Naval Submarine Medical Research Laboratory

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Impulse Assessment of the 3M™ E-A-R™ Skull Screws™ Corded Earplug

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The impulse peak insertion loss (IPIL) is the standard measure of attenuation provided by hearing protection devices (HPDs) in response to an impulsive noise. This technical memorandum describes the IPIL testing conducted and the calculated mean IPIL values for the 3M™ E-A-R™ Skull Screws™ Corded Earplug (Skull Screws™ Corded; Model: P1301). Testing was completed in accordance with the ANSI standard S12.42-2010. All device samples were tested at the nominal levels of 150, 160, and 170 decibel peak (dBP, re: 20 µPa). A total of five samples were fitted to an acoustic test fixture two times each for a total of 10 trials per test level. No samples of the HPD were rejected. The mean and standard deviation (SD) IPIL values were 48.4 (2.5) dB SPL at 150 dBP, 50.4 (2.4) dB SPL at 160 dBP, and 51.5 (2.2) dB SPL at 170 dBP (see Table 1). These results suggest that, when properly fit and functional, the Skull Screws™ Corded will adequately protect (i.e., reduce exposure to less than 140 dBP) against impulses below 180.0 dBP.

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CONTENTS

Executive Summary

The impulse peak insertion loss (IPIL) is the standard measure of attenuation provided by hearing protection devices (HPDs) in response to an impulsive noise. This technical memorandum describes the IPIL testing conducted and the calculated mean IPIL values for the 3M™ E-A-R™ Skull Screws™ Corded Earplug (Skull Screws™ Corded; Model: P1301). Testing was completed in accordance with the American National Standards Institute (ANSI) standard S12.42-2010, "Methods for the Measurement of Insertion Loss of Hearing Protection Devices in Continuous or Impulsive Noise Using Microphone-in-Real-Ear or Acoustic Test Fixture Procedures." All device samples were tested at the nominal levels of 150, 160, and 170 decibel peak (dBP, re: 20 µPa). A total of five samples were fitted to an acoustic test fixture two times each for a total of 10 trials per test level. No samples of the HPD were rejected. The mean and standard deviation (SD) IPIL values were 48.4 (2.5) dB SPL at 150 dBP, 50.4 (2.4) dB SPL at 160 dBP, and 51.5 (2.2) dB SPL at 170 dBP (see Table 1). These results suggest that, when properly fit and functional, the Skull Screws™ Corded will adequately protect (i.e., reduce exposure to less than 140 dBP) against impulses below 180.0 dBP.

Table 1.
Skull Screws™ Corded mean (SD) IPIL value (in dB) for all test conditions.

150 dBP	160 dBP	170 dBP
48.4 (2.5)	50.4 (2.4)	51.5 (2.2)

Introduction

The 3M™ E-A-R™ Skull Screws™ Corded Earplug (Skull Screws™ Corded; 3M™, St. Paul, MN) is a passive, reusable, one-size-fits-most, push-to-fit earplug made of slow-recovery soft foam. Per the manufacturer, Skull Screws™ Corded earplugs "feature one-of-a-kind Skull Screws 'threads' designed to create a stay-put seal in the ear canal," (3M Occupational Health and Environmental Safety Division, 2010, p. 3). In order to reuse, the Skull Screws™ Corded should be cleaned according to manufacturer guidelines (3M Company, n.d.).

The Department of Defense Instruction 6055.12 (2019) Hearing Conservation Program (HCP) limits impulse noise exposure to 140 peak decibels (dBP). Therefore, should an impulse noise meet or exceed 140 dBP (e.g., artillery fire, grenade, small arm weapon fire, large caliber weapon fire), hearing conservation efforts to prevent hearing loss resulting from occupational and operational illness and injury are mandated. One conservation measure used to reduce the user's noise hazard below the 140 dBP limit is the use of hearing protection devices (HPDs) (e.g., earplug or earmuff).

In order to calculate whether the issued HPD will reduce the noise exposure below the 140 dBP limit, the impulse peak insertion loss (IPIL) value of the issued and/or used HPD should be subtracted from the impulse noise level (Department of Defense, 2015). The IPIL value is the standard metric (ANSI/ASA S12.42) used to determine the amount of protection afforded by an HPD in response to impulse noise. At present, the IPIL value of the Skull Screws™ Corded at 150, 160, and 170 dBP is unknown. This report describes the methods and results used to determine the IPIL value for the 3M™ E-A-R™ Skull Screws™ Corded Earplug. In addition to reporting an overall device IPIL, ear-specific IPILs are reported for the tested nominal levels.

Methods

Facility

IPIL testing described herein was completed in the Naval Submarine Medical Research Laboratory (NSMRL) 1000 m^3 anechoic chamber in order to minimize any effects of sound reflections.

Equipment

Hardware. Acoustic impulses were generated by NSMRL's 4 inch (in., 10.2 centimeters [cm]) shock tube (B/C Precision, Inc., Greendale, IN). The shock tube pressure chamber is approximately 34 in. (86.4 cm) long, with an inner diameter of 4 in. (10.2 cm). A 64 in. (162.6 cm) long catenoidal tube horn consisting of four welded steel flat-projection sheets forming a square cross section was connected to the shock tube using a PVC 4.5 in. (11.4 cm) coupler. An industrial air compressor (ILA#1883054; Industrial Air Corporation, Memphis, TN) supplied pressurized air (900 kilopascal) to the shock tube.

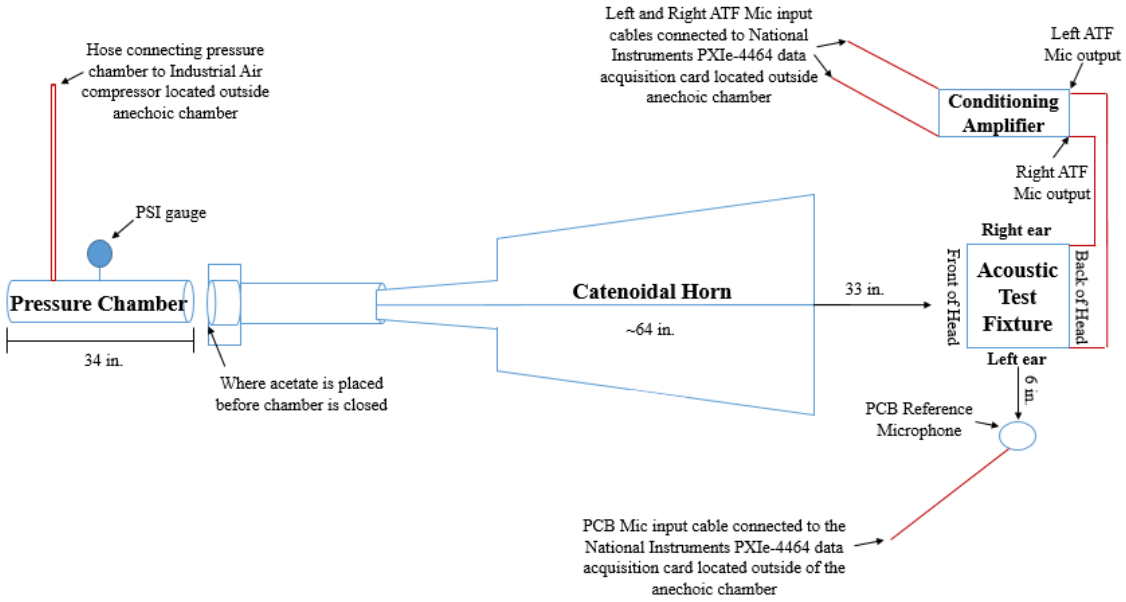
For each trial at 150 dBP, a 7 in. (17.8 cm) by 7 in. (17.8 cm) polyester sheet (SEVA Technical Services, Inc, Newport News, VA) was used as a membrane between the pressurized chamber and the catenoidal tube horn to enable pressurization of the air chamber. Each polyester sheet was 0.001 in. (1.0 mil, 25.4 micrometer [μm]) thick. For

each trial at 160 and 170 dBP, a 7 in. (17.8 cm) by 7 in. (17.8 cm) acetate sheet (Grafix Plastic, Maple Heights, OH) was used as a membrane to enable pressurization of the air chamber. Each acetate sheet was 0.002 in. (2.0 mil, 50.8 micrometer [µm]) thick.

All waveforms were recorded with the ANSI/ASA S12.42 (2010) compliant GRAS 45CB acoustic test fixture (ATF) along with GRAS RA0045-S7 Ear Simulators (GRAS Sound and Vibration, Twinsburg, OH). The ATF was connected to a conditioning amplifier which served as the power supply (GRAS Type 12AA; GRAS Sound and Vibration, Twinsburg, OH). As required by ANSI/ASA S12.42/2010, the ATF was placed to front-face (i.e., nose facing) the catenoidal tube horn at 0° elevation and 0° azimuth.

A reference microphone (Type 378C20; PCB Piezotronics Inc., Depew, NY) was placed 6 in. (15.2 cm) from the ATF left pinna. The reference microphone, the left ATF microphone, and the right ATF microphone were calibrated each morning prior to data collection at 124 dB sound pressure level (SPL) using a 250 hertz (Hz) tone. A diagram depicting the aerial view of the NSMRL 4 in. (10.2 cm) shock tube and test system is presented in Figure 1.

Figure 1.
Diagram of the NSMRL Acoustic Shock Tube and ATF.



Data Acquisition System. The data acquisition system (NI chassis PXIe-1071 with NI PXIe-4460 and NI PXIe-4464; National Instruments Corp., Austin, TX) was controlled by a standalone laptop computer running project specific software (LabVIEW; National Instruments Corp., Austin, TX). The data acquisition system was connected to the laptop using an MXI cord and host interface card (NI PXIe-8360). The software controlled the acquisition of waveforms from the three source microphones (left ATF microphone, right ATF microphone, and a reference microphone) at a sampling rate of 204.8 k Samples/second during each impulse recording. Pre-trigger

settings were 1024 samples per 0.005 seconds, with a trigger level of 110 dB SPL. Each recording was 0.3 seconds in duration.

Rather than using an ANSI/ASA S12.42-2010 standardized in-line analog external Bessel filter (6^{th} order, corner frequency 20.0 kHz [3 dB down]) to filter impulses during data acquisition, anti-alias filtering was accomplished by an analog filter and a digital filter. First, an electronic analog anti-aliasing filter (corner frequency of 93.0 kHz [3 dB down]) was applied to all waveforms by the National Instruments data acquisition system during data collection. This deviation was made due to equipment and software limitations.

The custom-written software program saved all recorded waveforms as files (*.tdms), which were exported and converted to data files using an additional custom software programming script. The script compiled the reference PCB microphone, left ATF microphone, and right ATF microphone channels into a file (*.mat) that saved variables for input to analysis script (MATLAB) similar to the script provided in Annex H of the ANSI/ASA S12.42-2010 standard. Minor alterations were made to the analysis script in order to accept 150 dBP, 160 dBP, and 170 dBP data (see Data Analysis below).

Hearing Protection Device Samples. Five samples (See Figure 2 for example) of the 3M™ E-A-R™ Skull Screws™ Corded Earplugs (Manufacturer Product Number: P1301) were tested in accordance with ANSI/ASA S12.42-2010. Each sample, consisting of one set of two earplugs, was randomly assigned a number 1 through 5. Each earplug in the sampled set was labeled ‘L’ for left or ‘R’ for right to indicate which ATF ear they were to be inserted for all trials.

Figure 2.
Photograph of a Skull Screws™ Corded Earplug Sample.

Procedure

Each HPD sample (left and right earplug pair) was fitted to the ATF twice, resulting in two trials (trials A and B) per sample, and 10 total trials per nominal level test condition (150, 160, and 170 dBP). No samples of the HPD were rejected. To achieve an appropriate fit that would provide maximum attenuation, each sample was expertly fitted to the ATF in accordance with instructions on the device packaging. The manufacturer fitting guidelines stated that all samples be inspected for any wear, extreme hardness, or damage prior to use. Once inspected, each earplug was inserted into the ear canal, pushed into place, and held in place until expanded. Earplugs were given at least two minutes to fully expand in the ATF ear canal before impulse testing was performed.

Testing at the 130 dBP nominal level was omitted, and the nominal level of 160 dBP was incorporated as impulses generated with the NSMRL 4 in. (10.2 cm) shock tube at levels below the nominal level of 150 dBP were found to be without a shock front. Measurement of IPIL at 160 dBP was included in order to provide accurate guidance for exposures between 155 and 165 dBP. At the measured levels described herein, all generated impulses had a shock front. In addition, the action level for the DoD is 140 dBP for impulse noises. Therefore, IPIL values below 140 dBP are of marginal value to the DoD. Due to non-linear effects of HPDs on IPIL, it is best to use IPIL values measured close to the level of the predicted exposure (Department of Defense, 2015).

Impulse noises were presented to the ATF in the occluded (i.e., HPD inserted) and unoccluded (i.e., without the HPD inserted) test configurations. For all occluded measures, the earplugs were fitted on the ATF in accordance with the specifications outlined in ANSI/ASA S12.42-2010. Each HPD sample was exposed to two impulses at each tested nominal level. Adequate pressure for each impulse was determined by increasing pressure (measured in pounds per square inch [psi]) to a point within a pre-specified range necessary for producing either 150 dBP (8.9 to 9.3 psi, 61 to 64 kilopascals [kPa]), 160 dBP (19.5 to 22.1 psi, 134 to 152 kPa), or 170 dBP (28.5 to 29.5 psi, 197 to 203 kPa). The acetate was then punctured using a manual trigger, releasing pressurized air into the catenoidal horn, which created an impulse wave through the catenoidal horn to the ATF. The peak decibel level emitted was dependent upon the amount of air pressure released.

In place of the ANSI/ASA S12.42-2010 standardized calibration impulses at 130 dBP, six calibration impulses were generated at the 150 dBP and 160 dBP nominal levels in the unoccluded (i.e., without HPD) test configuration. Three of these impulses were generated before testing, and three were generated after testing at 150 dBP and 160 dBP. Calibrations were not completed at the 170 dBP nominal level due to exposure limitations of the ATF right and left microphones.

Data Analysis

MATLAB (Natick, MA) was used to calculate IPIL values at the 150, 160, and 170 dBP nominal levels and to generate all waveform graphs (See Appendices A to I). The mean pressure of each waveform was subtracted from the waveforms to remove any constant offset. The peak levels were then calculated by converting the maximum absolute value of each waveform into dB SPL. The transfer functions of the free-field

probe to each ear of the ATF was calculated for the unoccluded waveforms gathered at the 160 dBP nominal levels. The mean transfer function for each ear at each level was then calculated, and the first elements of the transfer functions were set to zero in order to avoid calculations at 0 Hz. The fit of the mean transfer function was tested by applying the mean transfer function for each ear to the free-field probe data gathered in the 150 and 160 dBP nominal level. The difference of the maximum absolute values of the calculated values and the measured values was then calculated, converted to dB SPL, and displayed.

The calculated IPIL value (in dB) equaled the mean difference of the maximum absolute value of the waveforms from the ears of the ATF in dB SPL and the maximum absolute value of the estimated values of the unoccluded ears in dB SPL. The estimated values of the unoccluded ears are the waveforms from the free-field probe with the mean transfer function applied to them. These values were calculated for each ear in each trial and condition. The mean values were calculated across both ears and trials, resulting in a displayed mean for each nominal level (i.e., 150 dBP, 160 dBP, and 170 dBP). Every waveform was plotted with time on the x-axis and pressure on the y-axis. The transfer functions were not plotted.

Deviating from ANSI/ASA S12.42-2010, a second digital Butterworth filter (6^{th} order, low-pass, corner frequency of 20 kHz [3 dB down]) was applied to all recordings by the MATLAB post-processing script. This digital filter was used to mimic the effect of the ANSI/ASA S12.42-2010 standard required anti-aliasing Bessel filter which was omitted due to equipment limitations.

Results

As shown in Table 2, the overall mean (SD) IPIL value was 48.4 (2.5) dB for the 150 dBP test condition, 50.4 (2.4) dB for the 160 dBP test condition, and 51.5 (2.2) dB for the 170 dBP test condition. Calculated IPIL values for all individual sample trials ranged between 45.1 and 54.0 dB at 150 dBP, between 47.3 and 54.9 dB at 160 dBP, and between 48.6 and 56.5 dB at 170 dBP. The waveforms for all trials with the Skull Screws™ Corded are provided in Appendices A to I.

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Table 2.
Mean (SD) IPIL values (in dB) for Tested Skull Screws™ Corded Samples.

	150 dBP		160 dBP		170 dBP	
	Right	*Left*	*Right*	*Left*	*Right*	*Left*
HPD 1, Trial A	46.2	49.7	48.0	51.7	49.2	52.7
HPD 1, Trial B	46.3	50.9	49.6	53.8	50.6	54.7
HPD 2, Trial A	45.1	45.7	47.3	48.3	48.6	49.5
HPD 2, Trial B	49.9	52.8	52.0	54.8	52.3	54.9
HPD 3, Trial A	48.0	48.4	48.0	49.5	50.3	51.1
HPD 3, Trial B	46.8	54.0	48.4	54.9	49.6	56.5
HPD 4, Trial A	47.9	50.7	48.8	51.6	50.1	52.9
HPD 4, Trial B	48.1	45.9	50.4	48.2	51.7	49.8
HPD 5, Trial A	50.1	47.0	52.2	49.2	52.8	49.9
HPD 5, Trial B	49.7	45.7	52.4	48.2	53.5	49.4
Ear Specific Mean (SD)	47.8 (1.7)	49.1 (3.0)	49.7 (1.9)	51.0 (2.7)	50.9 (1.6)	52.1 (2.6)
Level Overall Mean (SD)	48.4 (2.5)		50.4 (2.4)		51.5 (2.2)	

Discussion

The overall mean IPIL value was 48.4 dB at 150 dBP, 50.4 dB at 160 dBP, and 51.5 dB at 170 dBP. Across ears, the individual trial mean IPIL values were found to vary as much as 8.9 dB at 150 dBP, 7.6 dB at 160 dBP, and 7.9 dB at 170 dBP. This may be due to a combination of inherent variance within the impulse system and/or variability in fit as a result of each HPD sample being fitted twice.

It is important to note that these results do not guarantee similar 3M™ E-A-R™ Skull Screws™ Corded product performance across all users and environments. Product performance may be impacted by factors such as variability in physical fit of the device and HPD configuration (e.g., single, double- or triple- configuration).

Conclusions

This report described the determination of the mean impulse peak insertion loss (IPIL) values provided by the 3M™ E-A-R™ Skull Screws™ Corded Earplug (Skull Screws™ Corded) at 150, 160, and 170 dBP nominal levels. The calculated overall mean (SD) IPIL values for the Skull Screws™ Corded were found to be 48.4 (2.5) dB at 150 dBP, 50.4 (2.4) at 160 dBP, and 51.5 (2.2) dB at 170 dBP. The results of this effort imply that, when properly fit and functional, the Skull Screws™ Corded will adequately protect (i.e., reduce the exposure below 140 dBP) the user from impulses below 180 dBP. This value is based on the 180 dBP limit of the applicability of IPIL values measured at 170 dBP in MIL-STD-1474E B.5.3.3 (Department of Defense, 2015).

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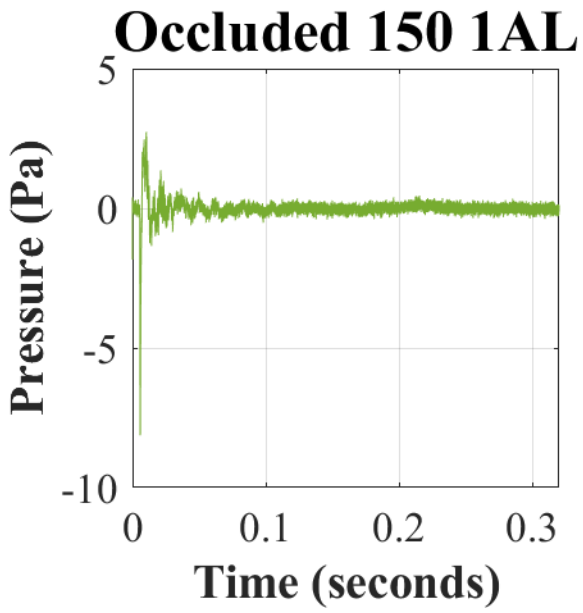
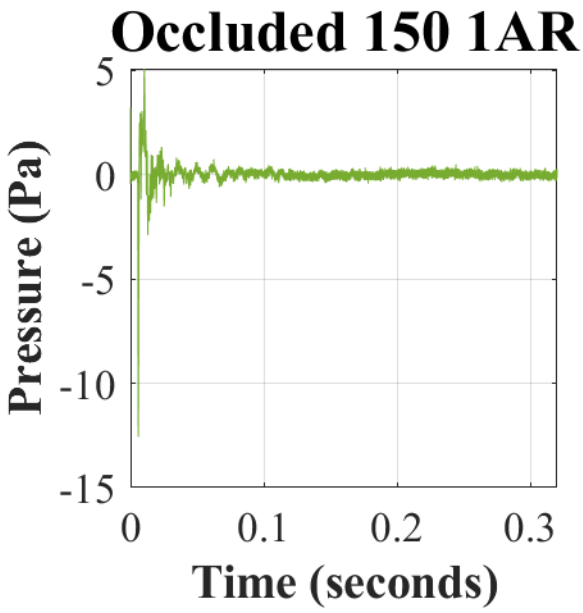
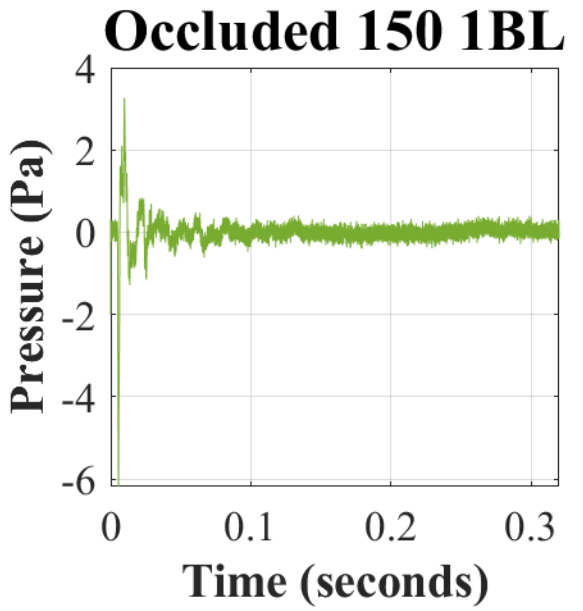
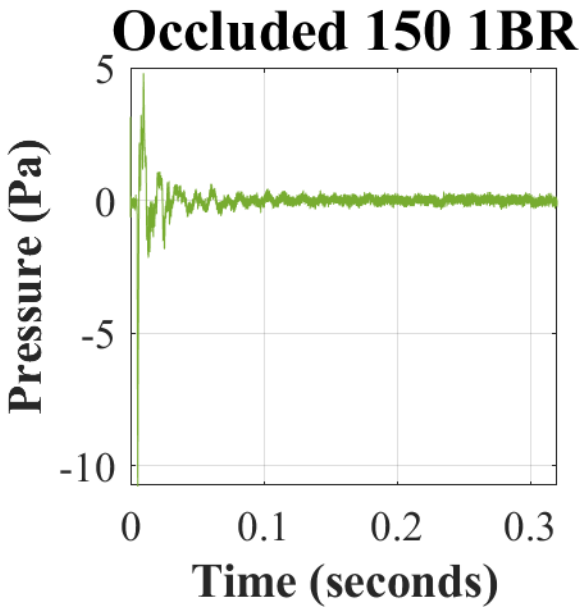
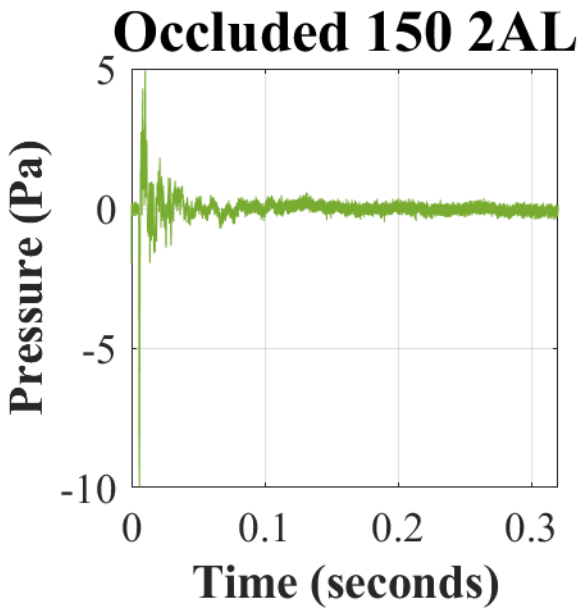
Appendix A. Recorded occluded (closed-ear) waveforms (in pascals [Pa]) over time (in seconds [s]) in response to 150 dBP with the Skull Screws™ Corded Earplugs.







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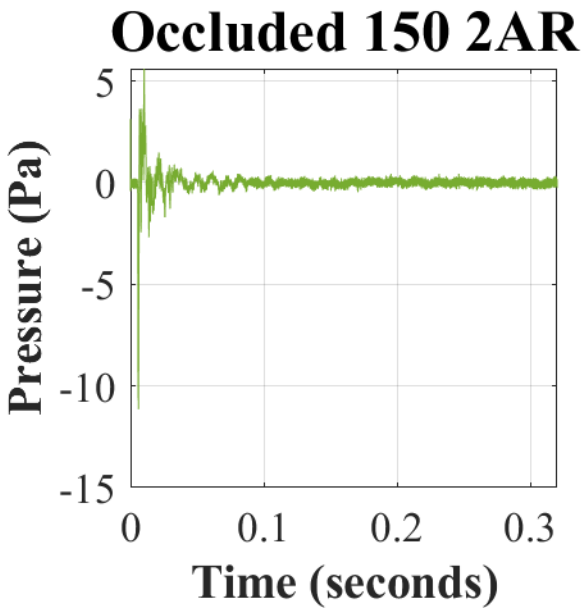
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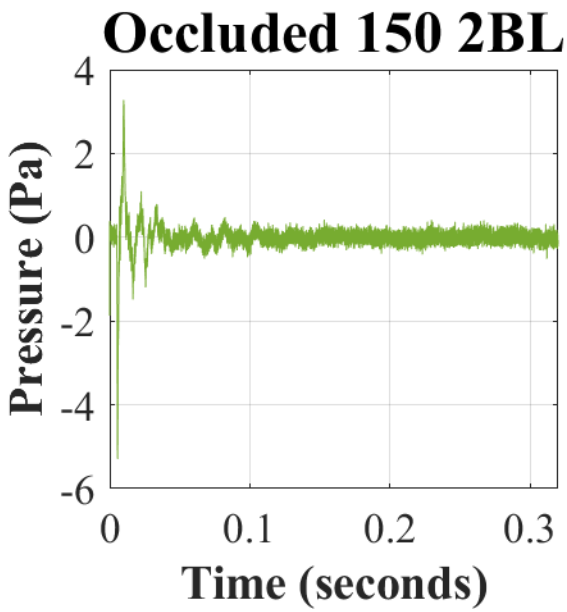
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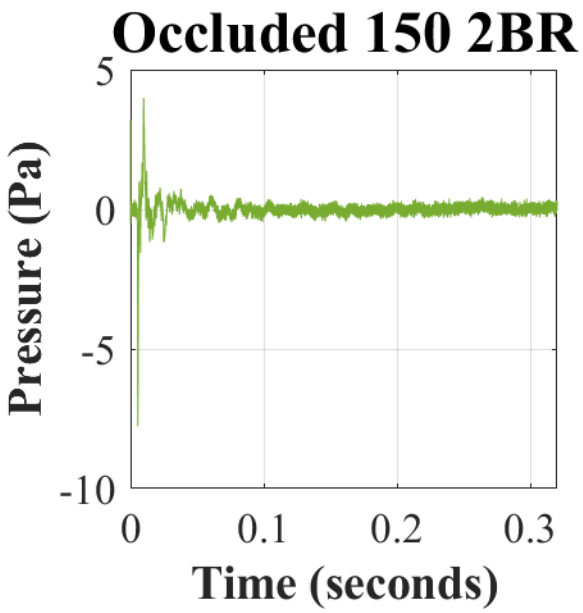
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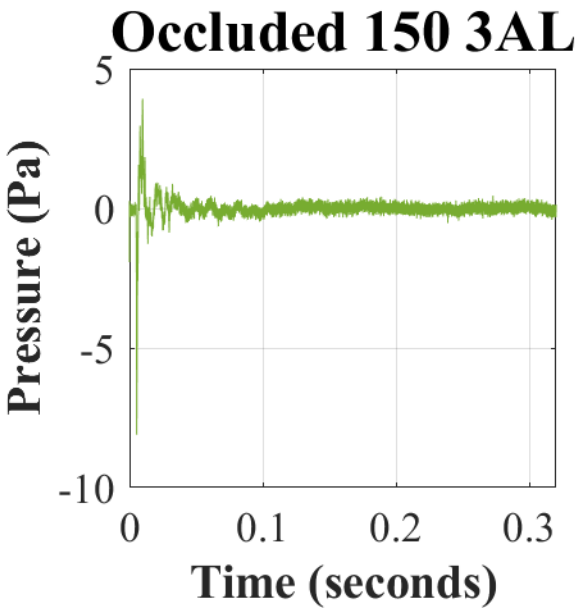
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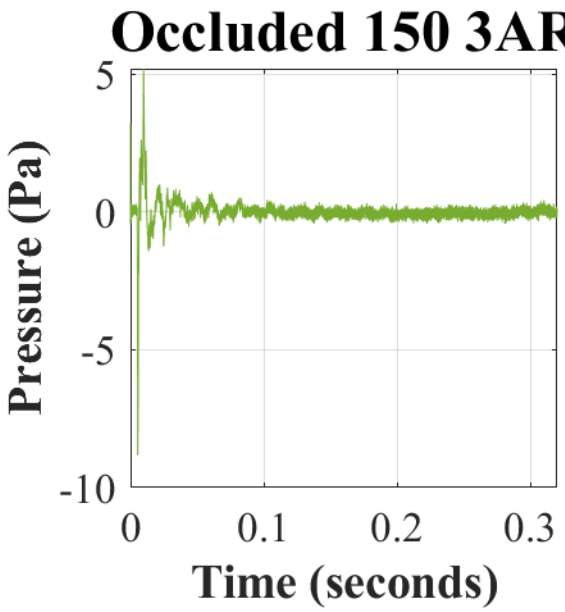
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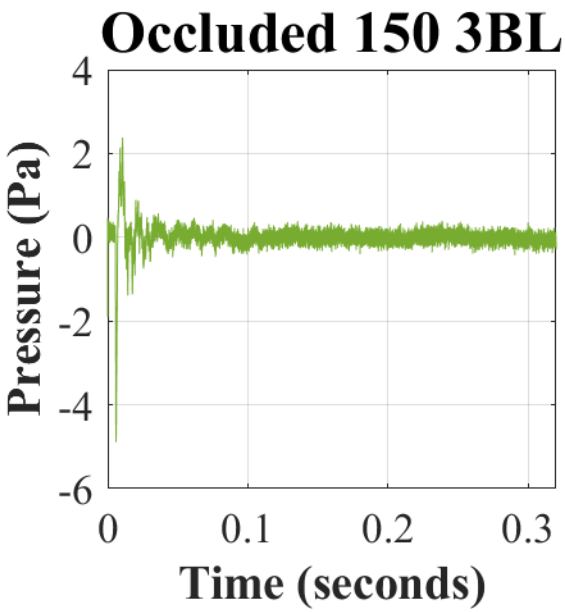
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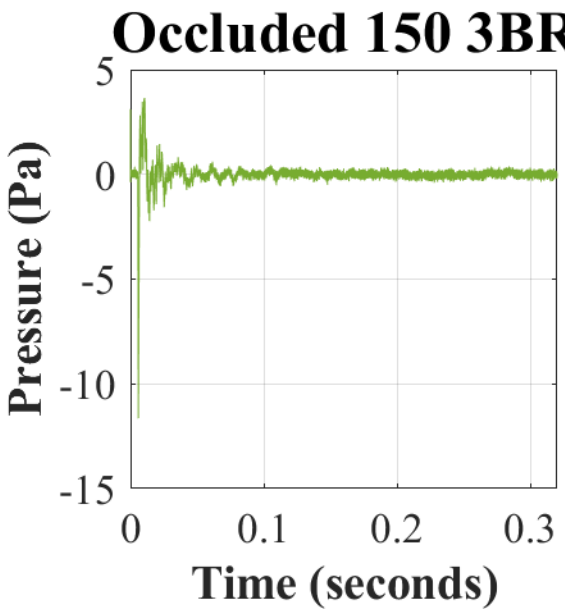
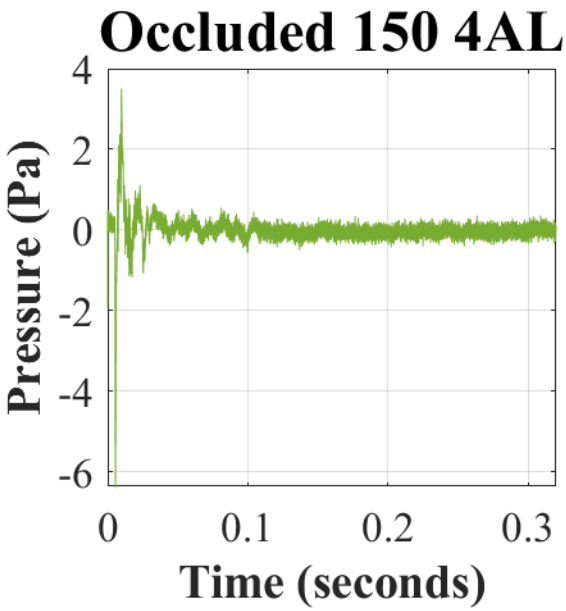
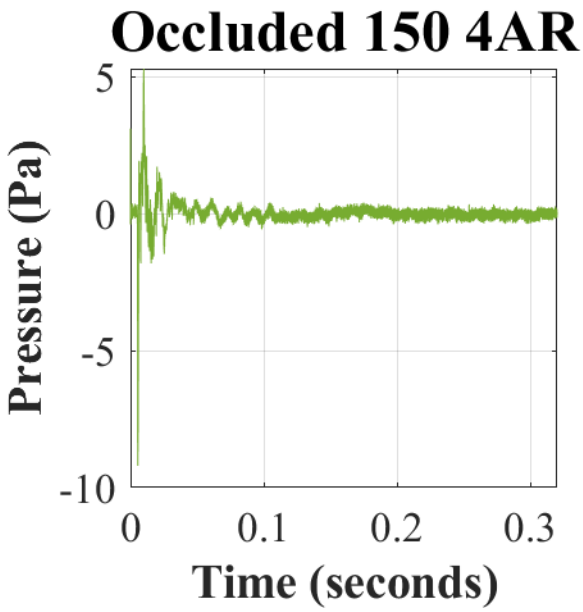
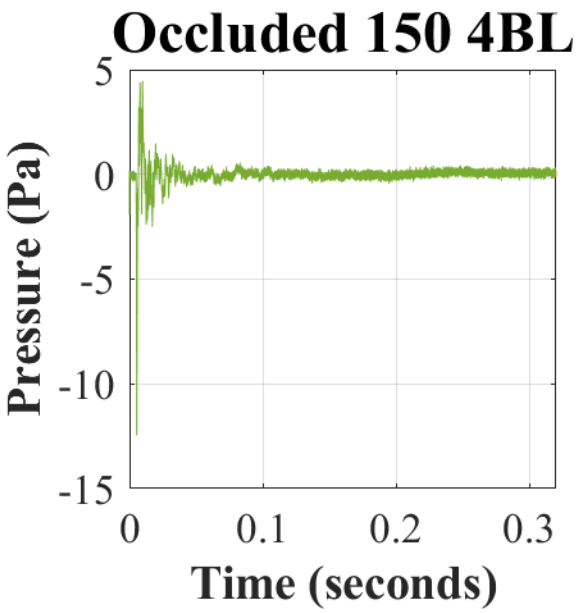
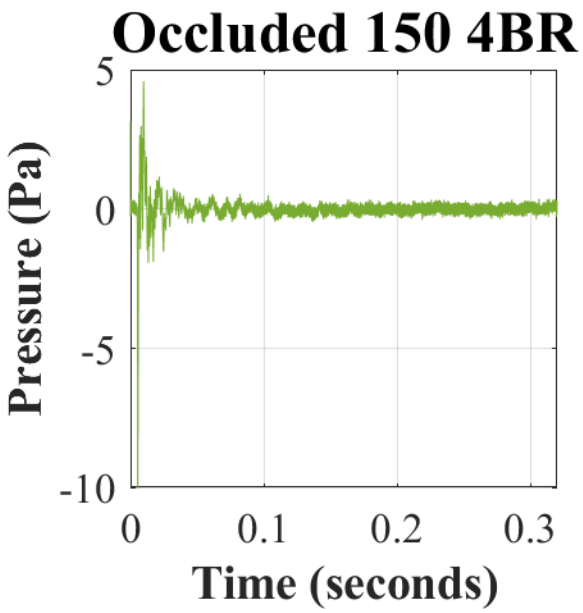
4
2
0
-2
-4
-6
0
0.1
0.2
0.3
Time (seconds)

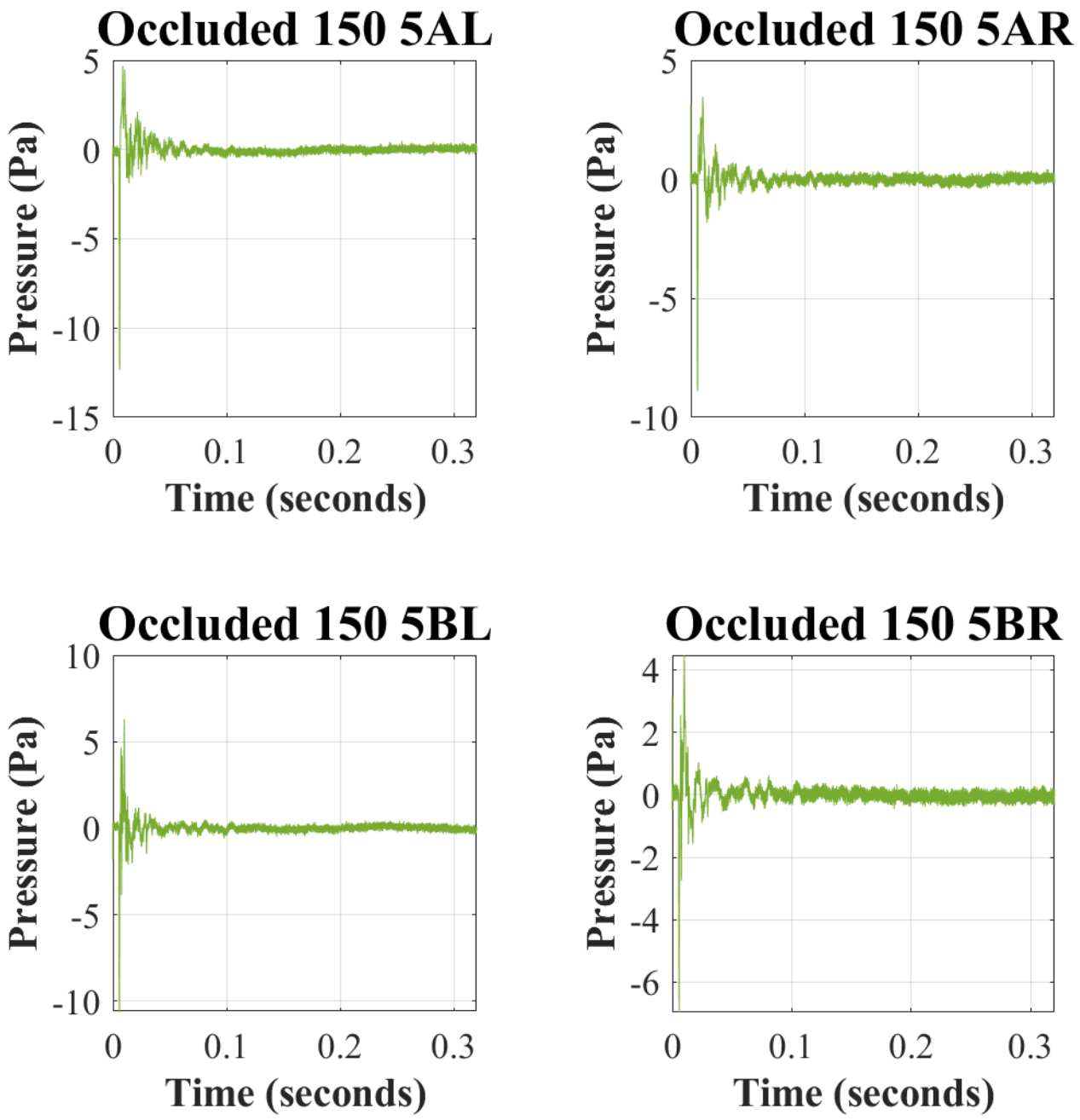

Occluded 150 3BR
Pressure (Pa)
5
0
-5
-10
-15
0
0.1
0.2
0.3
Time (seconds)


Occluded 150 4AL
Pressure (Pa)
Time (seconds)
4
2
0
-2
-4
-6
0
0.1
0.2
0.3


Occluded 150 4AR
Pressure (Pa)
Time (seconds)
5
0
-5
-10
0
0.1
0.2
0.3

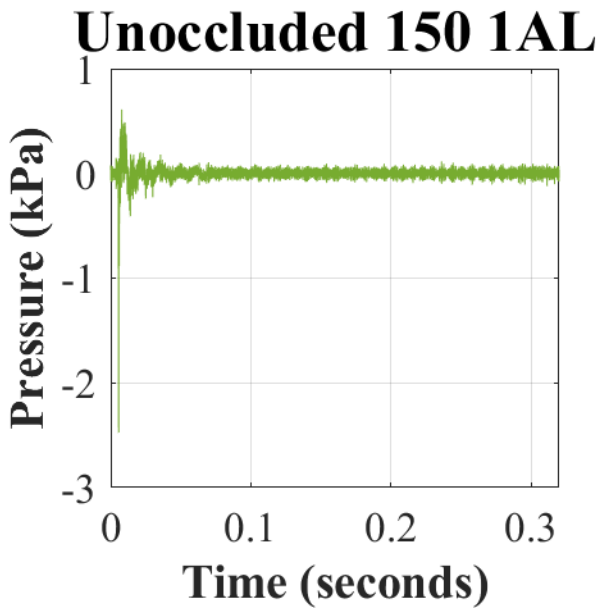

Occluded 150 4BL
Pressure (Pa)
Time (seconds)
5
0
-5
-10
-15
0
0.1
0.2
0.3

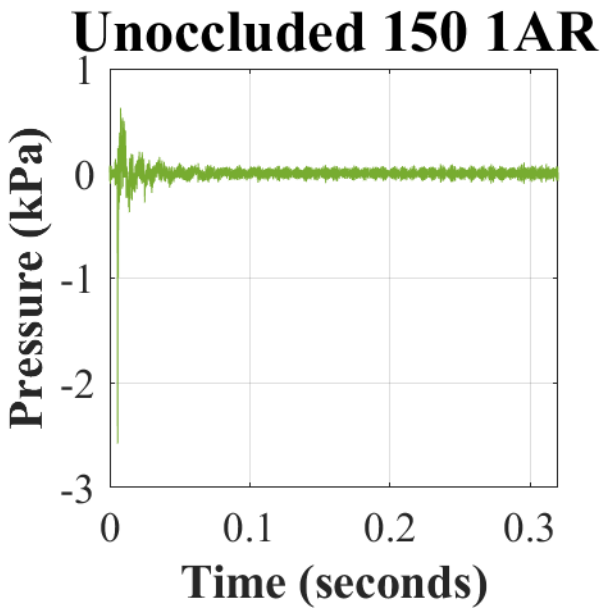

Occluded 150 4BR
Pressure (Pa)
Time (seconds)
5
0
-5
-10
0
0.1
0.2
0.3

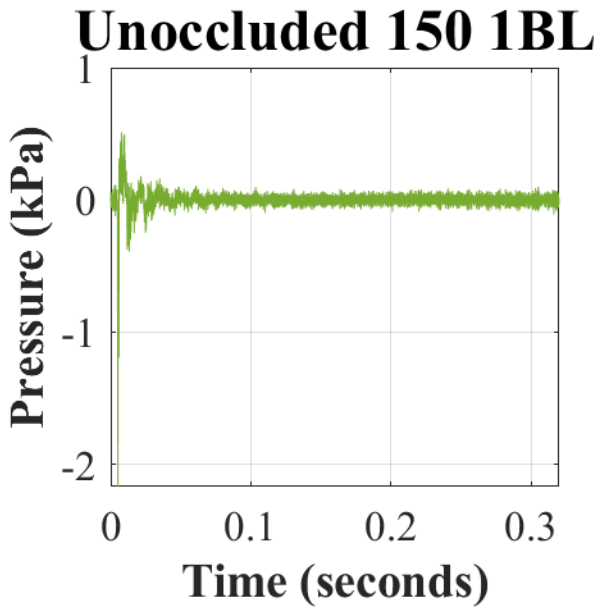


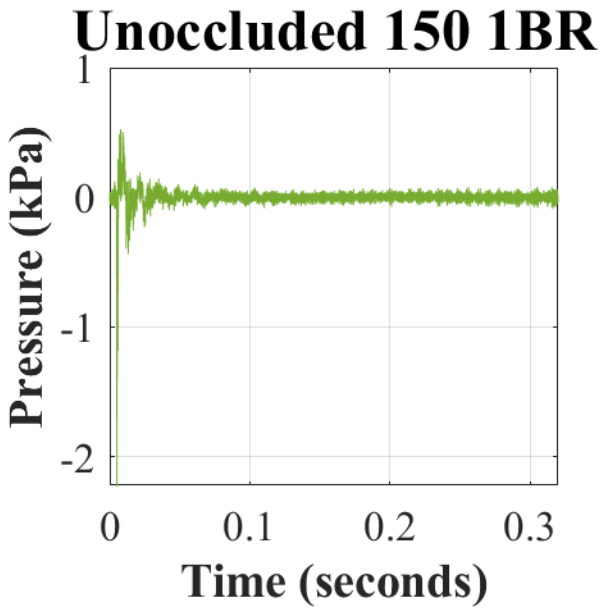
Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Occluded’ is the test condition (i.e., ATF has the HPD donned), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBP), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or B) indicating HPD fit (i.e., first or second, respectively), and ‘X’ indicates from what ATF microphone the recording is from (i.e., right [R] or left [L] pinnae).

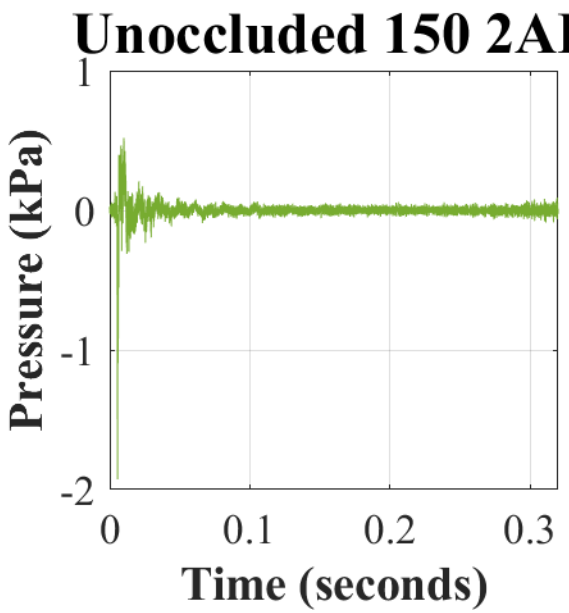
Appendix B. Estimated unoccluded (open-ear) waveforms (in kilopascals [kPa]) over time (in seconds [s]) in response to 150 dBP with the Skull Screws™ Corded Earplugs.

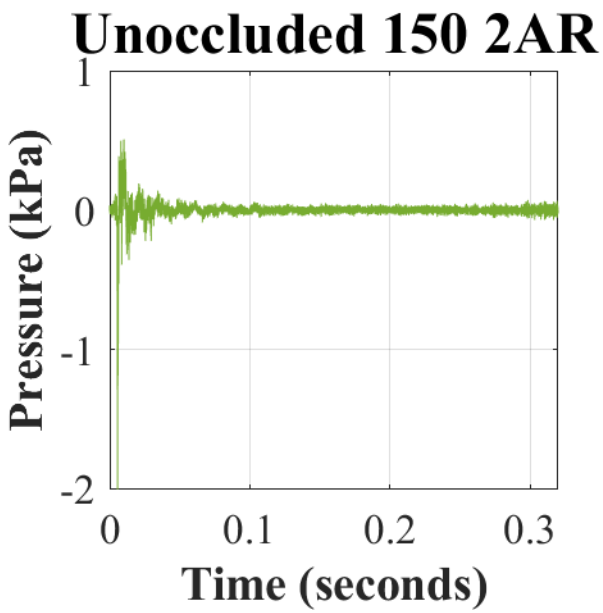


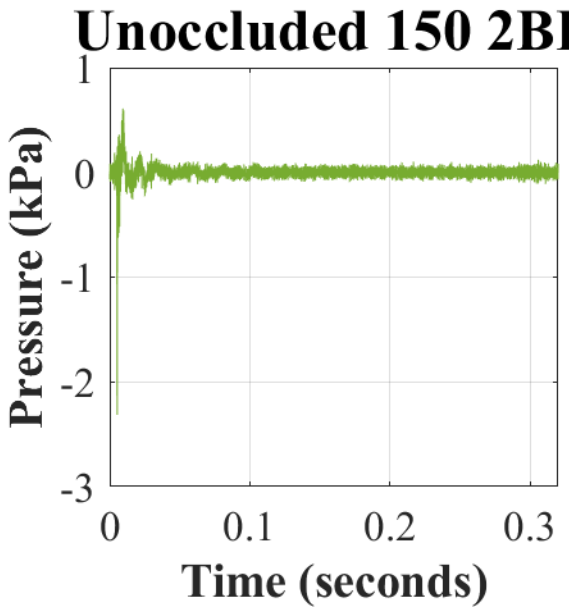


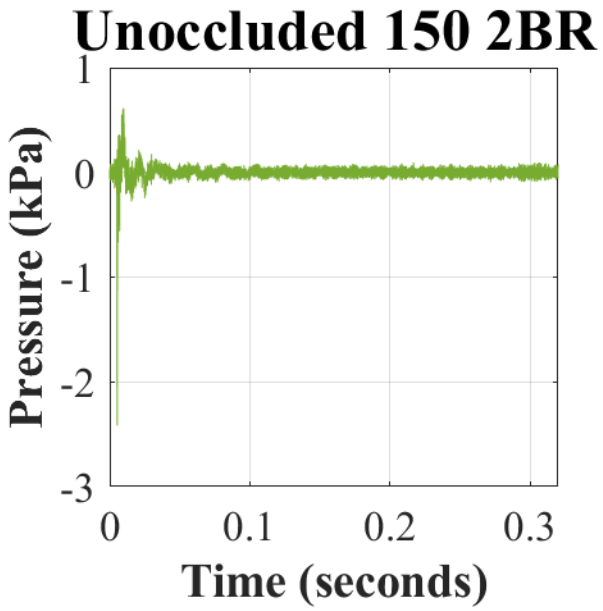


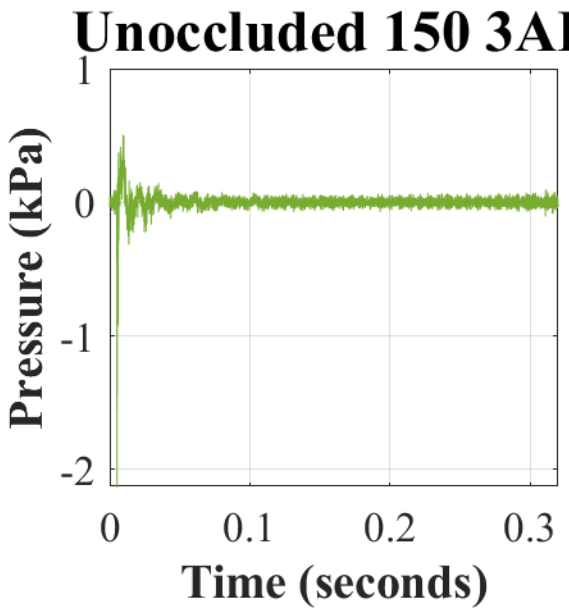


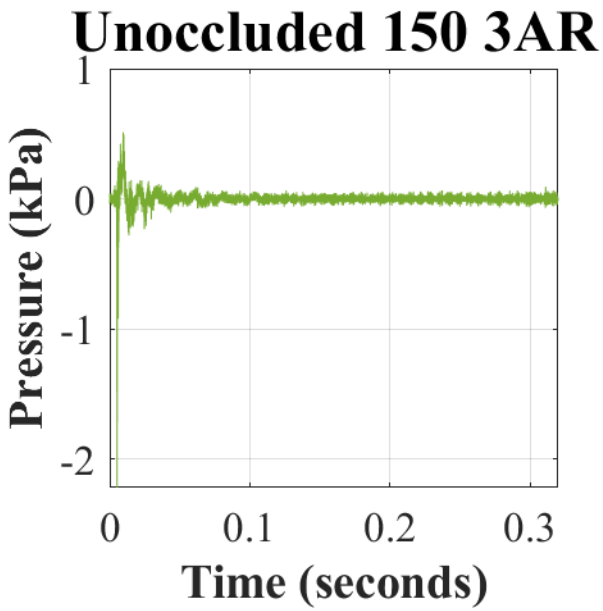

Unoccluded 150 2AL
Pressure (kPa)
1
0
-1
-2
0
0.1
0.2
0.3
Time (seconds)

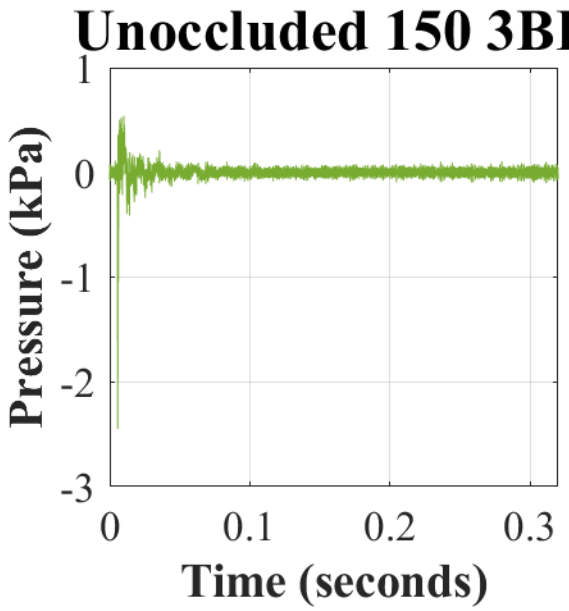

Unoccluded 150 2AR
Pressure (kPa)
1
0
-1
-2
0
0.1
0.2
0.3
Time (seconds)

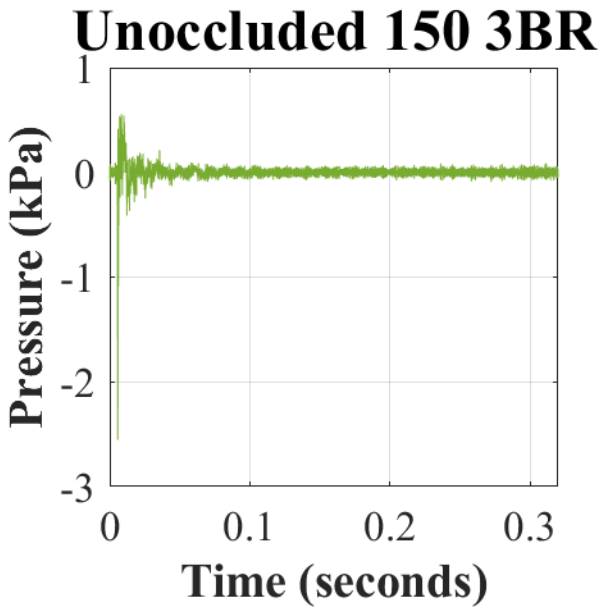

Unoccluded 150 2BL
Pressure (kPa)
1
0
-1
-2
-3
0
0.1
0.2
0.3
Time (seconds)

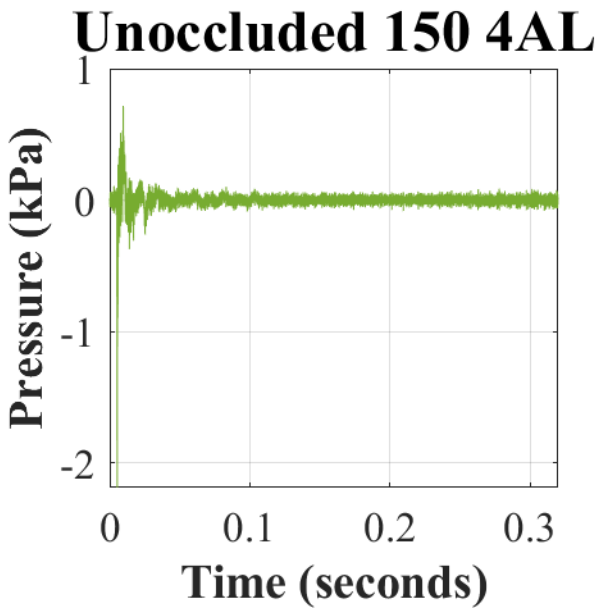

Unoccluded 150 2BR
Pressure (kPa)
1
0
-1
-2
-3
0
0.1
0.2
0.3
Time (seconds)

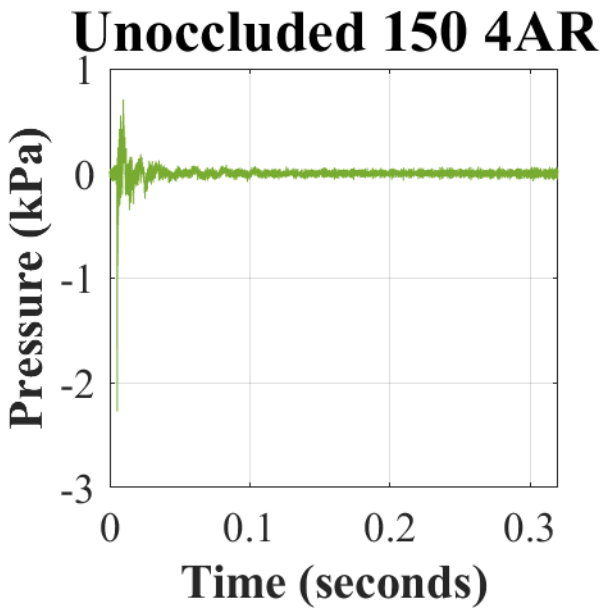

Unoccluded 150 3AL
Pressure (kPa)
1
0
-1
-2
0
0.1
0.2
0.3
Time (seconds)

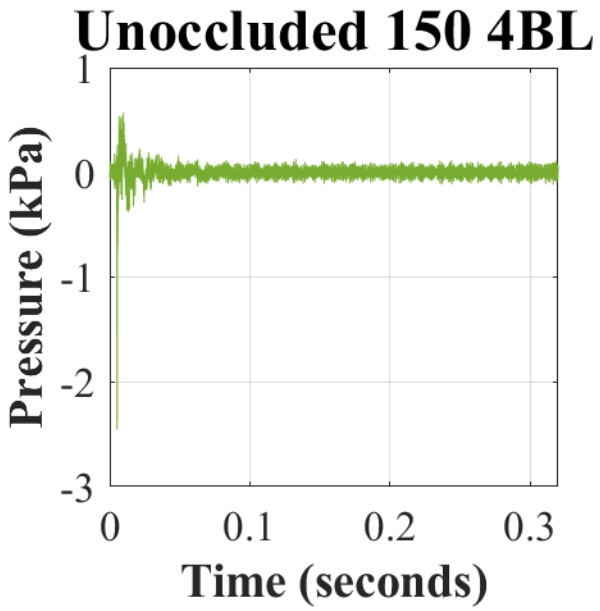

Unoccluded 150 3AR
Pressure (kPa)
1
0
-1
-2
0
0.1
0.2
0.3
Time (seconds)

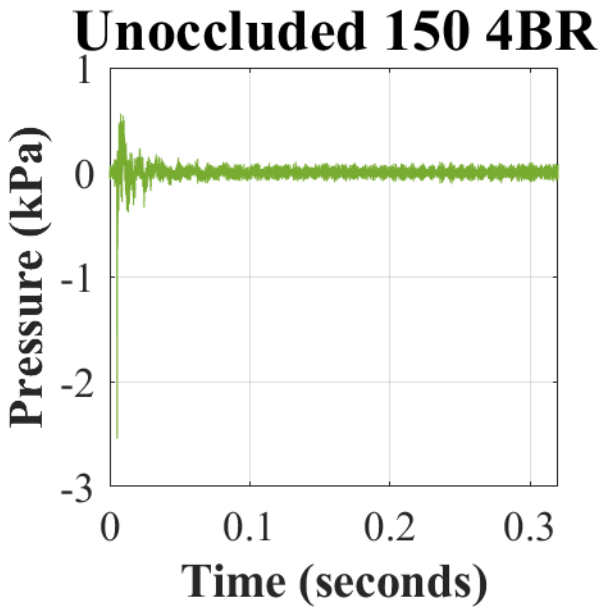

Unoccluded 150 3BL
Pressure (kPa)
1
0
-1
-2
-3
0
0.1
0.2
0.3
Time (seconds)

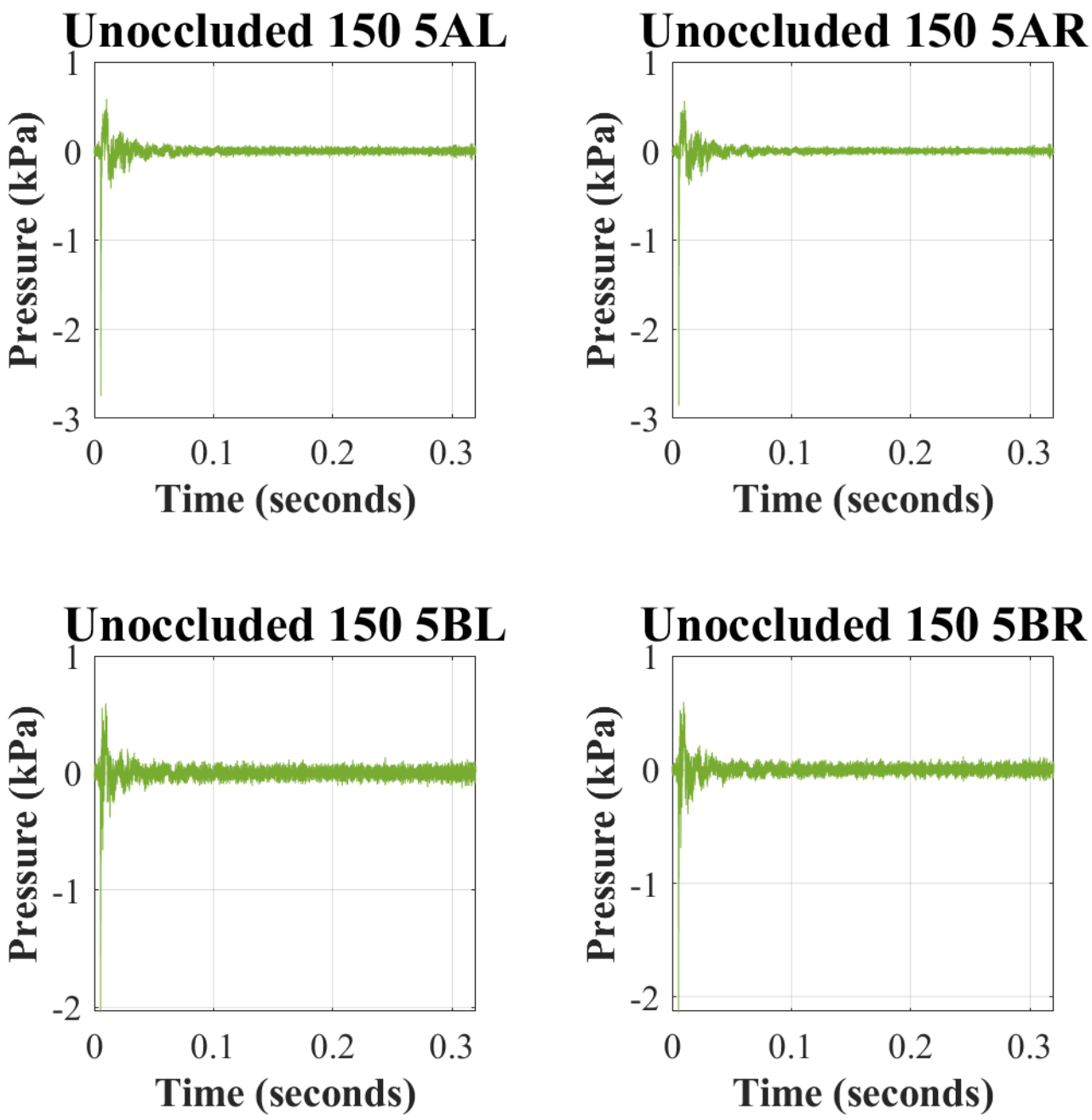

Unoccluded 150 3BR
Pressure (kPa)
1
0
-1
-2
-3
0
0.1
0.2
0.3
Time (seconds)


Unoccluded 150 4AL
Pressure (kPa)
1
0
-1
-2
0
0.1
0.2
0.3
Time (seconds)


Unoccluded 150 4AR
Pressure (kPa)
1
0
-1
-2
-3
0
0.1
0.2
0.3
Time (seconds)

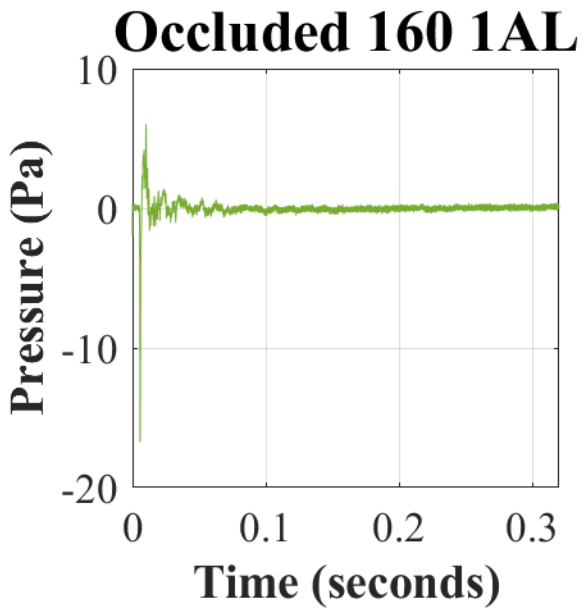

Unoccluded 150 4BL
Pressure (kPa)
1
0
-1
-2
-3
0
0.1
0.2
0.3
Time (seconds)

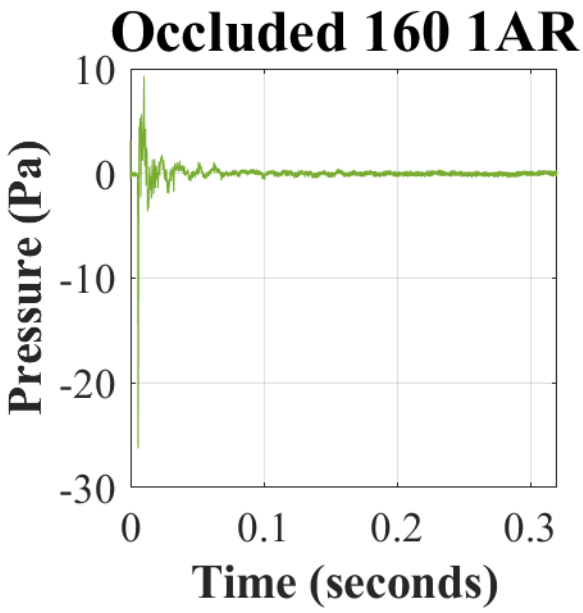

Unoccluded 150 4BR
Pressure (kPa)
1
0
-1
-2
-3
0
0.1
0.2
0.3
Time (seconds)

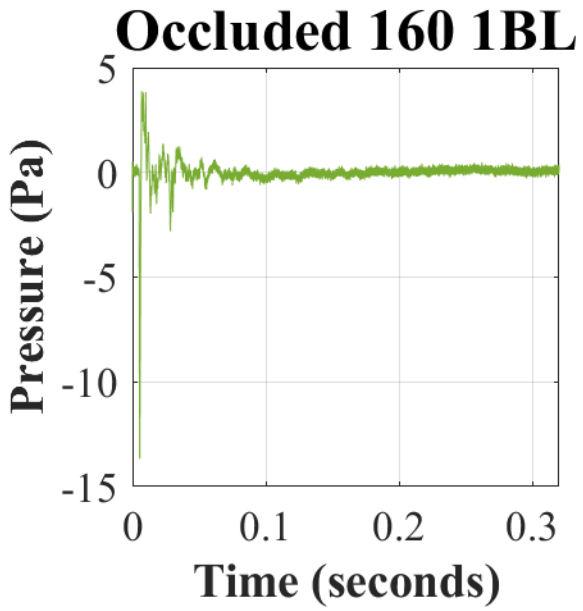


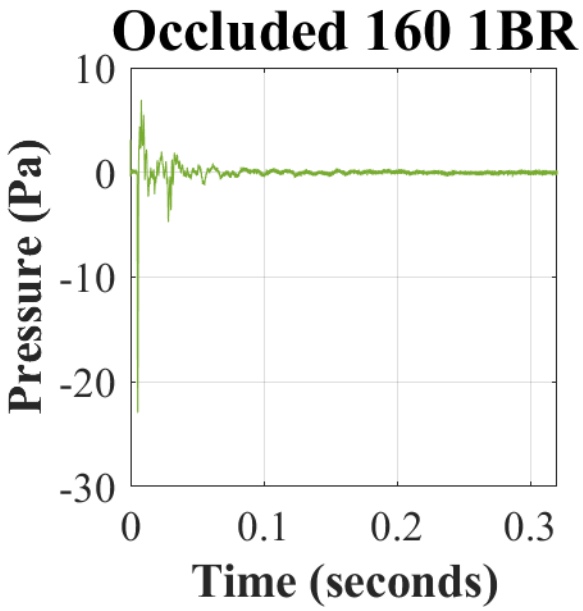
Note. The naming convention for all occluded waveforms is “Unoccluded LvL NnX”, where ‘Unoccluded’ is the test condition (i.e., ATF has the HPD doffed), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBP), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or B) indicating HPD fit (i.e., first or second, respectively), and ‘X’ indicates from what ATF microphone the recording is from (i.e., right [R] or left [L] pinnae).

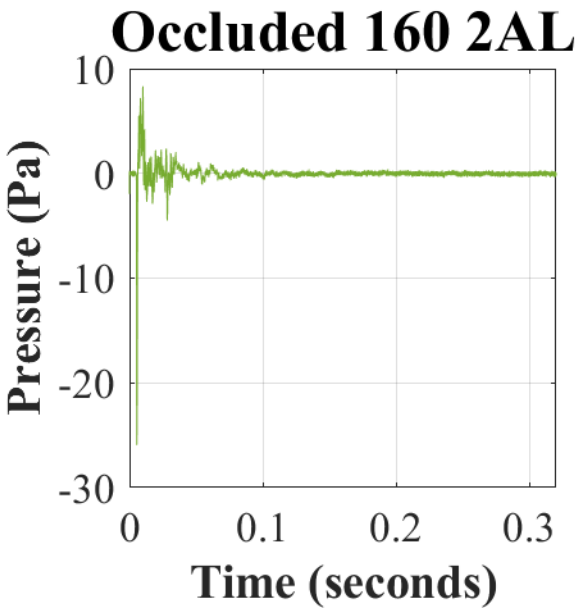
Appendix C. Recorded occluded (closed-ear) waveforms (in pascals [Pa]) over time (in seconds [s]) in response to 160 dBP with the Skull Screws™ Corded Earplugs.

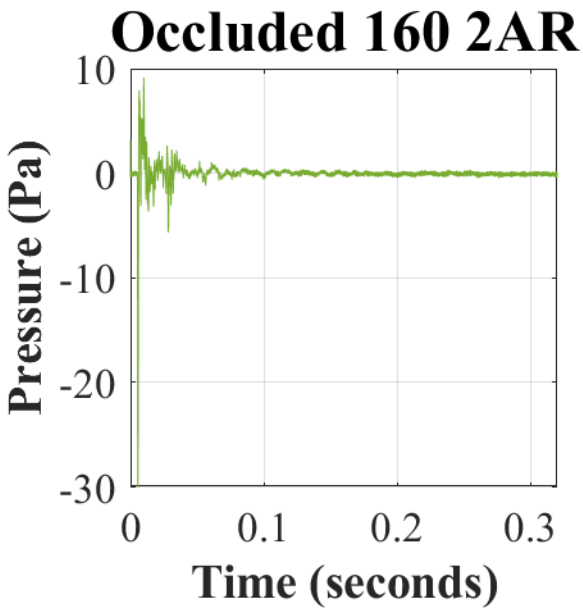


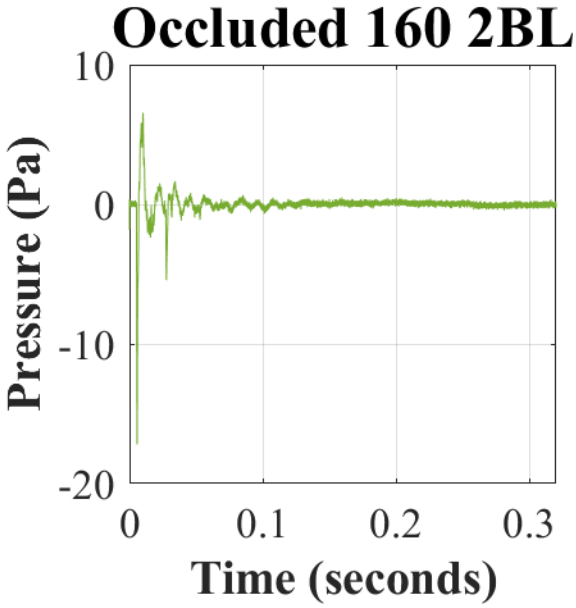


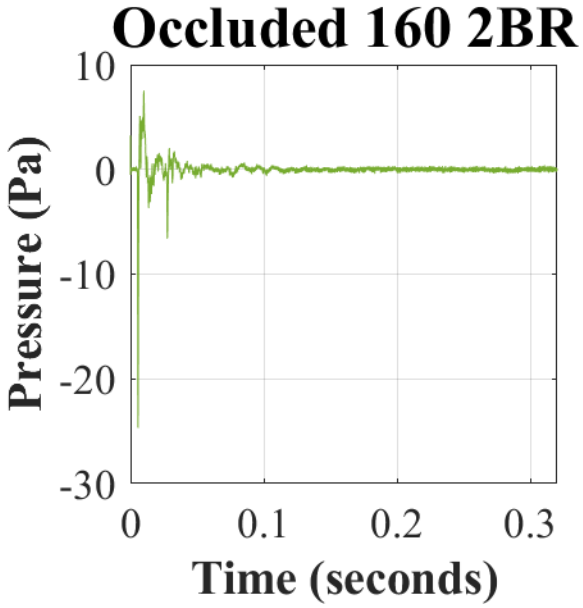


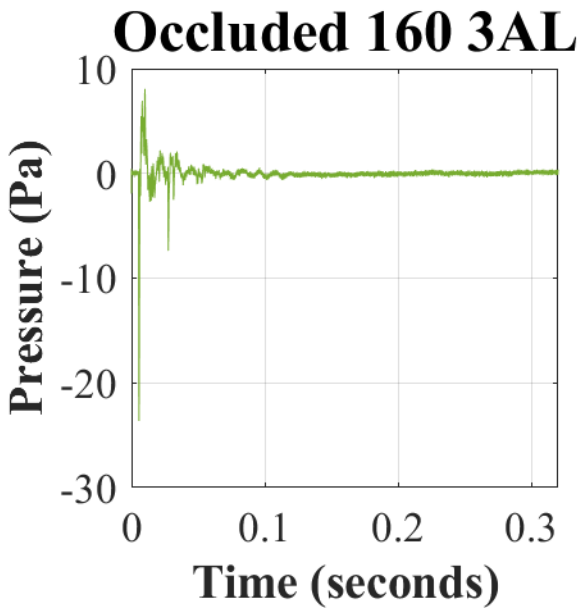


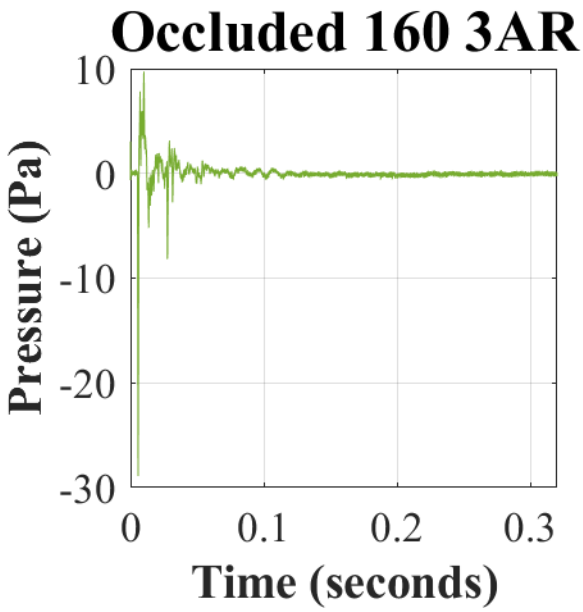

Occluded 160 2AL
Pressure (Pa)
10
0
-10
-20
-30
0
0.1
0.2
0.3
Time (seconds)

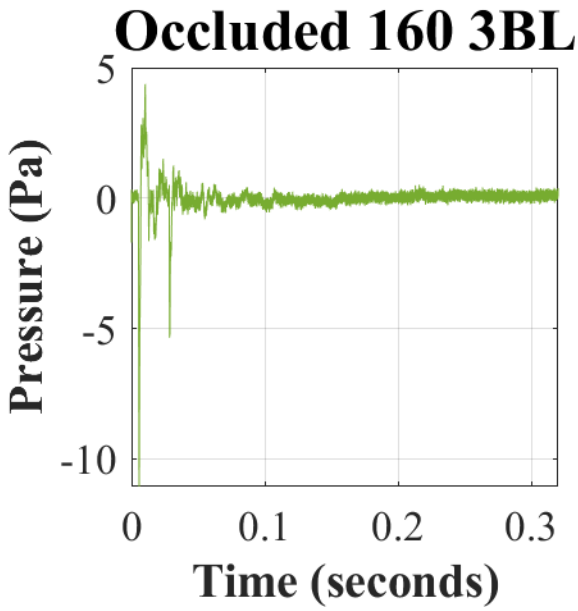

Occluded 160 2AR
Pressure (Pa)
10
0
-10
-20
-30
0
0.1
0.2
0.3
Time (seconds)

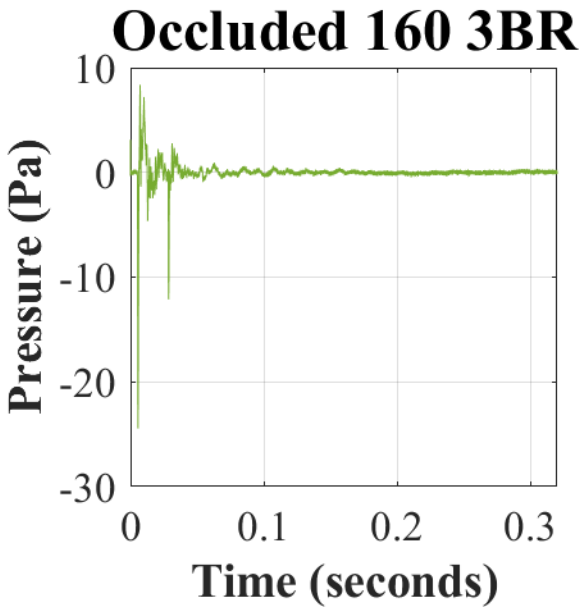

Occluded 160 2BL
Pressure (Pa)
10
0
-10
-20
0
0.1
0.2
0.3
Time (seconds)

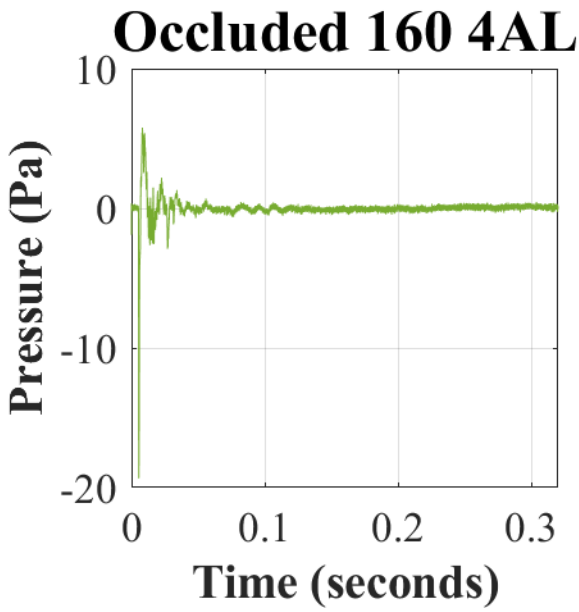

Occluded 160 2BR
Pressure (Pa)
10
0
-10
-20
-30
0
0.1
0.2
0.3
Time (seconds)

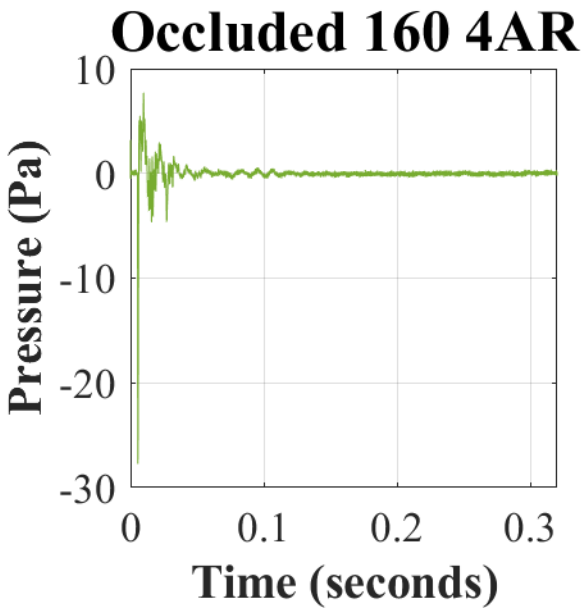

Occluded 160 3AL
Pressure (Pa)
10
0
-10
-20
-30
0
0.1
0.2
0.3
Time (seconds)

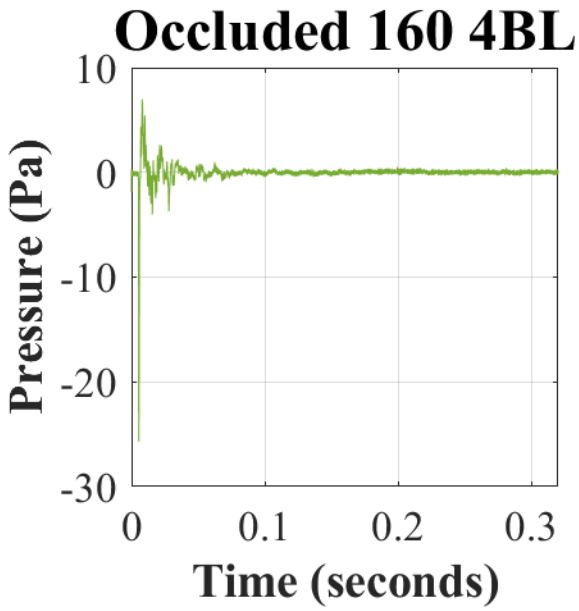

Occluded 160 3AR
Pressure (Pa)
10
0
-10
-20
-30
0
0.1
0.2
0.3
Time (seconds)

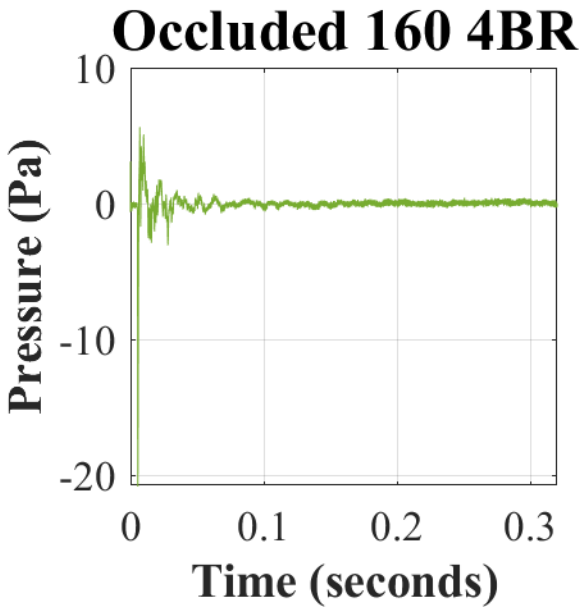

Occluded 160 3BL
Pressure (Pa)
5
0
-5
-10
0
0.1
0.2
0.3
Time (seconds)

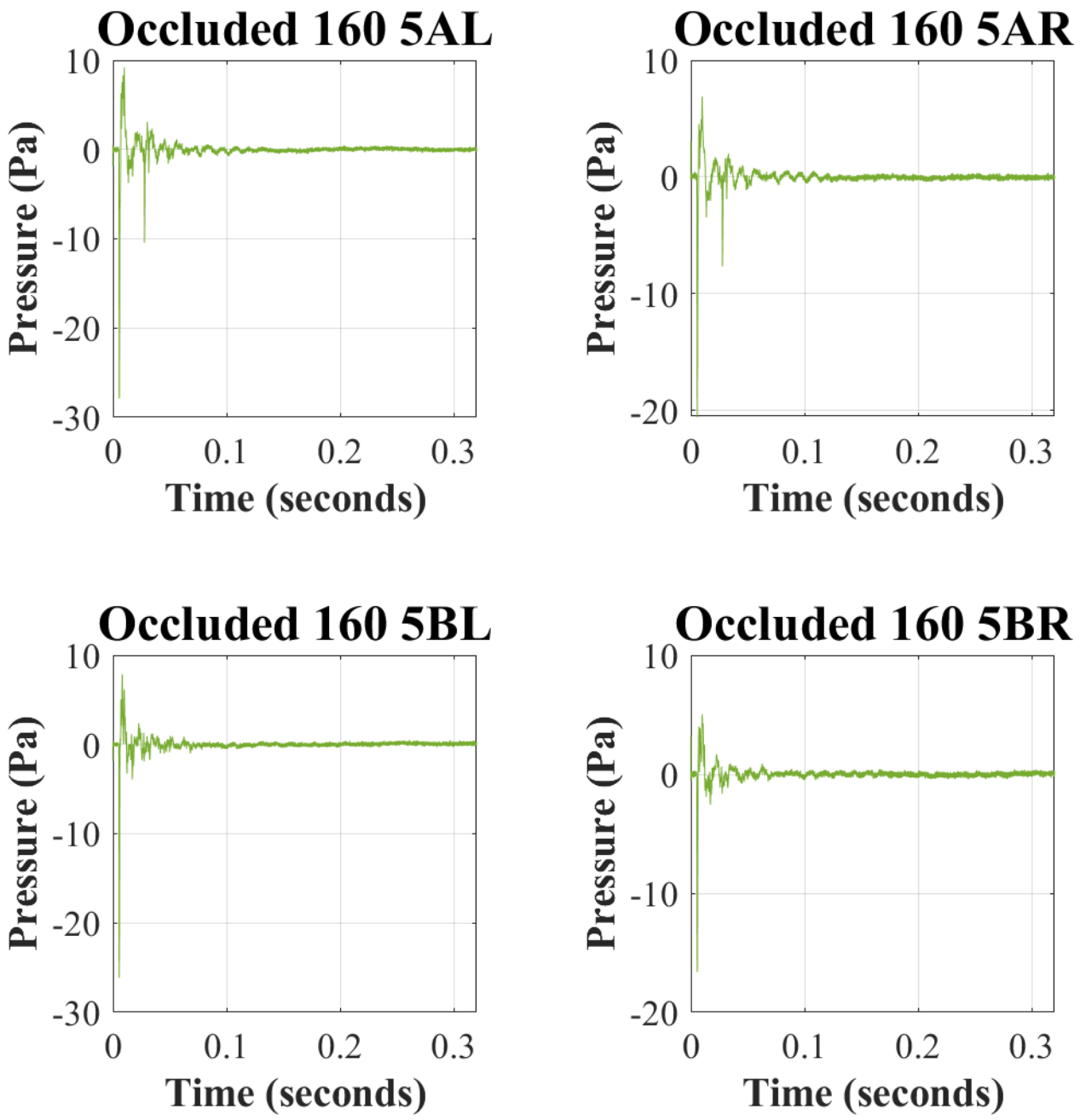

Occluded 160 3BR
Pressure (Pa)
10
0
-10
-20
-30
0
0.1
0.2
0.3
Time (seconds)


Occluded 160 4AL
Pressure (Pa)
10
0
-10
-20
0
0.1
0.2
0.3
Time (seconds)


Occluded 160 4AR
Pressure (Pa)
10
0
-10
-20
-30
0
0.1
0.2
0.3
Time (seconds)

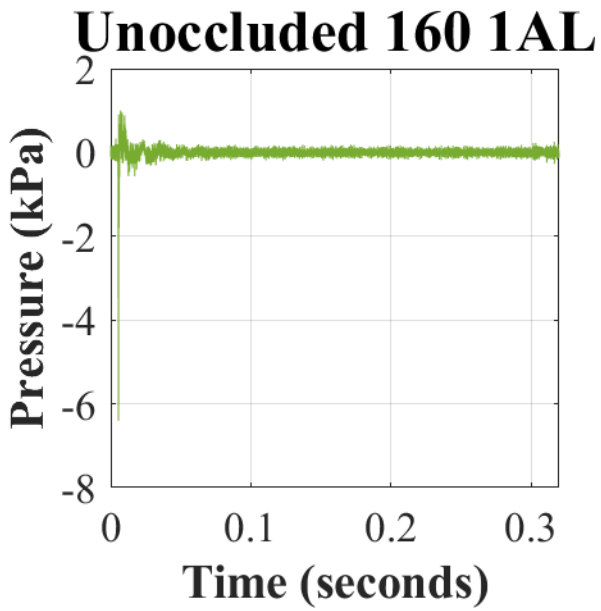

Occluded 160 4BL
Pressure (Pa)
10
0
-10
-20
-30
0
0.1
0.2
0.3
Time (seconds)

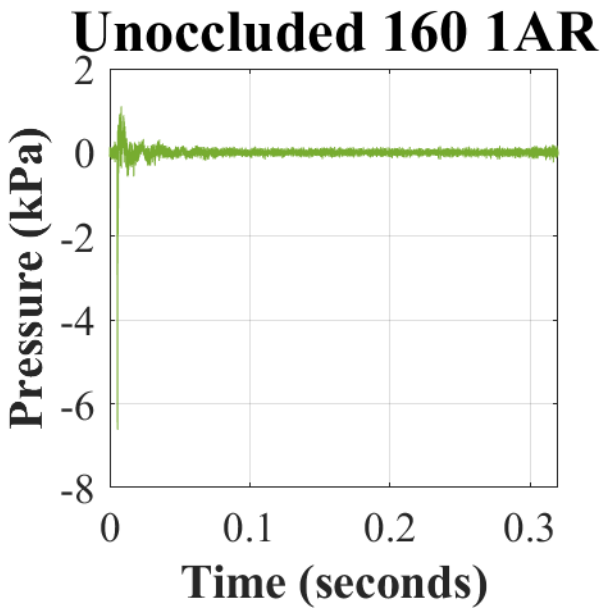

Occluded 160 4BR
Pressure (Pa)
10
0
-10
-20
0
0.1
0.2
0.3
Time (seconds)

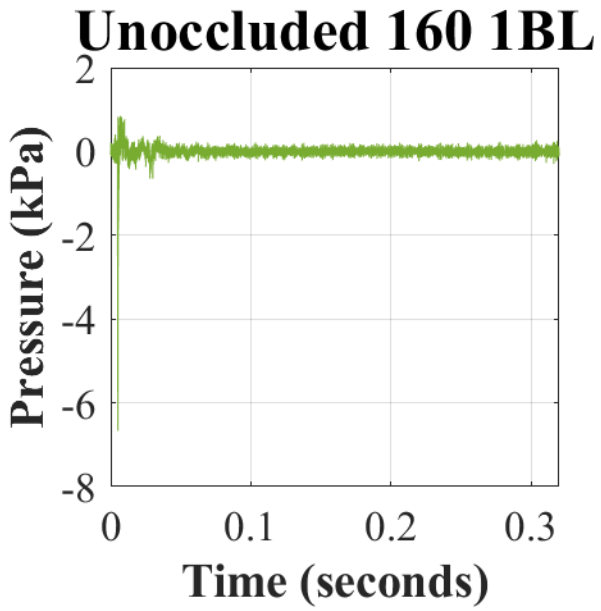


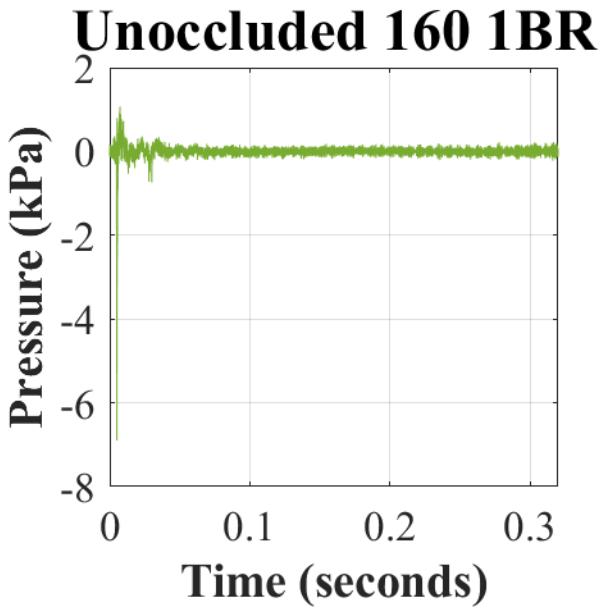
Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Occluded’ is the test condition (i.e., ATF has the HPD donned), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBP), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or B) indicating HPD fit (i.e., first or second, respectively), and ‘X’ indicates from what ATF microphone the recording is from (i.e., right [R] or left [L] pinnae).

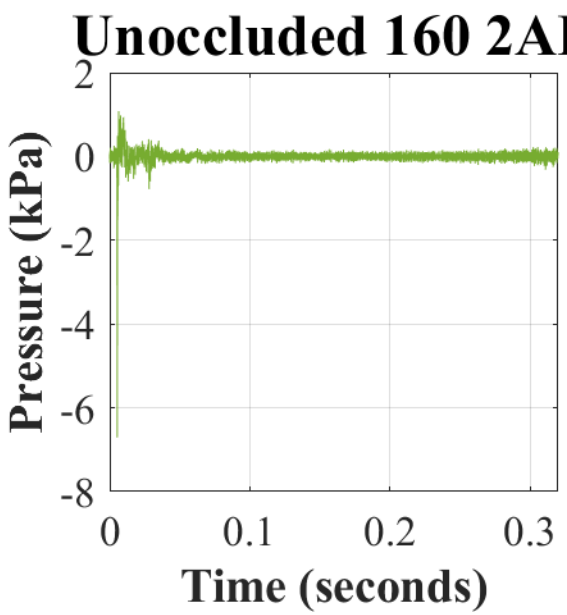
Appendix D. Estimated unoccluded (open-ear) waveforms (in kilopascals [kPa]) over time (in seconds [s]) in response to 160 dBP with the Skull Screws™ Corded Earplugs.

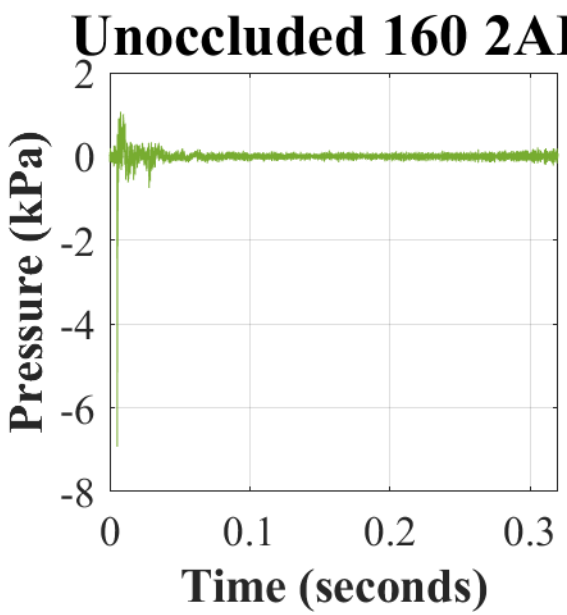


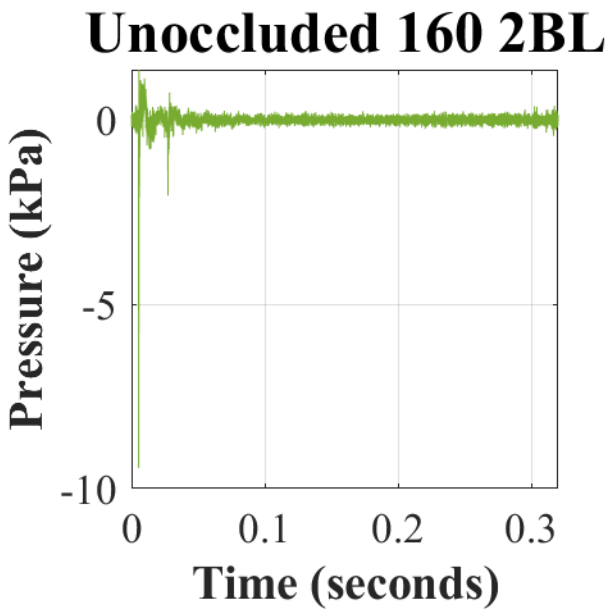


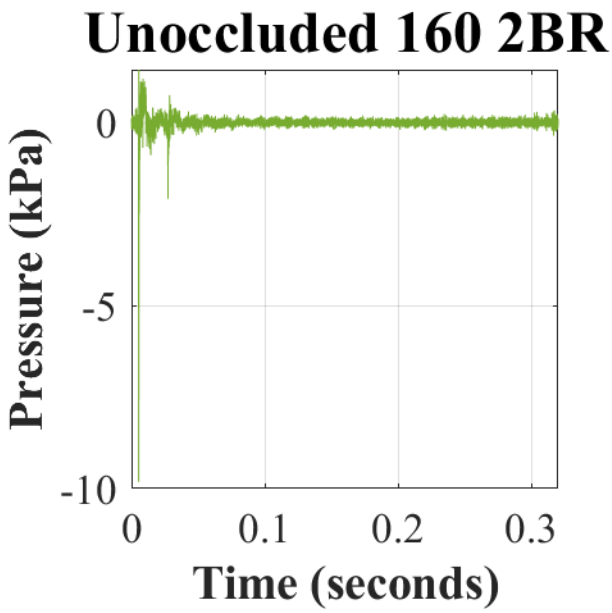


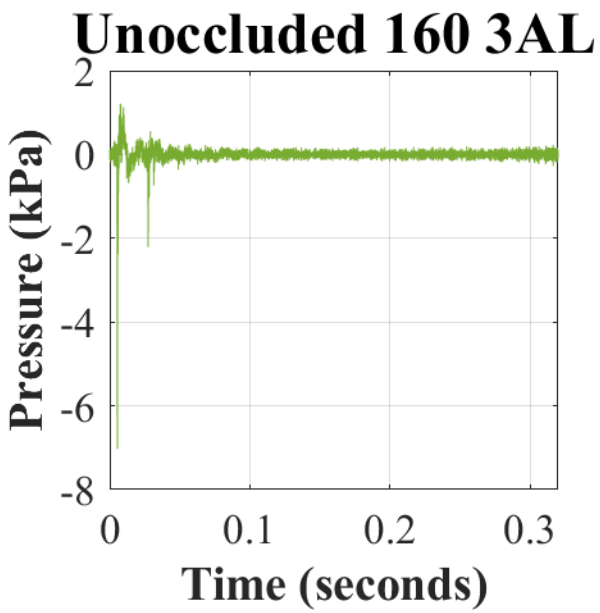


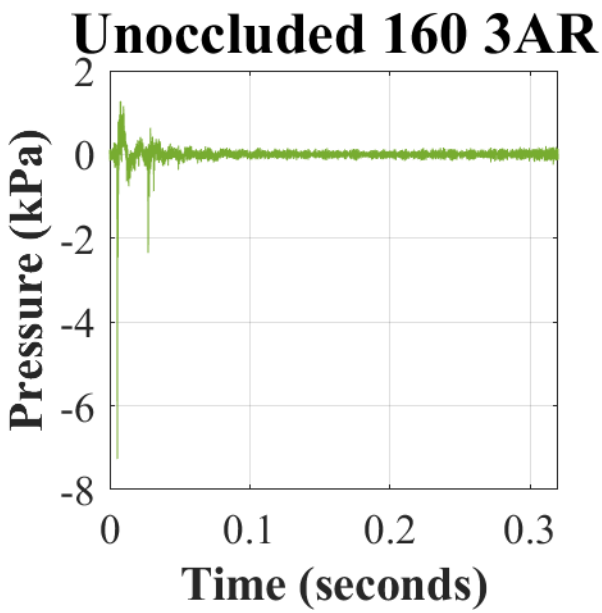

Unoccluded 160 2AL
Pressure (kPa)
2
0
-2
-4
-6
-8
0
0.1
0.2
0.3
Time (seconds)

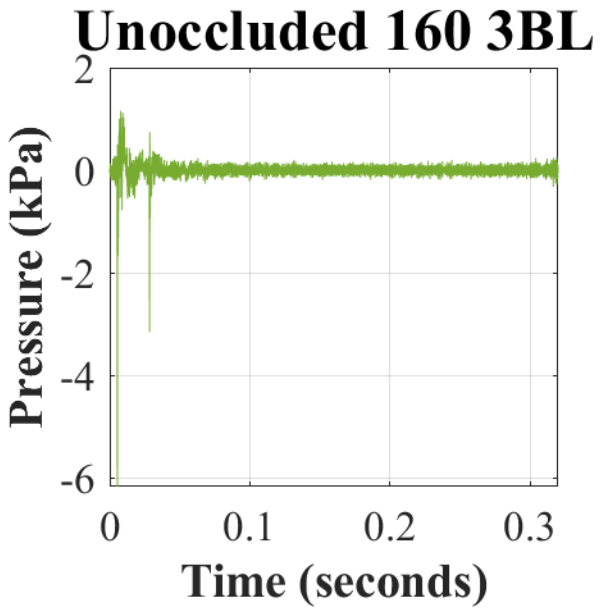

Unoccluded 160 2AR
Pressure (kPa)
2
0
-2
-4
-6
-8
0
0.1
0.2
0.3
Time (seconds)

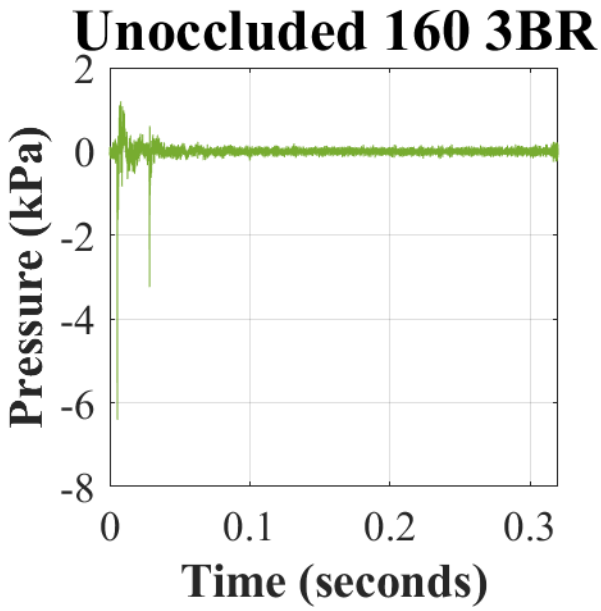

Unoccluded 160 2BL
Pressure (kPa)
0
-5
-10
0
0.1
0.2
0.3
Time (seconds)

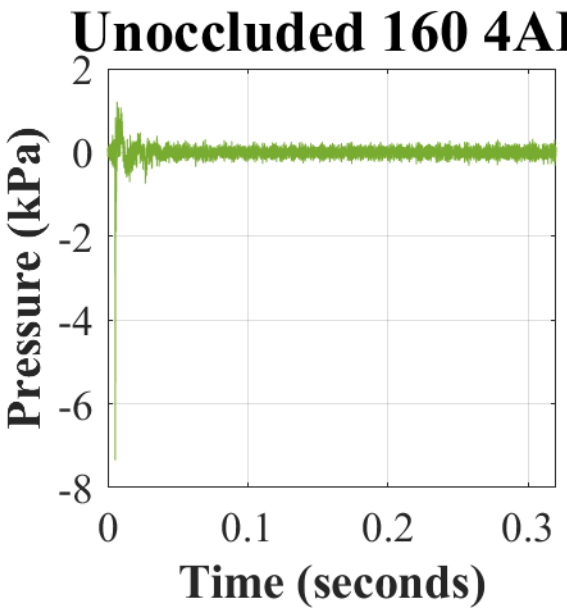

Unoccluded 160 2BR
Pressure (kPa)
0
-5
-10
0
0.1
0.2
0.3
Time (seconds)

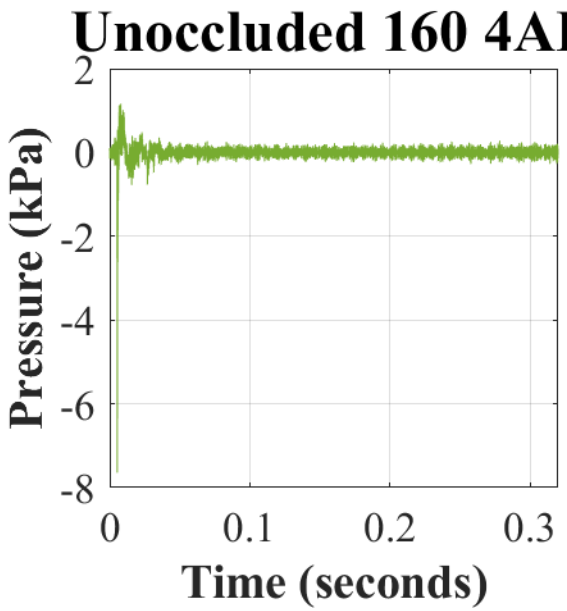

Unoccluded 160 3AL
Pressure (kPa)
2
0
-2
-4
-6
-8
0
0.1
0.2
0.3
Time (seconds)

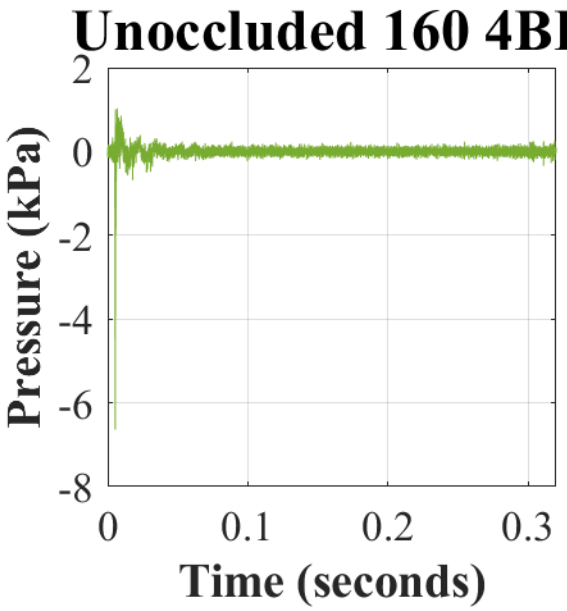

Unoccluded 160 3AR
Pressure (kPa)
2
0
-2
-4
-6
-8
0
0.1
0.2
0.3
Time (seconds)

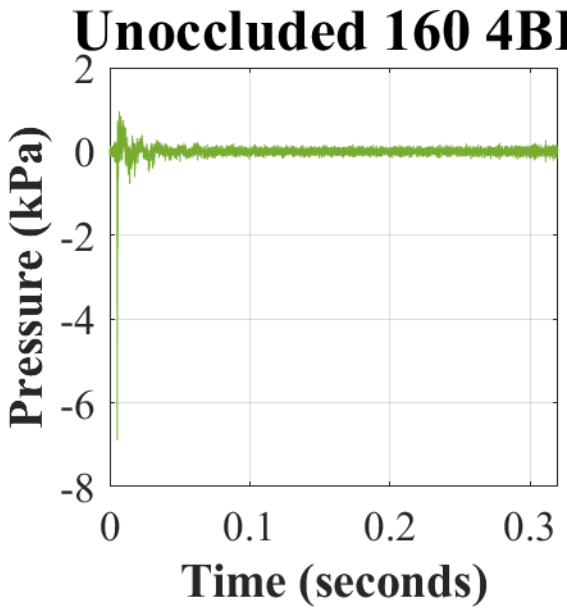

Unoccluded 160 3BL
Pressure (kPa)
2
0
-2
-4
-6
0
0.1
0.2
0.3
Time (seconds)

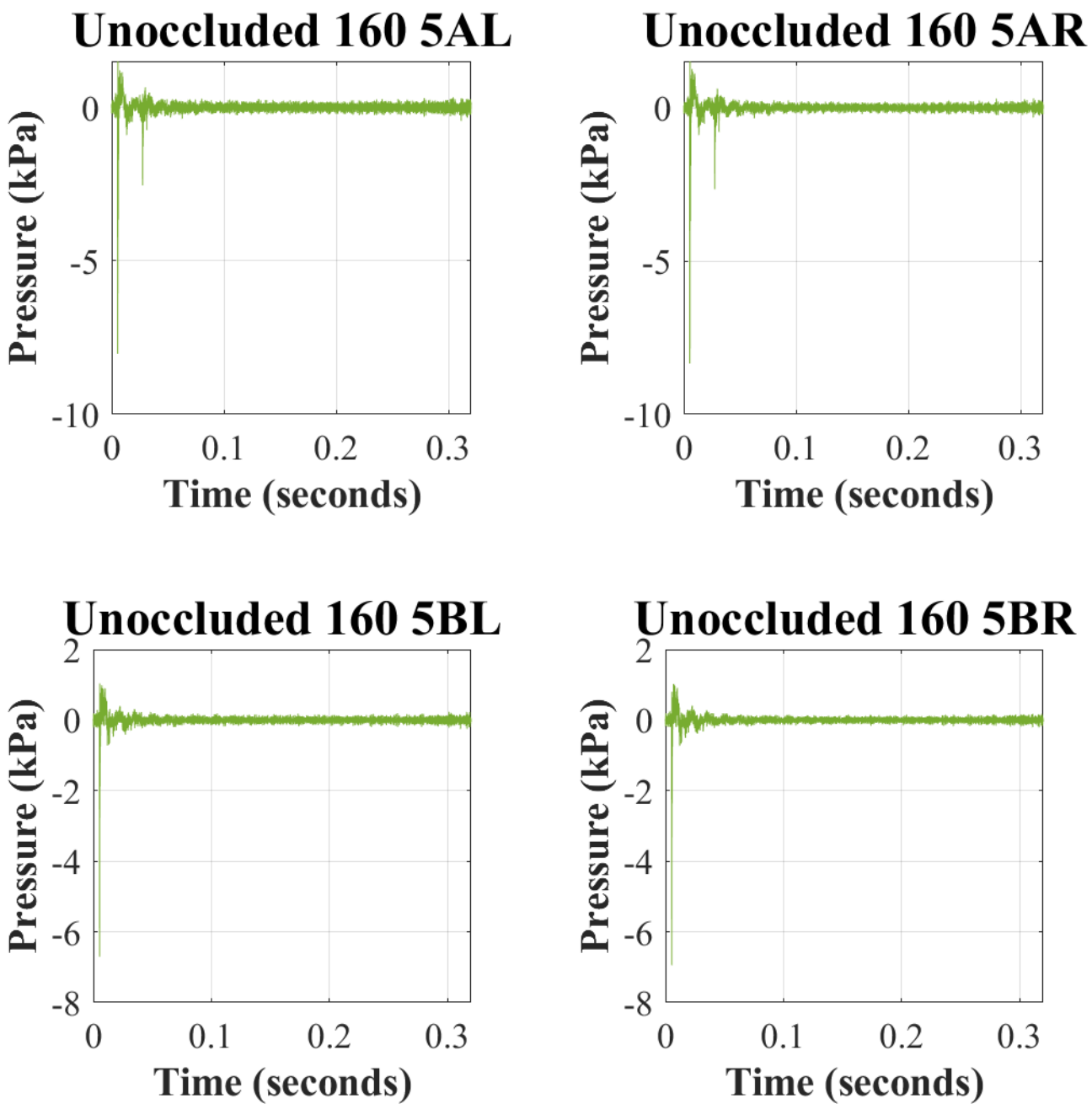

Unoccluded 160 3BR
Pressure (kPa)
2
0
-2
-4
-6
-8
0
0.1
0.2
0.3
Time (seconds)


Unoccluded 160 4AL
Pressure (kPa)
2
0
-2
-4
-6
-8
0
0.1
0.2
0.3
Time (seconds)


Unoccluded 160 4AR
Pressure (kPa)
2
0
-2
-4
-6
-8
0
0.1
0.2
0.3
Time (seconds)

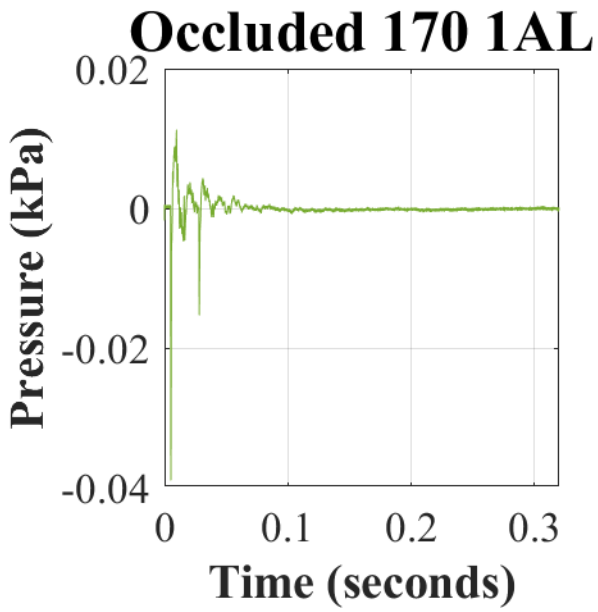

Unoccluded 160 4BL
Pressure (kPa)
2
0
-2
-4
-6
-8
0
0.1
0.2
0.3
Time (seconds)

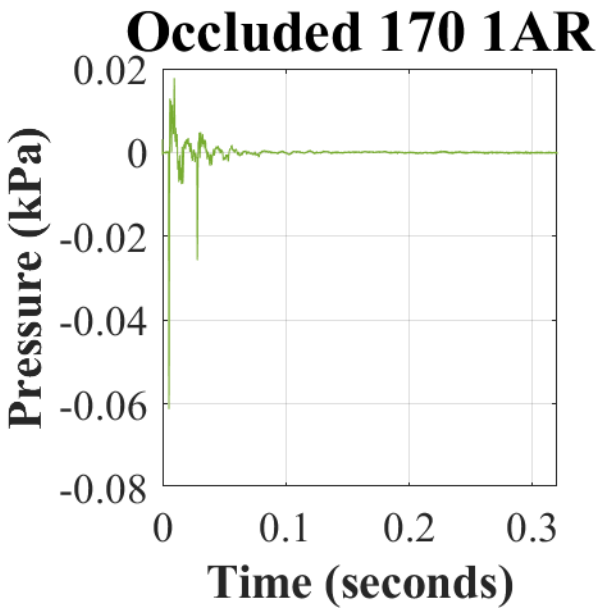

Unoccluded 160 4BR
Pressure (kPa)
2
0
-2
-4
-6
-8
0
0.1
0.2
0.3
Time (seconds)

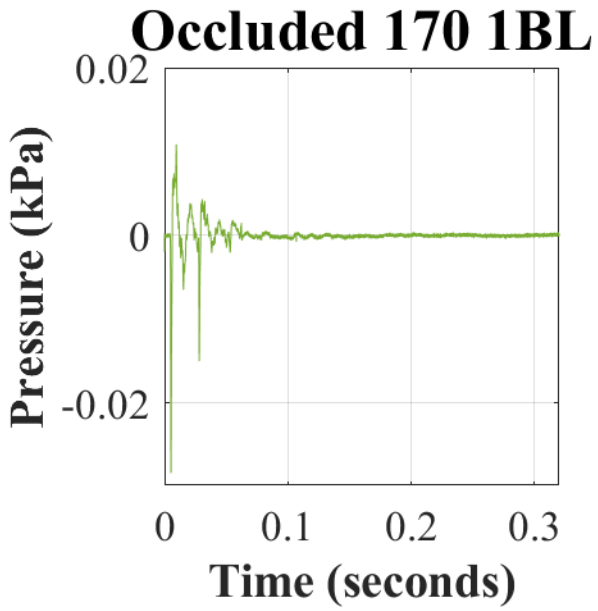


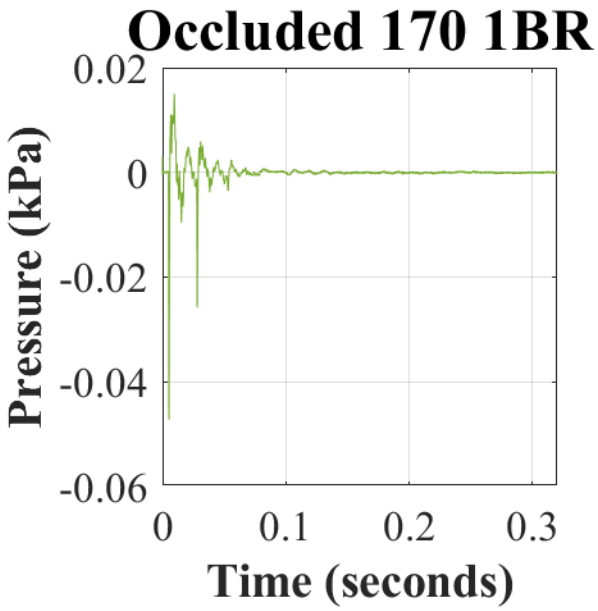
Note. The naming convention for all occluded waveforms is “Unoccluded LvL NnX”, where ‘Unoccluded’ is the test condition (i.e., ATF has the HPD doffed), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBP), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or B) indicating HPD fit (i.e., first or second, respectively), and ‘X’ indicates from what ATF microphone the recording is from (i.e., right [R] or left [L] pinnae).

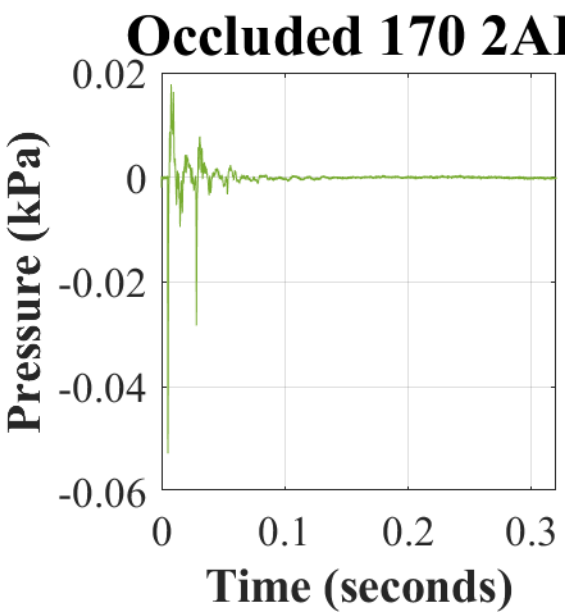
Appendix E. Recorded occluded (closed-ear) waveforms (in kilopascals [kPa]) over time (in seconds [s]) in response to 170 dBP with the Skull Screws™ Corded Earplugs.

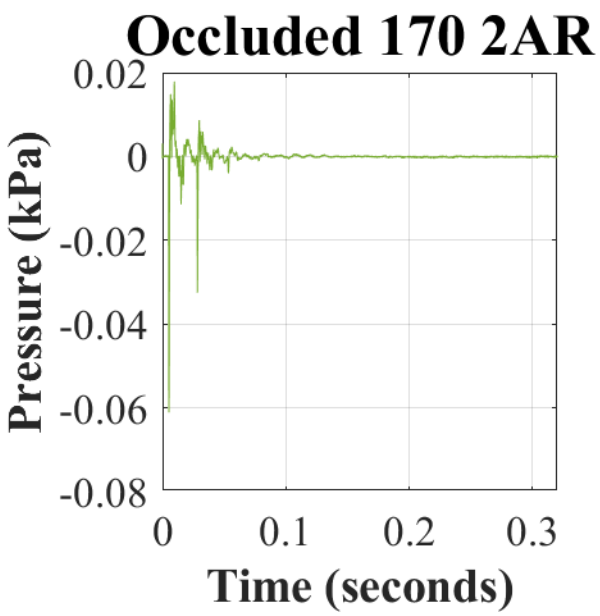


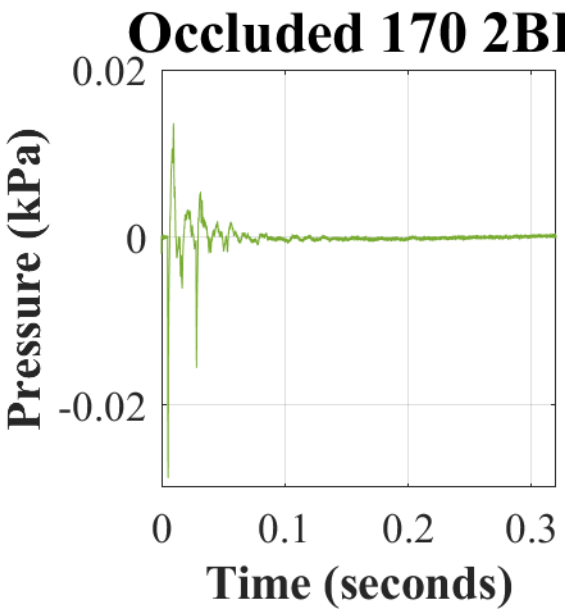


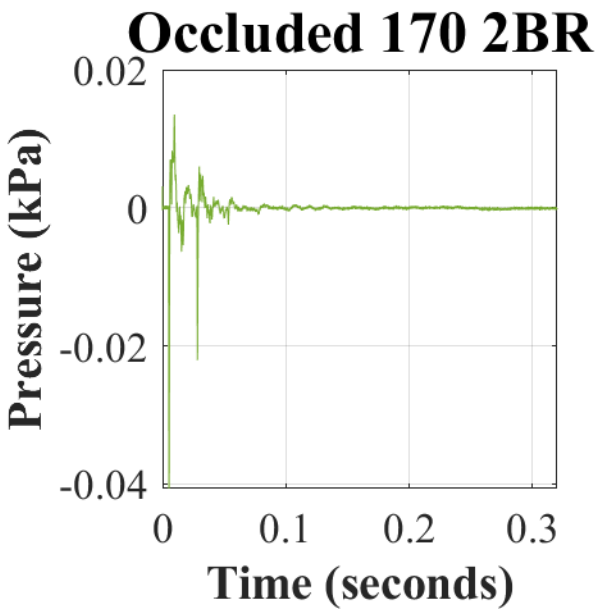


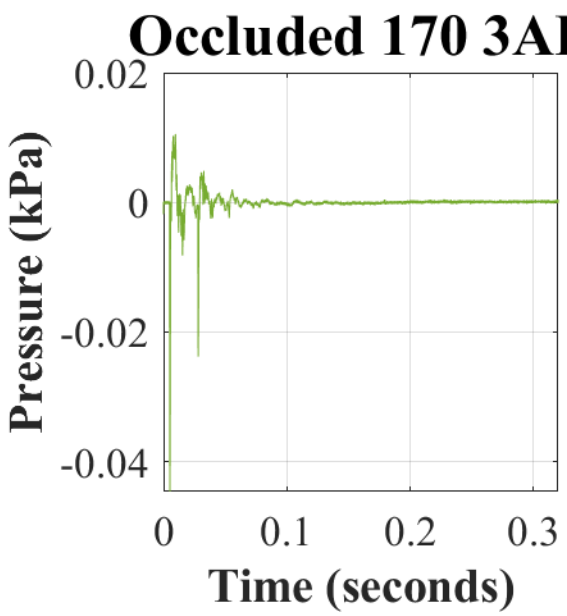


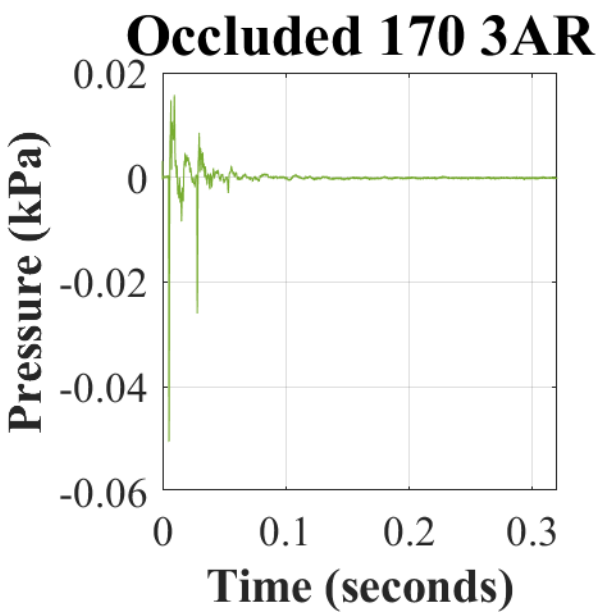

Occluded 170 2AL
Pressure (kPa)
0.02
0
-0.02
-0.04
-0.06
0
0.1
0.2
0.3
Time (seconds)

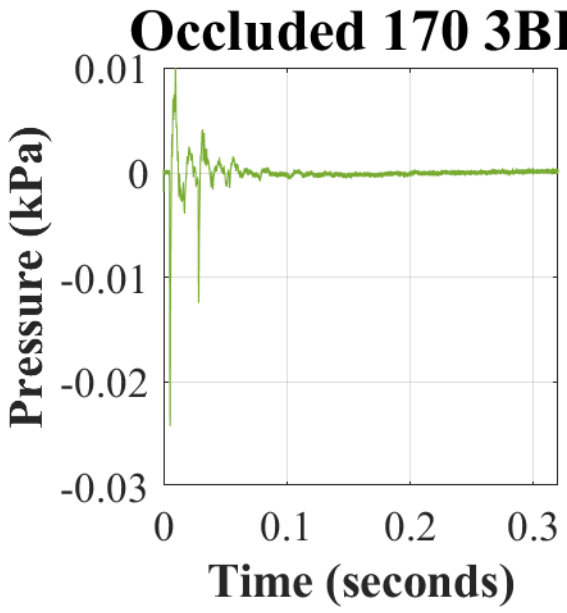

Occluded 170 2AR
Pressure (kPa)
0.02
0
-0.02
-0.04
-0.06
-0.08
0
0.1
0.2
0.3
Time (seconds)

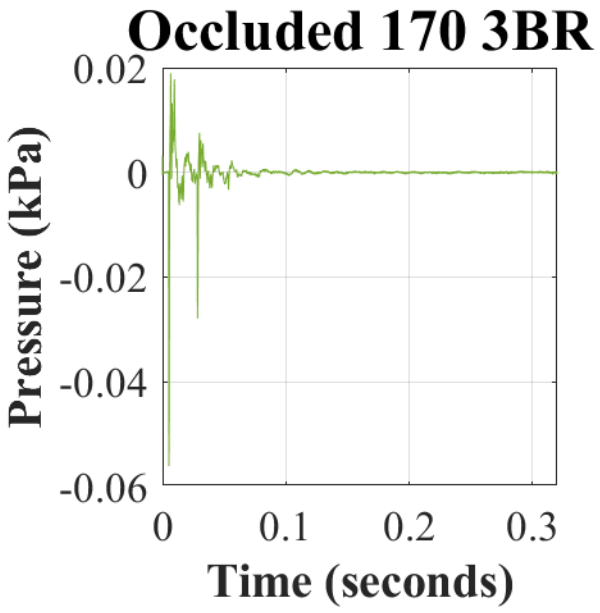

Occluded 170 2BL
Pressure (kPa)
0.02
0
-0.02
0
0.1
0.2
0.3
Time (seconds)

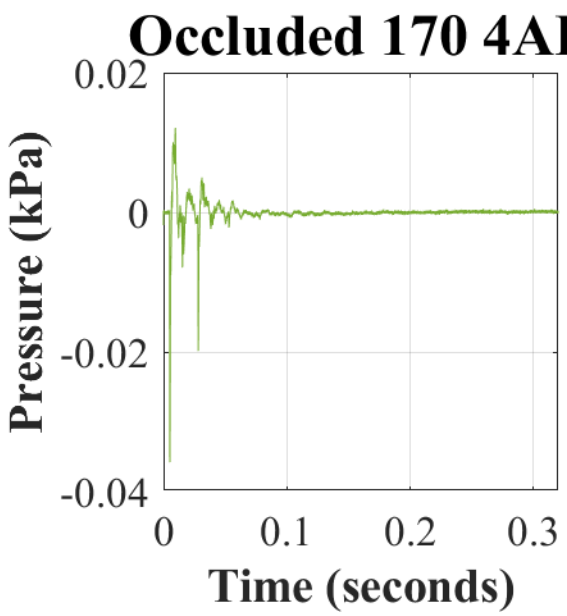

Occluded 170 2BR
Pressure (kPa)
0.02
0
-0.02
-0.04
0
0.1
0.2
0.3
Time (seconds)

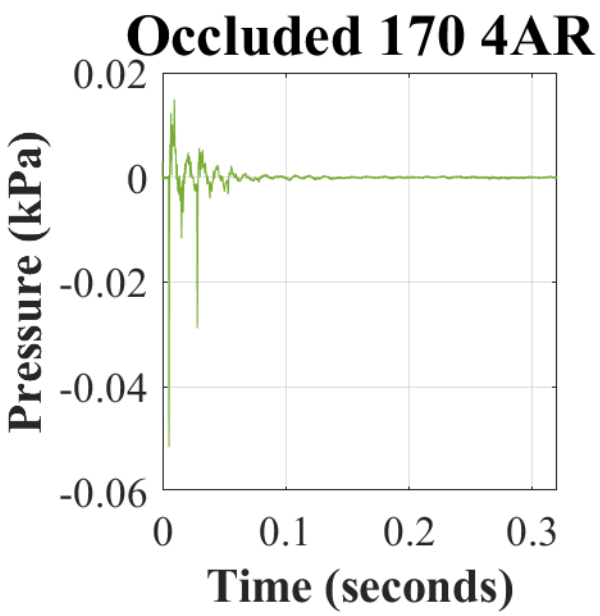

Occluded 170 3AL
Pressure (kPa)
0.02
0
-0.02
-0.04
0
0.1
0.2
0.3
Time (seconds)

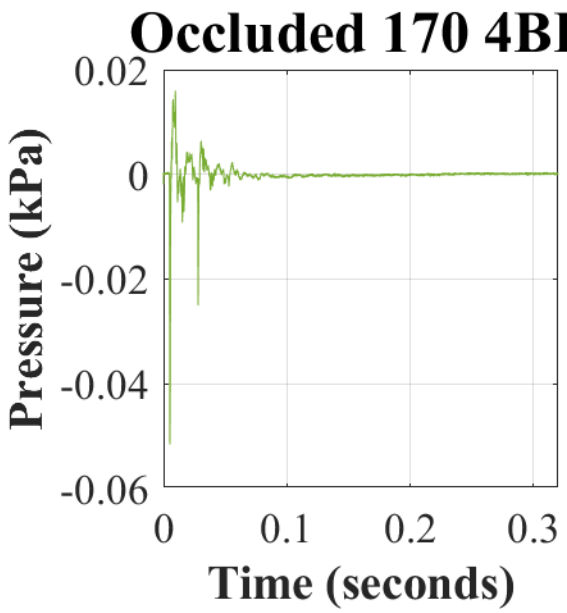

Occluded 170 3AR
Pressure (kPa)
0.02
0
-0.02
-0.04
-0.06
0
0.1
0.2
0.3
Time (seconds)

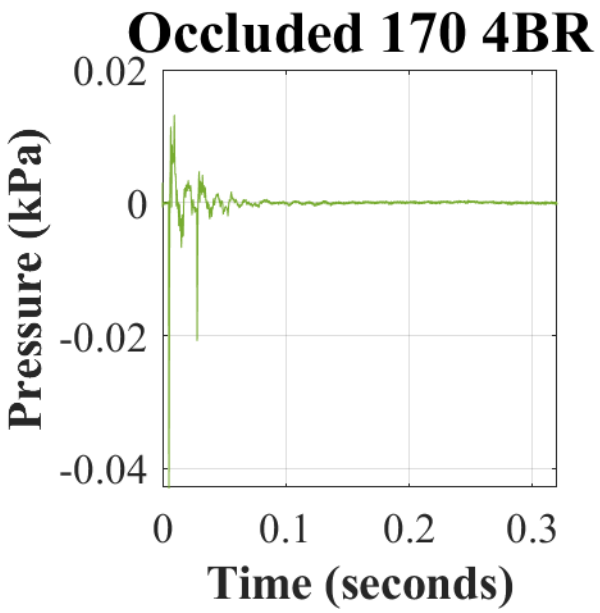

Occluded 170 3BL
Pressure (kPa)
0.01
0
-0.01
-0.02
-0.03
0
0.1
0.2
0.3
Time (seconds)

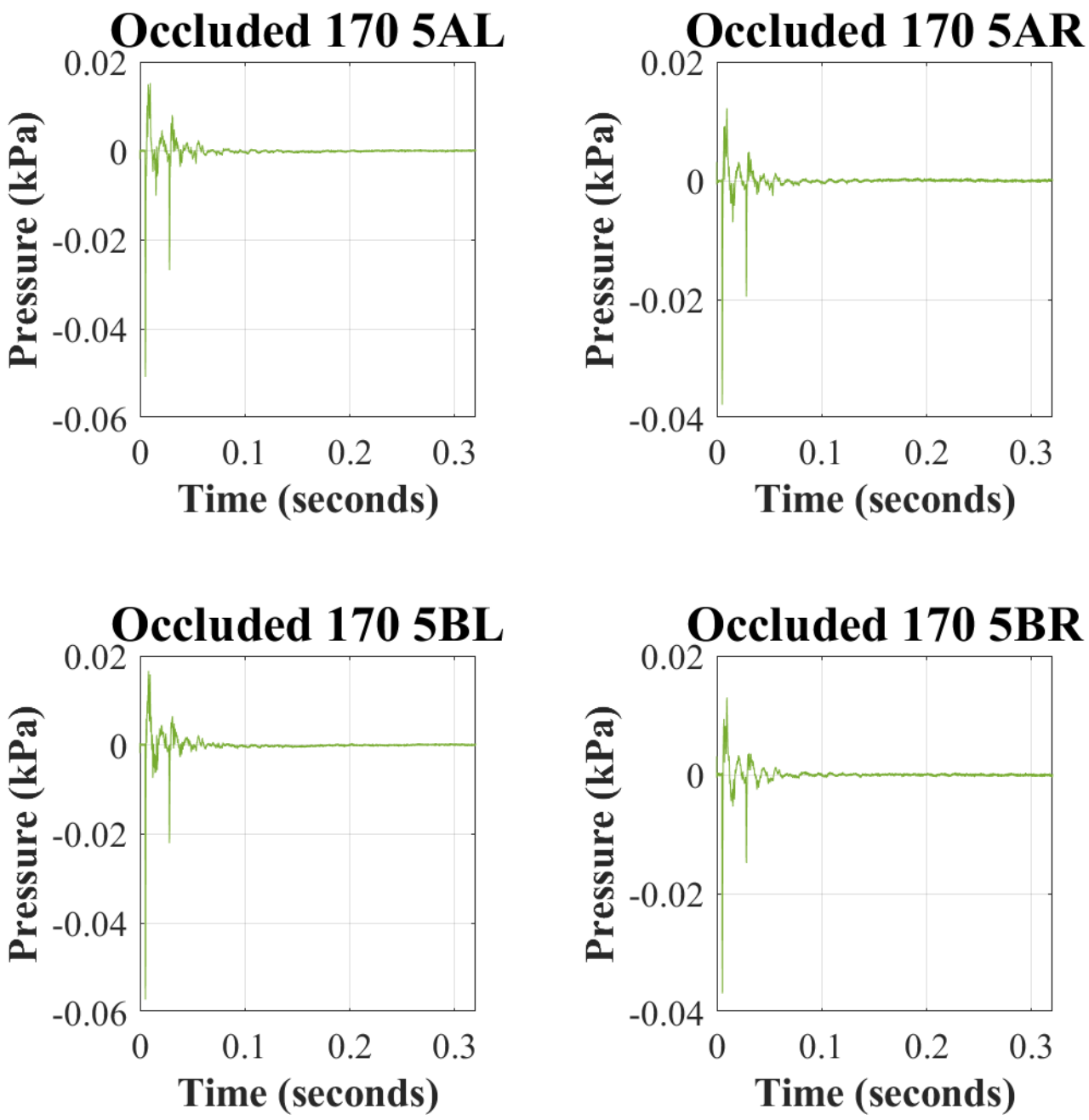

Occluded 170 3BR
Pressure (kPa)
0.02
0
-0.02
-0.04
-0.06
0
0.1
0.2
0.3
Time (seconds)


Occluded 170 4AL
Pressure (kPa)
0.02
0
-0.02
-0.04
0
0.1
0.2
0.3
Time (seconds)


Occluded 170 4AR
Pressure (kPa)
0.02
0
-0.02
-0.04
-0.06
0
0.1
0.2
0.3
Time (seconds)

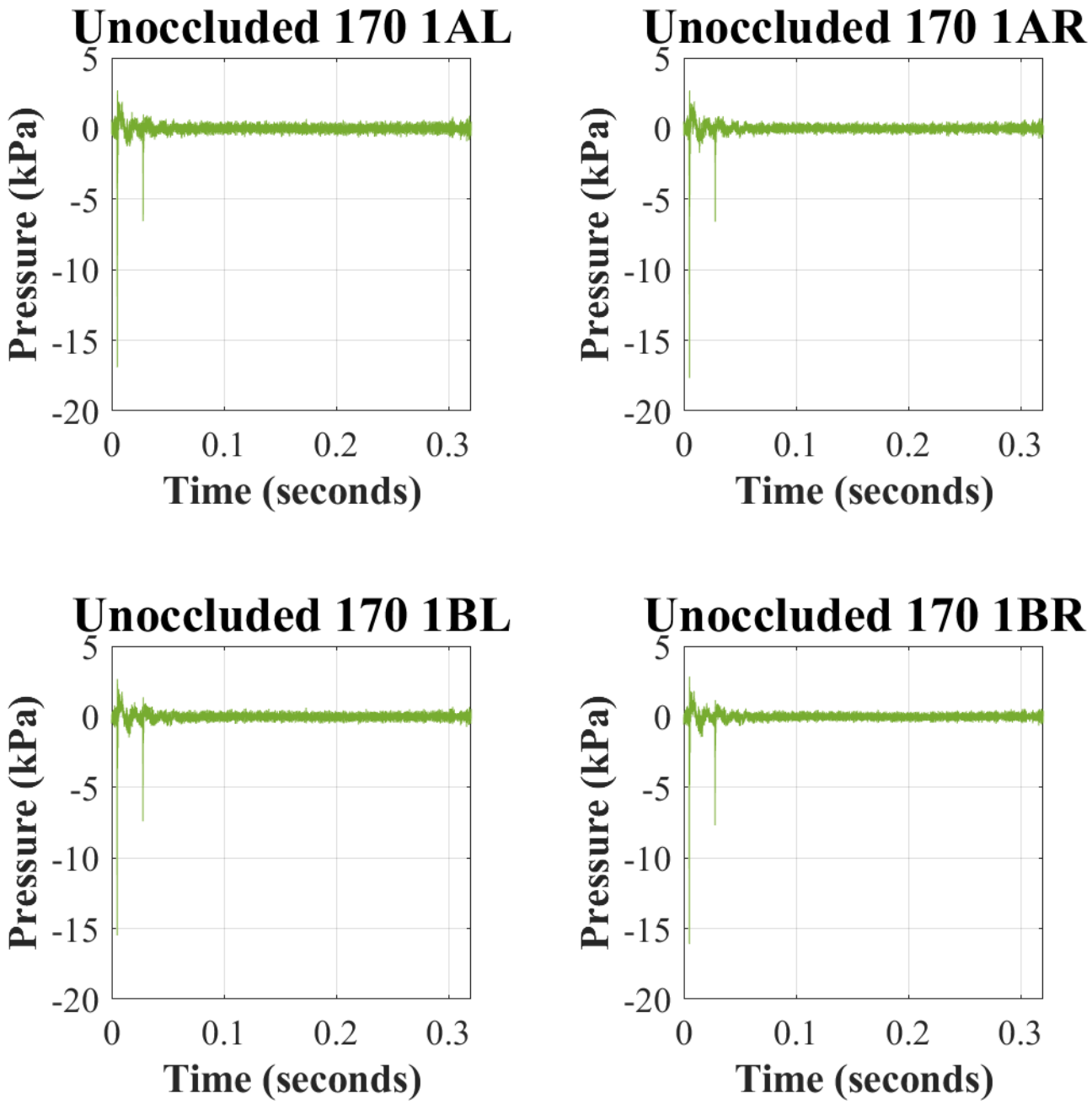

Occluded 170 4BL
Pressure (kPa)
0.02
0
-0.02
-0.04
-0.06
0
0.1
0.2
0.3
Time (seconds)

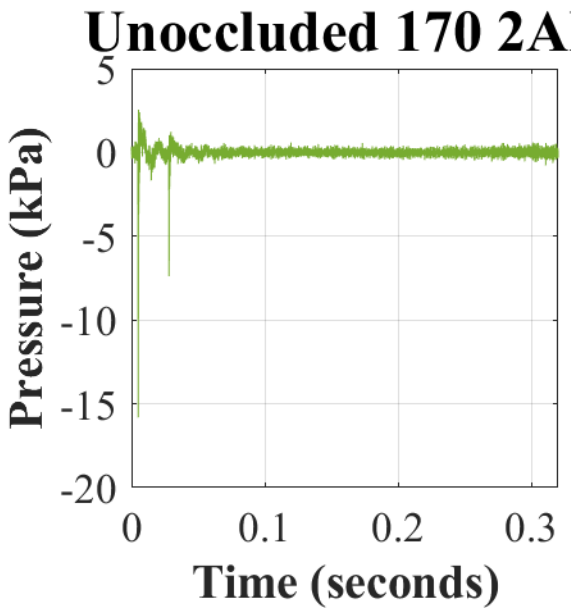

Occluded 170 4BR
Pressure (kPa)
0.02
0
-0.02
-0.04
0
0.1
0.2
0.3
Time (seconds)

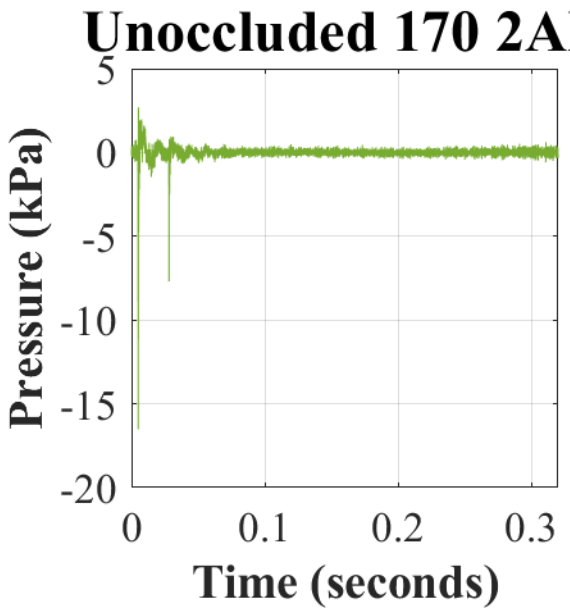


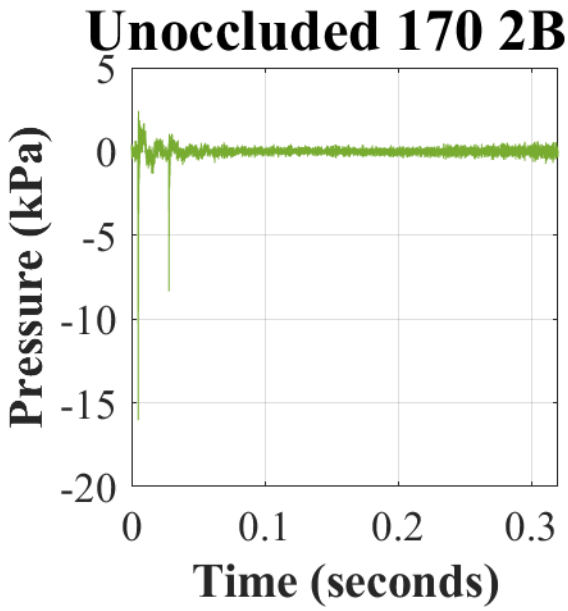
Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Occluded’ is the test condition (i.e., ATF has the HPD donned), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBP), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or B) indicating HPD fit (i.e., first or second, respectively), and ‘X’ indicates from what ATF microphone the recording is from (i.e., right [R] or left [L] pinnae).

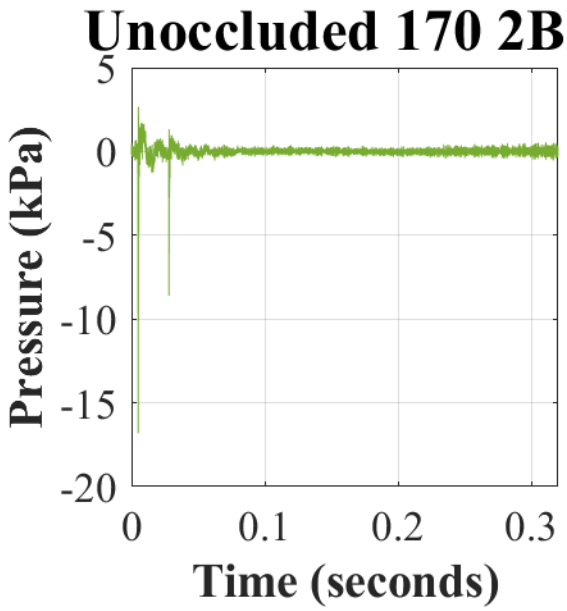
Appendix F. Estimated unoccluded (open-ear) waveforms (in kilopascals [kPa]) over time (in seconds [s]) in response to 170 dBP with the Skull Screws™ Corded Earplugs.

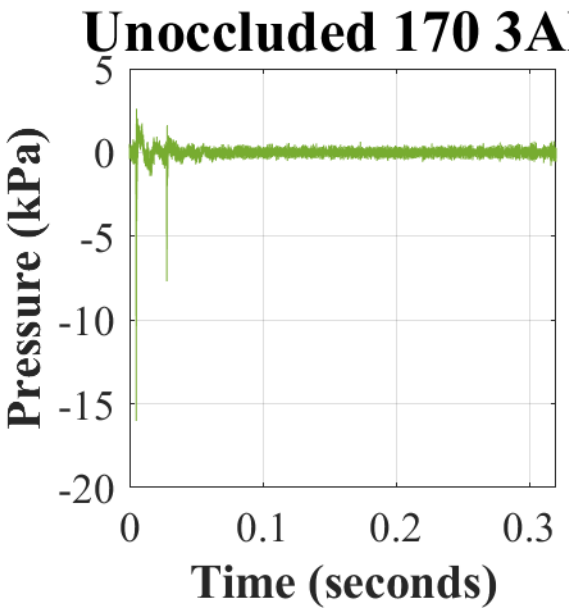


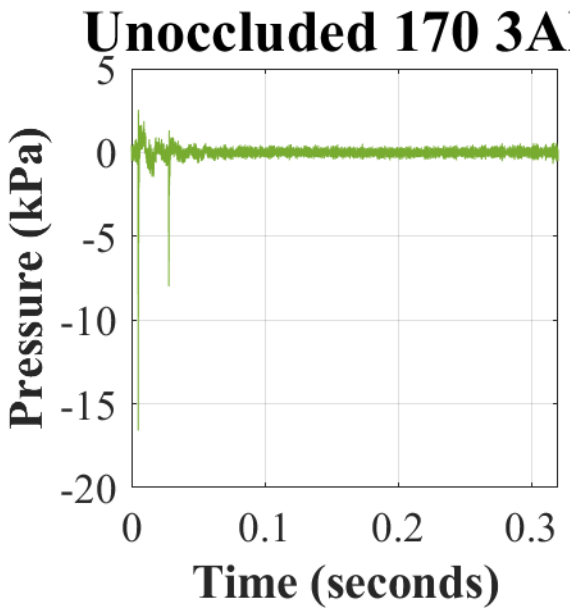

Unoccluded 170 2AL
Pressure (kPa)
5
0
-5
-10
-15
-20
0
0.1
0.2
0.3
Time (seconds)

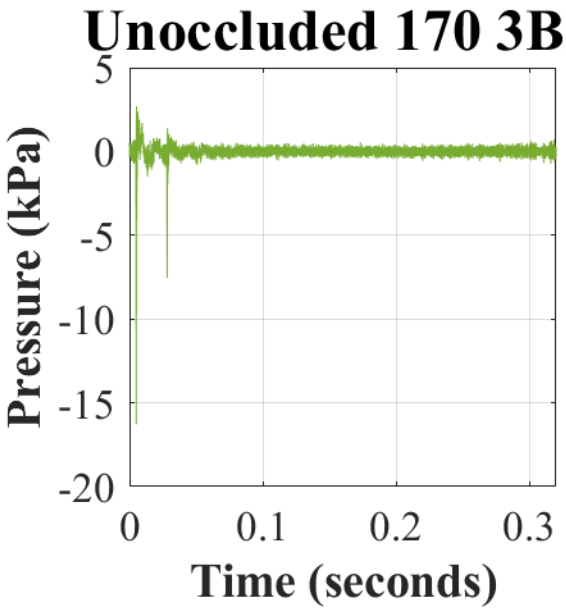

Unoccluded 170 2AR
Pressure (kPa)
5
0
-5
-10
-15
-20
0
0.1
0.2
0.3
Time (seconds)

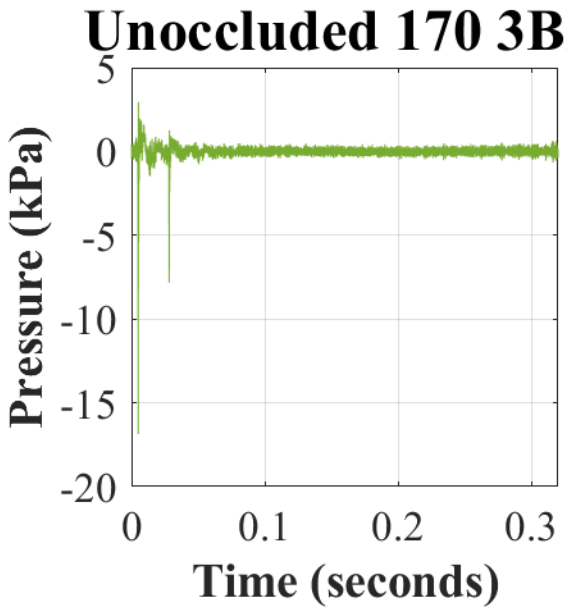

Unoccluded 170 2BL
Pressure (kPa)
5
0
-5
-10
-15
-20
0
0.1
0.2
0.3
Time (seconds)

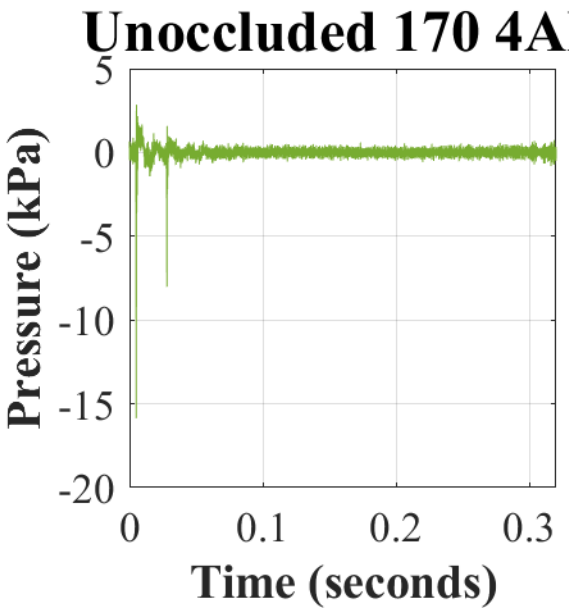

Unoccluded 170 2BR
Pressure (kPa)
5
0
-5
-10
-15
-20
0
0.1
0.2
0.3
Time (seconds)

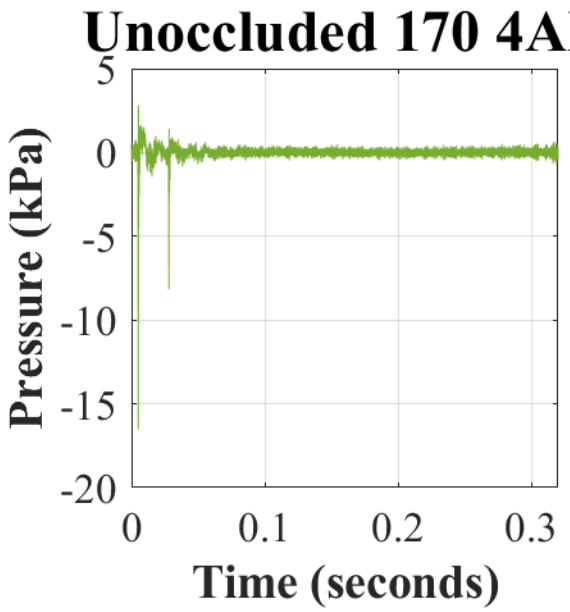

Unoccluded 170 3AL
Pressure (kPa)
5
0
-5
-10
-15
-20
0
0.1
0.2
0.3
Time (seconds)

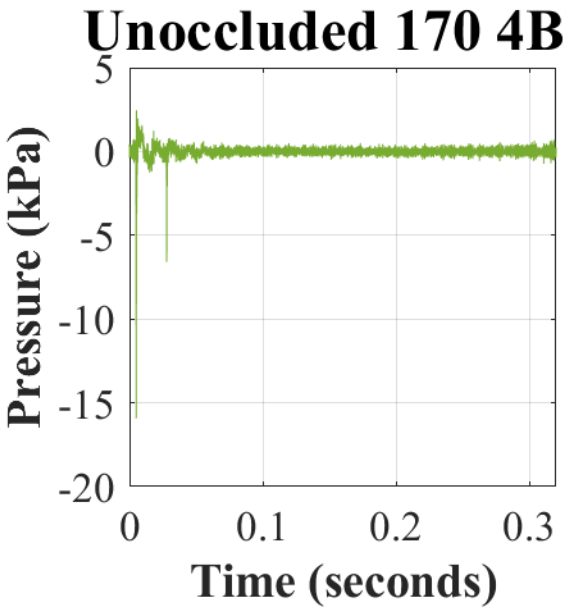

Unoccluded 170 3AR
Pressure (kPa)
5
0
-5
-10
-15
-20
0
0.1
0.2
0.3
Time (seconds)

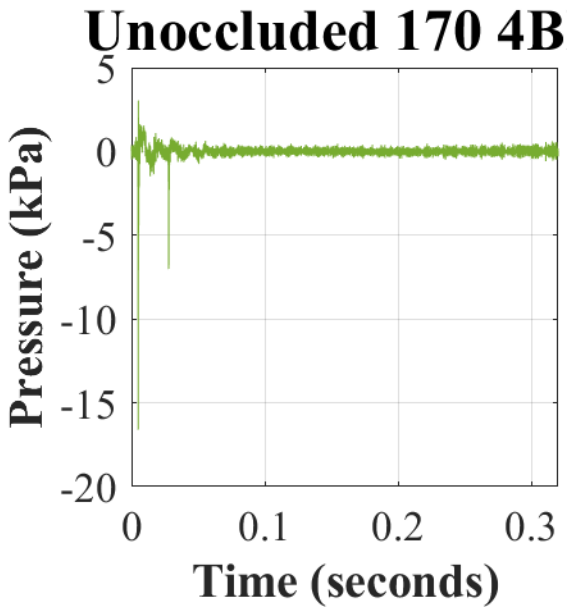

Unoccluded 170 3BL
Pressure (kPa)
5
0
-5
-10
-15
-20
0
0.1
0.2
0.3
Time (seconds)

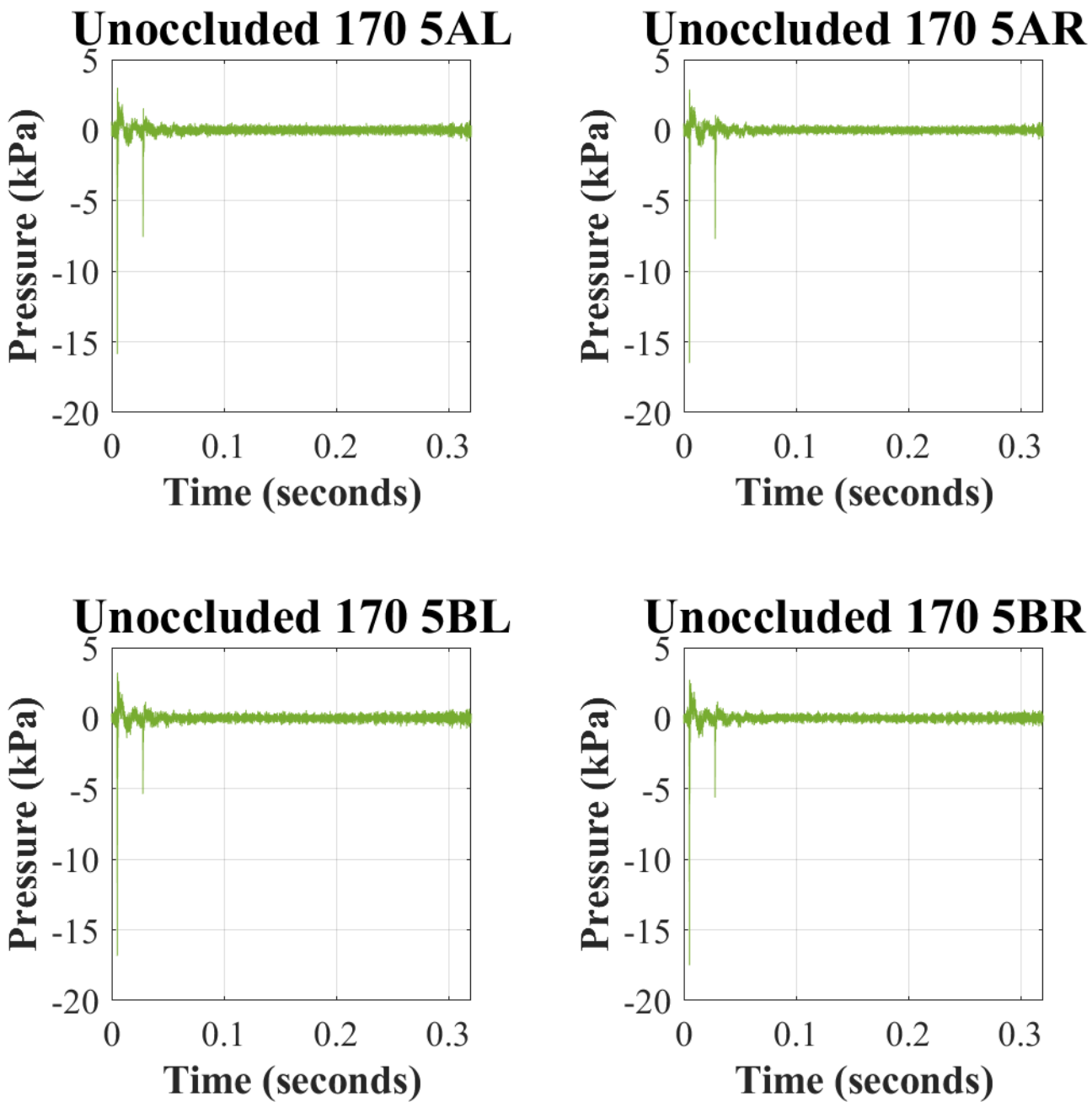

Unoccluded 170 3BR
Pressure (kPa)
5
0
-5
-10
-15
-20
0
0.1
0.2
0.3
Time (seconds)


Unoccluded 170 4AL
Pressure (kPa)
5
0
-5
-10
-15
-20
0
0.1
0.2
0.3
Time (seconds)


Unoccluded 170 4AR
Pressure (kPa)
5
0
-5
-10
-15
-20
0
0.1
0.2
0.3
Time (seconds)

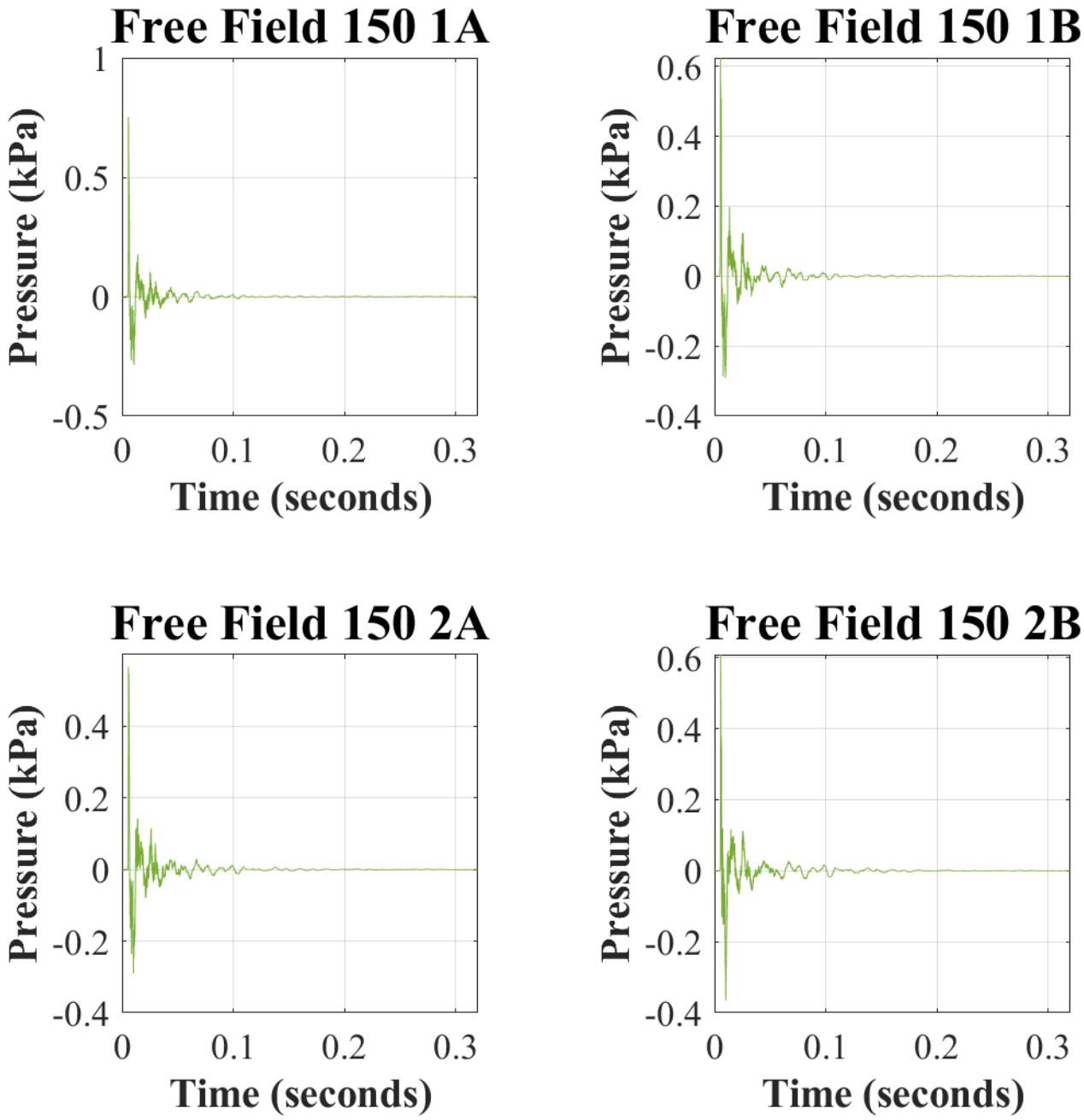

Unoccluded 170 4BL
Pressure (kPa)
5
0
-5
-10
-15
-20
0
0.1
0.2
0.3
Time (seconds)

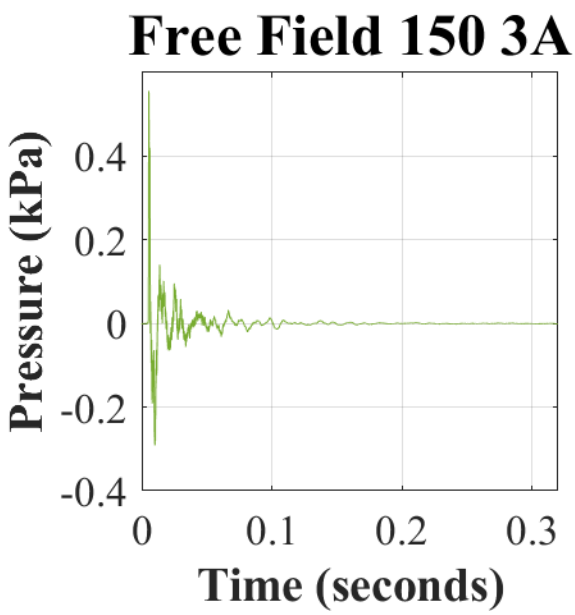

Unoccluded 170 4BR
Pressure (kPa)
5
0
-5
-10
-15
-20
0
0.1
0.2
0.3
Time (seconds)

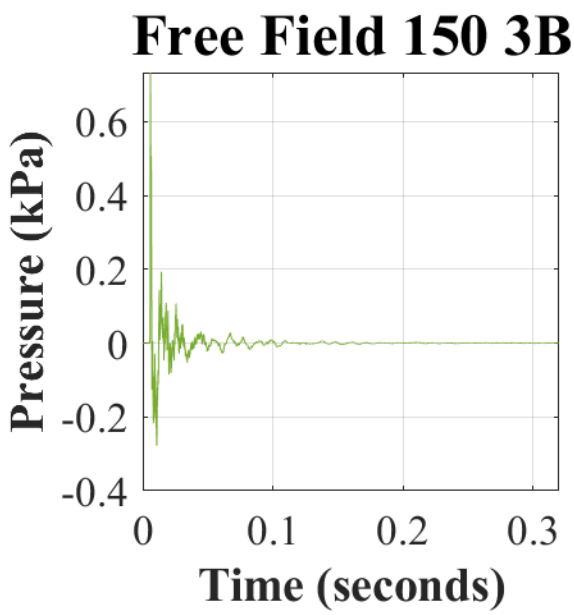


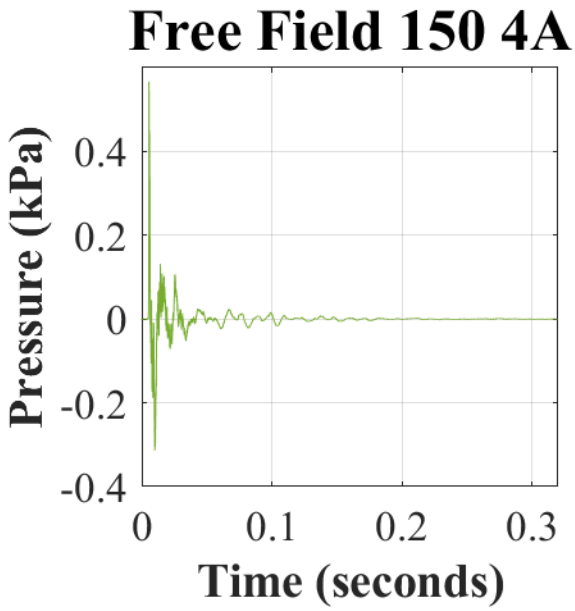
Note. The naming convention for all occluded waveforms is “Unoccluded LvL NnX”, where ‘Unoccluded’ is the test condition (i.e., ATF has the HPD doffed), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBP), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or B) indicating HPD fit (i.e., first or second, respectively), and ‘X’ indicates from what ATF microphone the recording is from (i.e., right [R] or left [L] pinnae).

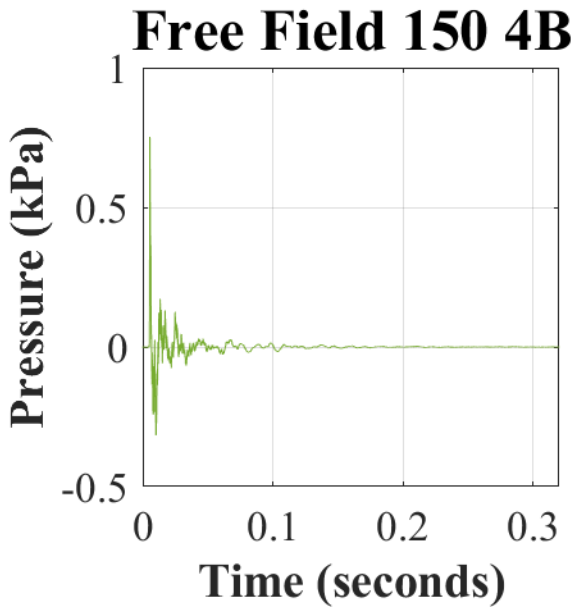
Appendix G. Recorded waveform (in kilopascals [kPa]) over time (in seconds [s]) of the impulse measured with the free-field probe at 150 dBP and the Skull Screws™ Corded donned.

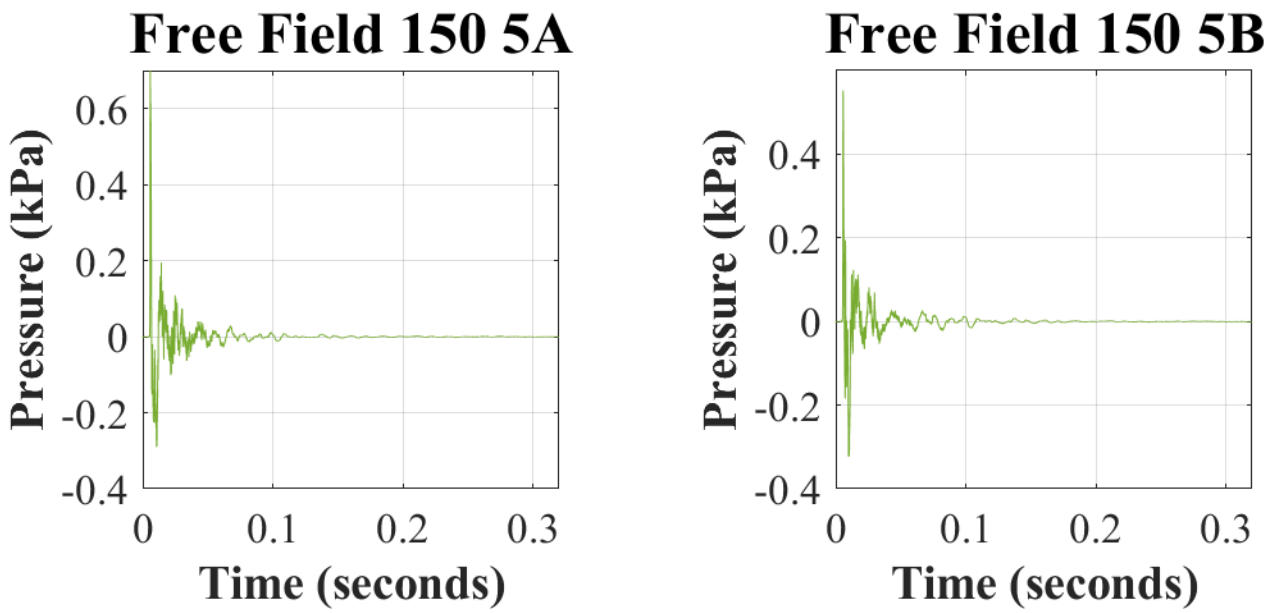



Free Field 150 3A
Pressure (kPa)
0.4
0.2
0
-0.2
-0.4
0
0.1
0.2
0.3
Time (seconds)


Free Field 150 3B
Pressure (kPa)
0.6
0.4
0.2
0
-0.2
-0.4
0
0.1
0.2
0.3
Time (seconds)

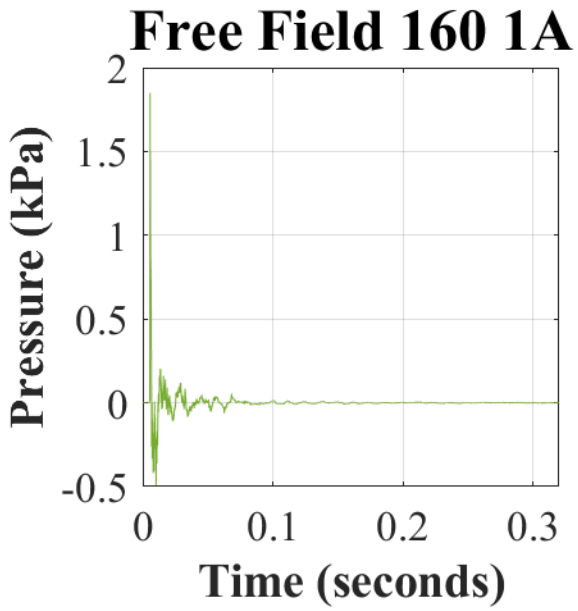

Free Field 150 4A
Pressure (kPa)
0.4
0.2
0
-0.2
-0.4
0
0.1
0.2
0.3
Time (seconds)

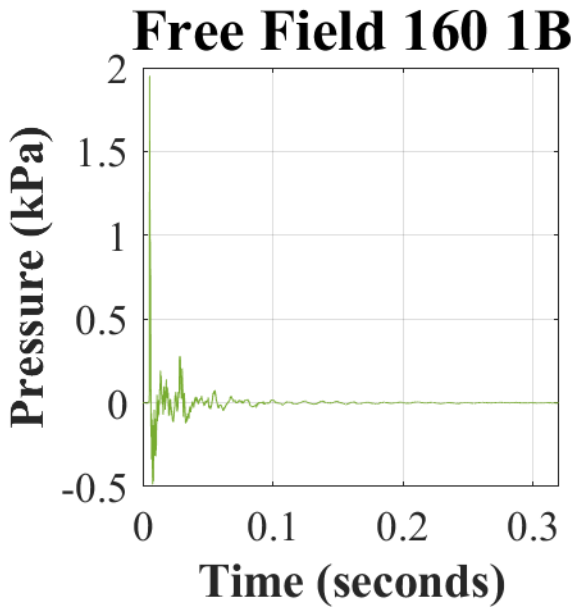

Free Field 150 4B
Pressure (kPa)
1
0.5
0
-0.5
0
0.1
0.2
0.3
Time (seconds)

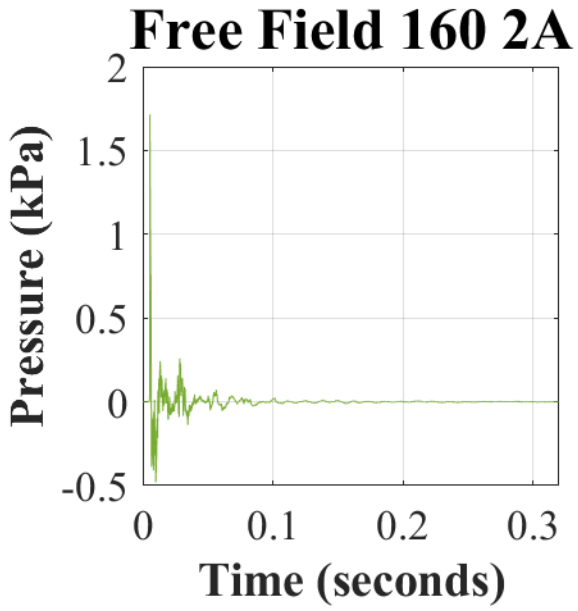


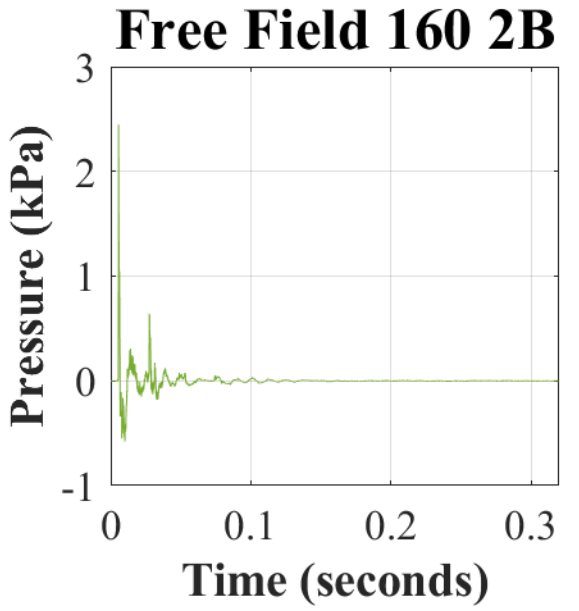
Note. The naming convention for all free-field waveforms is “Free Field LvL Nn”, where ‘Free Field’ indicates that the recording was obtained using the PCB reference microphone, ‘LvL’ is the nominal test level (150 dBP), ‘N’ is the device sample number (1 to 5), and ‘n’ is the device trial (i.e., A or B).

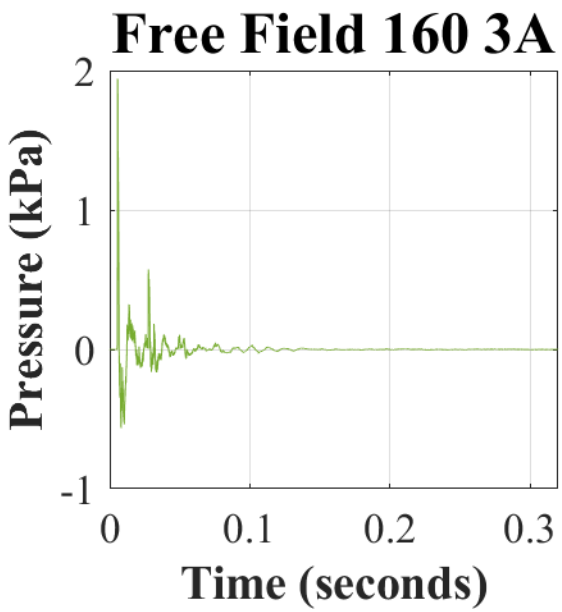
Appendix H. Recorded waveform (in kilopascals [kPa]) over time (in seconds [s]) of the impulse measured with the free-field probe at 160 dBP and the Skull Screws™ Corded donned.

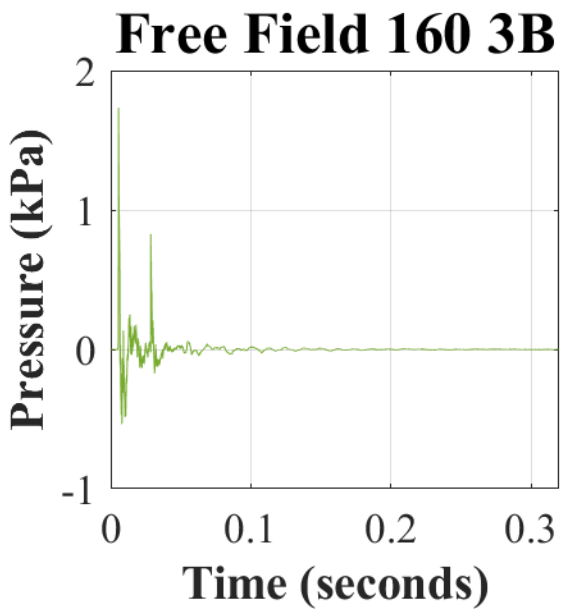


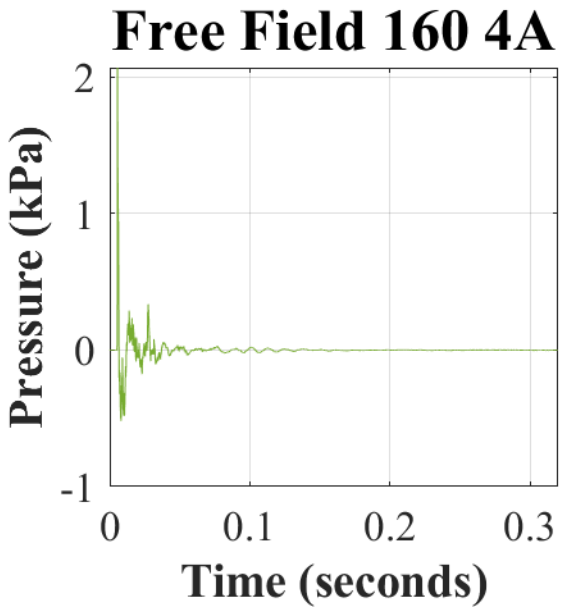


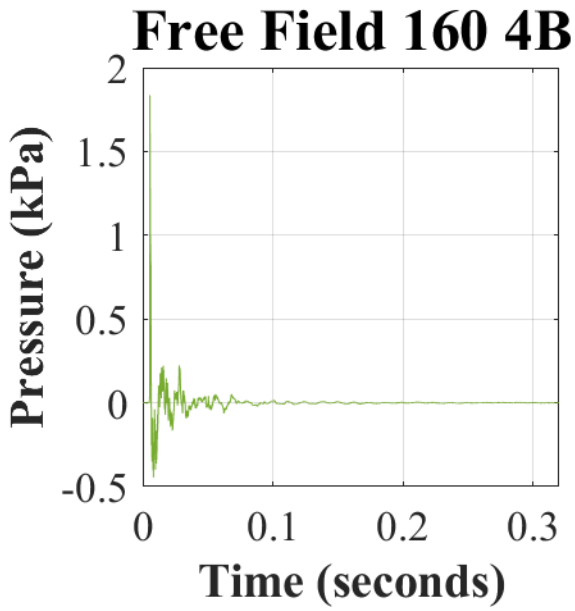


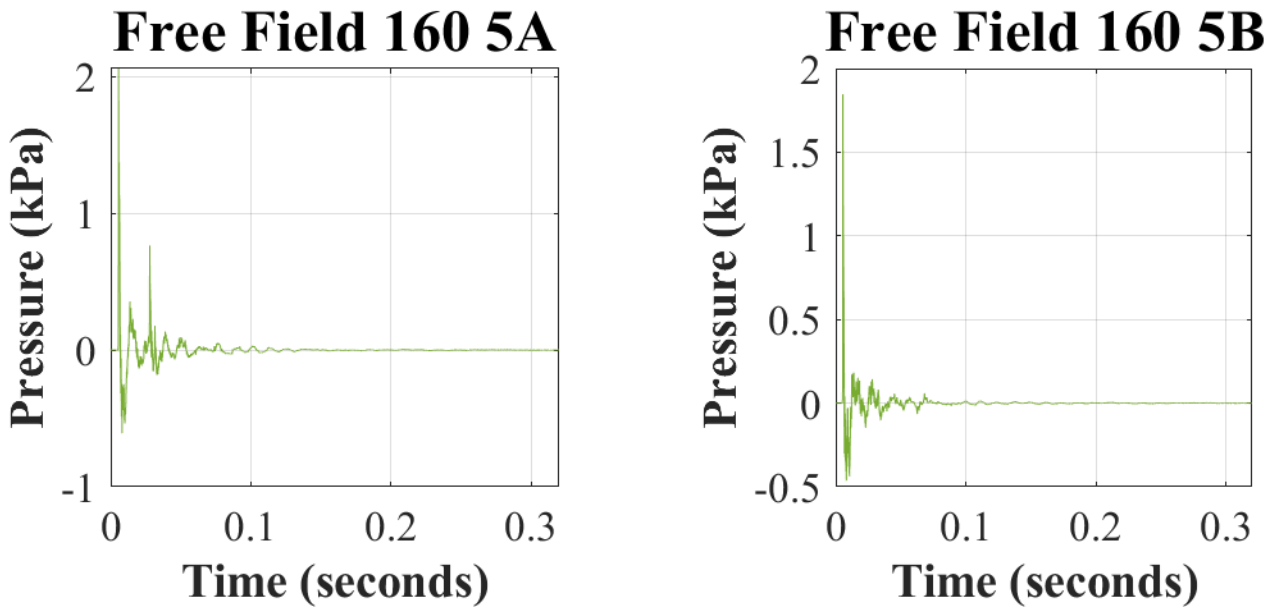



Free Field 160 3A
Pressure (kPa)
Time (seconds)
2
1
0
-1
0
0.1
0.2
0.3


Free Field 160 3B
Pressure (kPa)
Time (seconds)
2
1
0
-1
0
0.1
0.2
0.3

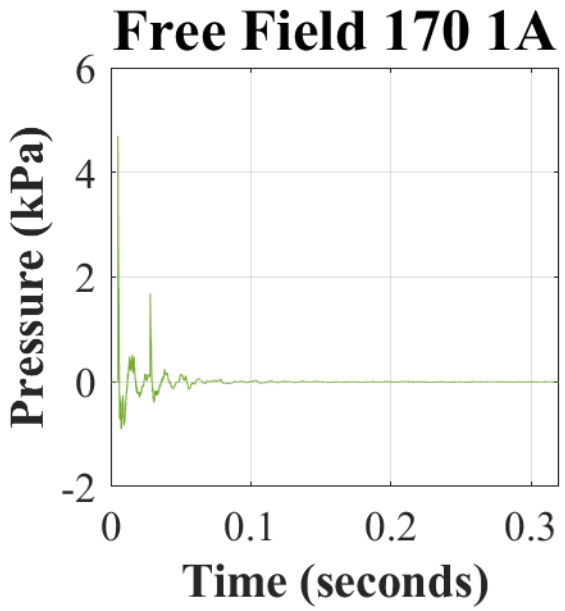

Free Field 160 4A
Pressure (kPa)
Time (seconds)
2
1
0
-1
0
0.1
0.2
0.3

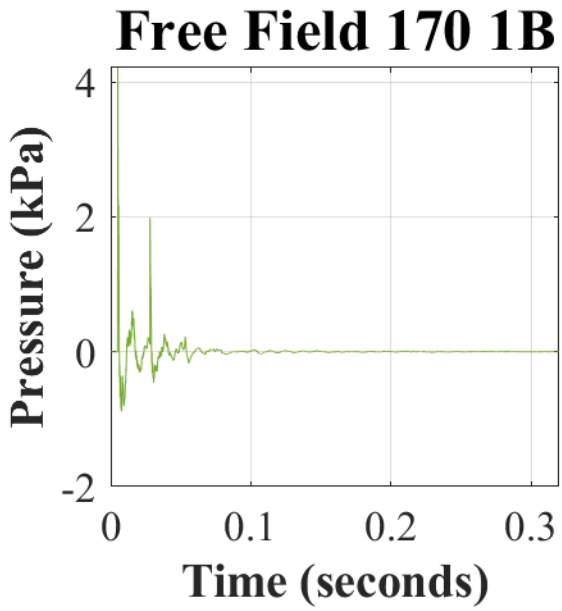

Free Field 160 4B
Pressure (kPa)
Time (seconds)
2
1.5
1
0.5
0
-0.5
0
0.1
0.2
0.3

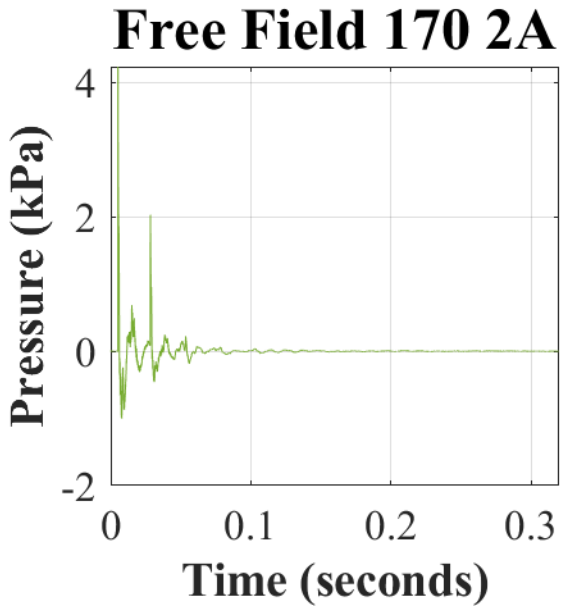


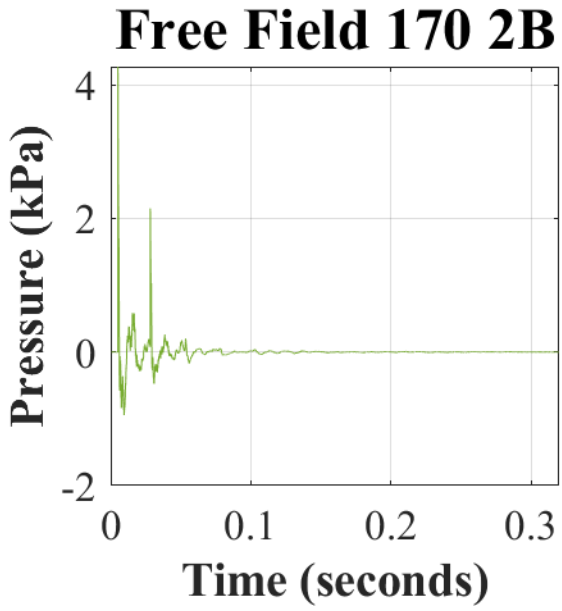
Note. The naming convention for all free-field waveforms is “Free Field LvL Nn”, where ‘Free Field’ indicates that the recording was obtained using the PCB reference microphone, ‘LvL’ is the nominal test level (160 dBP), ‘N’ is the device sample number (1 to 5), and ‘n’ is the device trial (i.e., A or B).

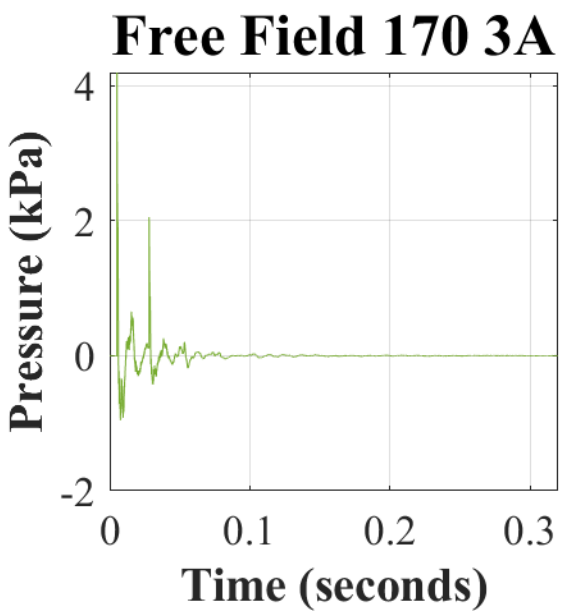
Appendix I. Recorded waveform (in kilopascals [kPa]) over time (in seconds [s]) of the impulse measured with the free-field probe at 170 dBP and the Skull Screws™ Corded donned.

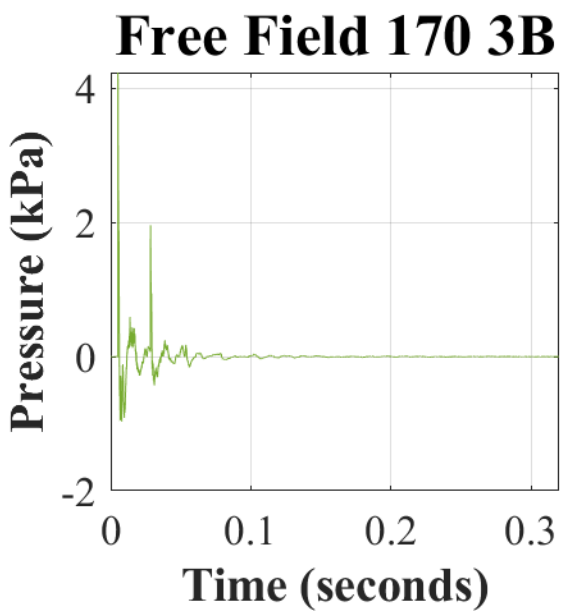


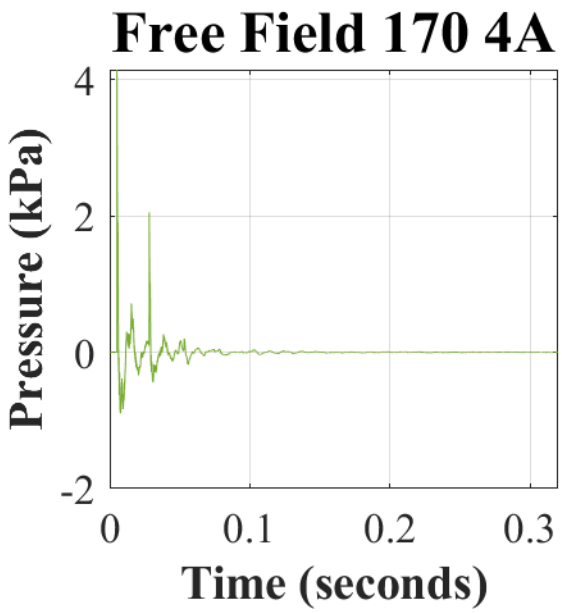


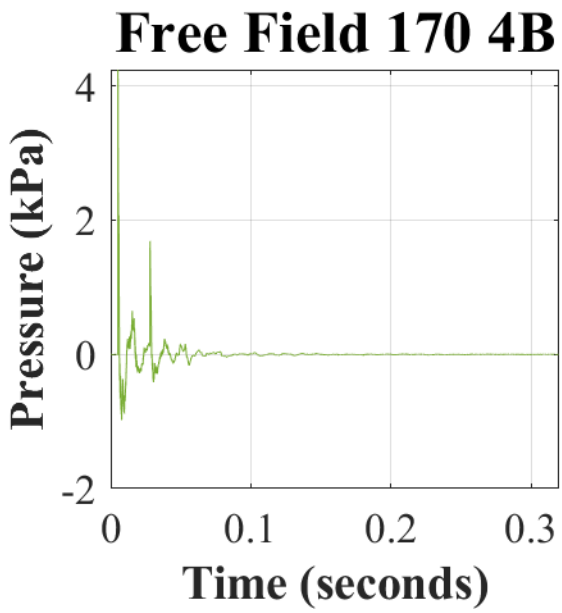


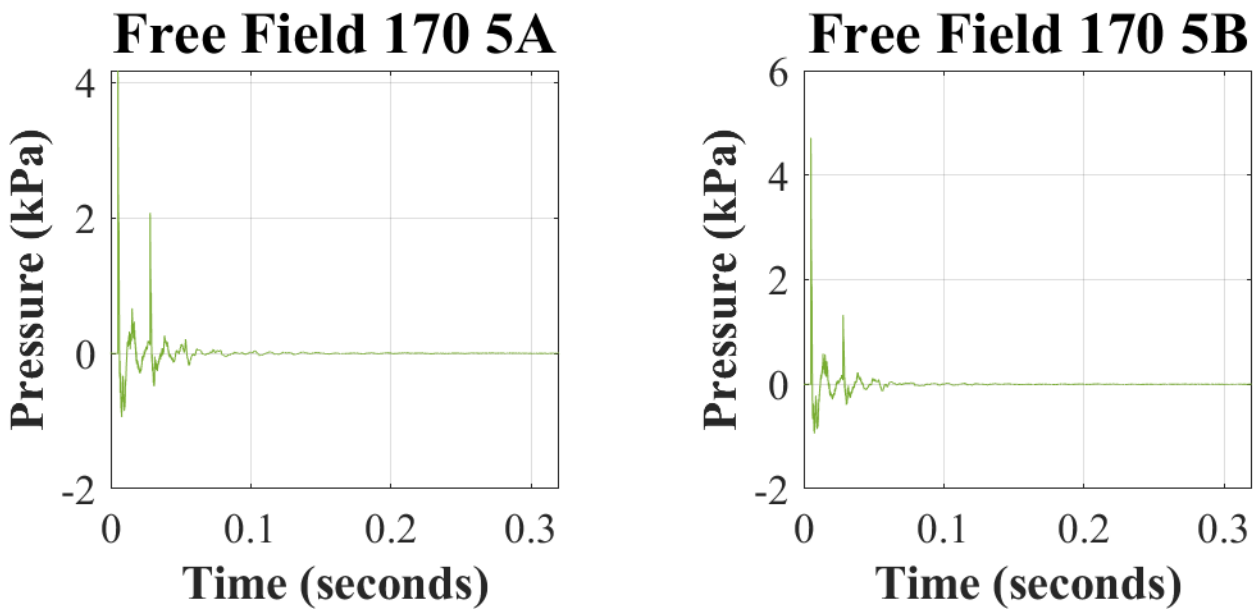



Free Field 170 3A
Pressure (kPa)
4
2
0
-2
0
0.1
0.2
0.3
Time (seconds)


Free Field 170 3B
Pressure (kPa)
4
2
0
-2
0
0.1
0.2
0.3
Time (seconds)


Free Field 170 4A
Pressure (kPa)
4
2
0
-2
0
0.1
0.2
0.3
Time (seconds)


Free Field 170 4B
Pressure (kPa)
4
2
0
-2
0
0.1
0.2
0.3
Time (seconds)



Note. The naming convention for all free-field waveforms is “Free Field LvL Nn”, where ‘Free Field’ indicates that the recording was obtained using the PCB reference microphone, ‘LvL’ is the nominal test level (170 dBP), ‘N’ is the device sample number (1 to 5), and ‘n’ is the device trial (i.e., A or B).