Field testing an in-ear monitor for real-time hearing protective device (HPD) testing in human subjects

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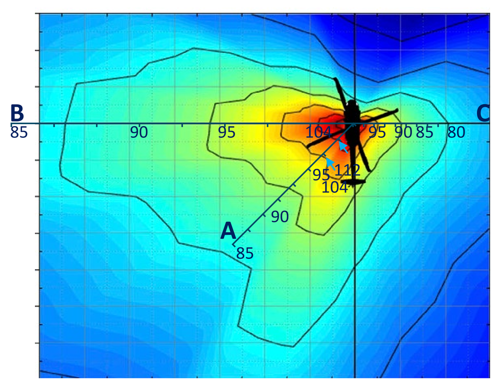
Introduction

Hearing protective devices (HPDs) & speech in noise (SIN)

Service Members routinely operate in high noise environments such as rotary-wing flight lines, where hazardous sound exposure can degrade communication, increase fatigue, and contribute to long term hearing loss – appropriate HPD selection is critical.

Real-world movement, mission demands, and prolonged wear can compromise fit, while the noise reduction rating (NRR) can overestimate attenuation in operational settings.

Here, we report on real-world testing of an in-ear monitoring system to simultaneously measure sound pressure levels (SPLs) in the environment and the ear canal beneath HPDs.



Jones, H. G., Greene, N. T., Chen, M. R., Azcona, C. M., Archer, B. J., & Reeves, E. R. (2018). The danger zone for noise hazards around the Black Hawk helicopter. *Aerospace Medicine and Human Performance*, 89(6), 547–551.

Methods

Noise Exposures

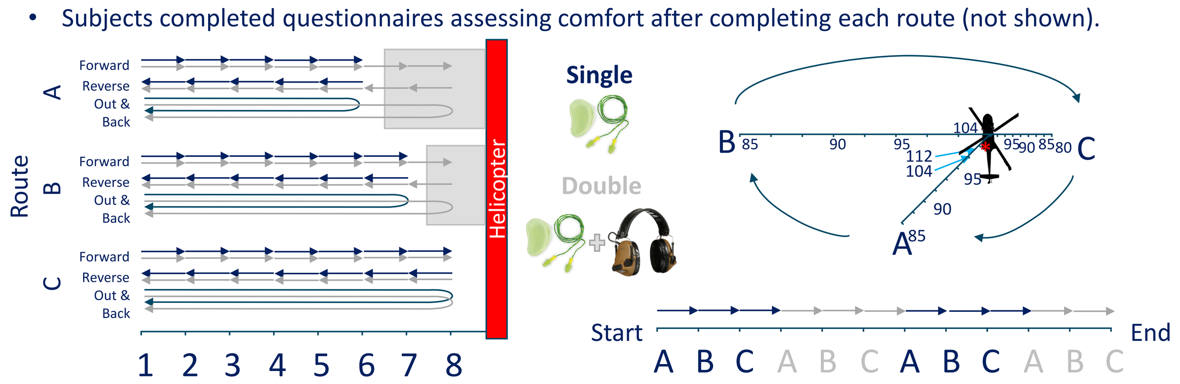
- Noise was generated by UH-60 Black Hawk auxiliary power unit (APU).
- Exposure levels were characterized with a Brüel & Kjær ½" microphone.

Human Subjects

- Human subject participants were recruited from the Ft. Rucker, AL area.
- Participant ear canals were scanned with a 3D scanning system (eFit, Aware Defense).
- Participants were fitted with in-ear monitors under single (flanged silicone earplugs) and double (earplugs plus earmuffs) protection.
  - Fit was visually verified by an audiologist.

Data Collection

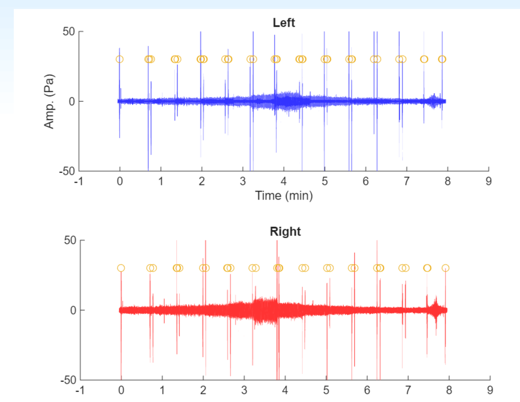
- Participants walked around the aircraft while in-ear recordings were collected.
- Three routes designed to replicate crew activities were marked around the aircraft.
  - Three participants were tested simultaneously.
  - Each participant walked with a study team escort, another 'timer' coordinated subjects.
  - Participants traversed from 'station' 1 (distant) to 8 (near) and back, pausing ~30 s at each.
  - Each route ended with a continuous walk from station 1 -> 8 -> 1, 'Out and Back'.
  - After completing each route the participant rotated to the next (A->B->C).
  - All three routes were completed twice, with both **single** and double HPDs worn.
- Participants 'tapped' on the microphones at the start and end of each station.
- Subjects completed questionnaires assessing comfort after completing each route (not shown).



Human Subject Performance

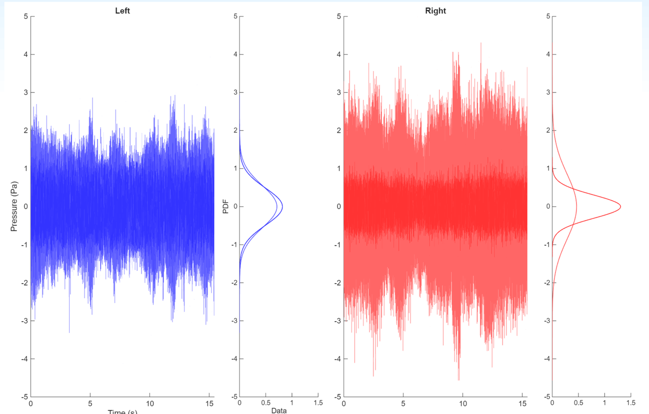
Noise Measurements

- Recording segments were identified from the 'tapping' on each microphone.
- A-weighted dB SPL was calculated from each microphone, in each recording segment.
- Environmental SPL ranged from ~85–112 dBA across routes, consistent with established measurements for UH-60 APU operations.



SPL & IL calculations

- Root-mean-square (RMS) amplitude was calculated as the standard deviation of a gaussian function fit (least squares) to the amplitude distribution.
- Insertion loss (IL) was calculated as the difference between the outer-ear and in-ear microphones.
- The example shown is a single individual/single condition, and not representative of the population.



$$p_{RMS} = \sqrt{\frac{\sum p^2}{n}}$$

$$SPL = 20\log_{10}\left(\frac{p_{RMS}}{20\mu Pa}\right)$$

Example SPL:

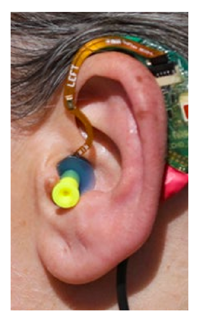
- L_{In}: 87.7 dB
- L_{Out}: 88.9 dB
- R_{In}: 83.6 dB
- R_{Out}: 92.7 dB

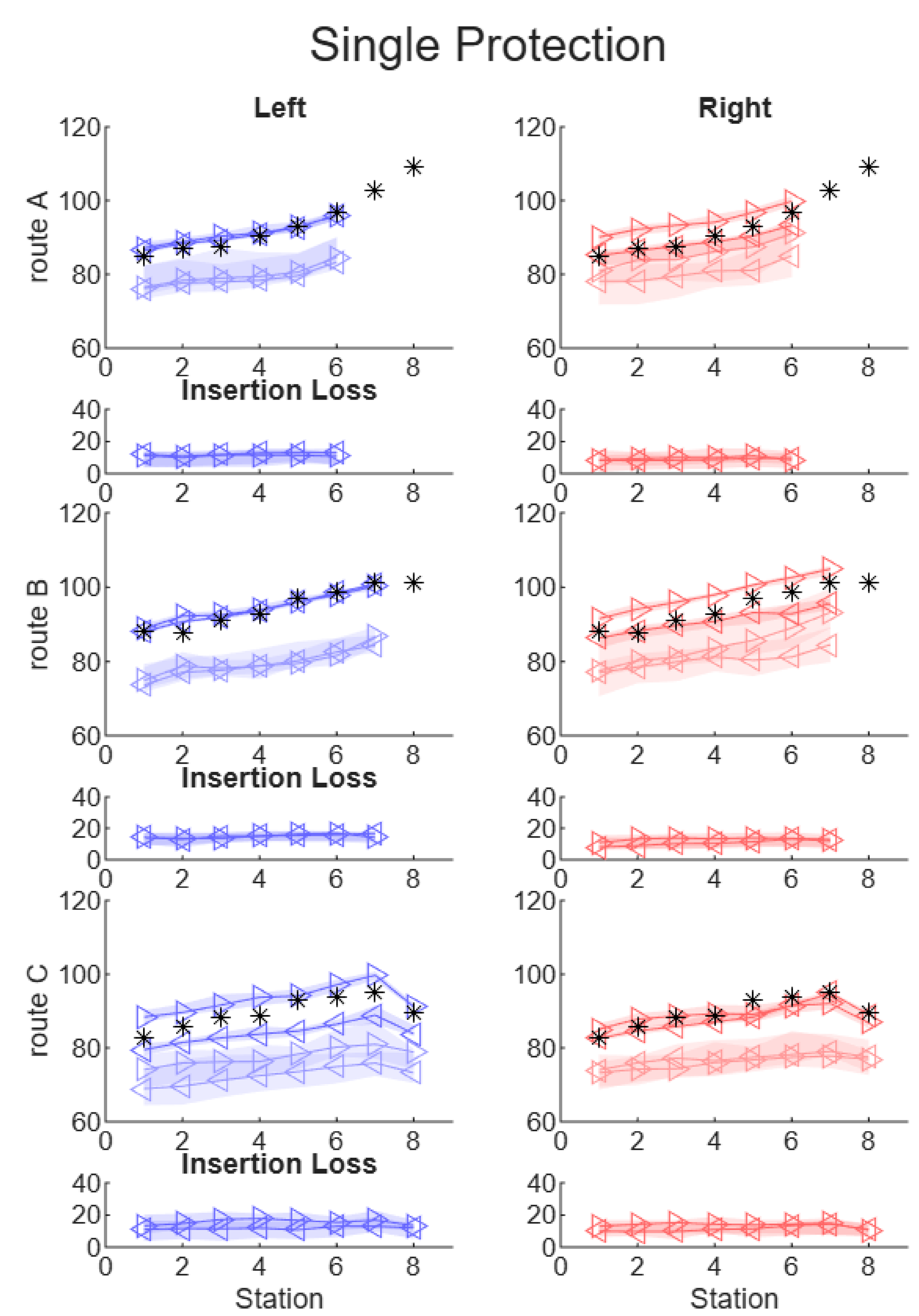
IL ($SPL_{Out} - SPL_{In}$):

- L: 1.2 dB
- R: 9.1 dB

Single protection

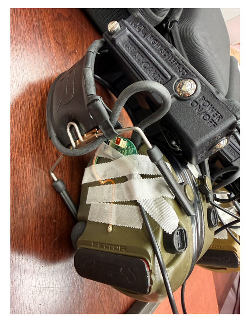
SPLs recorded with **outer-ear** microphones matched the reference microphone (*) SPLs in the **left** ear in routes A & B, and the **right** ear in route C, but revealed higher levels in the others, likely due to head position. SPLs in in-ear microphones reported lower levels, which consistently revealed 10-15 dB insertion loss.

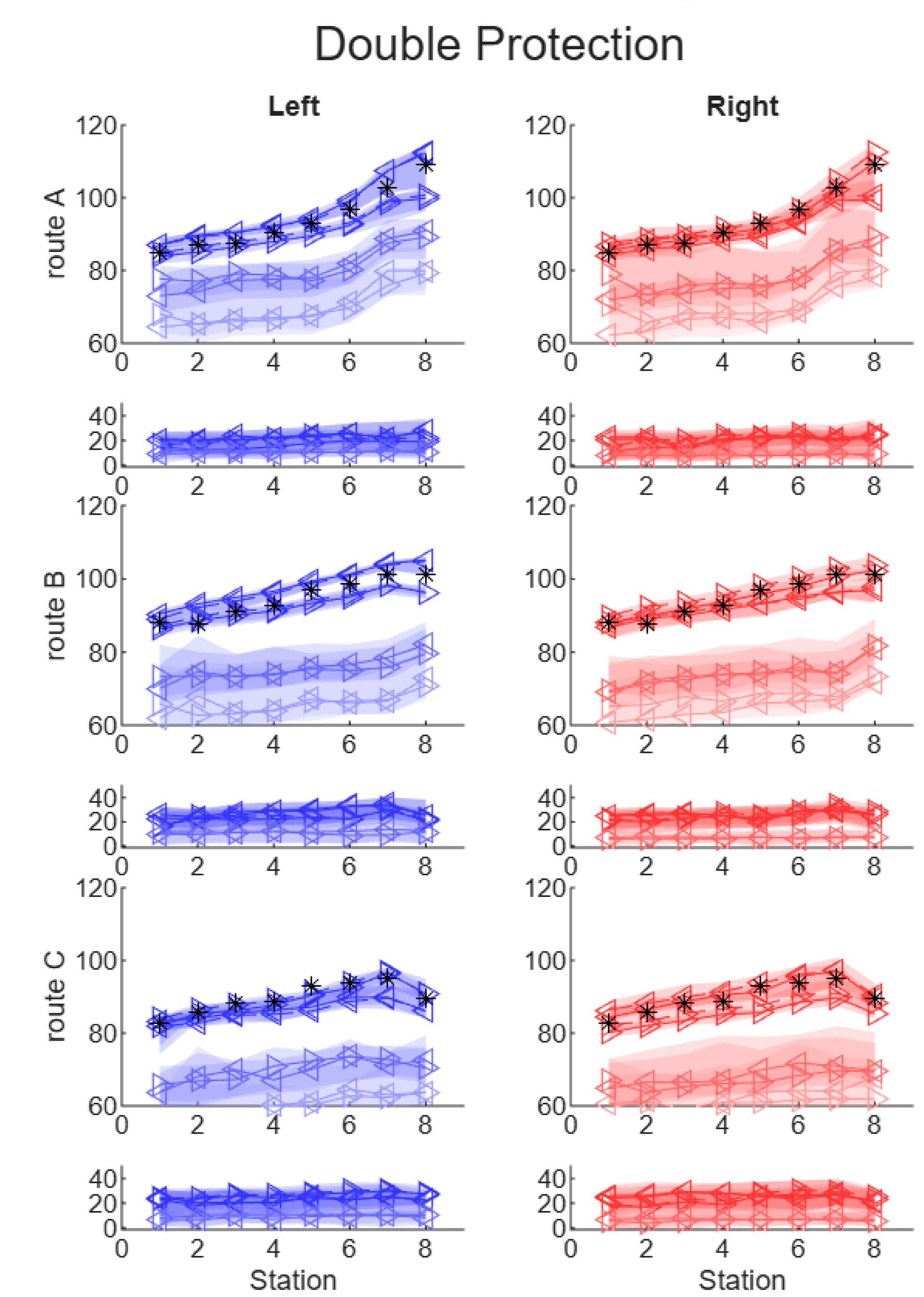




Double protection

SPLs recorded with **external** microphones more closely matched with reference microphone (*) SPLs in both ears, in all routes.
SPLs in **outer-ear** (under-muff), microphones revealed 10-15 dB protection, while in-ear microphones reported even lower levels, and an additional ~10-15 dB insertion loss for a total of ~30-35 dB insertion loss.



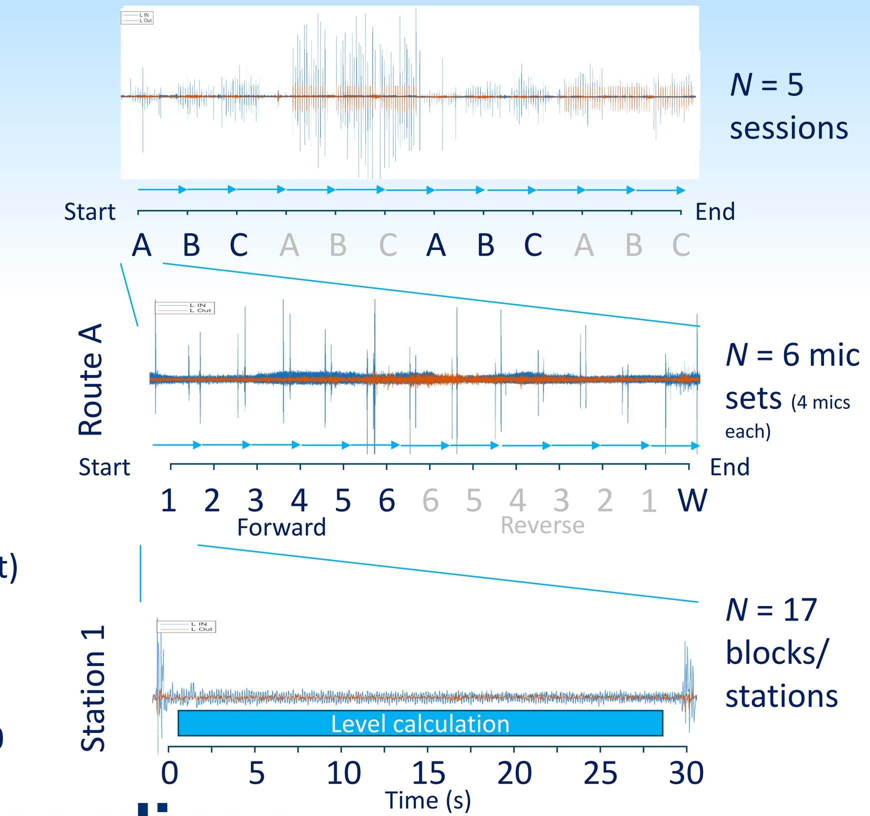


In-ear monitor

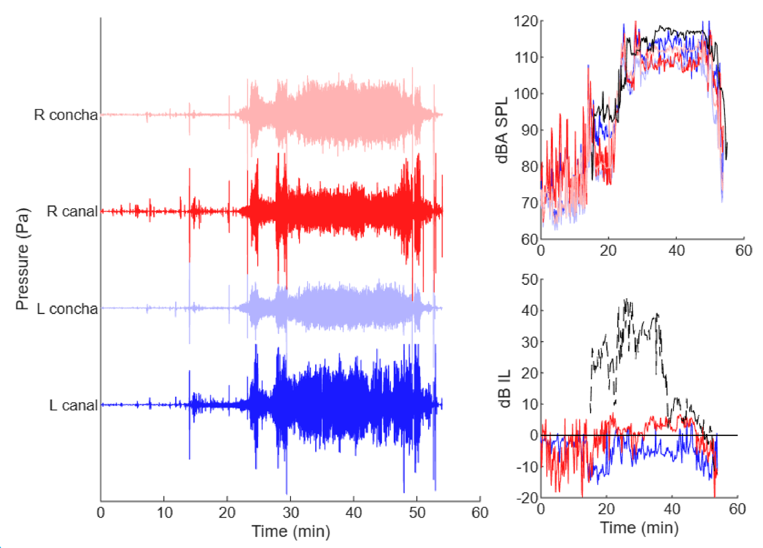
Route recordings

- Recordings were ~3.5 hours to complete all 3 routes 4 times
- Recordings included
  - 4 microphone channels for single HPDs
  - 8 channels for double HPDs

	N	N(tot)
Days:	5	5
Mic sets:	6	30
Runs:	12	360
Stations:	17	6120



Flight recordings

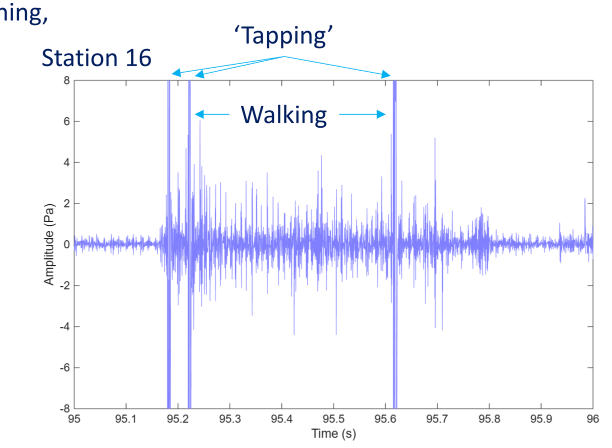


Following human subject data collection, the study team wore the in-ear microphones during the flight from the test site back to the airfield. The level on the **seat**, in-ear, and **outer-ear**, as well as the insertion loss (relative to the **seat**, or the **outer-ear**) is shown.

Discussion

Sensor Performance

- Observed attenuation during realistic operational activity was consistently lower and more variable than predicted by laboratory-derived ratings, particularly for single protection.
- Findings underscore that Warfighters' protection may be inadequate.
- In-ear monitoring provides a valuable method for characterizing:
  - true exposure at the tympanic membrane,
  - optimal HPD selection,
  - HPD personal attenuation for fit training,
  - and hearing conservation policies
- Unexpected results:
- a prominent occlusion effect:
  - Footsteps were prominently visible during personnel movement between stations, and during the final walk out and back.
  - Peak pressures in the ear canal could be substantial
    - 6 Pa = 109.5 dB SPL peak.
    - But they are low frequency!
- Significant directional dependence
  - Level



Conclusions

- The in-ear monitors work, and are tolerable in human subjects during extended recordings.
- Ear canal noise exposures are affected by gain resulting from the anatomy of the listener's external ear, head, and shoulders (i.e. the head-related transfer function, HRTF).
- HPD Insertion Loss (for this passive, linear HPD) is reasonably consistent across subjects, positions, and activities.
- The occlusion effect was present, leading to prominent low frequency impulses during footfalls.

Acknowledgements

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