Multimodal Remote Patient Monitoring Solutions for Neurologic Conditions

Remote monitoring of respiratory function using a cloud-based multimodal dialogue system

Hardik Kothare[1,2] & Vikram Ramanarayanan[1,2]
[1]Modality.AI, Inc. [2]University of California, San Francisco

Clinical importance of remote monitoring of respiratory function

- Weakness of respiratory muscles in neurological conditions like Parkinson's Disease or Amyotrophic Lateral Sclerosis may result in dysarthria[1]
- Respiratory function is key to efficient speech production and an objective measure for disease diagnosis and management
- Current clinical standard is a spirometry test[2]: patients exhale forcefully into a device that measures the flow of exhaled air
- Telemedicine has been gaining traction; current COVID-19 pandemic[3] highlights the need to make clinical tests available to patients at home
- Unmet need for remote spirometry to allow on-demand remote monitoring of patients' respiratory function

NEMSI bridges this gap!

- **NEurological and Mental health Screening Instrument (NEMSI)**[4]
  - cloud-based multimodal dialogue system that conducts automated screening interviews by engaging with conversational AI over a device of the user's choice (smartphone, tablet, laptop) from the comfort of their home
  - deployed in an automatically scalable cloud environment allowing it to serve an arbitrary number of end users at a very small cost per interaction
  - natively equipped with real-time speech and video analytics modules that extract a variety of features of direct relevance to clinicians, thus allowing for measurement of multiple subsystems (motoric, phonatory) in conjunction with lung function

Flowchart for a remote spirometry call

Users call a secure web link to start the interview → Users are guided to set up their webcam and microphone and greeted by an AI agent (Figure 1) → After asking for details like age, sex, height and weight, the AI agent instructs users to exhale forcefully into the microphone of their device → AI agent helps users fill out relevant questionnaires (Figure 2)

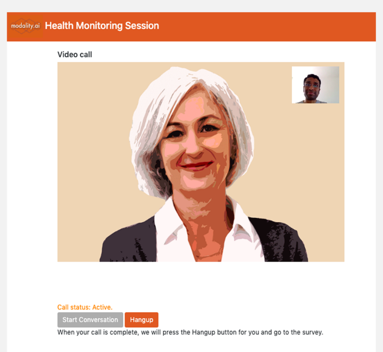

Figure 1: Example call

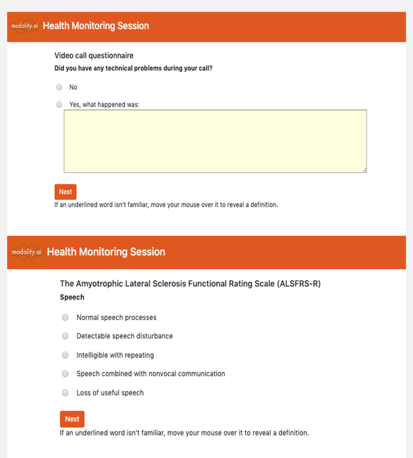

Figure 2: Questionnaires

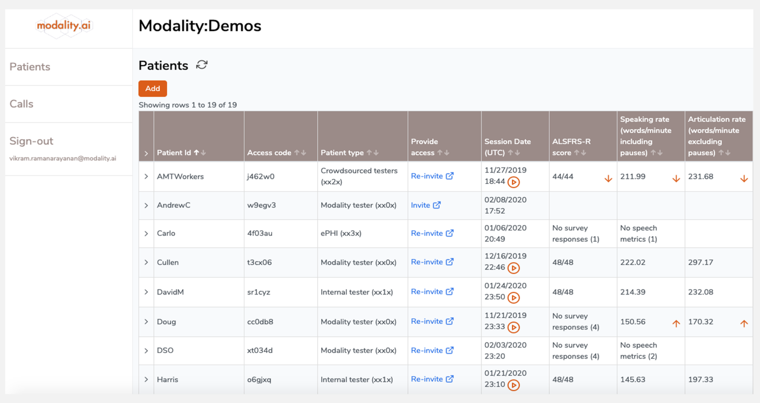

Figure 3: Dashboard

Analytics modules extract metrics automatically

- Amplitude envelope in units of pressure (pascals) extracted from the audio signal after calculating the Hilbert envelope and adding it to the raw signal.
- Pressure at lips or p_{lips} *(t)* is assumed to be equivalent to pressure at mic (by standardisation of mic-to-mouth distance as 2 inches or ~5cm) and flow rate at lips or $u_{lips}(t)$ is estimated as done in previous studies[5], $u_{lips}(t) \sim 2\pi r_{lips}^2 \sqrt{2p_{lips}(t)}$ where r_{lips} is the radius of the lip aperture. Exhaled volume of air is estimated by integrating flow with respect to time.
- Measures like Forced Vital Capacity (FVC) or the total exhaled volume of air and Forced Expiratory Volume in 1 second (FEV1) and FEV1/FVC ratio extracted.
- Measures displayed on a user-friendly dashboard accessible by clinicians and researchers (Figure 3).

Analysis of metrics

- The work presented here is currently still in early stages of development and has only undergone internal testing.
- We attempted to standardise various aspects of data collection like mic type and mic-to-mouth distance.
- However, as in clinical spirometry, poor user adherence to instructions and resulting user errors are a major hurdle.
- Slow exhalation (as opposed to a forced burst) may result in an overestimation of FVC values and underestimation of FEV_1 values (see Figure 4A) whereas incomplete exhalation results in an underestimation of FEV_1 and FVC values (see Figure 4B).
- Not holding the microphone at the recommended distance causes the audio signal to be too quiet resulting in incorrect FEV_1 and FVC values but an accurate FEV_1/FVC ratio (see Figure 4C).
- In the absence of user errors, all estimated metrics fall within the range of predicted values for the user's age, sex and height (see Figure 4D) as specified in reference charts[6].

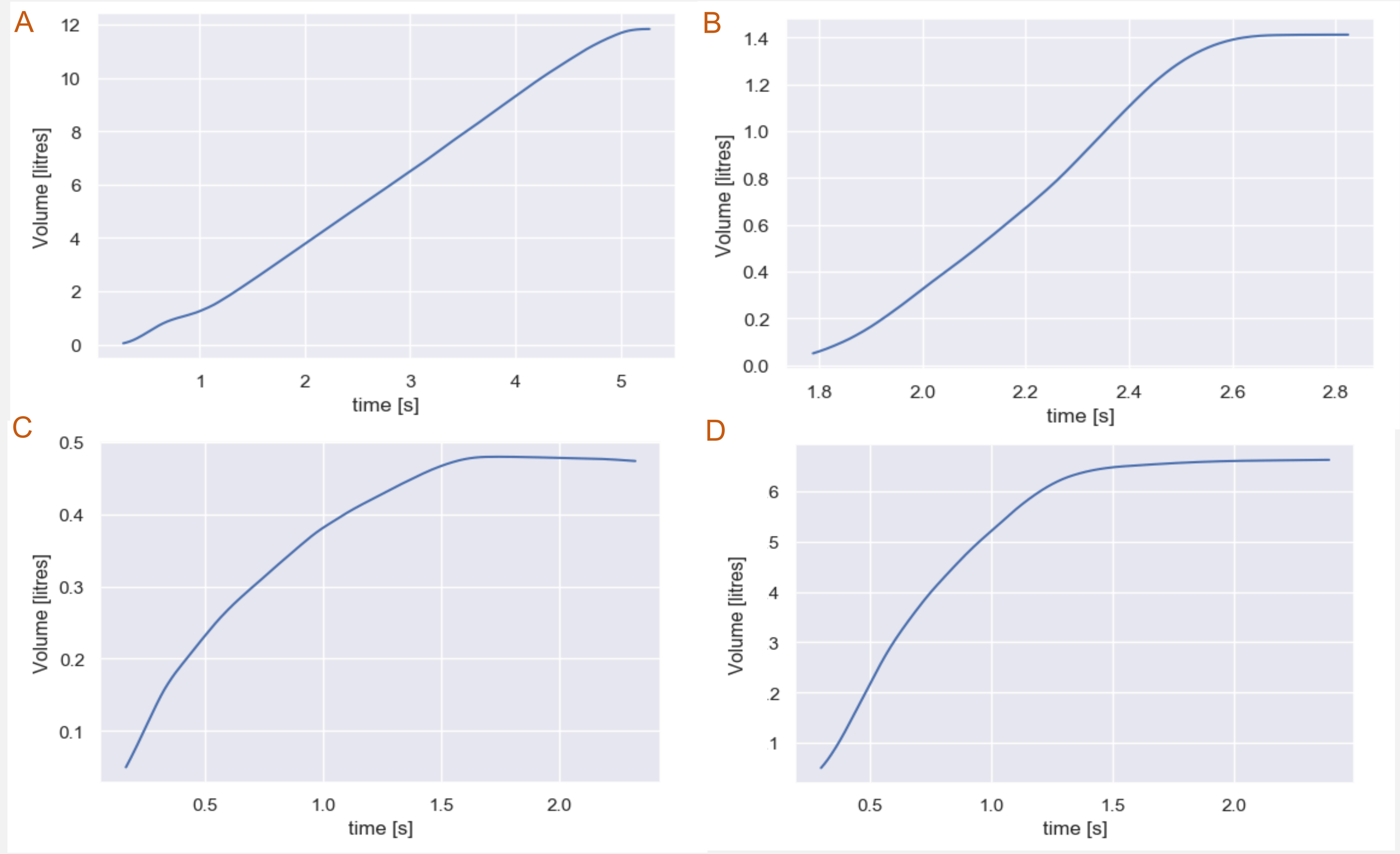

Figure 4: Volume vs Time plots
(A) Slow exhalation, (B) Incomplete exhalation,
(C) Microphone held far away, (D) No user errors
Note: The axes are not uniform across panels

Next steps

- Our cloud-based multimodal dialogue system provides an integrated scalable solution to remote diagnosis and monitoring of respiratory function in patients with respiratory muscle weakness and dysarthric speech.
- However, there are several limitations that need to be overcome before the solution can be implemented.
- We look forward to working with the research community on the following points:
  1. Ideas on ensuring user adherence by means of user training and intelligent feedback
  2. Developing a reliable method to calibrate microphones
  3. Collection of preliminary data from patient populations and healthy cohorts to validate and verify our methods.
- Remote spirometry is not a replacement for clinical spirometry but provides a valuable telehealth and telemedicine tool.

References

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