Analysing Articulatory Data with Vector Norms and Related Methods

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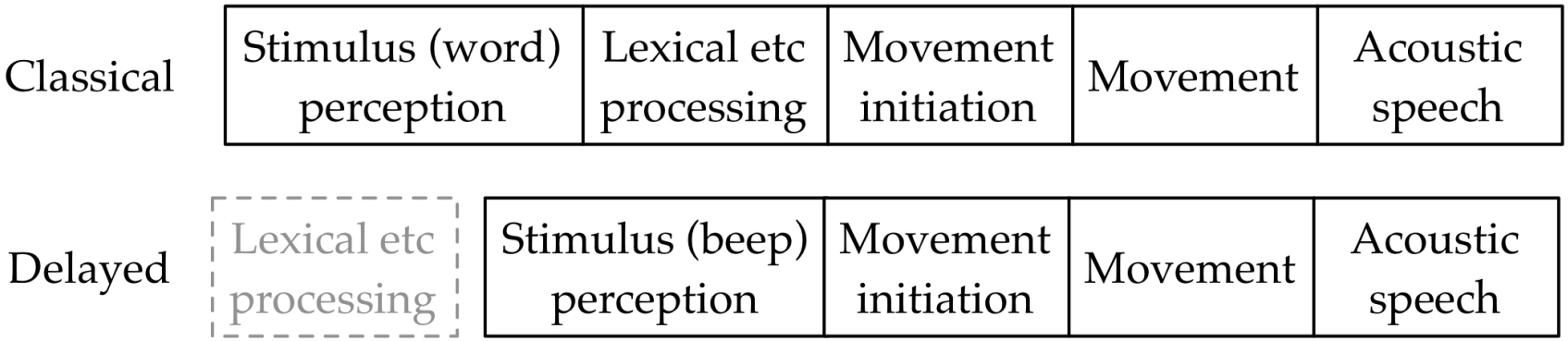
Outline

- I will then talk about what we can and cannot do with these methods in time domain analysis of articulatory data these days. I will take short side trips to look at similar methods applied to other articulatory data. We have looked at tongue splines and lip videos and I will discuss what kind of challenges and understanding has resulted from those attempts. Finally, analysing 3D/4D ultrasound has been a recent major focus, but unfortunately frame rate issues are not so easy to solve.
- I will finish the talk by discussing why MRI would be very interesting to analyse with these methods – or adapted versions of them – and which definite and possible challenges one might come across.

Introduction: The why

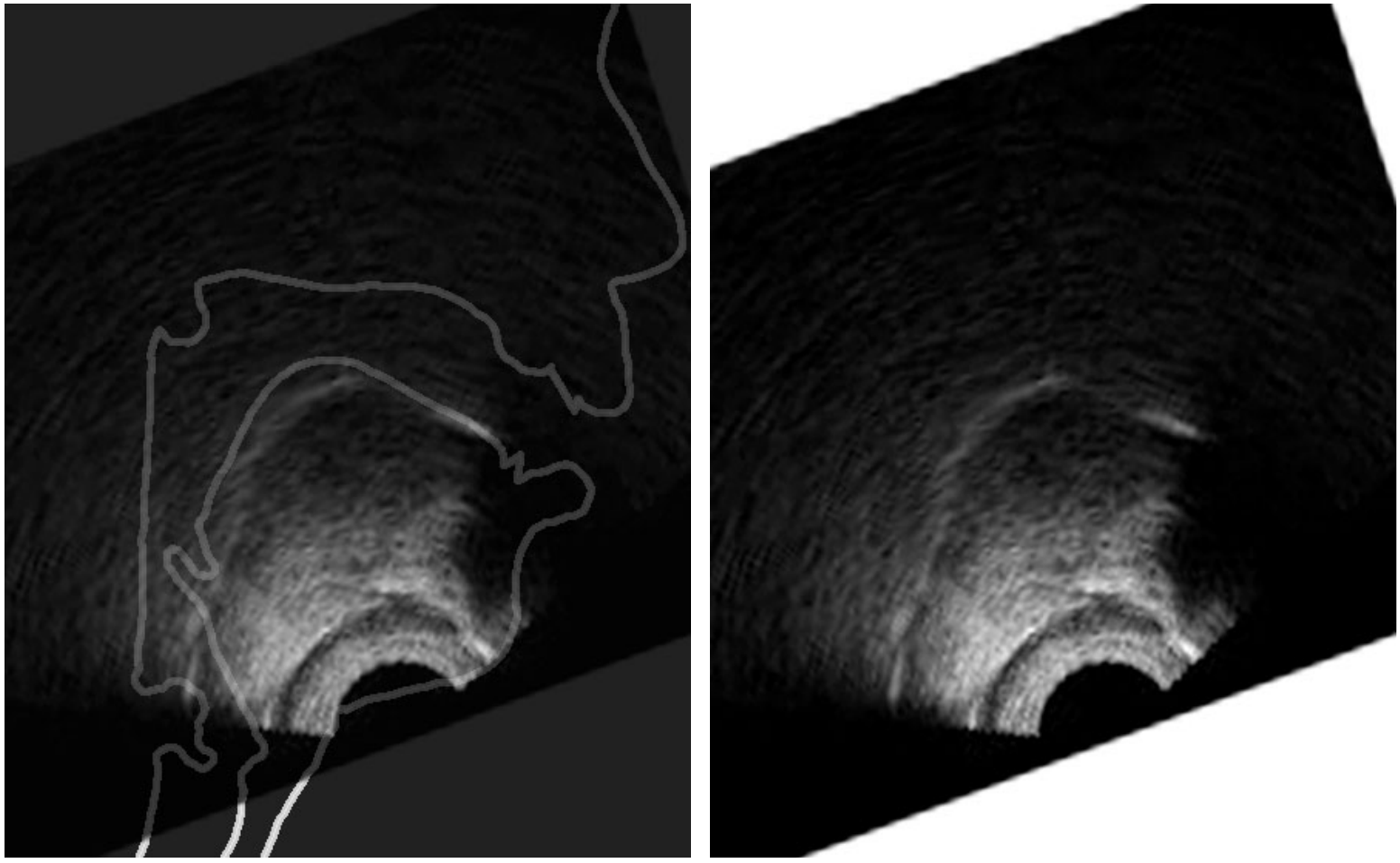
- Pre-speech articulation is interesting from several points of view, but analysing ultrasound videos manually is not great.
- In my thesis I concentrated on timing of utterance onset in both acoustics and articulation (Palo 2019).
- The data was high-speed tongue ultrasound from a delayed naming experiment – specifically one using the Rastle instructions (Rastle et al. 2005).
- 2D ultrasound has good time resolution: 80-120 fps in today's examples.



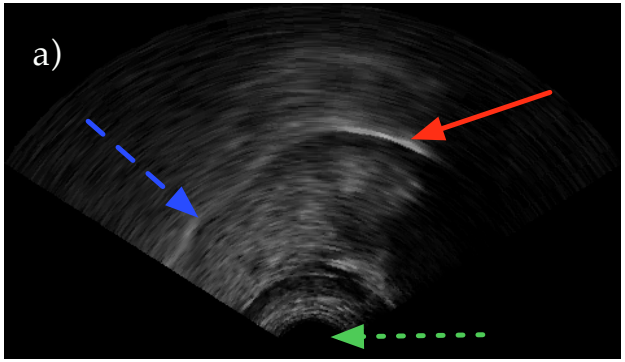
Introduction: The why

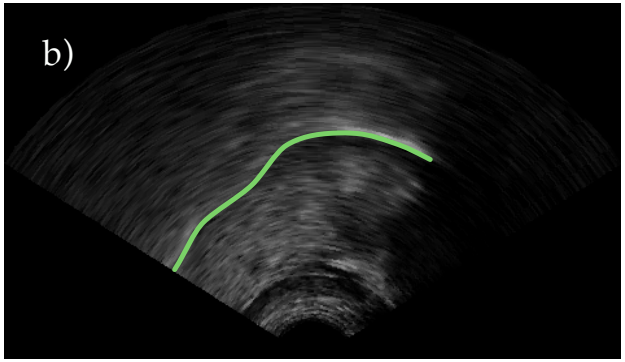
- When trying to identify movement onset in greyscale videos with a lot of speckle 'noise', it doesn't take long to grow a desire for an easier way.
- The speckle 'noise' maybe caused by a number of factors including bubbles in the acoustic gel between the chin and the probe, and more interestingly changes in internal structures of tissues – such as muscle fibres tensing and relaxing.

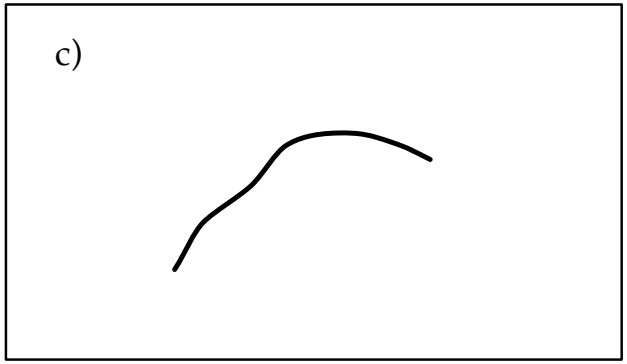
What is being imaged by tongue ultrasound?



Where is the tongue?



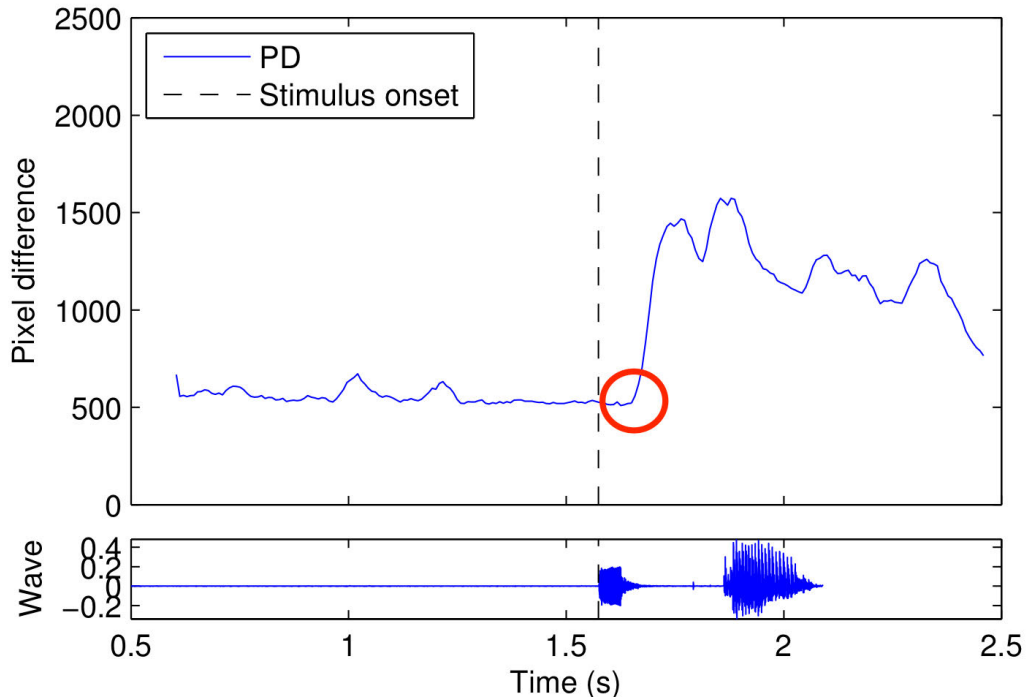




Pixel Difference (PD)

- The first tool out of the box happened to work adequately – and so for my thesis I used Euclidean distance or $l2$-norm to identify articulatory onsets:

$$l2(t+0.5) = \sqrt{\sum_{i,j}(x(i,j,t+1) - x(i,j,t))}$$



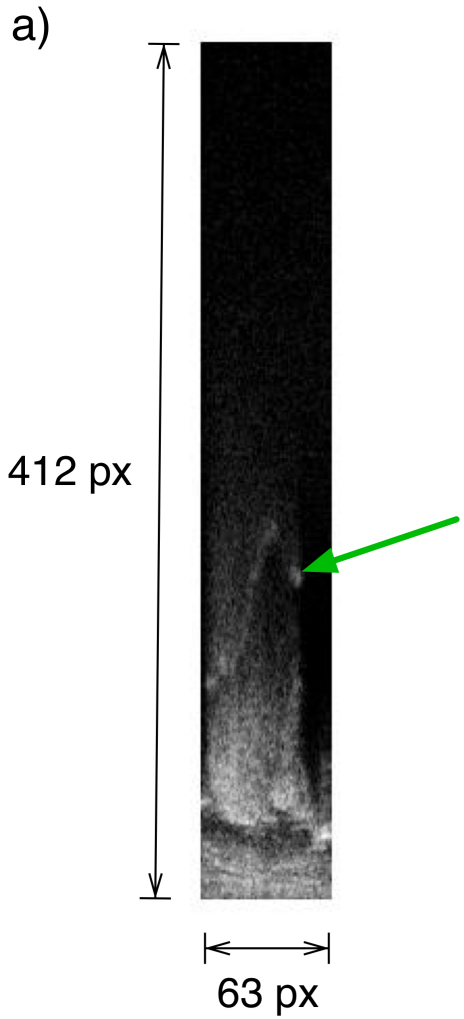
Background of PD

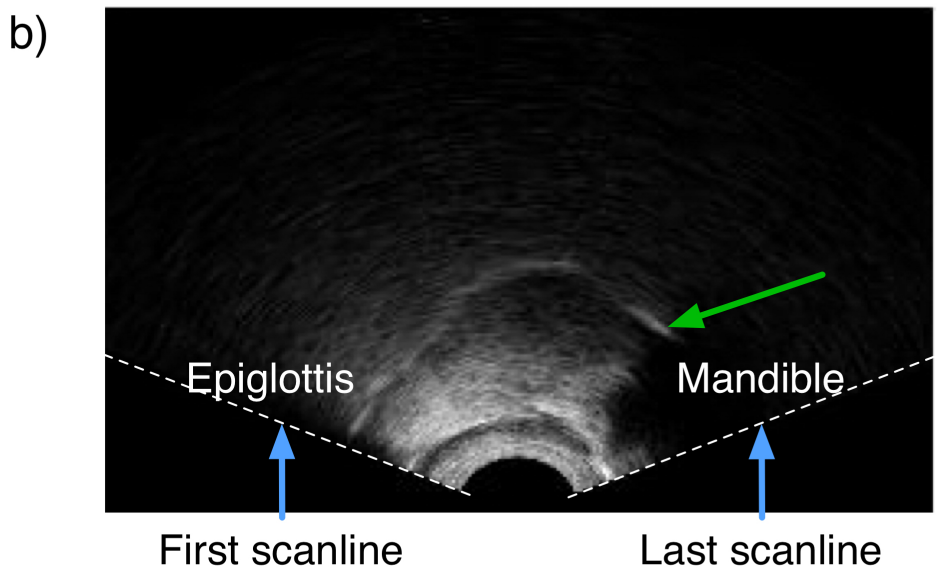
- The analysis methods presented here are similar to methods developed by
  - McMillan and Corley (2010), Drake et al. (2013) who used Euclidean distance on ultrasound frames and
  - Raeesy et al. (2011) who used a similar method on MRI data.

TODO: - get framerates for all data - get point numbers for splines - proof read each slide as typeset

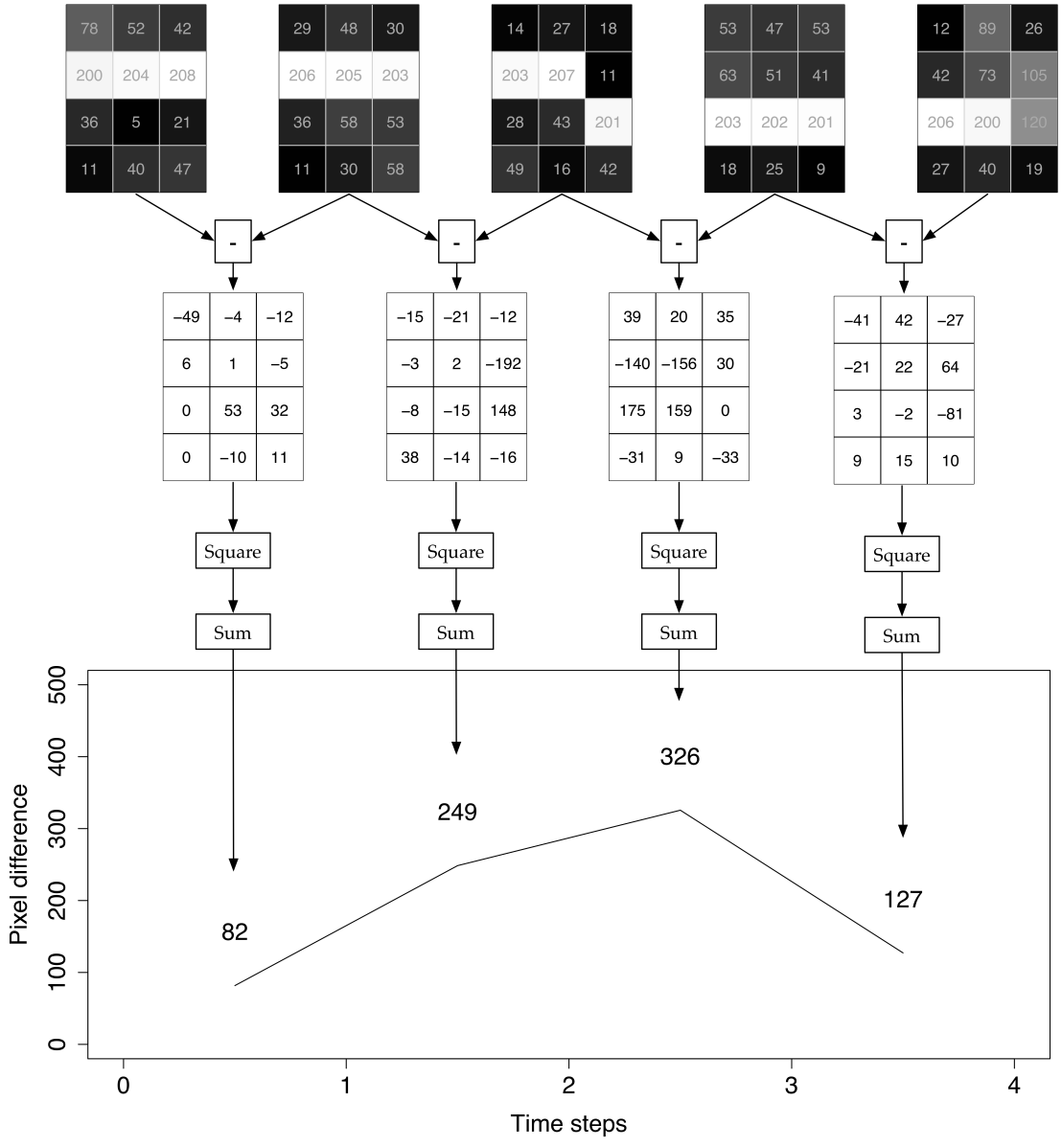
Pixel Difference (PD)

- PD is usually calculated on uninterpolated (probe-return) ultrasound data (a) as opposed to interpolated (human-readable) data (b).





Pixel Difference (PD)

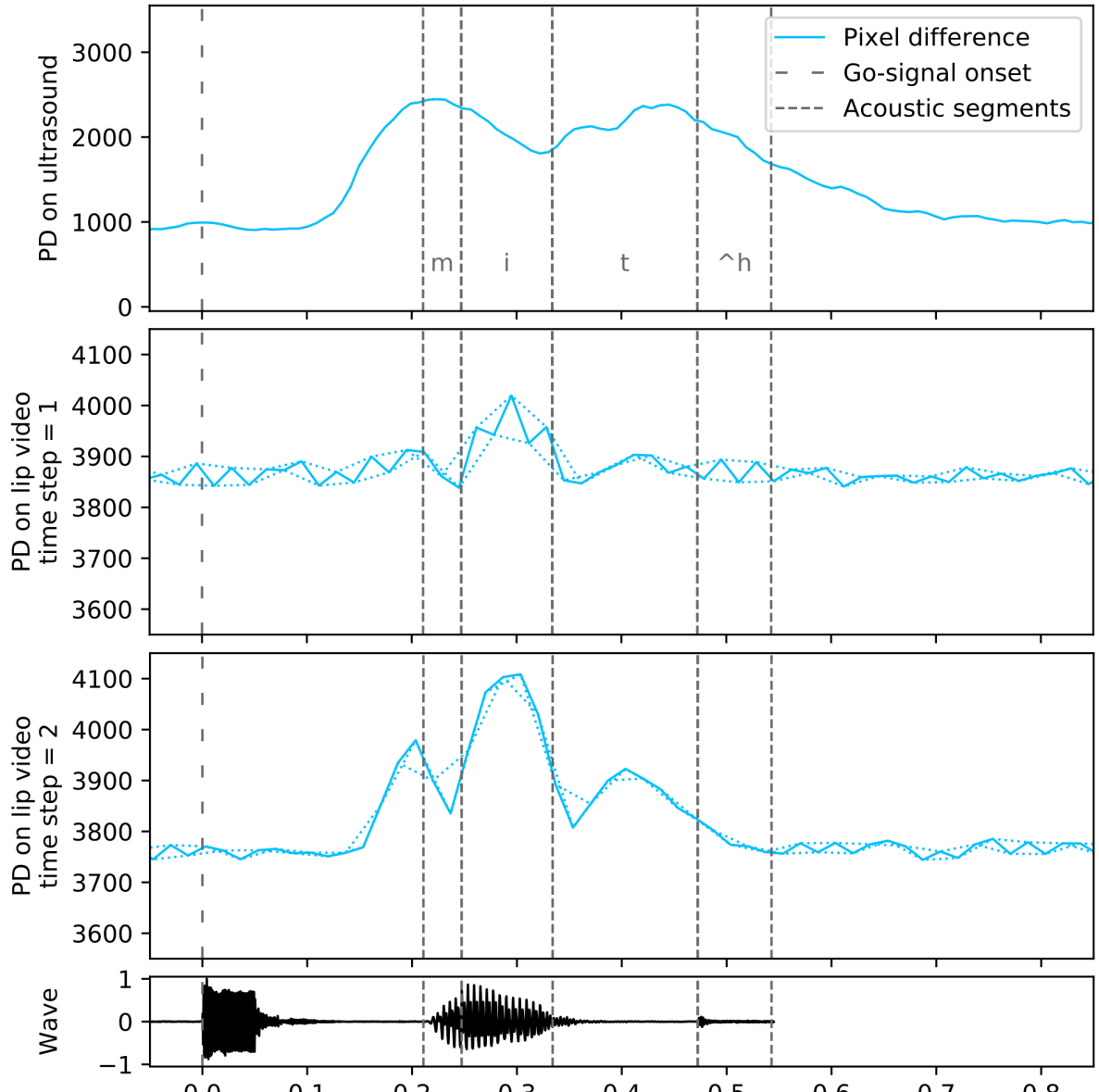


Introduction: The how

- de-interlaced video and the zigzag: time steps
- splines and the sparseness of the data
- PD on ultrasound and time resolution
- Choosing a metric

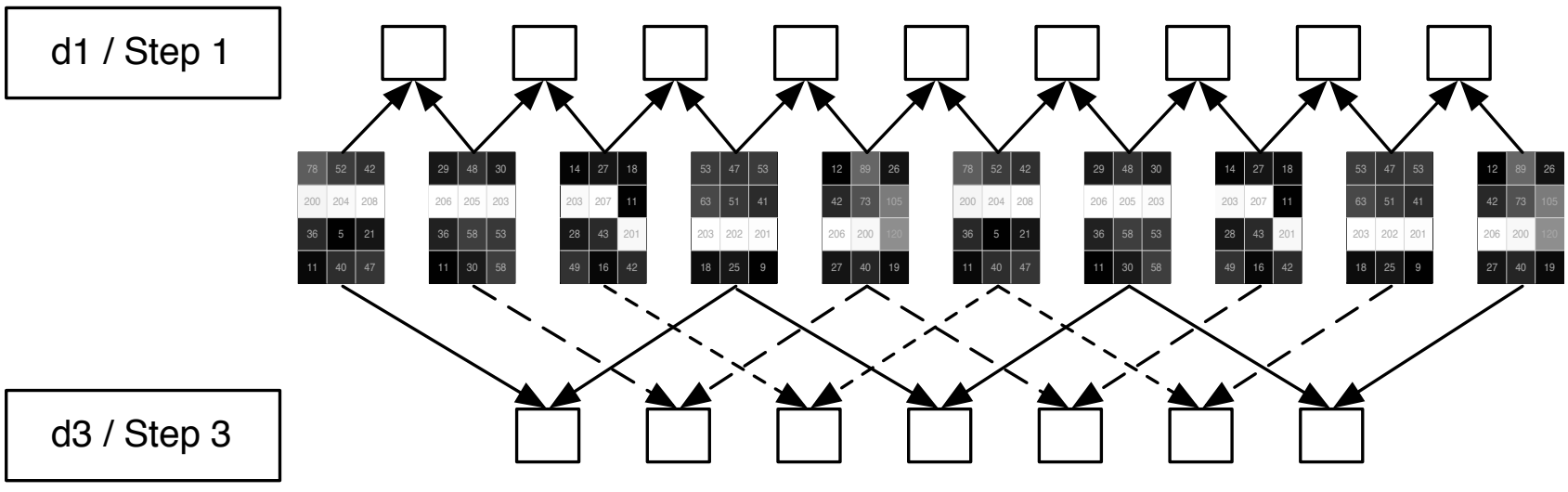
PD on de-interlaced videos

Lip video with camera attached to the ultrasound helmet.
De-interlaced at 59.94 fps.



PD on de-interlaced videos

Taking a different time step:



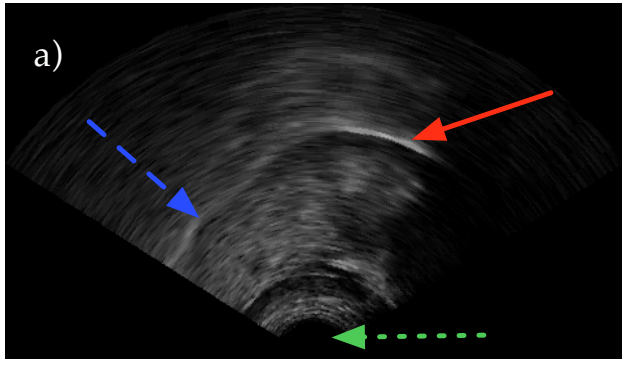
Tongue splines and problems from sparseness

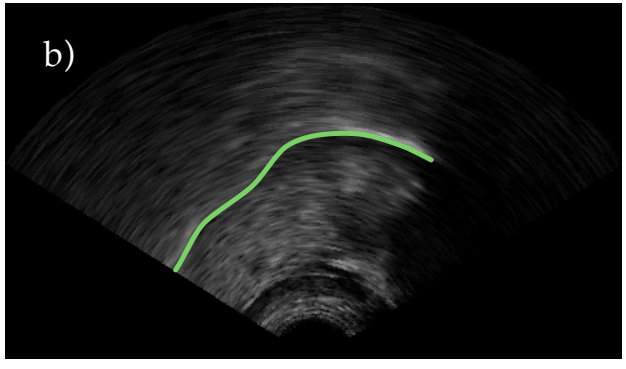
Raw ultrasound:

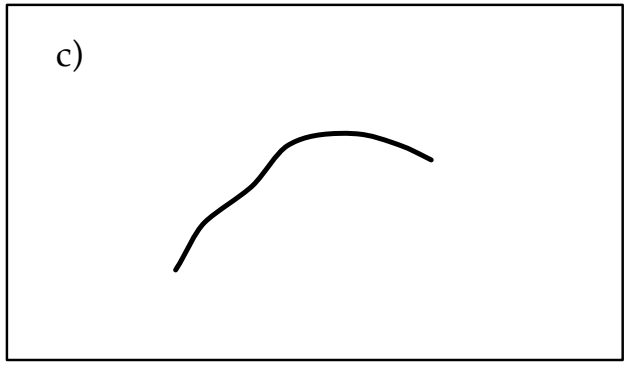
- Typically on the order of 10k pixels per frame, today 63x412 pixels per frame.
- Individual pixel's fluctuations get averaged out.

Tongue splines:

- Typically on the order of 30-50 control points per frame, today 42 control points per frame.
- Individual point's fluctuations may end up driving the data.

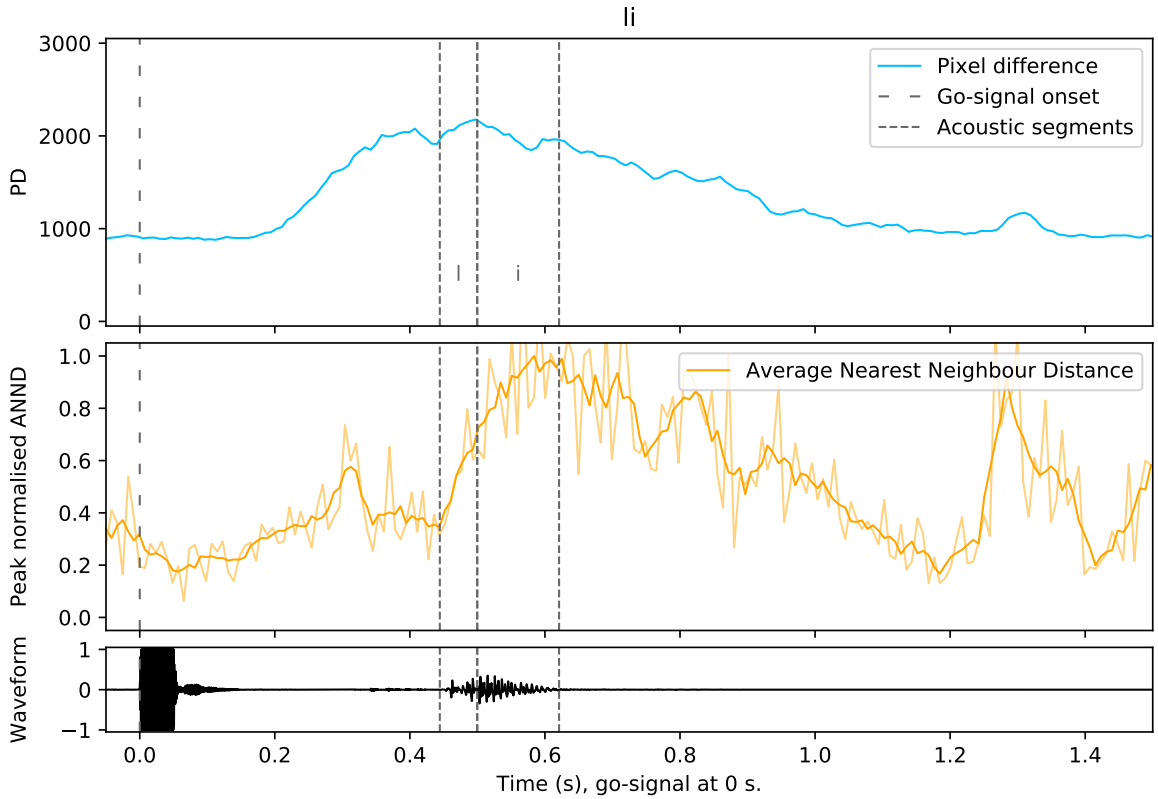






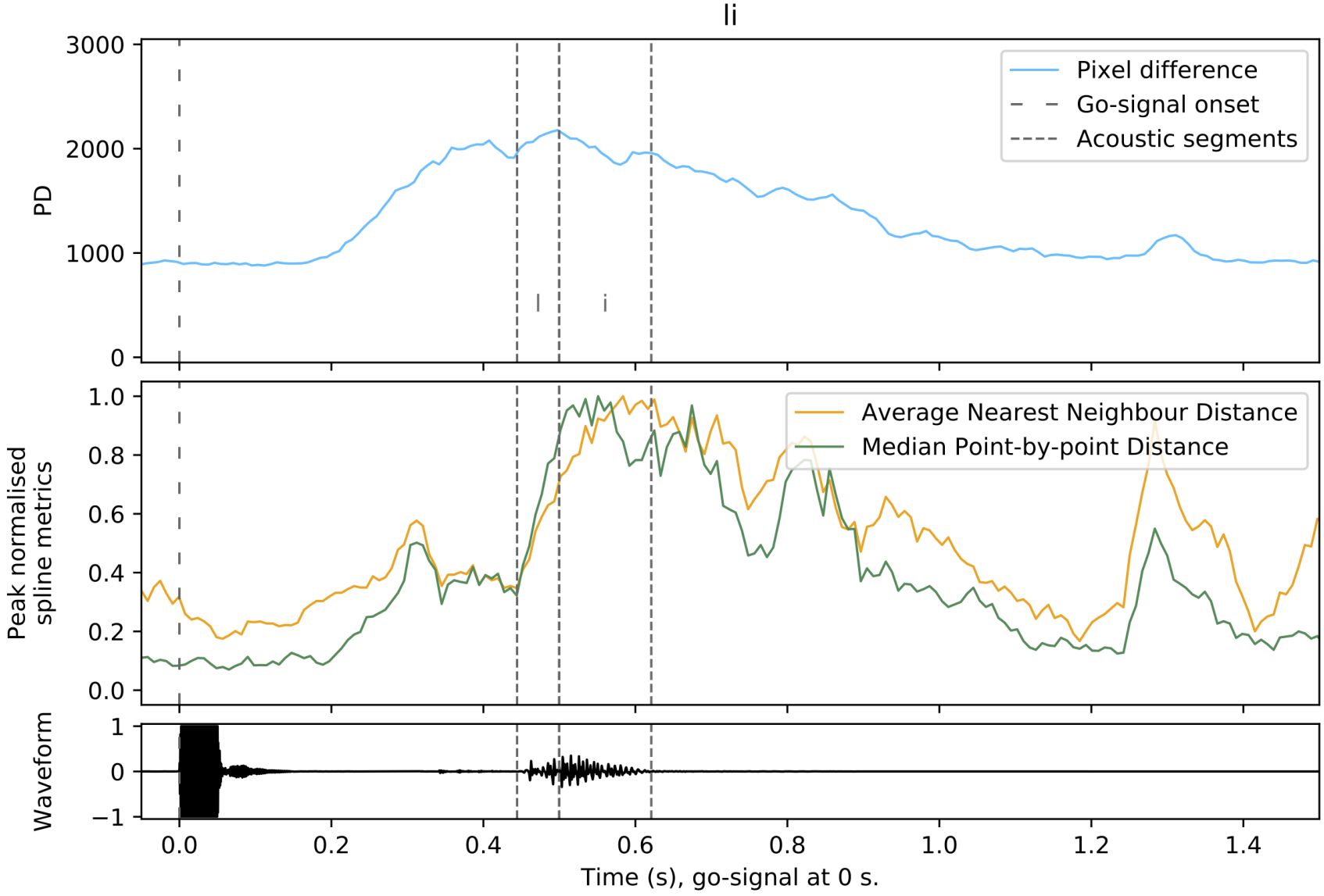
Tongue splines and problems from sparseness

- Longer time step and averaging improve the results.
- Here and in the next slide ANND (Zharkova and Hewlett 2009) and MPBPD (Palo 2020) have been calculated with time step 3 and smoothed with a moving average filter with a 5 frame window.



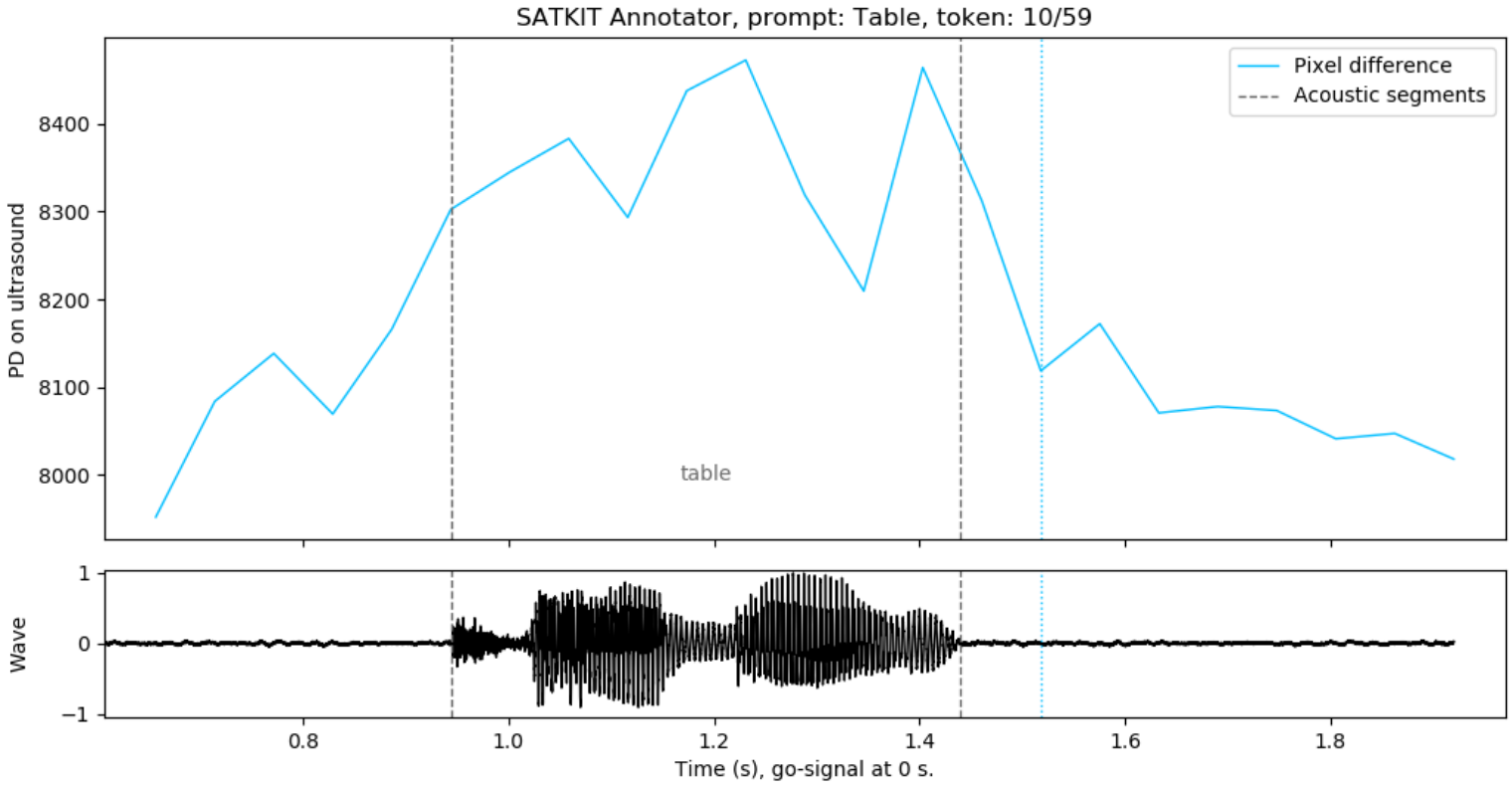
Tongue splines and problems from sparseness

- Choice of metric can help, but not with everything.

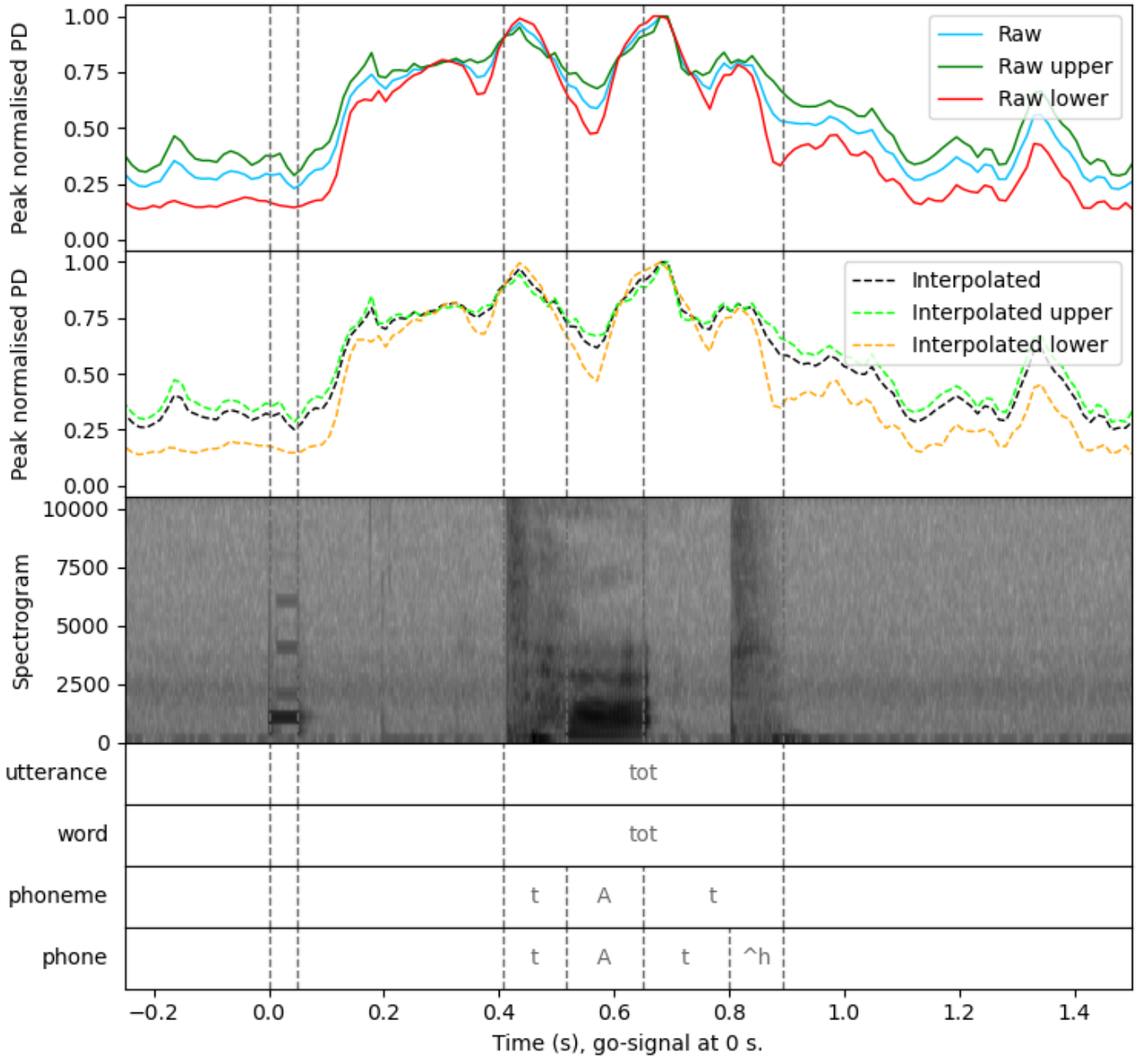


3D/4D ultrasound

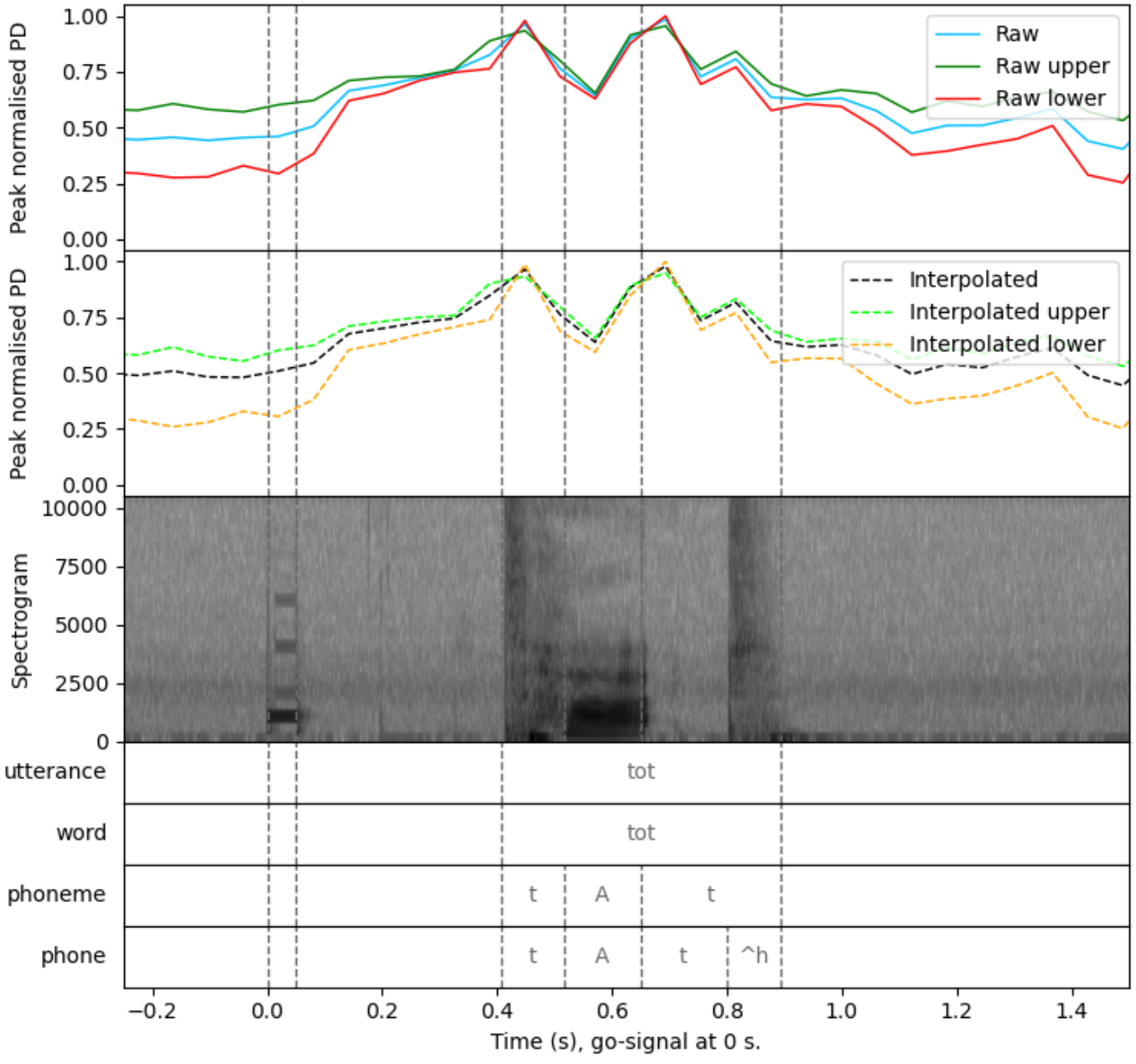
- Capturing a 3D frame takes a lot longer and we only have access to interpolated data.
- The images are always interpolated.
- In analysis even on good (lucky) samples onset and gesture recognition becomes difficult.



PD on Raw vs Interpolated 2D data



PD on data with artificially lowered frame rate



In the works: Choosing the metric for PD

- PD has so far usually been calculated as the Euclidean distance or $l2$-norm.
- We've recently been looking at principled ways of selecting the norm for a given data source – such as 2D ultrasound – from the different lp-norms where $p \in]0, \inf[$.
- It looks like the optimal norm for 2D ultrasound is $l1$ (or close to it):

$$l1(t + 0.5) = \sum_{i,j} |x(i, j, t + 1) - x(i, j, t)|$$

So how about MRI then?

- Frame rate can be a problem.
- If there are systematic changes frame-to-frame caused by the imaging and reconstruction these may show up in PD analysis.
- Best way to get ahead with using PD for analysis would be to get a small pilot sample and run the basic version on it: $l2$ or $l1$-norm, time step $= 1$, no smoothing.
- Apply larger time steps and smoothing if needed.
- Test different norms and/or look to different metrics all together.

References

Drake, E., Schaeffler, S., and Corley, M. (2013). ARTICULATORY EVIDENCE FOR THE INVOLVEMENT OF THE SPEECH PRODUCTION SYSTEM IN THE GENERATION OF PREDICTIONS DURING COMPREHENSION. In *Architectures and Mechanisms for Language Processing (AMLaP)*, Marseille.

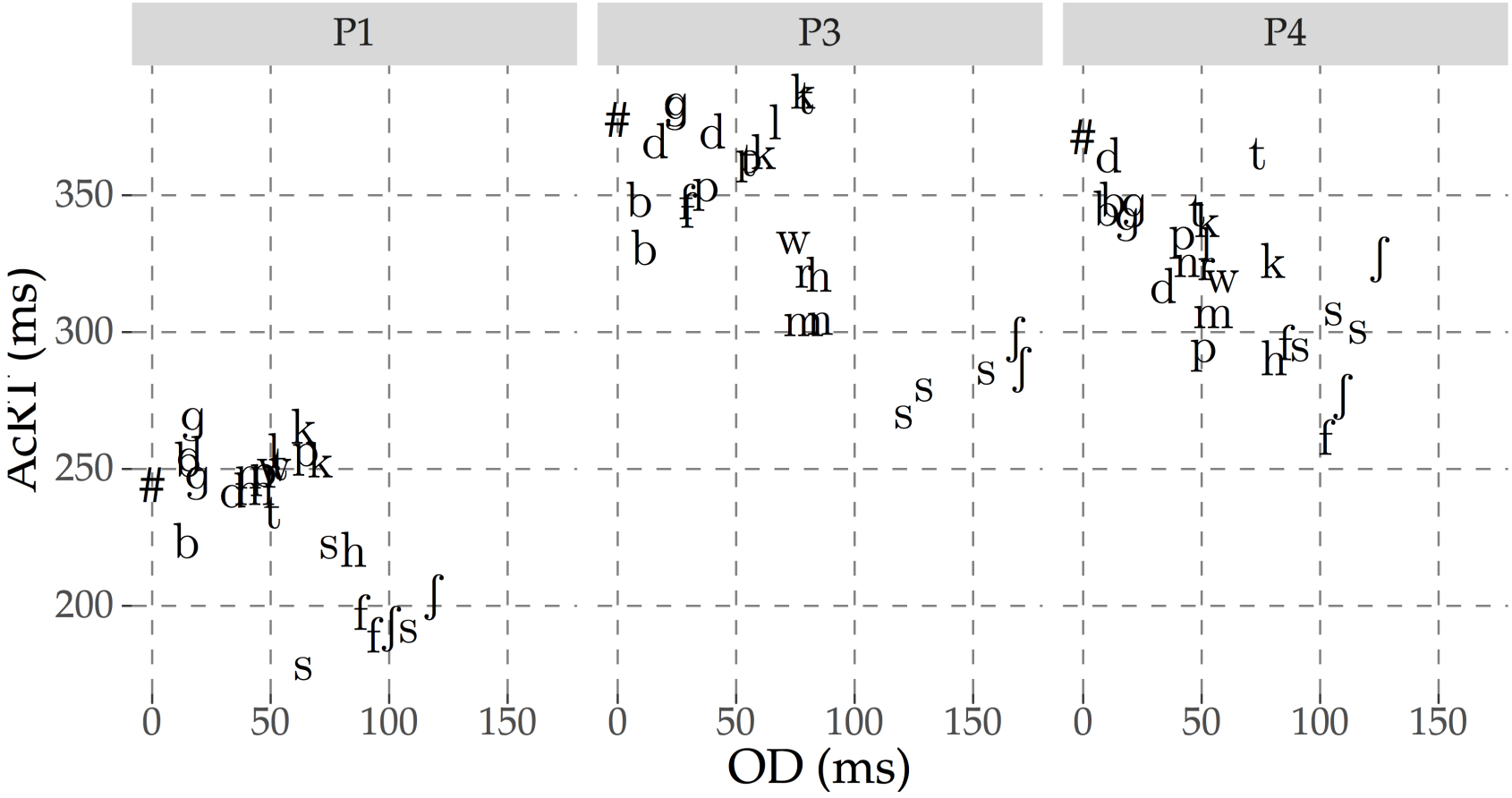
McMillan, C. T. and Corley, M. (2010). Cascading influences on the production of speech: Evidence from articulation. *Cognition*, 117(3):243–260.

Palo, P. (2019). *Measuring Pre-Speech Articulation*. PhD thesis, Queen Margaret University, Edinburgh.

Palo, P. (2020). Can we detect initiation of tongue internal changes before overt movement onset in ultrasound? In *Proceedings of the 12th International Seminar on Speech Production (ISSP 2020)*, pages 242–245, Online / New Haven, CT.

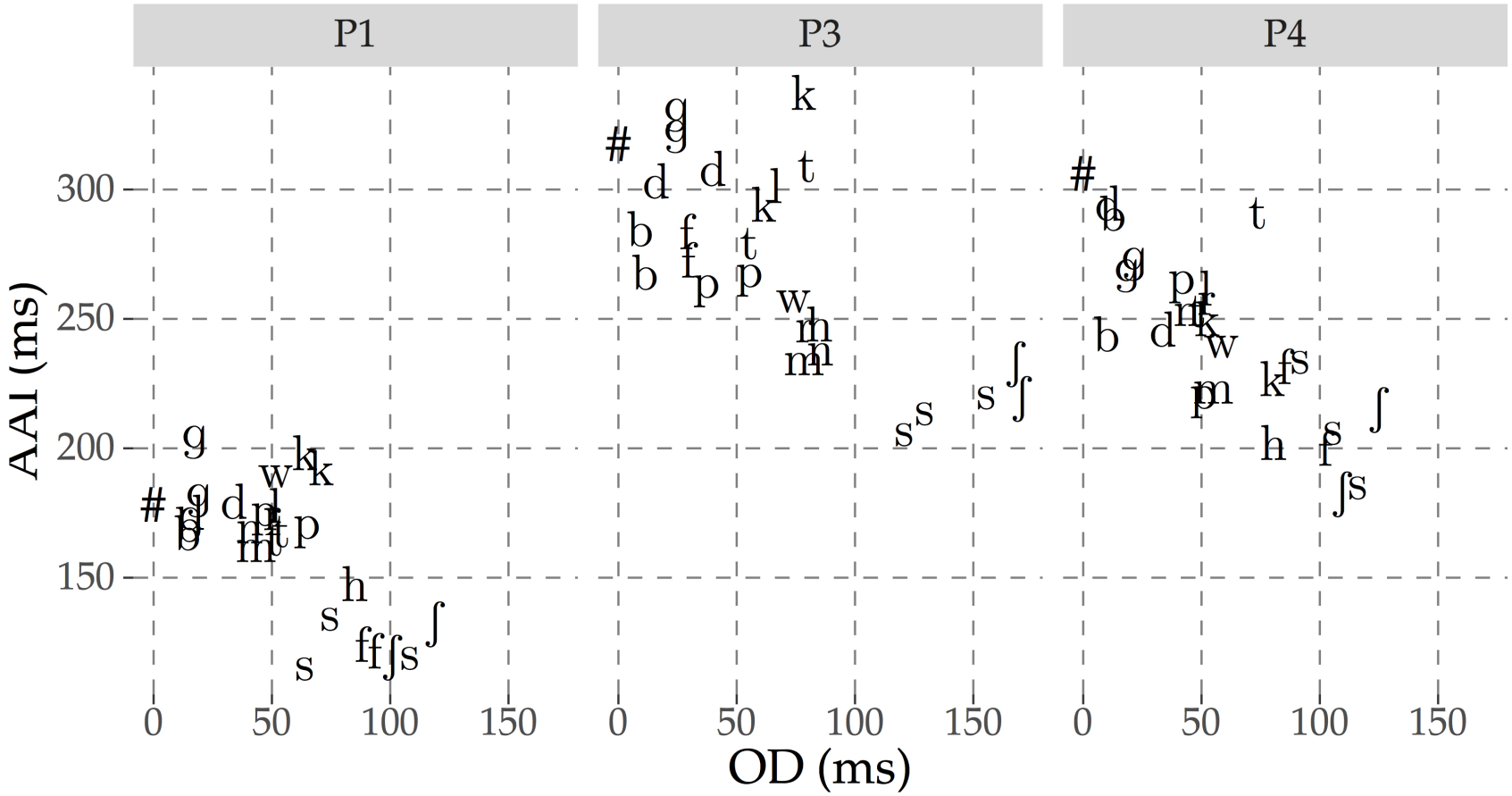
Extra material

Delayed naming results: Acoustics



Medianised within participant, over several repetitions and over the vowels /a,i,ɔ/. Over all analysable n = 1386: 439 from P1, 672 from P3, and 275 from P4.

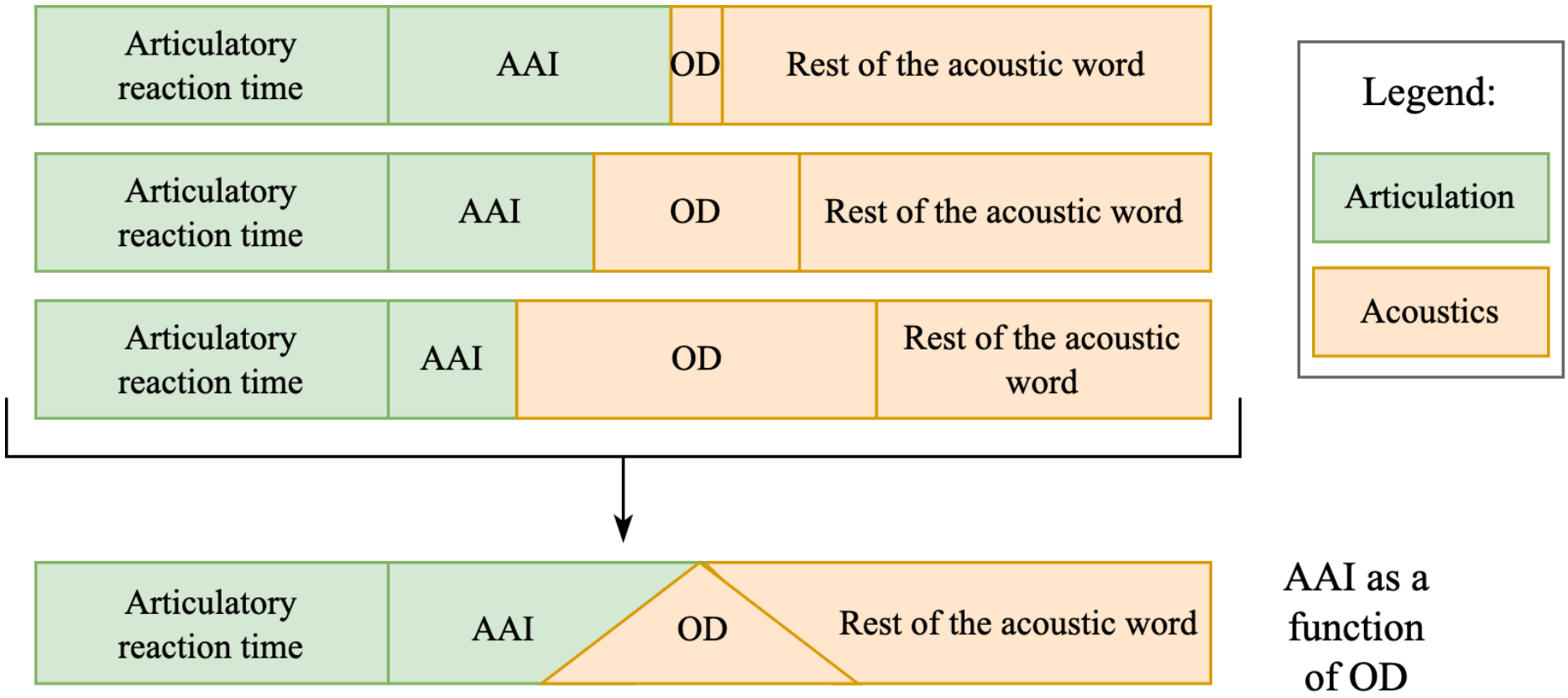
Delayed naming results: Articulatory to Acoustic Interval



Medianised within participant, over several repetitions and over the vowels /a,i,ɔ/. Over all analysable n = 1386: 439 from P1, 672 from P3, and 275 from P4.

Theory: Effect of OD on AAI

- As the Onset Duration (OD) gets longer, Articulatory to Acoustic Interval (AAI) shortens.
- First three lines represent individual utterances, final line is a conceptual model of the effect of continuously lengthening OD.6



Theory: Effect of articulatory rate on AAI

- If we keep the utterance content constant but vary articulation rate, all parts (AAI, OD, and acoustic word) get longer as articulation rate goes down.