Synthetic Speech References for Automatic Pathological Speech Intelligibility Assessment

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Outline

1. Pathological Speech Intelligibility Assessment
2. State-of-the-art Automatic Intelligibility Measures
3. P-ESTOI with Synthetic Speech References
4. Experimental Results
5. Summary

Pathological speech intelligibility assessment

- Disrupted speech production mechanism due to speech disorders, e.g., Cerebral Palsy (CP)
  - Reduced intelligibility and communicative ability

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- Speech intelligibility (degree of understandability of speech)
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- Subjective listening tests based on judgement of human listeners
  - Labor-intensive
  - Subject to the listener bias and to contextual and linguistic cues

- Automatic intelligibility measures
  - Frequent, economical, and objective assessment
  - Applicable in remote speech therapies

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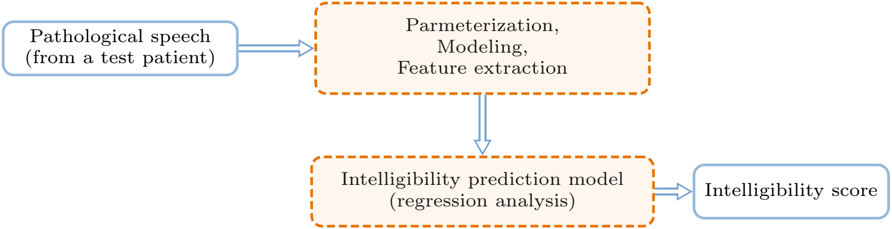
Automatic pathological intelligibility measures (State-of-the-art)

» Reference-free approaches

» Reference-based approaches



Pathological speech
(from a test patient)

Parmeterization,
Modeling,
Feature extraction

Intelligibility prediction model
(regression analysis)

Intelligibility score

Automatic pathological intelligibility measures (State-of-the-art)

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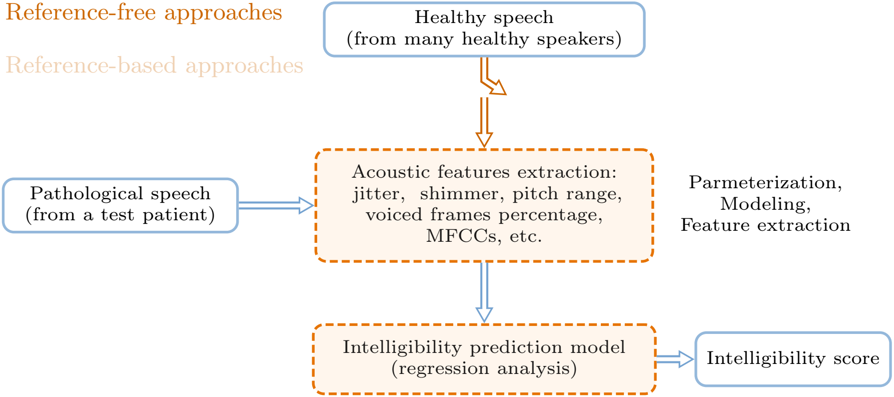
- » Reference-based approaches

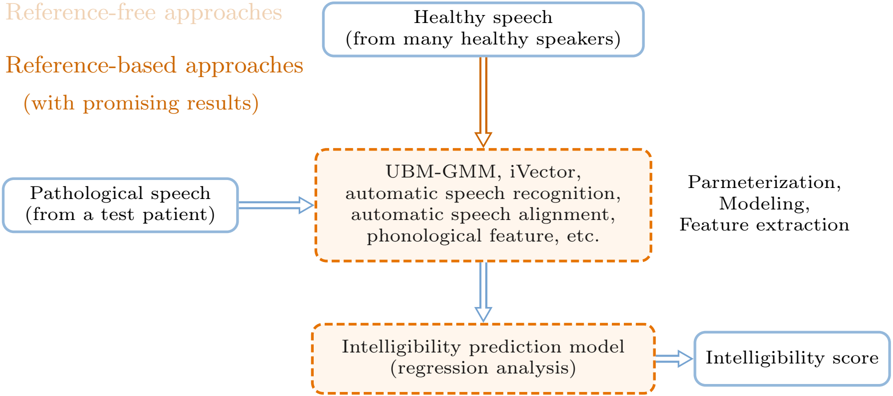


Automatic pathological intelligibility measures (State-of-the-art)

» Reference-free approaches

» Reference-based approaches

(with promising results)



Healthy speech
(from many healthy speakers)

Pathological speech
(from a test patient)

UBM-GMM, iVector,
automatic speech recognition,
automatic speech alignment,
phonological feature, etc.

Parmeterization,
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Feature extraction

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Intelligibility score

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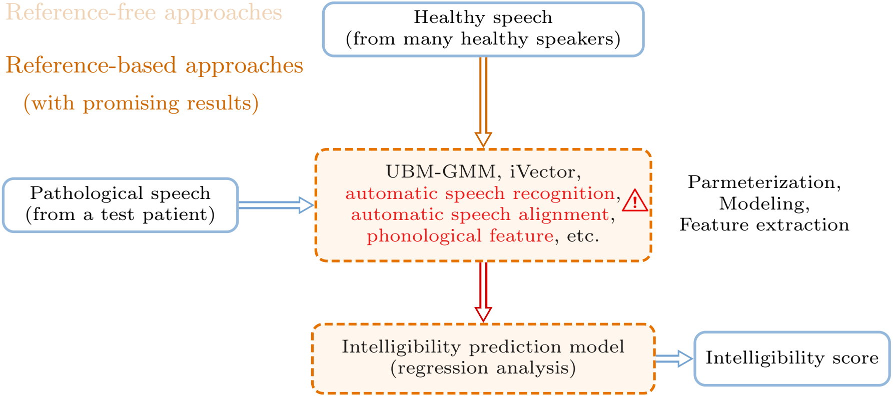

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Modeling,
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Intelligibility prediction model
(regression analysis)

Intelligibility score

⚠ Unpredictability for severe patients

Automatic pathological intelligibility measures (State-of-the-art)

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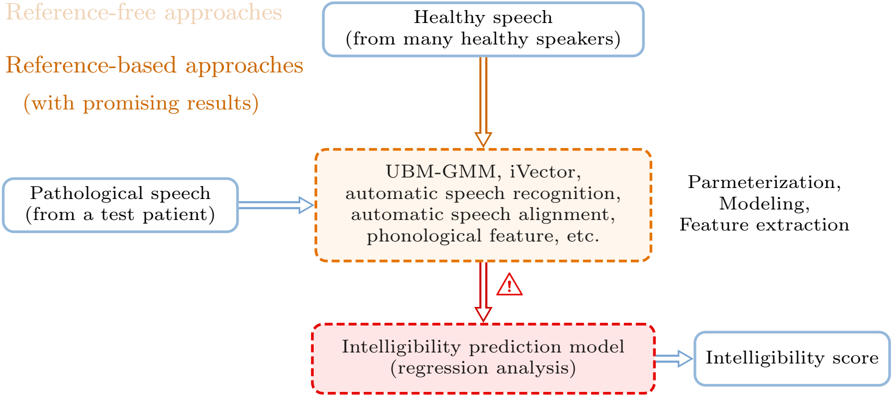

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Parmeterization,
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⚠

Intelligibility prediction model
(regression analysis)

Intelligibility score

⚠ Large number of features
(increasing the risk of over-fitting)

Our previously proposed referenced-based intelligibility measures (State-of-the-art)

- Pathological short-time objective intelligibility (P-ESTOI) measure (Janbakhshi et al., 2019a)
  - Simple structure
  - Based on a single feature without training (no risk of overfitting)
  - Generalizable across languages and neurological diseases

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  - Requires healthy recordings matching the phonetic content of the pathological speech to create a reference model (phonetically-balanced scenarios)
    - Not applicable to phonetically-unbalanced scenarios

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  - Requires healthy recordings matching the phonetic content of the pathological speech to create a reference model (phonetically-balanced scenarios)
    - Not applicable to phonetically-unbalanced scenarios
- Subspace-based intelligibility measure (SIM) (Janbakhshi et al., 2019b)
  - Applicable to phonetically-unbalanced scenarios
  - Ignores temporal cues for intelligibility assessment ⇒ lower performance than P-ESTOI

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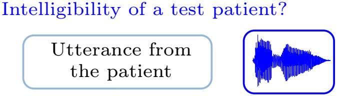
P-ESTOI with synthetic speech references

- Goal ⇒ Flexible version of P-ESTOI (applicable in phonetically-unbalanced scenarios)

P-ESTOI with synthetic speech references

- P-ESTOI$_H$ with healthy speech references (applicable in phonetically-balanced scenarios)

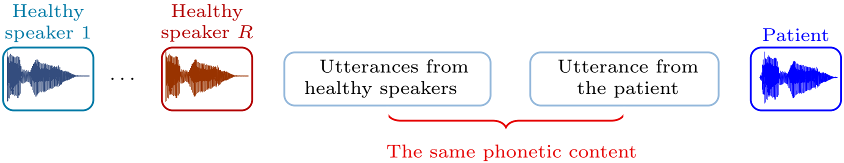


Intelligibility of a test patient?

Utterance from the patient

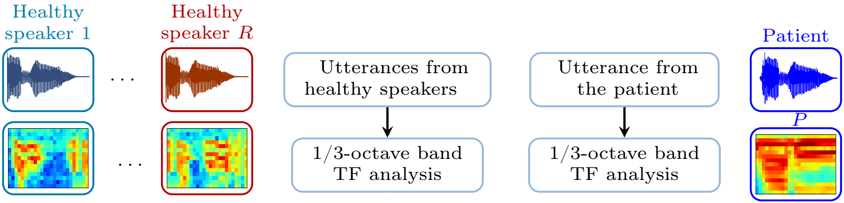
P-ESTOI with synthetic speech references

- P-ESTOI$_H$ with healthy speech references (applicable in phonetically-balanced scenarios)


Healthy speaker 1
. . .
Healthy speaker R
Utterances from healthy speakers
Utterance from the patient
Patient
The same phonetic content

P-ESTOI with synthetic speech references

- P-ESTOI$_H$ with healthy speech references (applicable in phonetically-balanced scenarios)



Healthy speaker 1

. . .

Healthy speaker R

Utterances from healthy speakers

1/3-octave band TF analysis

Utterance from the patient

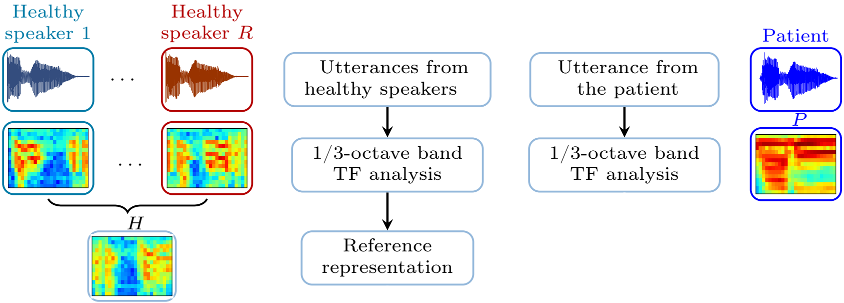
1/3-octave band TF analysis

Patient

P

P-ESTOI with synthetic speech references

- P-ESTOI$_H$ with healthy speech references (applicable in phonetically-balanced scenarios)



Utterances from healthy speakers

1/3-octave band TF analysis

Reference representation

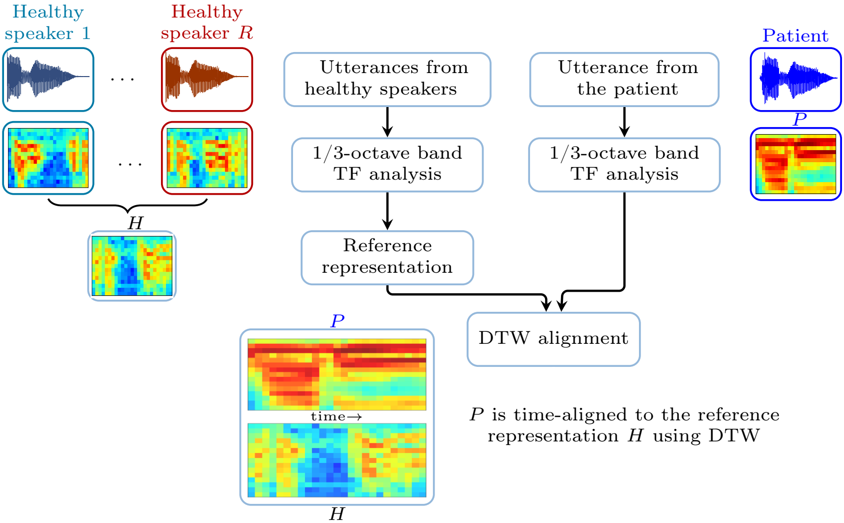
Utterance from the patient

1/3-octave band TF analysis

Creating an utterance-dependent reference H by:
dynamic time warping (DTW) + temporal clustering

P-ESTOI with synthetic speech references

- P-ESTOI$_H$ with healthy speech references (applicable in phonetically-balanced scenarios)



Healthy speaker 1

Healthy speaker R

Patient

. . .

. . .

H

P

Utterances from healthy speakers

1/3-octave band TF analysis

Reference representation

Utterance from the patient

1/3-octave band TF analysis

DTW alignment

P

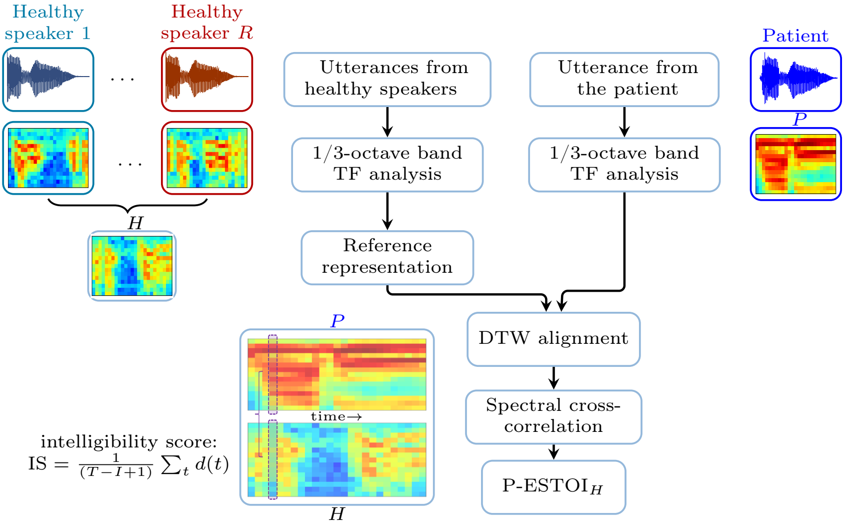
time→

H

P is time-aligned to the reference representation H using DTW

P-ESTOI with synthetic speech references

- P-ESTOI$_H$ with healthy speech references (applicable in phonetically-balanced scenarios)



Healthy speaker 1

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H

Patient

P

Utterances from healthy speakers

1/3-octave band TF analysis

Reference representation

Utterance from the patient

1/3-octave band TF analysis

DTW alignment

Spectral cross-correlation

P-ESTOI$_H$

P

time→

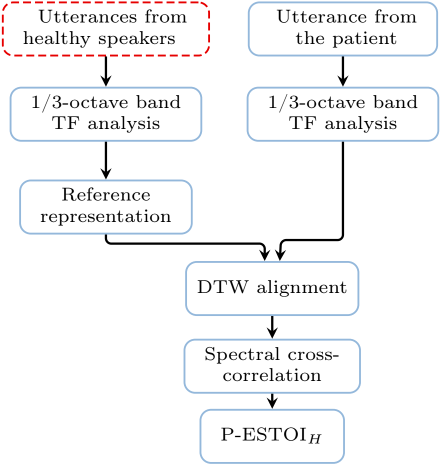
H

intelligibility score:

$$\text{IS} = \frac{1}{(T-I+1)} \sum_t d(t)$$

P-ESTOI with synthetic speech references

- Goal ⇒ Flexible version of P-ESTOI (applicable in phonetically-unbalanced scenarios)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Utterance from the patient
1/3-octave band TF analysis
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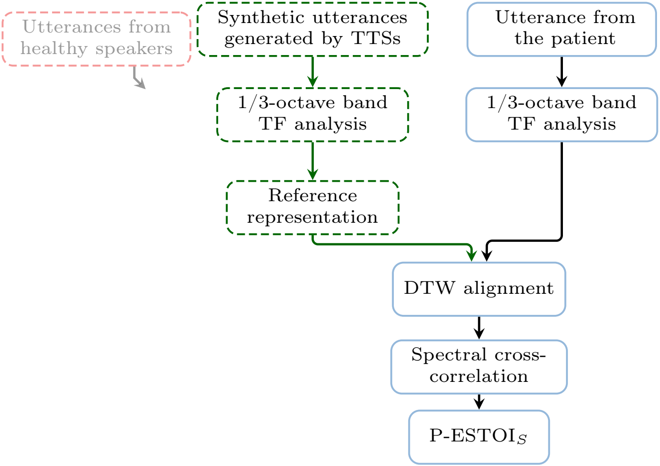
Reference representation
DTW alignment
Spectral cross-correlation
P-ESTOI$_H$

P-ESTOI with synthetic speech references

- Proposing to use synthetic speech generated by high-quality text-to-speech (TTS) systems to create intelligible references models

Using TTS systems as "average" intelligible speakers


Utterances from healthy speakers
Synthetic utterances generated by TTSs
Utterance from the patient
1/3-octave band TF analysis
1/3-octave band TF analysis
Reference representation
DTW alignment
Spectral cross-correlation
P-ESTOI$_S$

P-ESTOI with synthetic speech references

- Synthetic speech references generated with state-of-the-art TTS system
- Speaker-dependent TTS systems trained on multiple healthy speakers
  - Deep Neural Network (DNN)-based TTS system inspired by the state-of-the-art Merlin TTS system (Wu et al., 2016)
  - Festival front-end, two Bidirectional long short-term memory networks as duration and acoustic models, and the WORLD vocoder (Schnell and Garner, 2018)

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- Databases
  - English Universal Access database (Kim et al., 2008)
    - Recordings of 764 word utterances from 15 CP patients and 4 healthy speakers
  - English CMU ARCTIC database (Kominek and Black, 2004)
    - Recordings of 1132 utterances from 4 healthy speakers ⇒ 4 TTS systems

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- State-of-the-art intelligibility measures
  - P-ESTOI$_H$ with natural speech references (Janbakhshi et al., 2019a)
  - SIM (Janbakhshi et al., 2019b)
  - iVector and ASR-based approaches (Martínez et al., 2015)

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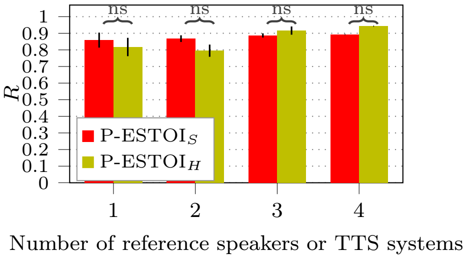
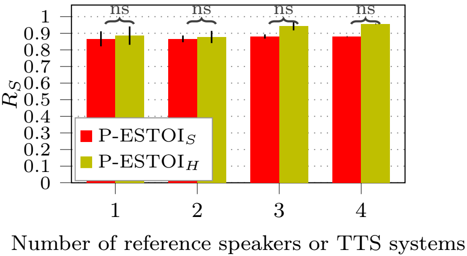
- Evaluation
  - Pearson correlation coefficient (R)
  - Spearman rank correlation coefficient (R_S)

Experimental results (phonetically-balanced scenarios)

» Assuming all speakers (healthy and pathological) utter the same utterances

- Considering 764 utterances for each speaker





- P-ESTOI$_S$: P-ESTOI with *synthetic speech* references
- P-ESTOI$_H$: P-ESTOI with natural *healthy speech* references

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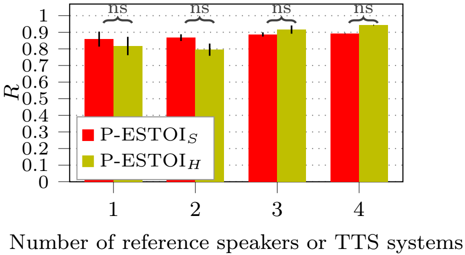

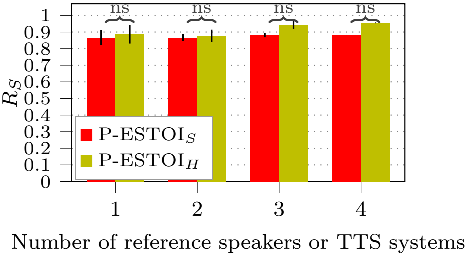

Measures	R	p	R_S	p
P-ESTOI$_S$	0.89	1e−5	0.88	6e−5
SIM	0.77	9e−4	0.84	7e−5
iVector	0.74	–	–	–
ASR	0.55	–	–	–

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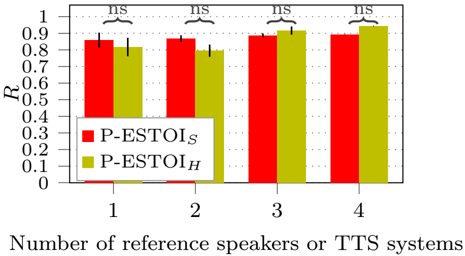

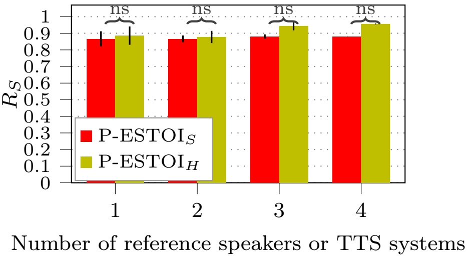

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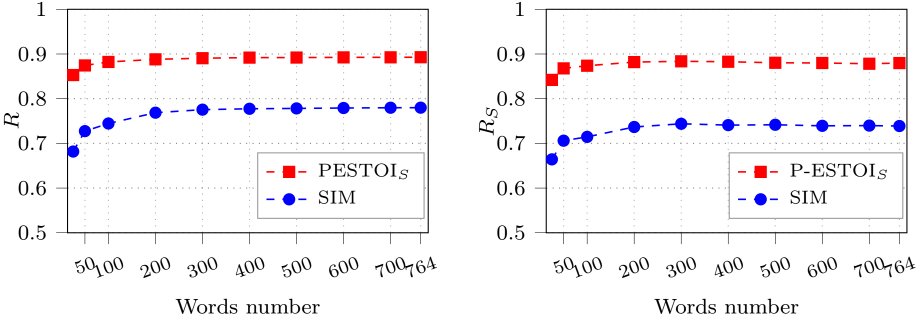
- No significant difference between P-ESTOI$_S$ and P-ESTOI$_H$
- P-ESTOI$_S$ yields high and significant correlations outperforming other measures

Experimental results (phonetically-unbalanced scenarios)

- Assuming all speakers (healthy and pathological) utter different set of utterances
  - Random selection of sets of utterances from the 764 available utterances for each speaker



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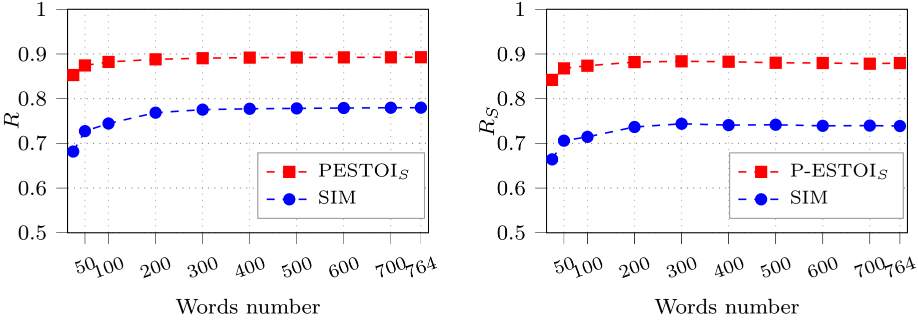

» P-ESTOI$_S$ outperforms SIM in phonetically-unbalanced scenarios

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Summary

- Creating the reference representations required in P-ESTOI using synthetic utterances generated by state-of-the-art TTS systems
    - Making P-ESTOI a flexible measure to be also used in phonetically-unbalanced scenarios
- Based on experimental results on CP patients, the performance of P-ESTOI using synthetic speech references is comparable to using natural speech references
- P-ESTOI using synthetic speech references outperforms state-of-the-art automatic intelligibility measures

Thank You

Reference

Janbakhshi, P., Kodrasi, I., and Bourlard, H. (2019a). Pathological speech intelligibility assessment based on the short-time objective intelligibility measure. In *Proc. IEEE International Conference on Acoustics, Speech, and Signal Processing*, Brighton , UK.

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