (FFT). In this study, the Cooley-Tukey FFT algorithm was used for the FFT calculation.

3. Protocol of animal experiments.

All animal experiments in this study were following Southern Illinois University institutional guideline regarding animal experimentation. The animal model comprised 3-year-old male *Chinchillas* (Ryerson Chinchilla Ranch; Plymouth, OH). 10 Chinchillas were used in this study. Animals were placed into a sound booth (Industrial Acoustics Company) and exposed impulse noise with peak SPL = 155dB at 2 Hz pulse repetition frequency for 75 seconds. Animals received five inraperitoneal (ip) sterile saline injections every 12 hours before and after noise exposure for a total of 10 injections. Auditory brainstem responses (ABRs) were measured at baseline, prior to any saline or noise exposure, and again 21 days after noise exposure cessation using tone-burst stimuli centered at 2, 4, 6, 8, 14 and 20 kHz frequencies. ABR threshold was defined as the lowest intensity capable of eliciting a replicable, visually detectable response.

Results and Discussions

Figure 2 shows the time history of a representative waveform of impulse noise generated by the developed noise exposure system at 6.0 V. The waveform is leading by a compressive waveform segment with ~ 0.3 ms duration, followed by a rarefaction waveform segment with ~ 0.6 ms duration, and ending with a oscillation tails with about 5 ms duration. The peak positive pressure is about 1600 Pa and the peak negative pressure is about -500 Pa. The waveform was generated to mimic the impulse noise produced by a M-16 rifle, and it is comparable with the waveform of impulse noise measured in military fields [14].
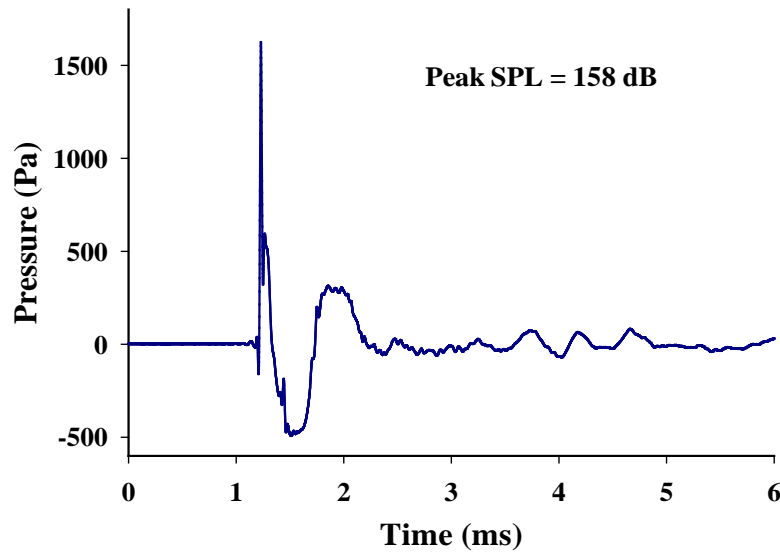
Figure 2: A representative waveform of the impulse noise generated by the developed system at 5V output voltage.The peak sound pressure level is about 158 dB and A-duration is about 0.3 ms.

Figure 3 shows the SPL of peak positive pressure P^+ of impulse noise at different output voltages. The P^+ increases, from 130 dB to 160 dB, with the output voltage increasing, and it is saturated when the output voltages greater than 4 V. In addition, the variation of peak pressure can be found to become larger at high output voltages (> 4V). That may be caused by the measurement uncertainty of the condense microphone when measuring the high-pressure and short-time shock front [15].
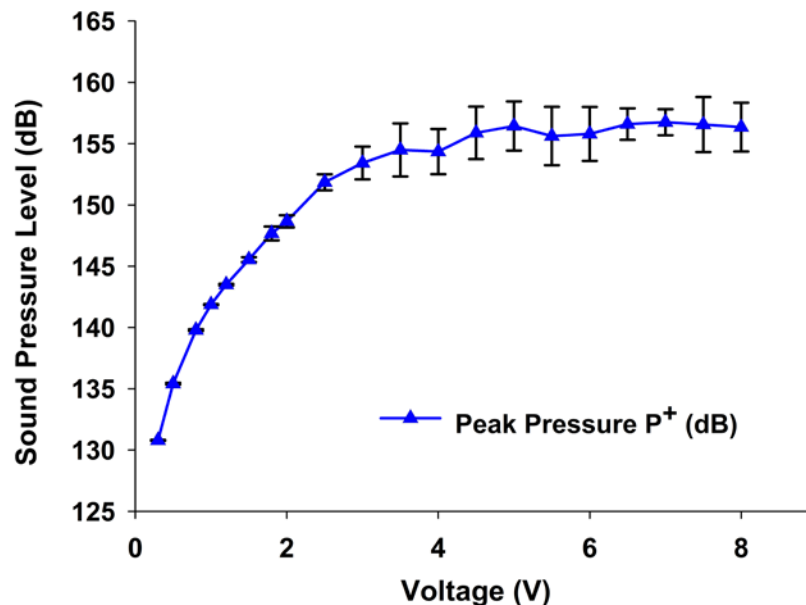

Figure 3: Sound pressure level of the peak positive pressure P^+ vs. the output voltages.
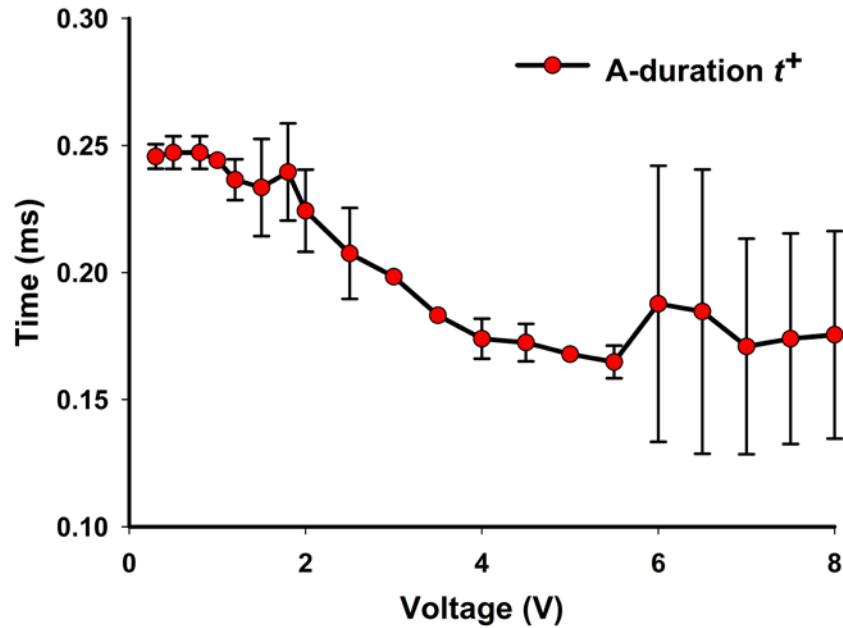
Figure 4: A-duration of the peak positive pressure t^+ vs. the output voltages.

As shown in Figure 4, the A-duration t^+ of impulse noise is decreasing (from 0.25 ms to about 0.19 ms) with the output voltages increasing. It indicates the impulse noise became sharper at higher voltages. Similar to the peak positive pressure, the large variation can be found at high output voltages.
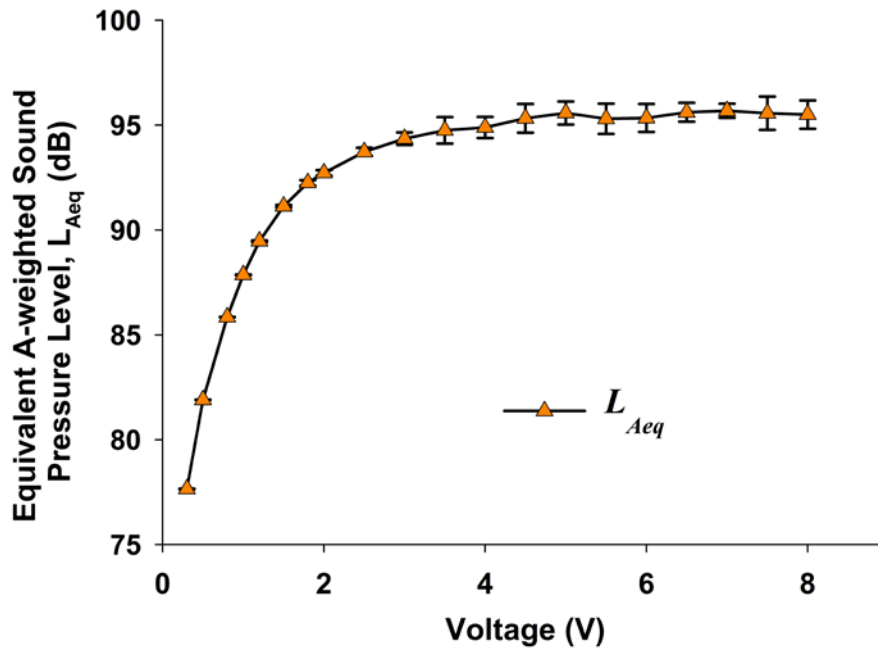

Figure 5: Equivalent A-weighted SPL L_{Aeq} vs. the output voltages.
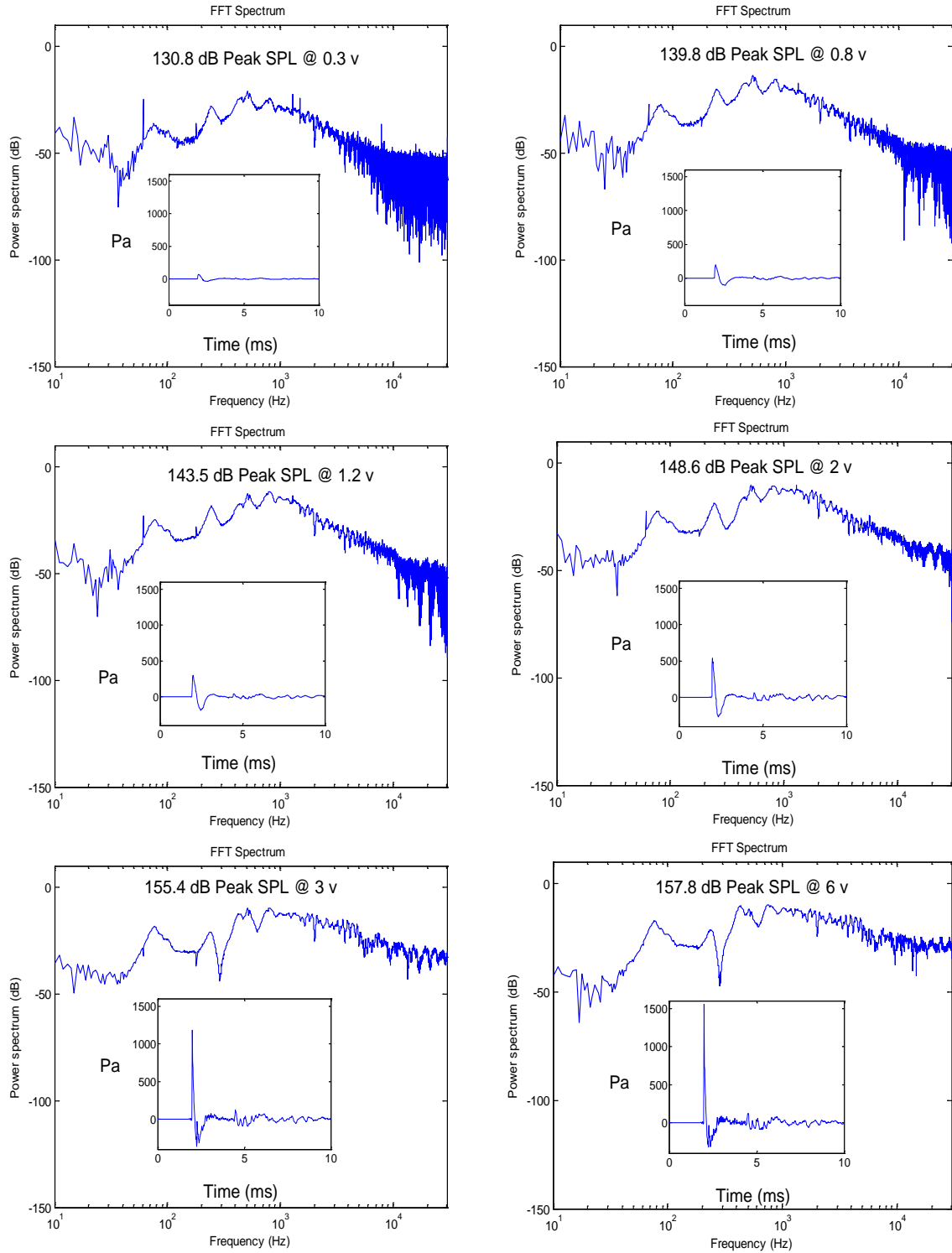
Figure 6: Power spectrums of impulse noise signals generated at various output voltages (0.3, 0.8, 1.2, 1.5, 3.0, and 6.0 V) obtained by applying the FFT.

Figure 5 shows the equivalent A-weighted SPL L_{Aeq} calculated using the measured impulse noise signals at different output voltages. Overall, the L_{Aeq} increases, from 77 dB to 95 dB, with the output voltage increasing, and it also can be found to be saturated at higher output voltages. The L_{Aeq} is calcualted the averaged energy over the time, and it cannot accarately reflect the instantaneous hazard pressure level in the impulse noise.

Figure 6 shows the spectrums of impulse noise signals generated at six output voltage (0.3, 0.8, 1.2, 1.5, 3.0, and 6.0 V) obtained by applying the FFT analysis. The stectrums of impulse showed brand band at all output voltages. It is responding to the short time duration in the impulse noise signals (as shown in inserted figures in Figure 6). The peak amplitude appear at about 1000 Hz frequency in the spectrums of all six signals. In addition, with the output voltages increasing, the high frequency part of spectrum increases significantly.
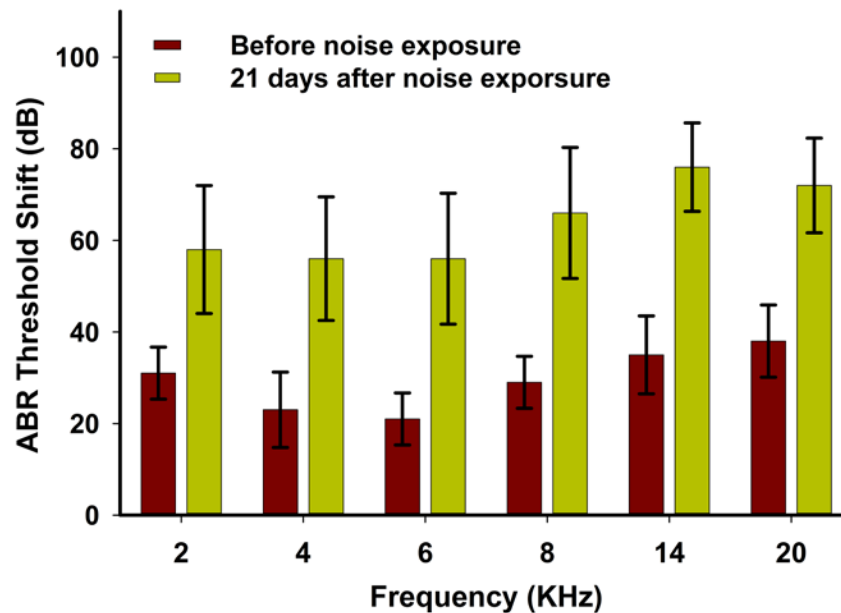

Figure 7: ABR threshold shift measured at different frequencies before and 21 days after a 75 seconds impulse noise exposure with peak SPL=155 dB at 2 Hz pulse repetition frequency.

Figure 7 shows ABR threshold shift of the animals before and 21 days after the 75 seconds at 2 Hz pulse repetition frequency impulse noise exposure. The impulse noise signals were generated by the developed system at 5 V output voltage, and the averaged peak SPL was about 155 dB. ABR thresholds shifted more than 30 dB at all frequencies. The results showed a significant permanent hearing loss can be produced by 90 shocks impulse noise generated by the developed system.

Conclusions

In this study, a novel digital noise exposure system has been developed for research on the NIHL. The impulse noise can be successfully generated by the developed

system to mimic the noise produced by a military weapon (e.g., M-16 rifle). The peak SPL of the impulse noise can reach to 160 dB. The results of animal experiments show a significant hearing loss produced by the impulse noise generated by the developed system. In summary, the developed digital noise exposure system replicates environmental noise, and it allows researchers to study impulse noise induced hearing loss in a controlled situation.

Acknowledgments

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