

Spectral Analysis of Tympanic Membrane Pulse Signal: An Approach for Noninvasive Detection of Elevated Intracranial Pressure

R. Dhar, R. Sandler, K. Manwaring and H. Mansy

Biomedical Acoustics Research Laboratory, University of Central Florida, Orlando, Florida, USA
{raj कुमार.dhar@knights., hansen.mansy@} ucf.edu, rhsandler@gmail.com, manwaringmd@gmail.com

Elevated intracranial pressure (ICP) is a major neurological issue that can occur in traumatic brain injury, cerebral edema, subarachnoid hemorrhage, intracerebral hemorrhage, hydrocephalus, etc. The normal range of ICP is 5-15 mmHg for healthy adults [1]. Elevated ICP (>20 mmHg) can cause serious complications including seizures and death. The current gold standards for ICP measurement require a high level of expertise and are invasive, costly and associated with intracranial infection risks [2]. Therefore, non-invasive monitoring of ICP would be useful for improved patient diagnosis and management. Previous studies [3-4] have suggested potential utility of tympanic membrane pulsation (TMp) measurements for detection of elevated ICP. The current study reports consistent TMp waveform and spectral changes with elevated ICP.

Five healthy subjects participated in the study after IRB approval (#00279). ICP is expected to be normal in healthy subjects at head up tilt (HUT) while it is expected to increase at head down tilt (HDT) (due to fluid shift to the upper body) [5]. The subjects first rested on a tilt table for 2 minutes at 45° HUT before TMp signals were acquired for 1 minute from both ears using stethoscope earpiece and tubing (Sprague rappaport stethoscope, ESR-112, Elite Medical Instrument Inc., Fullerton, CA 92831, USA) connected to a variable reluctance pressure transducer (DP103, diaphragm range dash number: 10, Validyne Engineering, Los Angeles, CA 91324, USA). Subjects were then tilted to the 45° HDT while TMp was acquired for 30 seconds. The earlobe pulse signal was acquired simultaneously using an earlobe pulse sensor (Sparkfun Electronics, Niwot, CO, USA) as a reference signal.

At HUT (i.e., normal ICP), the TMp signal showed distinctive waveform with multiple smaller peaks occurring after the strongest peak [figure 1.a]. At HDT (i.e., elevated ICP) these peaks tended to be attenuated [figure 1.b].

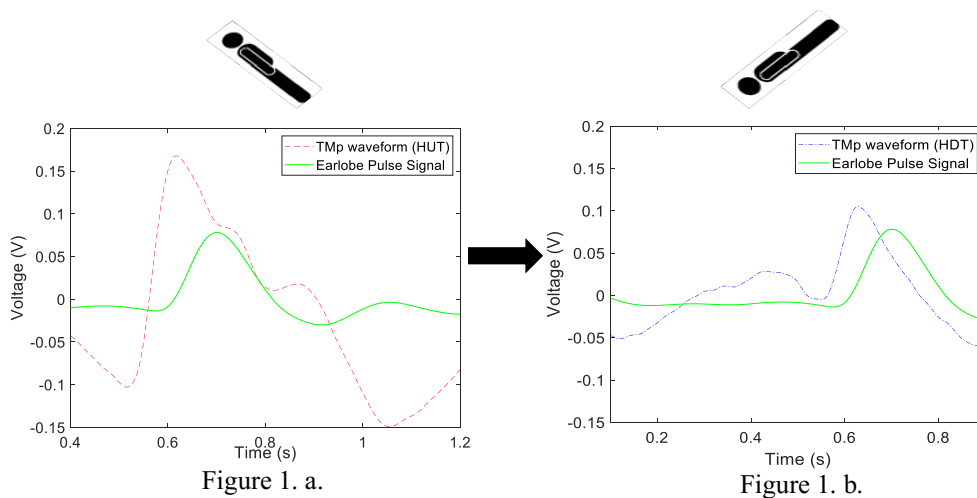


Figure 1: Red curve is the average TMp waveform at 45° HUT with multiple peaks (3); blue curve shows average TMp waveform at 45° HDT with lesser peaks (1). Green waveform is the earlobe pulse signal. These signals are obtained from Subject 1.

Spectral analysis on the Tmp signal was also performed in the current study. Figure 2 shows power spectral density of Tmp signals of one subject for both the HUT and HDT states. This analysis revealed the presence of stronger peaks with high values for HUT (normal ICP) compared to HDT (elevated ICP). Similar trend was noticed in the other 4 subjects.

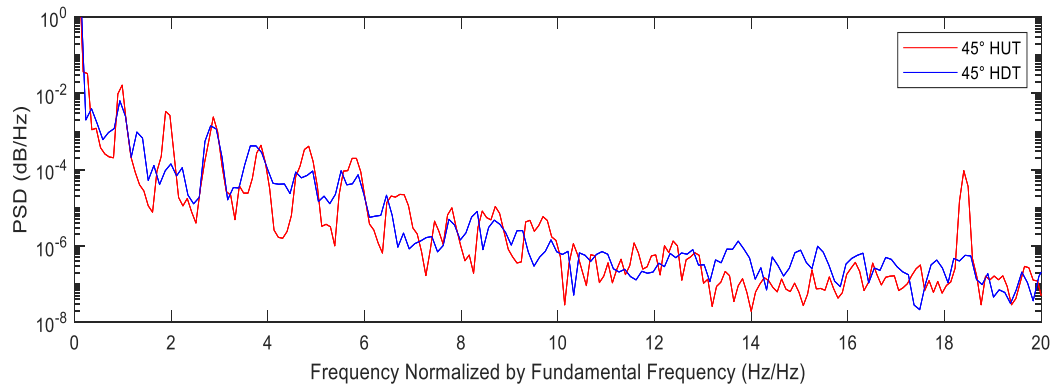


Figure 1: Power spectral density of Tmp signals at HUT (red) and HDT (blue) of subject 1

The observed waveform trend is similar to the findings of a previous study of patients and healthy subjects [6] where the mean number of peaks in the Tmp waveform was lower with elevated ICP. This may be explained by the observation that the tympanic membrane's ability to vibrate decreases with elevated ICP [7]. This also leads to the observed weakening of the spectral peaks of Tmp signals for HDT state. An amplitude ratio between low and high frequencies may be a useful parameter to quantify this phenomenon. More studies are needed to confirm these findings in a larger number of subjects.

REFERENCES

- [1] L. T. Dunn, "Raised Intracranial Pressure," *Journal of Neurology, Neurosurgery & Psychiatry*, 2002, vol. 73, no. suppl 1, pp. i23–i27.
- [2] S. Tavakoli, G. Peitz, W. Ares, S. Hafeez, and R. Grandhi, "Complications of invasive intracranial pressure monitoring devices in neurocritical care," *Neurosurgical Focus*, 2017, vol. 43, no. 5.
- [3] M. K. Azad, A. Spiewak, R. H. Sandler, K. Manwaring, P. Manwaring, and H. A. Mansy, "Monitoring Intracranial Pressure Using Non-Invasive Brain Stethoscope," 2018, *SoutheastCon 2018*.
- [4] R. Dhar, R. H. Sandler, K. Manwaring, and H. A. Mansy, "Noninvasive Detection of Elevated Intracranial Pressure Using Tympanic Membrane Pulse," 2019, *IEEE Signal Processing in Medicine and Biology Symposium (SPMB)*.
- [5] Hargens AR, "Recent bed rest results and countermeasure development at NASA", *Acta Physiologica Scandinavica. Supplementum*, 1994, 616:103-114.
- [6] E. Stettin, K. Paulat, C. Schulz, U. Kunz, and U. M. Mauer, "Noninvasive intracranial pressure measurement using infrasonic emissions from the tympanic membrane," *Journal of Clinical Monitoring and Computing*, 2011, vol. 25, no. 3, pp. 203–210.
- [7] Hommerich KW, "Hearing disorders and disturbances of the olfactory system in intracranial diseases", *Arch Ohren Nasen Kehlkopfheilkd*, 1964; 183: 86–124.

Abstract

Background: Elevated intracranial pressure (ICP >15 mmHg) is a major neurological issue that can cause severe health damages leading to death. Gold standard to monitor ICP are invasive methods which are expensive and associated with infection risks. Hence, a reliable noninvasive ICP monitoring method is required.

ICP waves are believed to be propagated via cerebrospinal fluid (CSF) from subarachnoid space of brain to inner ear through cochlear aqueduct channel which finally causes tympanic membrane pulsation (TMp) [1]. Consequently, change in ICP is expected to be seen in TMp.

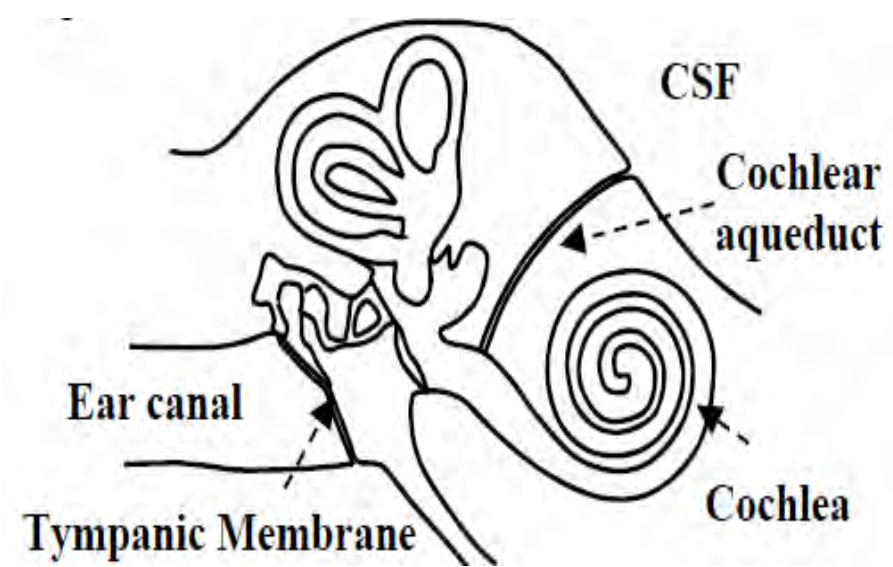


Figure 1 Transmission of ICP from CSF space to the tympanic membrane [2]

Method: Pathological change in ICP was simulated in healthy subjects using simple well-established maneuvers. Stethoscope was used as a channel to transmit TMp from ear canal to pressure transducers. At normal and high ICP states, TMp signal was acquired and later processed.

Results: At normal ICP, TMp waveform shows multiple peaks at downslope while at high ICP these peaks tend to diminish. Effect of attenuation of peaks in the TMp waveform was evident in the power spectral density (PSD) of the signal.

Conclusion: Change in ICP level was reflected on the PSD of TMp signals acquired while doing maneuvers that are responsible for changing ICP. This suggests that spectral analysis of TMp signal can be used to monitor elevated ICP in patients with neurological disorders.

Power Spectral density (PSD)

PSD represents the power content of the signal in frequency domain. If a signal contains multiple peaks, that will boost the energy level of the signal which can be observed in the frequency domain. On the other hand, absence of peaks will lower the energy content. This theory has been followed in this study to differentiate between elevated and normal ICP using PSD of TMp signal.

Methodology

Equipment Setup

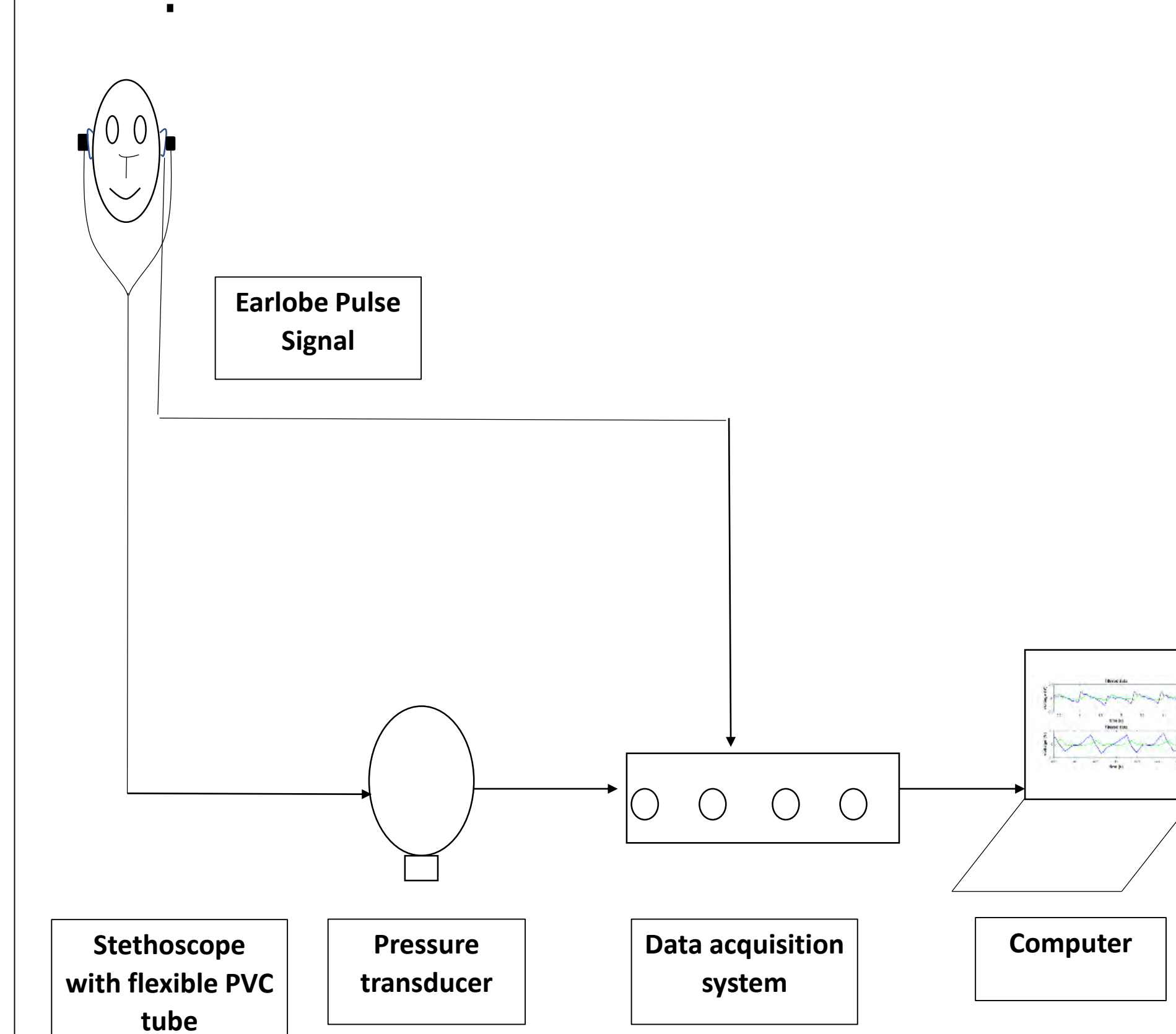


Figure 2 Schematic diagram of experiment setup

Study Protocol

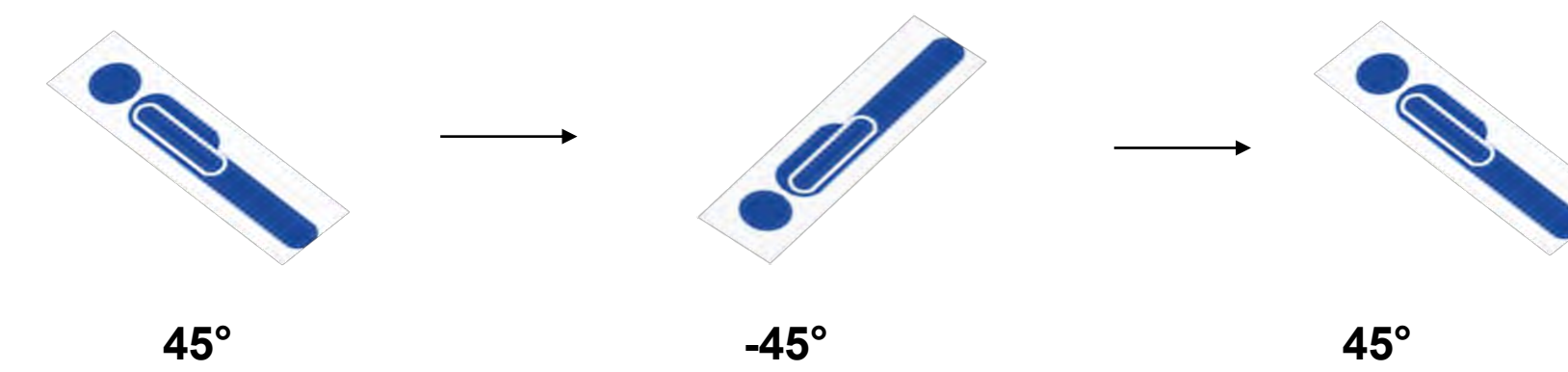
Subjects: 5 healthy male

Maneuvers:

- i. 45° Head up tilt (HUT): Resembling normal ICP
- ii. -45° head down tilt (HDT): To raise ICP [3]

Experiment Steps:

- i. Subjects rest in tilt table at HUT position
- ii. Table tilted to -45° HDT
- iii. Tilt the table back to HUT



Acquired Data:

- i. Tympanic membrane pulsation
- ii. Earlobe pulse

Acquisition Period:

- i. HUT: 60 seconds
- ii. HDT: 30 seconds
- iii. HUT: 60 seconds

Results

- At HUT, TMp waveform showed multiple peaks at the downslope just after the maximum peak [figure 3a]
- At HDT, the smaller peaks tend to diminish [figure 3b]

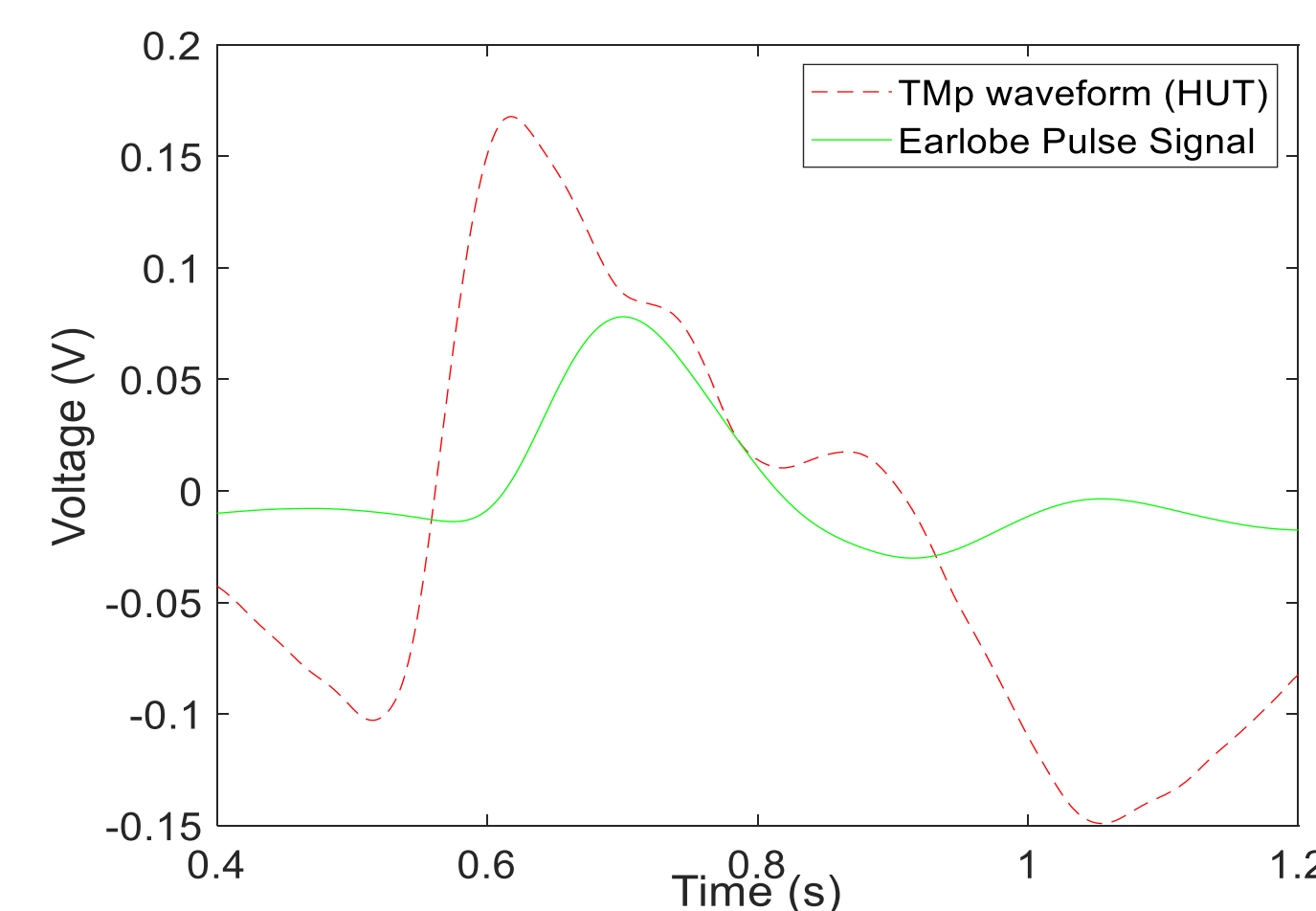


Figure 3a TMp and earlobe pulse signals at HUT

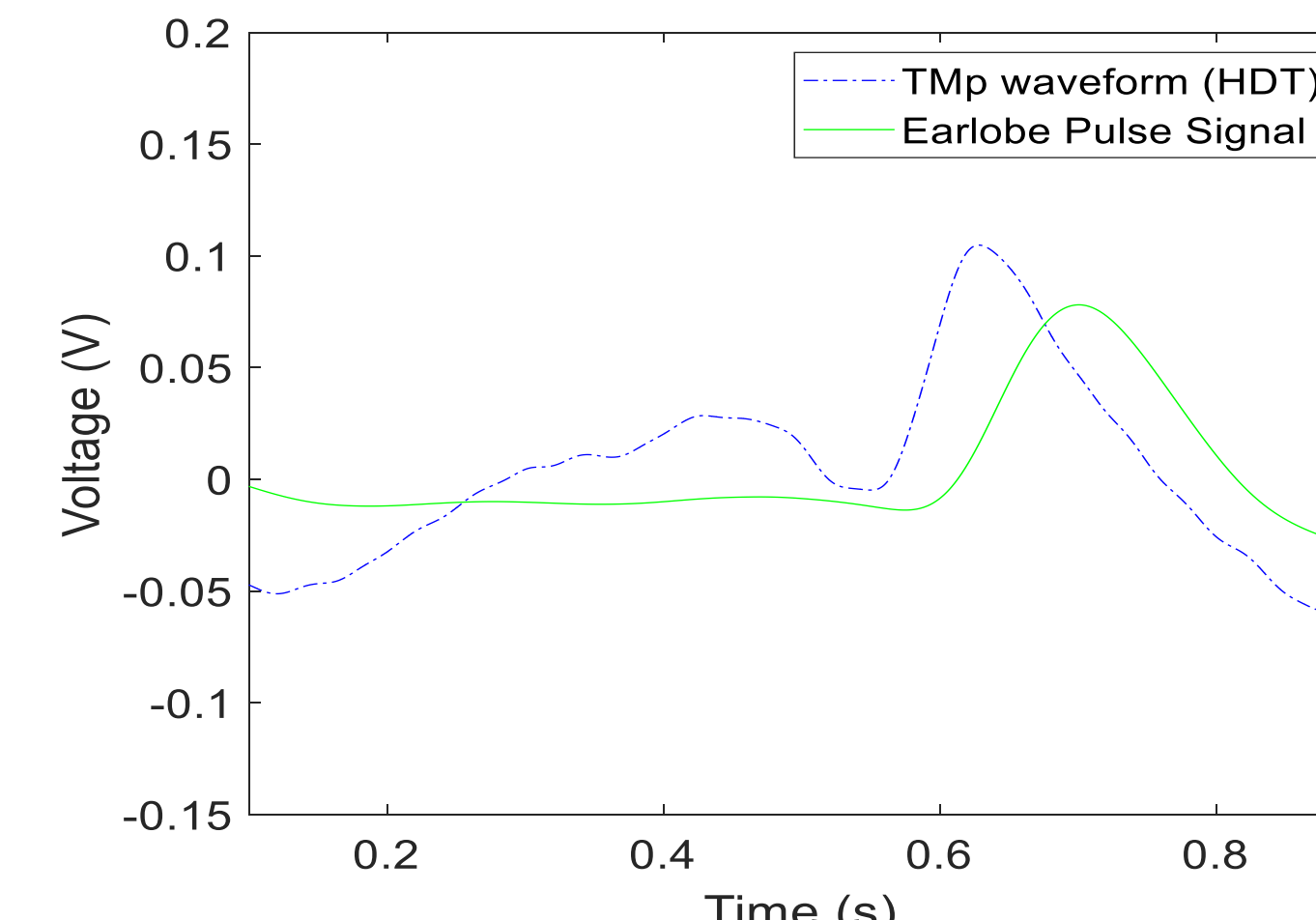


Figure 3b TMp and earlobe pulse signals at HDT

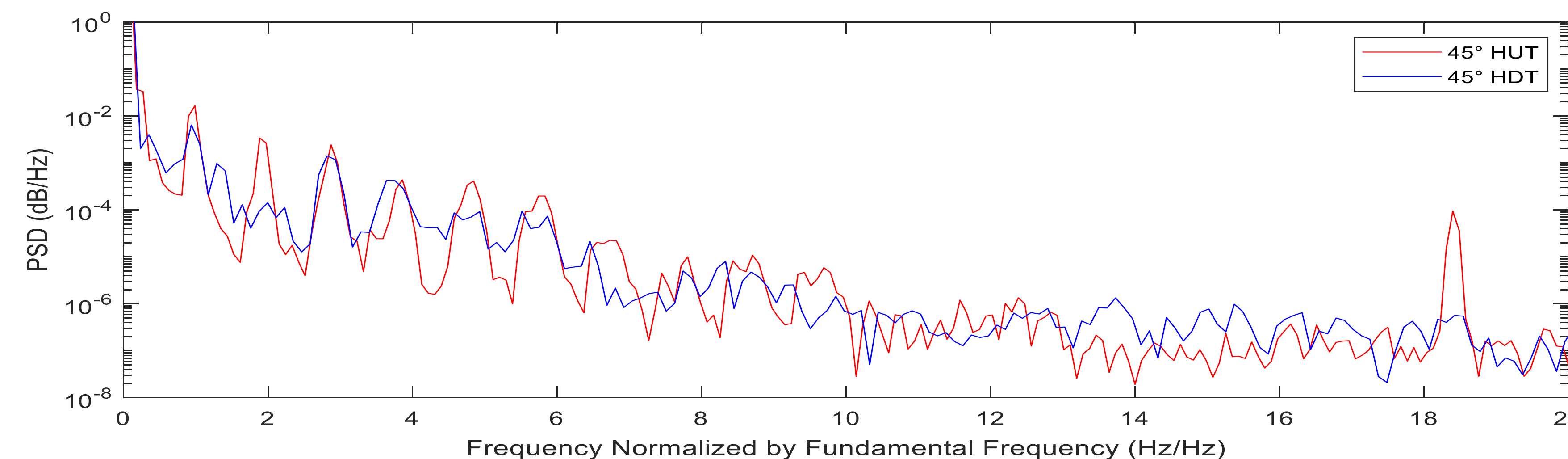


Figure 4 PSD of TMp signals at HUT and HDT

Conclusions

- Stettin et al. followed similar approach in their study to measure ICP noninvasively using tympanic membrane infrasonic emissions [4]. They observed the decrease of number of peaks in the tympanic membrane waveform when ICP was higher compared to lower ICP.
- In another study, it was concluded that when ICP rises, tympanic membrane's ability to vibrate decreases consequently [5]. This observation helps to explain the reason behind the decrease of number of peaks in TMp waveform.
- In this study this phenomenon was also noticed, and spectral analysis was utilized to present the distinction in TMp waveforms as ICP rises following the change in subject's tilt position [figure 4].
- PSD of TMp signal at HUT showed stronger spikes than TMp signal at HDT due to the presence of additional smaller peaks after the initial high peak. The effect was consistent in all 5 subjects.
- Amplitude ratio between spectral peaks in a specific frequency range may be used as a parameter in later study to quantify the phenomenon.
- Future plan is to perform the study in bigger scale to have more confidence in the proposed hypothesis and acquire data from patients with neurological disorders.

References

- [1] R.J. Marchbanks: Hydromechanical interactions of the intracranial and intralabyrinthine fluids, in A. Ernst, R. Marchbanks, M. Samii (eds): Intracranial and Intralabyrinthine Fluids: Basic Aspects and Clinical Applications. Berlin: Springer, 1996, pp 51–62
- [2] M. K. Azad, A. Spiewak, R. H. Sandler, K. Manwaring, P. Manwaring, and H. A. Mansy, "Monitoring Intracranial Pressure Using Non-Invasive Brain Stethoscope," 2018, SoutheastCon 2018.
- [3] L. G. Petersen, J. C. G. Petersen, Andresen, M. Secher, N. H., & M. Juhler, (2016). Postural influence on intracranial and cerebral perfusion pressure in ambulatory neurosurgical patients. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 310(1), R100–R104.
- [4] E. Stettin, K. Paulat, C. Schulz, U. Kunz, and U. M. Mauer, "Noninvasive intracranial pressure measurement using infrasonic emissions from the tympanic membrane," Journal of Clinical Monitoring and Computing, 2011, vol. 25, no. 3, pp. 203–210.
- [5] K.W. Hommerich, "Hearing disorders and disturbances of the olfactory system in intracranial diseases", Arch Ohren Nasen Kehlkopfheilkd, 1964; 183: 86–124.