Noninvasive Detection of Elevated Intracranial Pressure Using Tympanic Membrane Pulse

Rajkumar Dhar, Richard H Sandler, Kim Manwaring, Hansen A Mansy

Biomedical Acoustics Research Laboratory, University of Central Florida, Orlando, FL 32816, USA
{rajkumar.dhar@knights., hansen.mansy@} ucf.edu, rhsandler@gmail.com, manwaringmd@gmail.com

Elevated intracranial pressure (ICP) can lead to serious health complications. Hence, this pressure needs to be monitored in patients at risk of increased ICP. The gold standard for ICP measurements are invasive manometers and pressure transducers [1]. However, the risks, discomforts, and expenses of invasive diagnostic can be avoided if satisfactory non-invasive approaches are used. In this presentation, a noninvasive method of monitoring ICP utilizing measurements of Tympanic Membrane pulsation (TMp) is discussed. TMp signals were acquired from 5 healthy subjects at different tilt positions where ICP is expected to increase with head-down positioning. Consistent TMp waveform morphological changes were observed in each subject with the head down position, which is known to increase ICP [2]. The changes tended to reverse with hyperventilation, which is a process known to decrease ICP [3]. These results suggest that TMp waveform measurements may provide a reliable non-invasive method for monitoring ICP.

The subjects were asked to rest on the tilt table at 45° head up position. Stethoscope (Sprague rappaport stethoscope, ESR-112, Elite Medical Instrument Inc., Fullerton, CA 92831, USA), earlobe pulse sensor (Sparkfun Electronics, Niwot, CO, USA) and nasal cannula were placed on the subjects. The stethoscope was connected to a variable reluctance pressure transducer (DP103, diaphragm range dash number: 10, Validyne Engineering, Los Angeles, CA 91324, USA) by flexible PVC tube (6 feet long and 5 mm of diameter) to acquire TM vibration from both ears. The nasal cannula was connected to an end-Tidal CO_2 ($ETCO_2$) sensor (MicroCap9, MDPro, San Diego, CA 92117). The signal output from pressure sensor and earlobe pulse sensor were acquired by a data acquisition system (IX-TA-220, iWORX, Dover, NH 03820, USA) at 45° of tilt table position for 1 minute. The table was tilted to the -45° head down position, where data was taken for 30 seconds after 5 seconds of stabilization time. This was followed by subject hyperventilation and with continuously monitoring the $ETCO_2$ sensor reading (in mmHg). When the partial pressure reading dropped by 15-20 mmHg subjects were asked to stop hyperventilating (typically 10-30 sec). After hyperventilation, TMp and pulse signals were recorded for another 30 seconds following 5 seconds of stabilization time. Then subjects were tilted back to 45° head up position. After stabilization for 10-15 seconds, 1 minute of data was acquired from pressure and earlobe pulse sensor.

Acquired data was processed (loaded, filtered and plotted) in Matlab [4]. The raw signal was filtered (bandpass: 1-20 Hz) to remove noise (environmental, electronic and that of respiratory origin). The data after post processing is shown in figure 1. TMp events were segmented using the relatively repeatable earlobe pulse as a reference signal. Following the methods proposed in previous studies [5], TMp events were segmented by specifying a certain amount of time before and after the earlobe pulse peaks in order to extract full cycles of TMp events corresponding to earlobe pulses. Individual TMp events were averaged to reduce noise and the mean TMp event was used for further analysis.

Similar to the data shown in figure 1, the data obtained from all 5 subjects showed significant TMp waveform changes when subjects were tilted from 45° to -45°. At the head down position, the waveform showed steeper slope after the peak compared to the head up position which is similar to the study reported by Stettin et al [6]. After hyperventilation the waveform tended to shift to the waveform shape of the head up position. This trend suggests that the observed waveform change may be due to ICP changes since both head up and hyperventilation would tend to decrease ICP. After returning to the 45° head up position, TMp waveform regained its initial shape, which suggests high intra-session repeatability.

To quantify the change in TMp waveforms, the slopes of mean TMp waveforms before and after the peak were calculated, followed by calculating the ratio of these slopes for each tilt table state and for all the subjects. These slope ratios are shown in figure 2. The ratios are negative and their sign will be ignored in this discussion. The slope ratios were smallest in the initial head up position, where ICP is expected to be smallest. In the head down position where an elevated ICP was induced, the slope ratio increased (i.e., became more negative). The slope ratio became smaller after hyperventilation (which induces ICP reduction). Then the ratios became close to their initial values as the subject returned to the head up position. There trends were consistent in all 5 subjects.

The current pilot study proposes a new non-invasive method for monitoring ICP changes. The observed consistent changes in TMp waveform slope ratio suggest the potential utility of the proposed method for detecting elevated ICP. More studies are warranted to test this method in a larger number of subjects, and in patients with elevated ICP, which will be helpful in the field of neurological pathology.

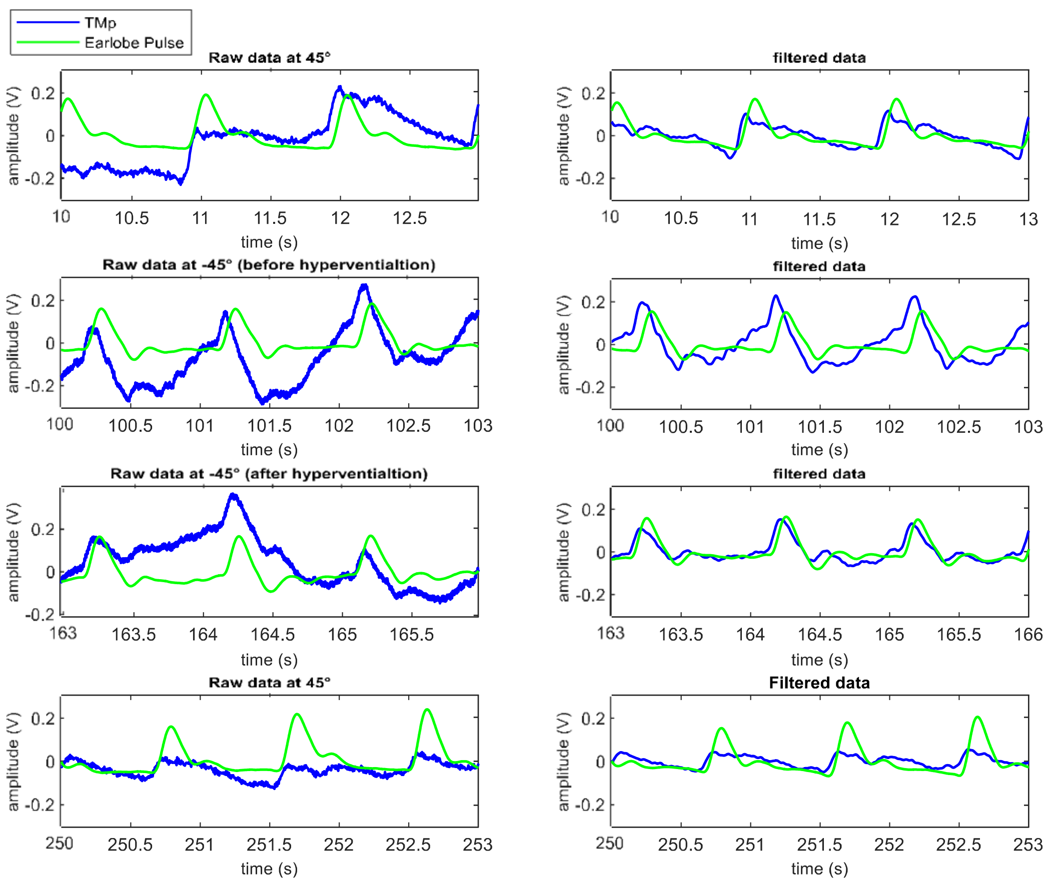


Figure 1. Raw (left column) and filtered (right column) TMp and Earlobe pulse signals (blue and green lines, respectively) from both ears of Subject 4 at different tilt angle positions. 1st row: head up, 2nd row: head down, 3rd row: head down after hyperventilation, 4th row: back to the head up position

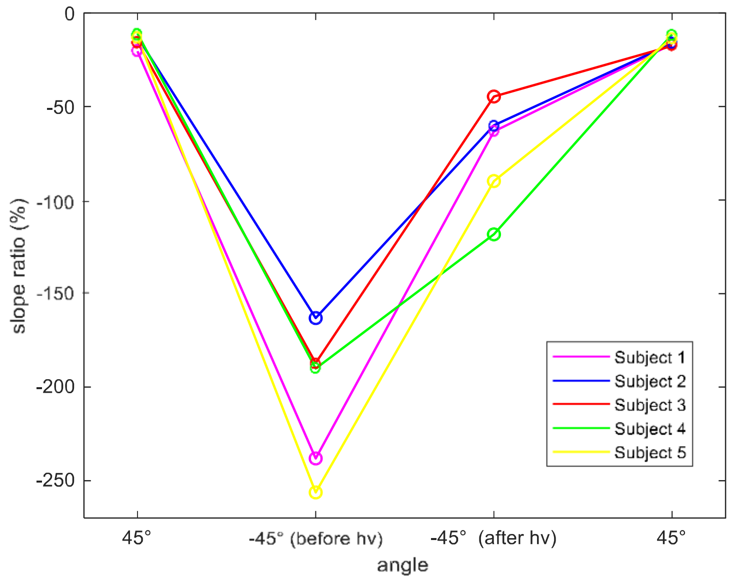


Figure 2. Slope ratio at different states for 5 subjects

REFERENCES:

1. Raboel, P. H., Bartek, J., Andresen, M., Bellander, B. M., & Romner, B. (2012). Intracranial Pressure Monitoring: Invasive versus Non-Invasive Methods—A Review. Critical Care Research and Practice, 2012, 1–14.

2. Petersen, L. G., Petersen, J. C. G., Andresen, M., Secher, N. H., & Juhler, M. (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.

3. Raichle, M. E., & PLUM, F. (1972). Hyperventilation and Cerebral Blood Flow. Stroke, 3(5), 566–575.

4. MATLAB and Statistics Toolbox Release 2018a, The MathWorks, Inc., Natick, Massachusetts, United States.

5. A. Taebi and H. A. Mansy, "Effect of Noise on Time-frequency Analysis of Vibrocardiographic Signals," J. Bioeng. Biomed. Sci., vol. 6(202), p. 2, 2016.

6. Eduard Stettin, Klaus Paulat, Chris Schulz, Ulrich Kunz, Uwe Max Mauer, "Noninvasive Intracranial Pressure Measurement Using Infrasonic Emissions from the Tympanic Membrane", Journal of Clinical Monitoring and Computing (2011) 25:203–210.

Noninvasive Detection of Elevated Intracranial Pressure Using Tympanic Membrane Pulse

UCF College of Engineering and Computer Science

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

Department of Mechanical and Aerospace Engineering, University of Central Florida

Biomedical Acoustics Research Laboratory

Abstract

- Intracranial pressure (ICP) is the pressure of cerebrospinal fluid (CSF) and brain tissue inside the skull.
- This pressure needs to be monitored in patients at risk of increased ICP as elevated ICP (>15 mmHg) can lead to serious health complications..
- This poster presents a noninvasive method to detect elevated ICP using tympanic membrane pulse (TMp), which was measured using a pressure transducer connected to the outer ear canal.
- Results show that elevated ICP causes consistent TMp waveform changes.

Background

- The subarachnoid space which contains CSF is connected with the inner ear's perilymphatic space through cochlear aqueduct.

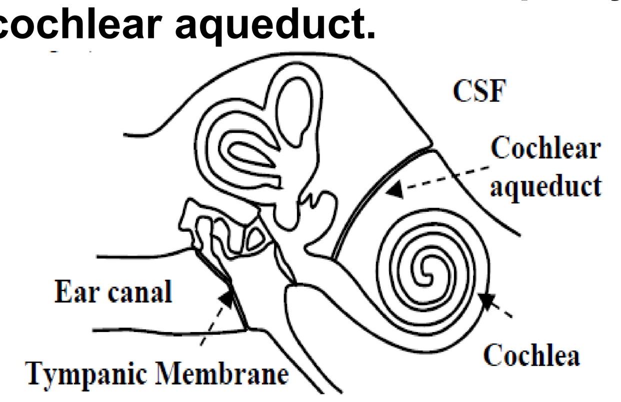


Figure 1 Transmission of ICP from CSF space to the tympanic membrane [1],[4]

- ICP pulsations are believed to be transmitted via CSF into inner ear through cochlear aqueduct.
- Pressure wave propagates from inner ear to middle ear ossicles (malleus, incus and stapes) and finally vibrates tympanic membrane.
- The current study exploits the possible connection between ICP and TMp to potentially detect elevated ICP
- TMp may be measured by a pressure transducer with an air-tight connection to the external ear canal.

Equipment

- Variable reluctance pressure transducer
- Stethoscope
- Optical earlobe pulse sensor
- Data Acquisition System (DAQ)
- End tidal CO2 sensor

Setup

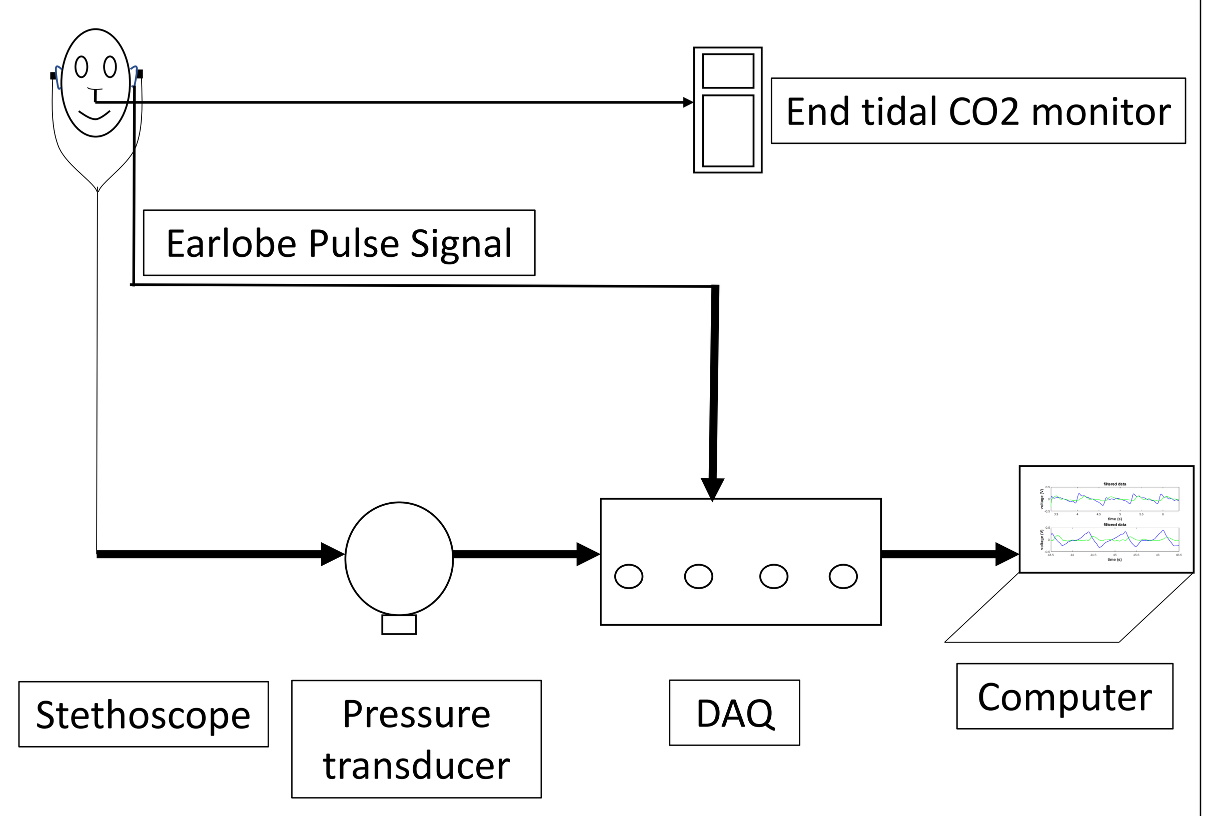
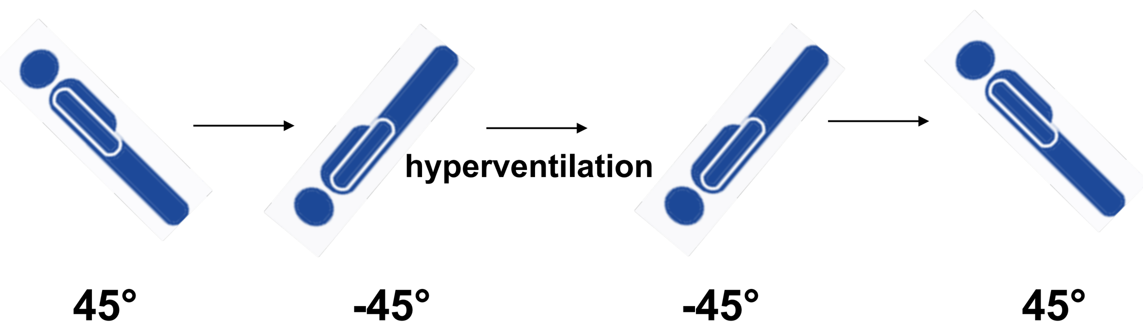


Figure 2 Equipment Setup

- Stethoscope was worn by the subject while the pulse sensor was attached to subject earlobe
- The other end of stethoscope was connected to the pressure transducer
- TMp and earlobe pulse signals were acquired using DAQ and computer
- End tidal CO_2 monitor was attached to subjects using nasal canula

Protocol

- 5 healthy subjects
  - Age: 25 to 35 years
- 60 seconds of data acquisition at 45° head up position on an inversion table
- Subjects were tilted from 45° to -45°
- Acquisition of signals for 30 seconds at -45°
- Hyperventilation by subjects until significant drop in partial pressure of CO2 in exhaled air observed (~15-20 mmHg). This is known to reduce ICP.
- Data acquisition after hyperventilation at -45° for 30 seconds
- Subjects were tilted back to 45°
- Acquire signals for 60 seconds at 45°



Results- Acquired Signals (Subject 4)

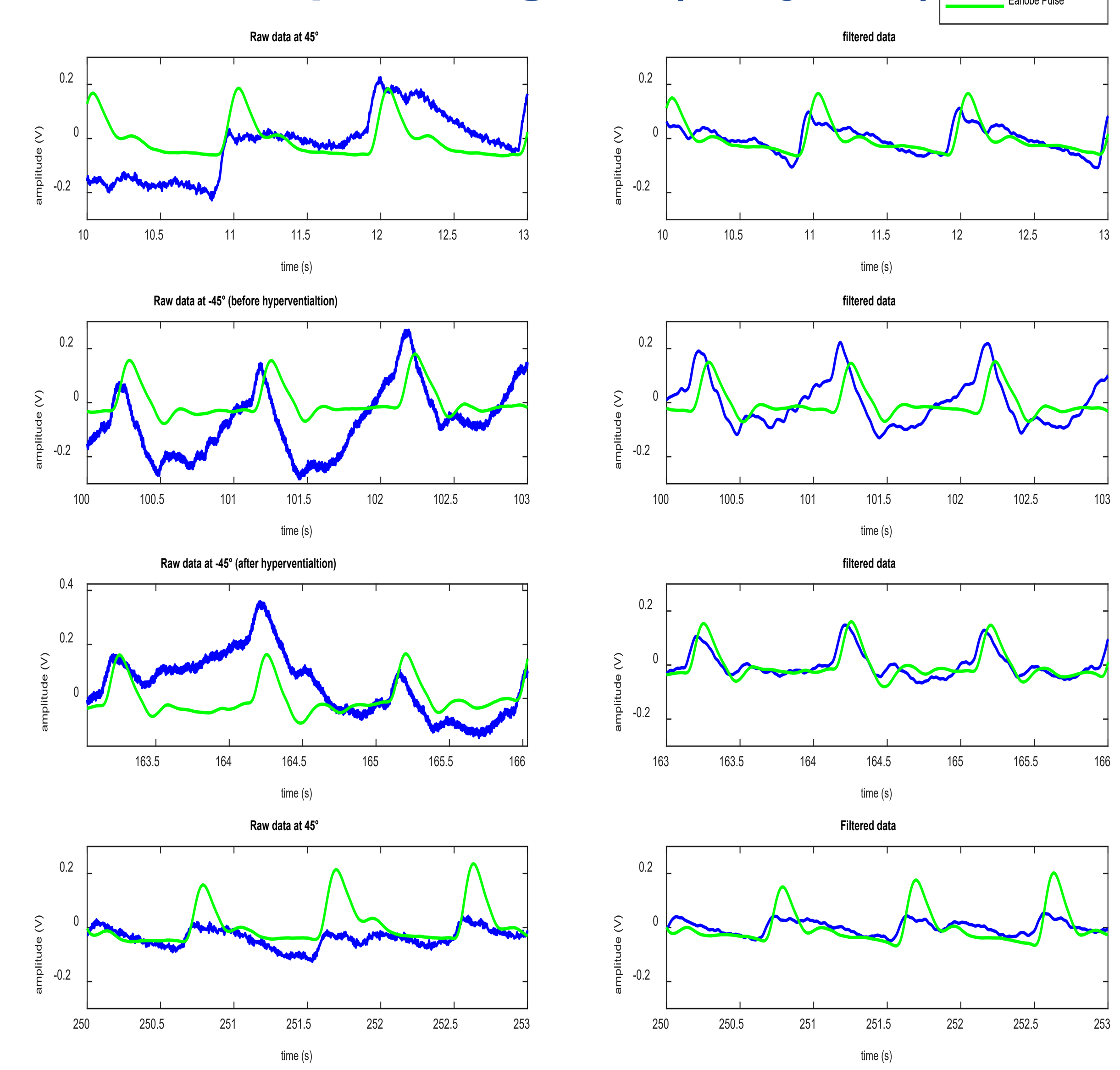


Figure 3 Raw (left column) and filtered (right column) TMp and Earlobe pulse signals (blue and green lines, respectively) from left ear of Subject 3 at different tilt angle positions. 1st row: head up, 2nd row: head down, 3rd row: head down after hyperventilation, 4th row: back to the head up position.

Results

- At the head down position (-45°), the waveform showed steeper slope after TMp peak compared to the head up position (45°).
- After hyperventilation the waveform tended to shift to the waveform shape of the head up position.
- After returning to the 45° head up position, TMp waveform regained its initial shape suggesting high intra-session repeatability.
- Average TMp waveforms at different states for subject 4 is shown below:

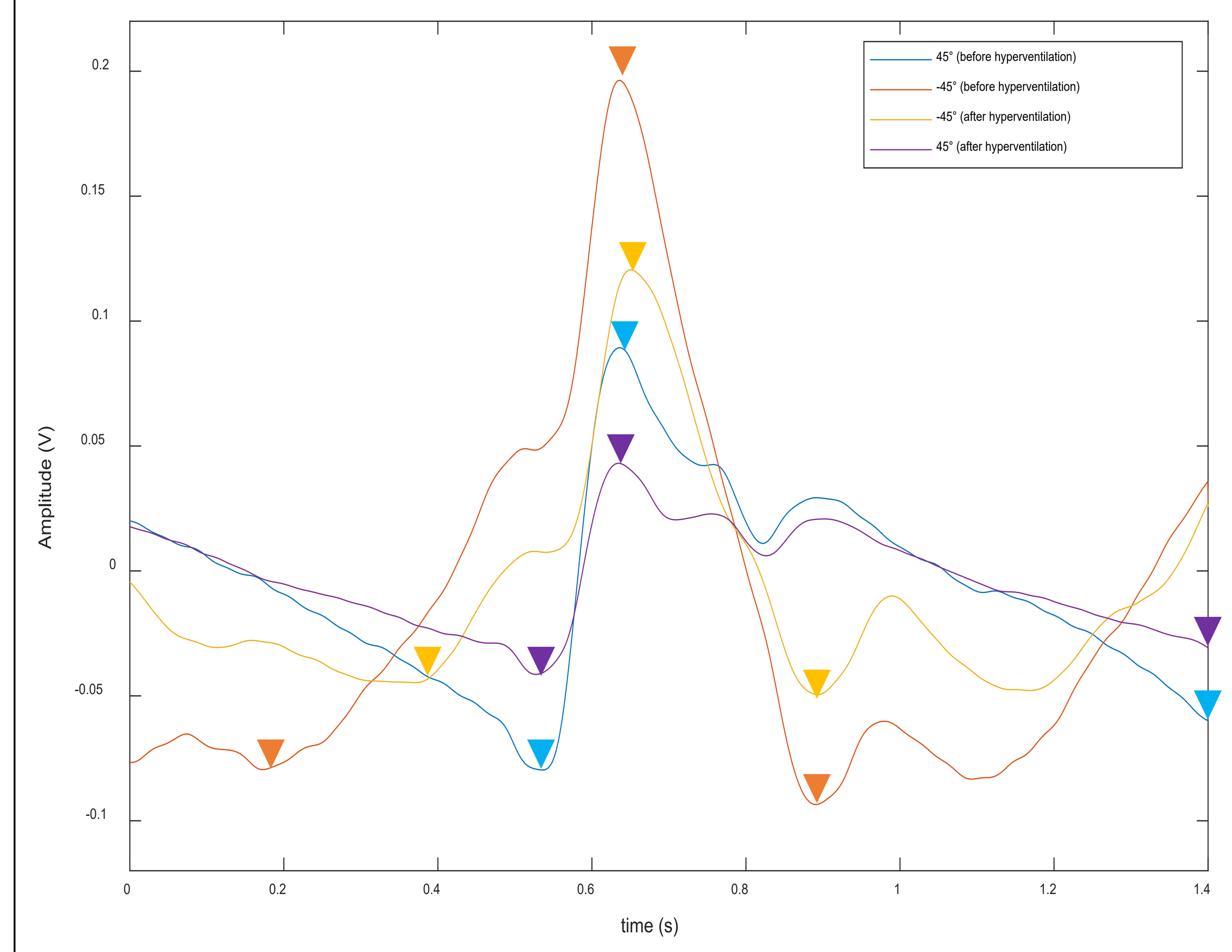


Figure 4 Average TMp waveforms of Subject 4 at different states in tilt table with maxima and minima labeled by triangles

Results (continued)

Change in waveform was quantified using the following formula:

$$\text{Slope ratio} = \frac{\text{slope of TMp signal after TMP peak}}{\text{slope of TMp signal before TMP peak}} * 100$$

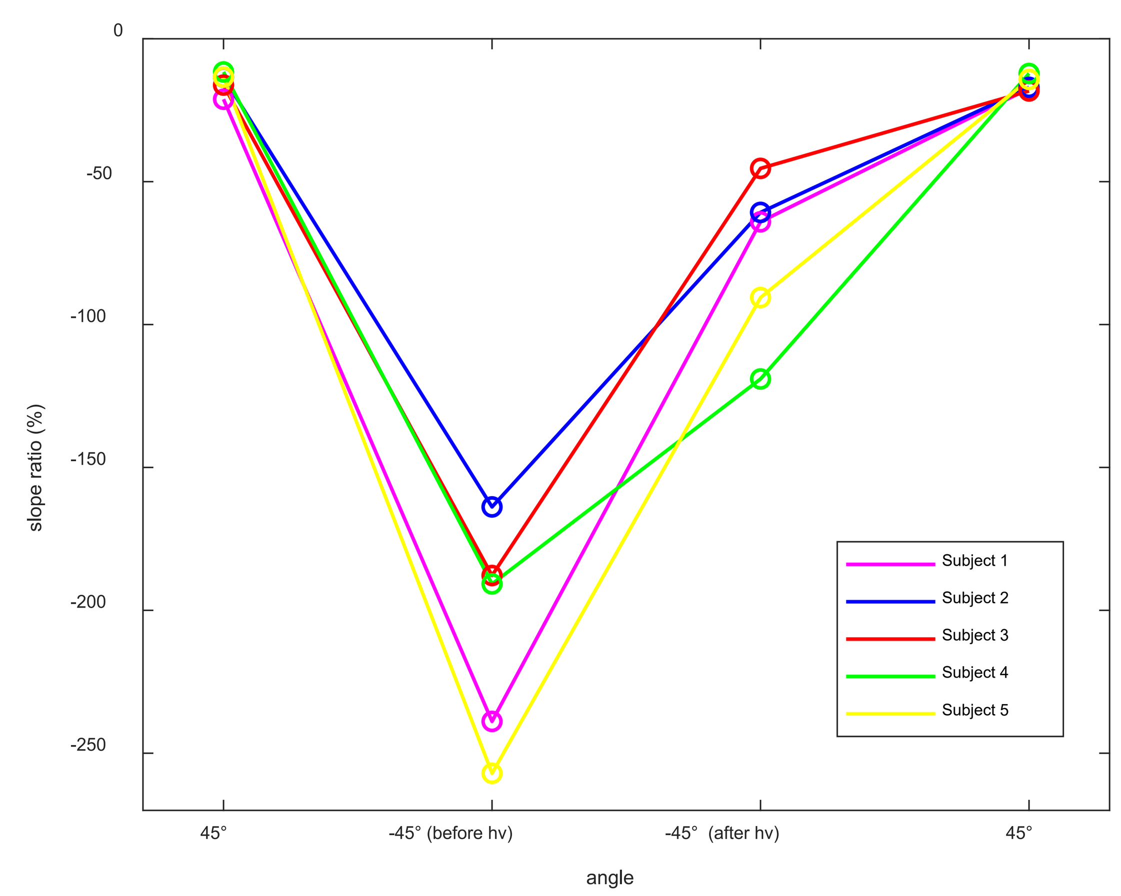


Figure 5 Slope ratio at different states for 5 subjects

Discussion and Conclusions

- Tilting body down increases ICP [2] and hyperventilation reduces it [3].
- Change in TMp waveform at -45° and retrieval of the initial shape at -45° after hyperventilation suggests that the change is due to ICP change.
- Absolute value of slope ratio is low for low ICP and high for high ICP in all the subjects.
- This consistent change in TMp waveform slope ratio suggests the potential utility of the proposed method for detecting elevated ICP.

References

[1] Azad MK, Spiewak A, Sandler RH, Manwaring K, Manwaring P, Mansy HA. Monitoring Intracranial Pressure Using Non-Invasive Brain Stethoscope. InSoutheastCon, 2018, IEEE, pp. 1-5.
[2] Petersen, L. G., Petersen, J. C. G., Andresen, M., Secher, N. H., & Juhler, M., 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, 2016.
[3] Raichle, M. E., & PLUM, F., Hyperventilation and Cerebral Blood Flow. Stroke, 3(5), 566–575, 1972.
[4] Condo SM, Simms LA, Mansy SH, Azad MK, Sandler RH, Cosby JL, Mansy HA. Effects of Intracranial Pressure on Tympanometric Parameters. InSoutheastCon, Apr 19, 2018, IEEE, pp. 1-4.