Predicting End Tidal CO_2 from Respiration Volume Per Time for Breath-Hold Cerebrovascular Reactivity Mapping

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Background

- Cerebrovascular reactivity (CVR) is the ability of brain vasculature to dilate, increasing blood flow to the brain.
  - CVR is used in analyzing brain health in various conditions such as stroke, TBI, arteriosclerosis, brain tumors, substance abuse, and aging.[1]
- Clinicians measure CVR by modulating blood gases: blood CO_2 is a strong vasodilator and can be temporarily increased using breath-holding (BH).
- The vasodilatory response in the brain is measured using a functional MRI scan.
- Exhaled CO_2 is used to calculate end-tidal CO_2 ($P_{ET}CO_2$), an estimate of arterial CO_2, to calculate CVR.
- It may be difficult for some populations to BH or follow instructions, decreasing $P_{ET}CO_2$ measurement quality.
- A respiratory belt measures changes in thoracic expansion at the peaks of inspiration and expiration, which is used to calculate respiration volume per time (RVT).[2-3]
  - This metric of changes in ventilation *rate* should, in theory, relate to changes in blood CO_2 levels.

Purpose

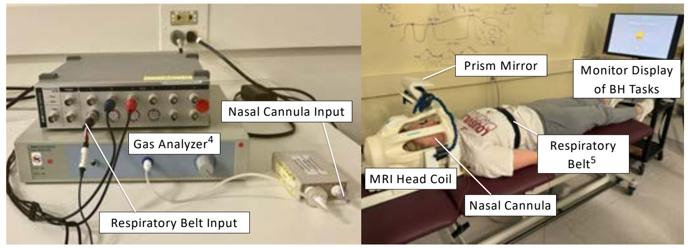
The purpose of this project is to develop machine learning methods to predict blood CO_2 changes using respiratory belt data. This will make CVR measurements more feasible in a wider range of patient populations, improving our ability to characterize, monitor, and improve the brain's vascular health.

Methods

- Each subject performed BH task in supine with a nasal cannula attached to gas analyzer and respiratory belt at the xiphoid process.
- An MRI head coil was placed around the head with a mirror secured above to monitor displaying instructions.
- Participants performed 1 practice BH followed by 10 BH trials, with paced breathing, BH, and recovery time parameters randomized.
- BH's without sufficient increase in CO_2 were excluded.
- Each data set was randomly split into segments consisting of 2-7 "good" BHs resulting in a final total of 293 data sets.

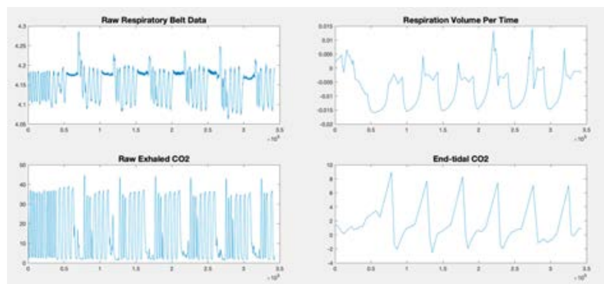
Breath-Hold Video Animation

Breath-Hold Task Set Up



- Randomized protocol
  - Initial period of paced breathing: 24, 30, 36s
  - End-expiratory breath hold duration of 10-20s.
  - Participants exhaled after breath-hold for 2 sec (needed to estimate end-tidal CO_2 change).
  - Recovery breathing time of 6-12s.
  - There was a 10% chance of individual breath-hold trial being skipped with instructions to "relax" instead.

Example of Raw RVT, and End-Tidal CO_2 Data



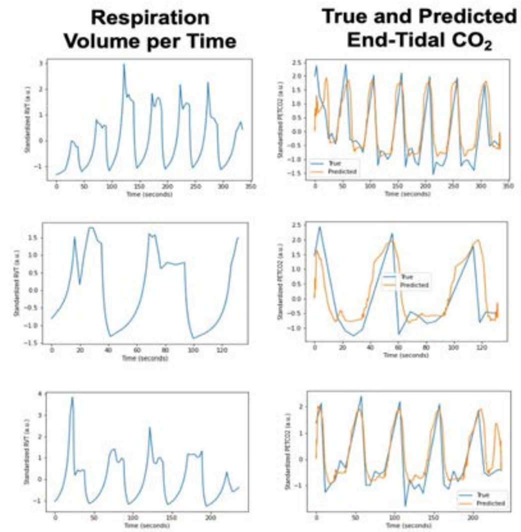
Summary of 4 Machine Learning Models

	1 Layer Model	2 Layer Model	4 Layer Model	6 Layer Model
r	0.756 ± 0.0682	0.702 ± 0.0722	0.834 ± 0.0775	0.846 ± 0.0772
MAE	0.642 ± 0.0748	0.798 ± 0.0440	0.477 ± 0.0914	0.421 ± 0.0950
MAPE (%)	5.99 ± 4.92	4.67 ± 3.52	4.33 ± 4.75	3.36 ± 3.55
MSE	0.682 ± 0.150	0.860 ± 0.089	0.451 ± 0.181	0.353 ± 0.160

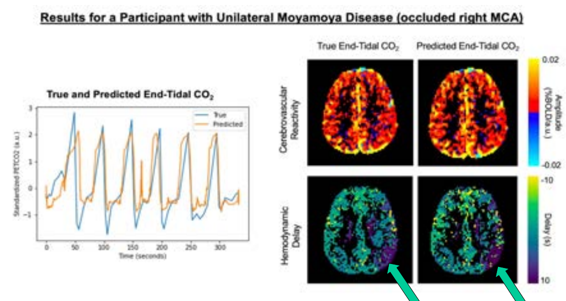
- In collaboration with doctoral biomedical engineering students, machine learning models were trained to predict $P_{ET}CO_2$ from RVT in breath-hold task data.
- The correlation coefficient between true $P_{ET}CO_2$ and predicted $P_{ET}CO_2$ for the best model is 0.846 ± 0.0772.
- This model is applied to sample data from 3 different subjects shown in the following graph to demonstrate the high correlation between true and predicted $P_{ET}CO_2$.

Scan QR code for Reference List.

True vs. Predicted End-Tidal CO_2 for 3 Representative Datasets



CVR Maps with True vs. Predicted End-Tidal CO_2 in a Participant with Moyamoya Disease



Conclusions

- **The best-performing model produced a correlation coefficient of r=0.846±0.077, suggesting the feasibility of machine learning to predict $P_{ET}CO_2$ from RVT.**
- This work has clinical research applications on improving CVR accuracy in clinical populations.
- The generalizability of the algorithm would further improve with increased data sets of a more diverse population, including cohorts with varying lung volumes, ages, CVP conditions, and cognitive abilities.

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