High-resolution cervical auscultation's capability in detecting the duration of upper esophageal sphincter opening across patient populations and healthy adults

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Problem

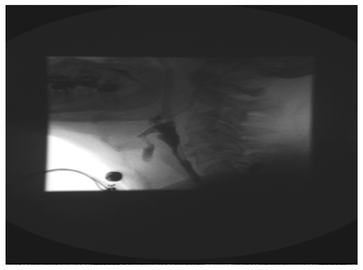
- Swallowing dysfunction (dysphagia) occurs frequently in a variety of different patient populations including patients post-stroke (29-64%), patients with head and neck cancer (50%), patients with dementia (13-57%), and patients with neurodegenerative diseases (up to 98%).
- Dysphagia can lead to clinically meaningful adverse events including malnutrition/dehydration, aspiration pneumonia, and increased length of hospitalization/health care costs.
- Several invasive imaging methods including videofluoroscopic swallow studies (VFSSs), fast pharyngeal CT/MRI, and fiberoptic endoscopic evaluation of swallowing can generate images and signals that can be used to detect the presence and the underlying pathophysiology of dysphagia; however, they are invasive, expensive, and are not feasible or easily accessible in all clinical settings or with all patients.
- Among the most important physiologic correlates of swallowing is the duration of upper esophageal sphincter (UES) opening, whcih enables food and liquid to enter the esophagus. A reduced UES opening diameter, delayed onset of opening, or premature closure attenuate UES opening duration can result in pharyngeal residue that in turn can enter the upper (laryngeal penetration) or lower (aspiration) airway.

Videofluoroscopy Swallowing Study (VFSS): Gold Standard for measuring UES opening duration
Pros:

- Evaluation of the entire swallowing process.
- Relatively noninvasive.

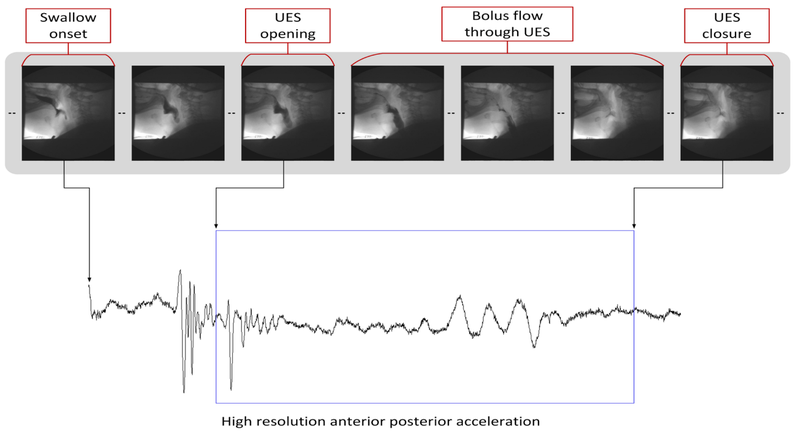
Cons:

- High x-ray dose.
- Not available in all clinics.
- An expert is always needed to interpret results.



Objective

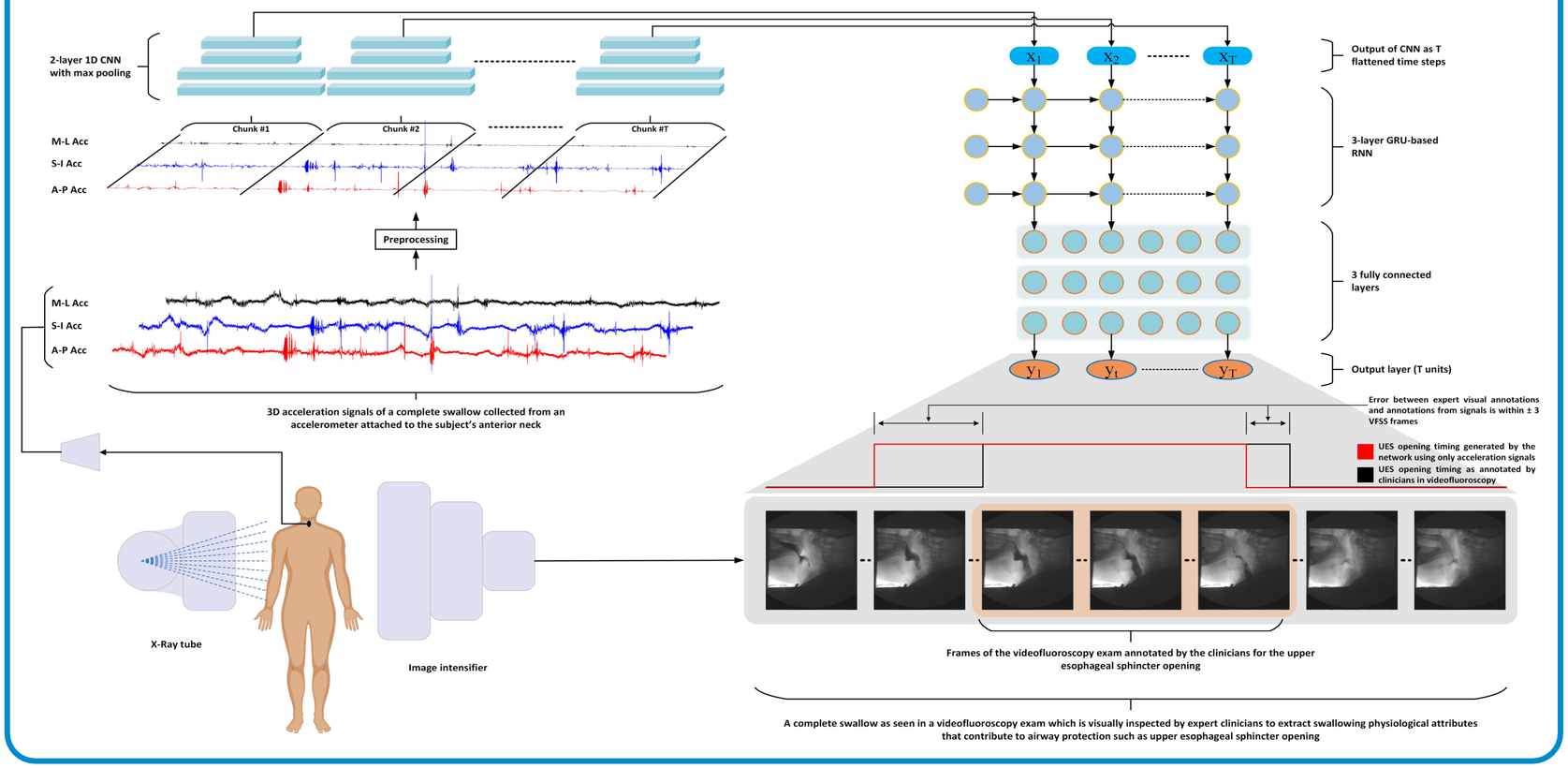
- Investigating the use of sensor-based technology as an affordable, feasible, non-invasive bedside assessment tool for dysphagia.
- We provide a deep learning framework that uses signals from neck-attached accelerometer and a microphone to detect UES opening duration and validate against ratings in VFSS.



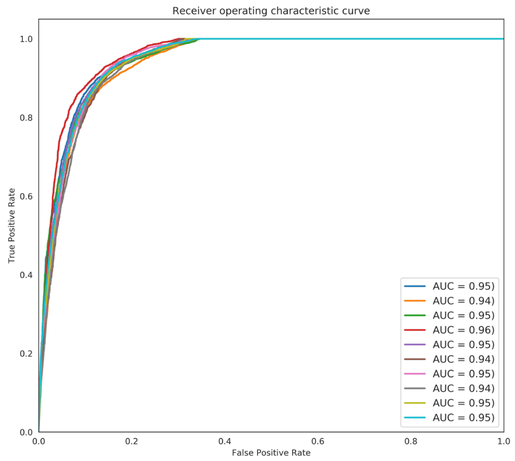
Dataset and Evaluation

- We analyzed neck-sensor signals of 710 thin liquid swallows from 116 patients (72 males, 44 females, age: 62.7±15.5) with suspected dysphagia and 584 thin liquid swallows from 70 healthy community dwelling adults (31 males, 39 females, age:62.66±14.8) who underwent VFSSs concurrently with neck-sensor recordings. Human judges rated UES opening and closure for all swallows by viewing VFSS images and the times were reflected on the concurrent signals as labels.
- A 10-fold cross validation scheme was used to evaluate the performance of the deep learning framework over the dataset. The UES opening detected by the network was validated against the ground truth provided by the judges using accuracy, sensitivity, specificity and error between the detected UES opening/closure moments and the ground truth.
- Area under the reciever operating characteristic (ROC) curves was also used as a quality indicator for the detection performance of the framework across the 10 folds.

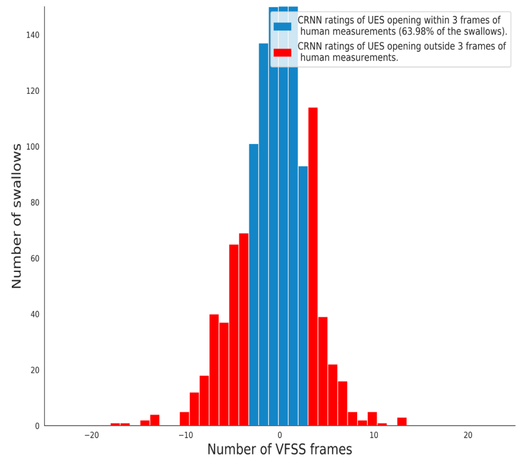
Methods



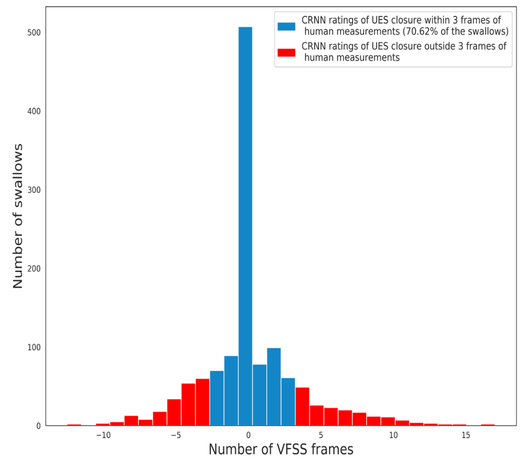
Results



ROC curves with the AUC values for the results of each fold of the 10 folds performed for evaluation.



The error between the network-detected UES opening frame and the opening frame marked by the judges for the 10 folds (blue bars indicate swallows with error within 3 VFSS frames [0.1 sec]).



The error between the network-detected UES closing frame and the closing frame marked by the judges for the 10 folds (blue bars indicate swallows with error within 3 VFSS frames [0.1 sec]).

Conclusion

- The proposed deep learning framework detected UES opening and closure with a high degree of accuracy when compared to expert human judges.
- Most of the swallows in the used dataset had their UES opening and closure detected by the proposed framework within a short 3-VFSS frames window (0.1 sec) of the same opening and closure times rated by experts.
- This research study promotes the use of HRCA as a dysphagia screening and diagnostic adjunct when imaging assessments are unavailable in clinical settings or are undesired by patients.
- Future research studies should expand upon this work by including various bolus conditions and a broader range of patients with varying dysphagia severity profiles to improve the robustness and accuracy of the deep learning framework.

Acknowledgment

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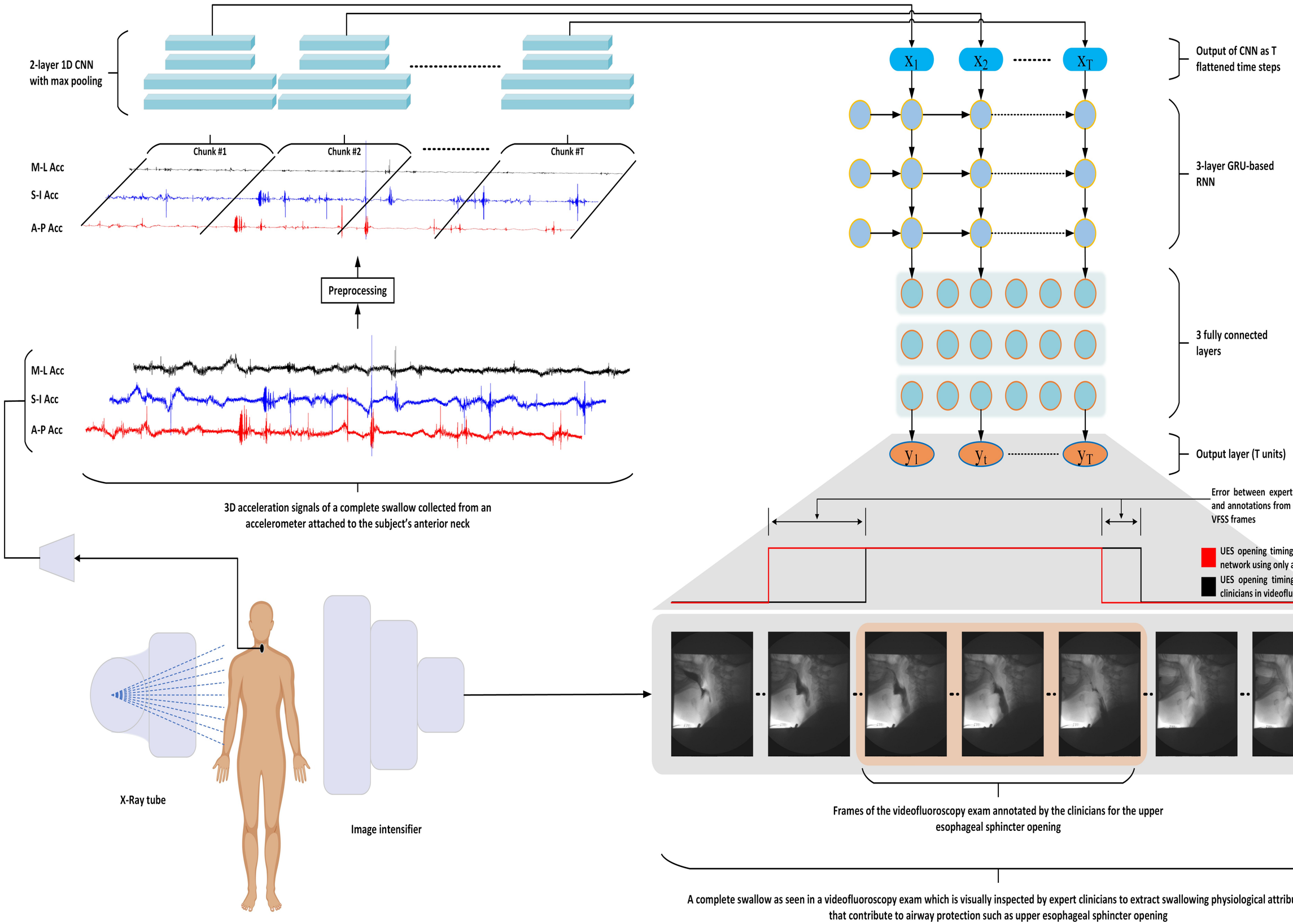
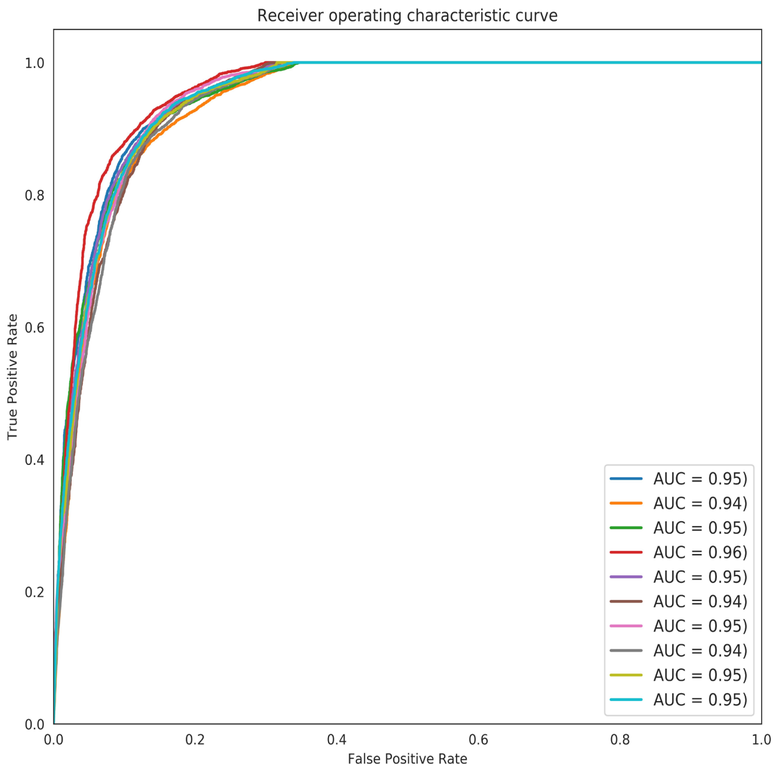
Methods


2-layer 1D CNN
with max pooling
Chunk #1
Chunk #2
Chunk #T
M-L Acc
S-I Acc
A-P Acc
Preprocessing
M-L Acc
S-I Acc
A-P Acc
3D acceleration signals of a complete swallow collected from an accelerometer attached to the subject's anterior neck
X-Ray tube
Image intensifier
x_1
x_2
x_T
Output of CNN as T flattened time steps
3-layer GRU-based RNN
3 fully connected layers
y_1
y_t
y_T
Output layer (T units)
Error between expert visual annotations and annotations from signals is within ± 3 VFSS frames
UES opening timing generated by the network using only acceleration signals
UES opening timing as annotated by clinicians in videofluoroscopy
Frames of the videofluoroscopy exam annotated by the clinicians for the upper esophageal sphincter opening
A complete swallow as seen in a videofluoroscopy exam which is visually inspected by expert clinicians to extract swallowing physiological attributes that contribute to airway protection such as upper esophageal sphincter opening

Results



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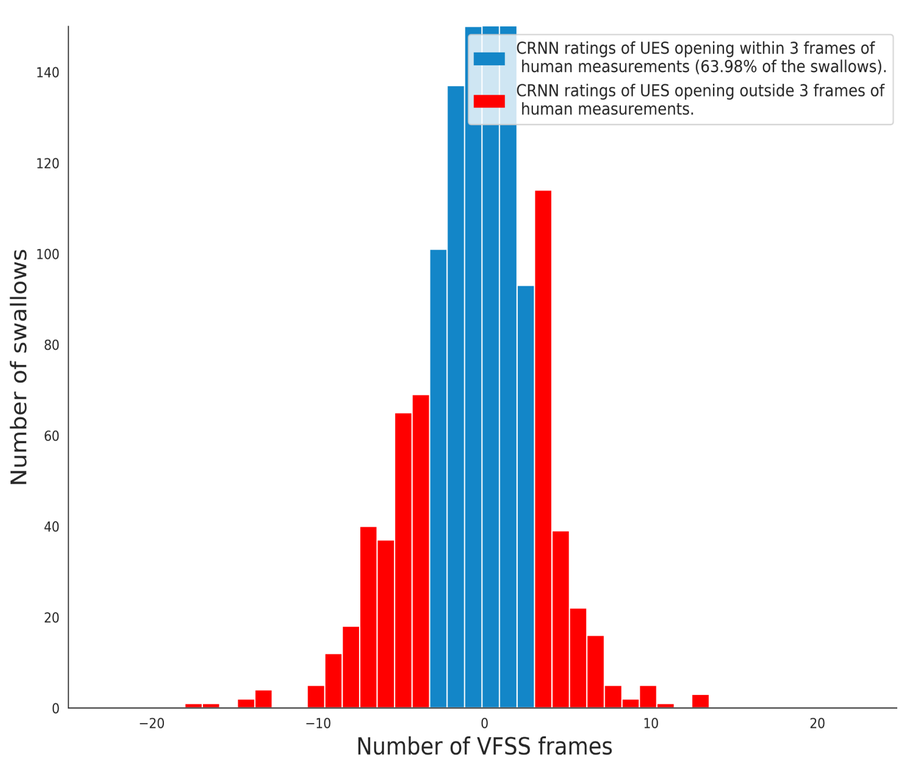

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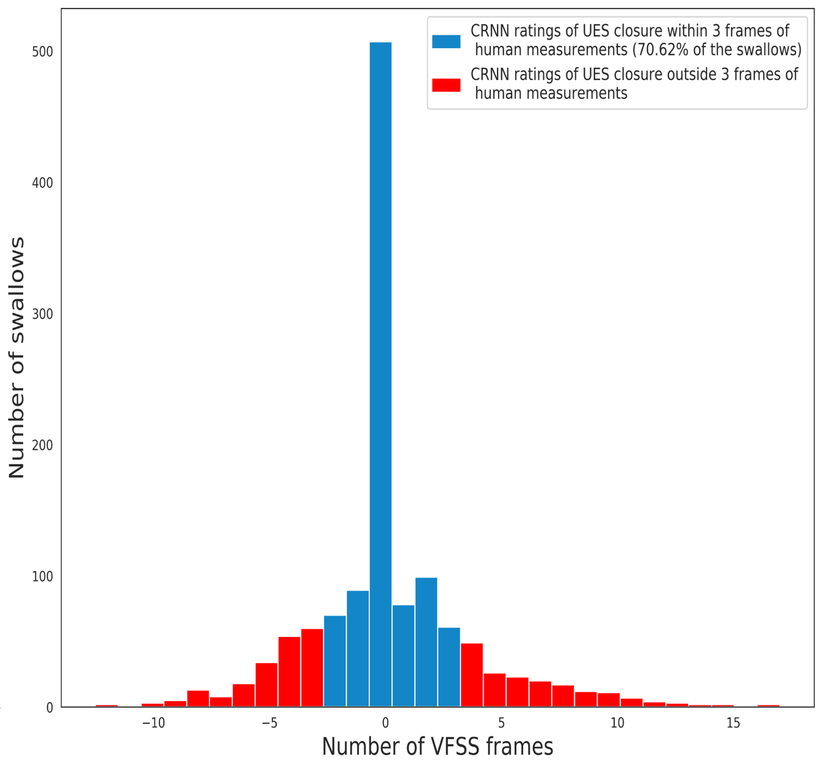

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