Background
High-intensity impulse sounds are generally considered to be more damaging than continuous sounds (Dunn et al. 1991; Dietz et al. 2010). The mechanisms involved in damage have not been identified, but these sounds induce hearing threshold shifts, tinnitus, and presbycusis. A potential mechanism of damage from impulse noise is direct tissue damage caused by pressure waves generated by the sound. The pressure waves can be transmitted through bone and fascia, which are largely incompressible, and cause vibrations in the skull, which are transmitted to the inner ear and can cause damage to hair cells in the cochlea.

Objectives
- Preliminary investigation into how bone-conducted impulse sound is transmitted through the human head.
- Develop new tools to assess the effects of impulse noise on the human hearing system.
- Evaluate effectiveness of head protection from bone-conducted acoustic transient of impulse noise.

Methods
The Creare head simulator is built from CT scans of a live human head using material with bulk sound speed similar to bone. The simulator is instrumented with accelerometers on the temporal bones, the mastoids, the forehead, and the back of the skull, as well as a hydrophone. Silicone gel, which is similar to brain tissue in density, was injected between the 2 halves to create a complete skin covering. The simulator is a hollow stainless steel tube with a height of 5.5 m (designated to fit in the middle of a small Sound Room).

Impulse noise was generated with an AR/15 Assault Rifle mounted on a stand and shooting into a sand pile. The head was located to the right of the rifle and 1.18 m away. Microphone was located next to the rifle to the right. Data from both temporal bones, accelerometers, and hydrophone were acquired at a sampling frequency of 51,200 samples per second using a data acquisition system developed and in use at Creare.

Impulse levels were measured at three locations relative to the gun producing peak sound pressures of about 105 dB, 110 dB, and 130 dB.

Results and Discussion
The figures above show the average impulse of six shots taken without any hearing protection device (HPD) at left and with the Creare Flight Data Collector (FDC) mounted on the head simulator at right. The shots were taken with a temporal bone microphone and a hydrophone. The impulse response was obtained from the FDC at right.

With the helmet on the head simulator, the hydrophone and accelerometer responses are considerably reduced with peak values of about 6-12 dB below the values obtained without HPD. We note, however, that the wave increases in amplitude inside the helmet, reaching a maximum about 4.5 m/sec after the start of the impulse, thereby increasing the duration of the wave.

The figures below show the peak response of the hydrophone (left) and the accelerometer (right) for all the shots taken at each of the three locations versus the peak microphone amplitude. The lines show the average peak response. Responses appear to be linear with peak impulse amplitude.

The figures above show the frequency response to the impulse (left) and the frequency response of the head simulator in a sound field (right). We note that the response on the hydrophone follows the resonances observed in the response shown on the left, notably around 800-1,000 Hz. Their frequency is recognized as the dominant in the time domain plots shown at left.

Below, the transfer functions of the hydrophone response (left) and the accelerometer response (right) are given relative to the external microphone measurement (averaged across 3rd octave bands). Four cases are shown. No HPD, with the FDC, with the HGU-84/P, and with the HGU-84/P helmet both head-rght ear helmet. Because the FDC was specifically designed to reduce bone-conducted noise, we observe a transfer function that is significantly below one at most frequencies, except at the lowest frequencies, where the FDC is known to actually perform poorly (see FDC attenuation performance chart, top right corner). The HGU-84/P appears to do a better job than the HGU-84/P helmet at the lower frequencies, which may be due to its better fit around the head.

Conclusions
In this preliminary investigation, we have shown that when exposed to high acoustic impuls noise, such as from a weapon, the impulse sound can go through the body and cause damage to the eardrum and other conductions pathways. The amplitude of the responses at the temporal bone versus the head simulator appear similar, and the peak with peak impulse amplitude.

Hearing protection that has been designed to reduce the effects of bone-conducted sound for continuous noise exposure can indeed reduce the peak amplitude inside the head as well as the vibrations of the temporal bone. However, a helmet has the effect of increasing the duration of inside the head.

It is unknown at this time, whether such vibrations and acoustic levels inside the head may exceed or neurological damage in the case of repeated exposure. However, the bone conduction path is clearly transmittable the impulse inside the head.

Future research into damage risk criteria will require an audit simulator which can measure both sound-conducted and bone-conducted transmission path to understand their relative contribution to hearing loss associated with impulse sounds.

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References
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- Specifically applied for the design of a new noise reduction system.
- ACLU (American Civil Liberties Union)
- Data provided to the National Institute for Occupational Safety and Health for statistical purposes only.