

Analysis of the individual listening effort reflected by the pupillary responses during speech perception in noise

Patrycja Książek¹, Dorothea Wendt^{1,2}, Emina Alickovic^{1,3}, Thomas Lunner^{1,2,3}

¹Eriksholm Research Centre, Snekersten, Denmark ²Technical University of Denmark, Kgs. Lyngby, Denmark ³Linköping University, Linköping, Sweden

Introduction

Listening effort can be reflected in the enlarged pupil size. It has been found e.g. during speech perception in noise^{4,6} with use of commonly known measures such as the peak or mean pupil dilation.

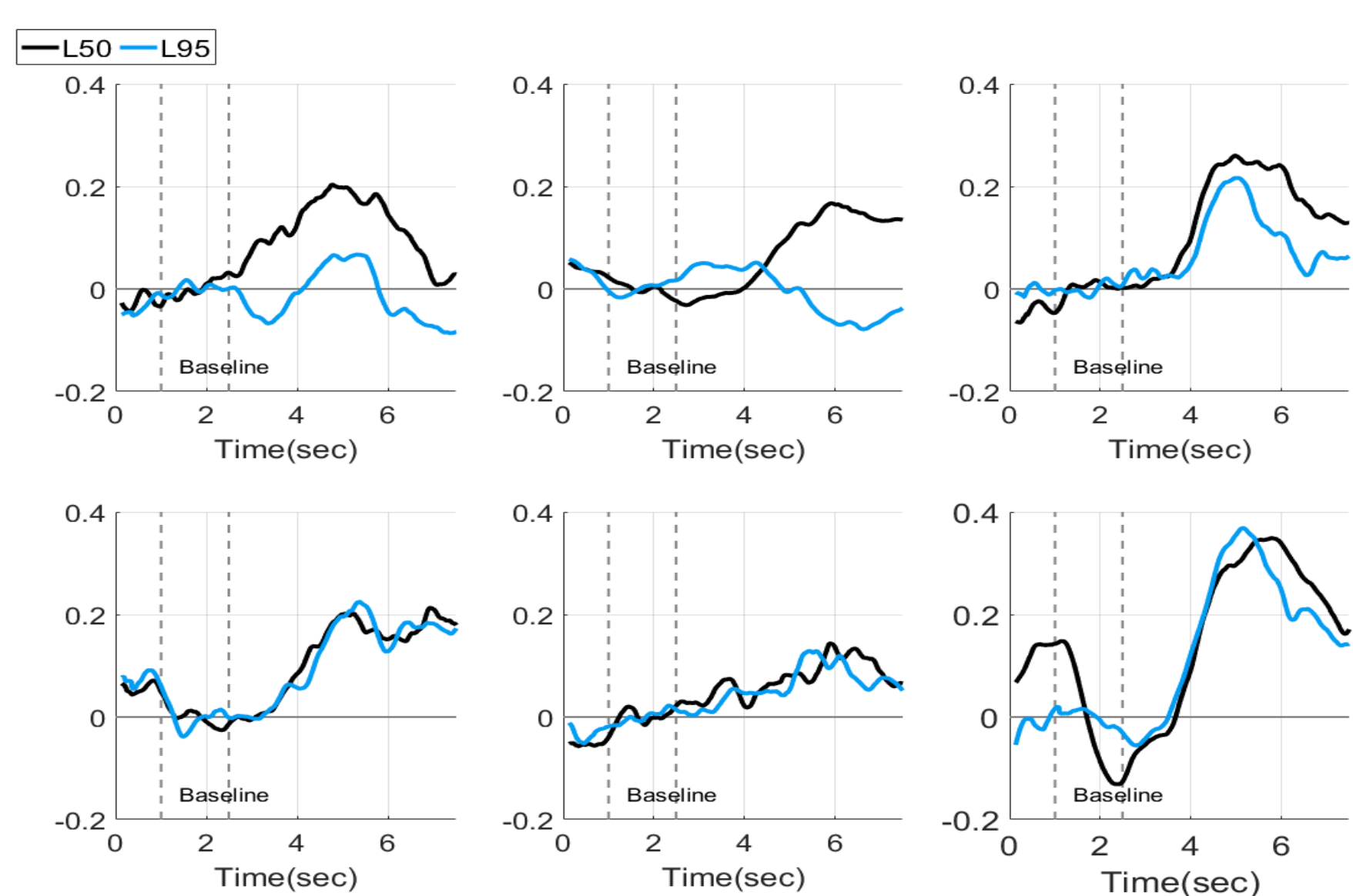
Recent pupillometry studies^{5,6} investigate further time-dependent aspects of the pupillary response through Growth Curve Analysis (GCA).

This study aims to classify the individual listening effort reflected in the pupil size based on the GCA outcome measures.

Pupillometry Data

Pupillary responses were recorded while listeners performed a Danish Speech-in-Noise test at either 50% or 95% correct recognition in a 4-talker babble⁴, divided into two independent data sets:

- Training (D1) – 22 listeners, 25 trials per condition,
- Test (D2) – 18 listeners, 25 trials per condition.

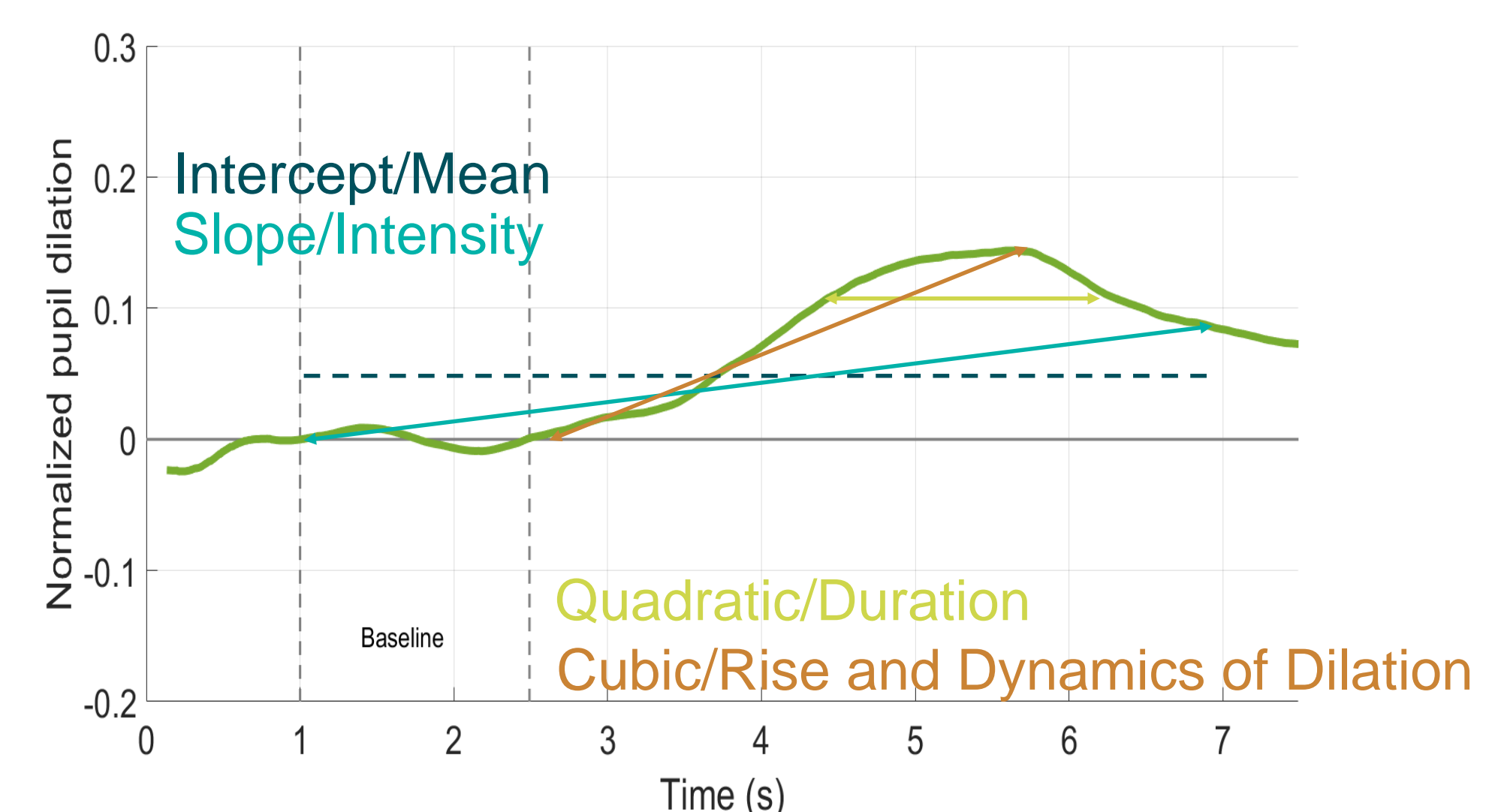


Examples of the individual pupil responses recorded during speech perception in noise test. Two tested conditions were L50 – Individual signal-to-noise ratio at 50% correct, L95 – Individual signal-to-noise ratio at 95% correct. Examples shown come from the test data set.

Methods Used to Classify Individual Listening Effort

Pupil Features

GCA based on the 3rd order polynomial model with varying intercept was used to extract relevant pupil features: intercept - 0th, slope - 1st, quadratic - 2nd and cubic - 3rd order polynomials⁷.



Additional features:

- Pupil Peak Dilation – maximum pupil size,
- Congruence – measure of alikeness between an individual response and the group average.

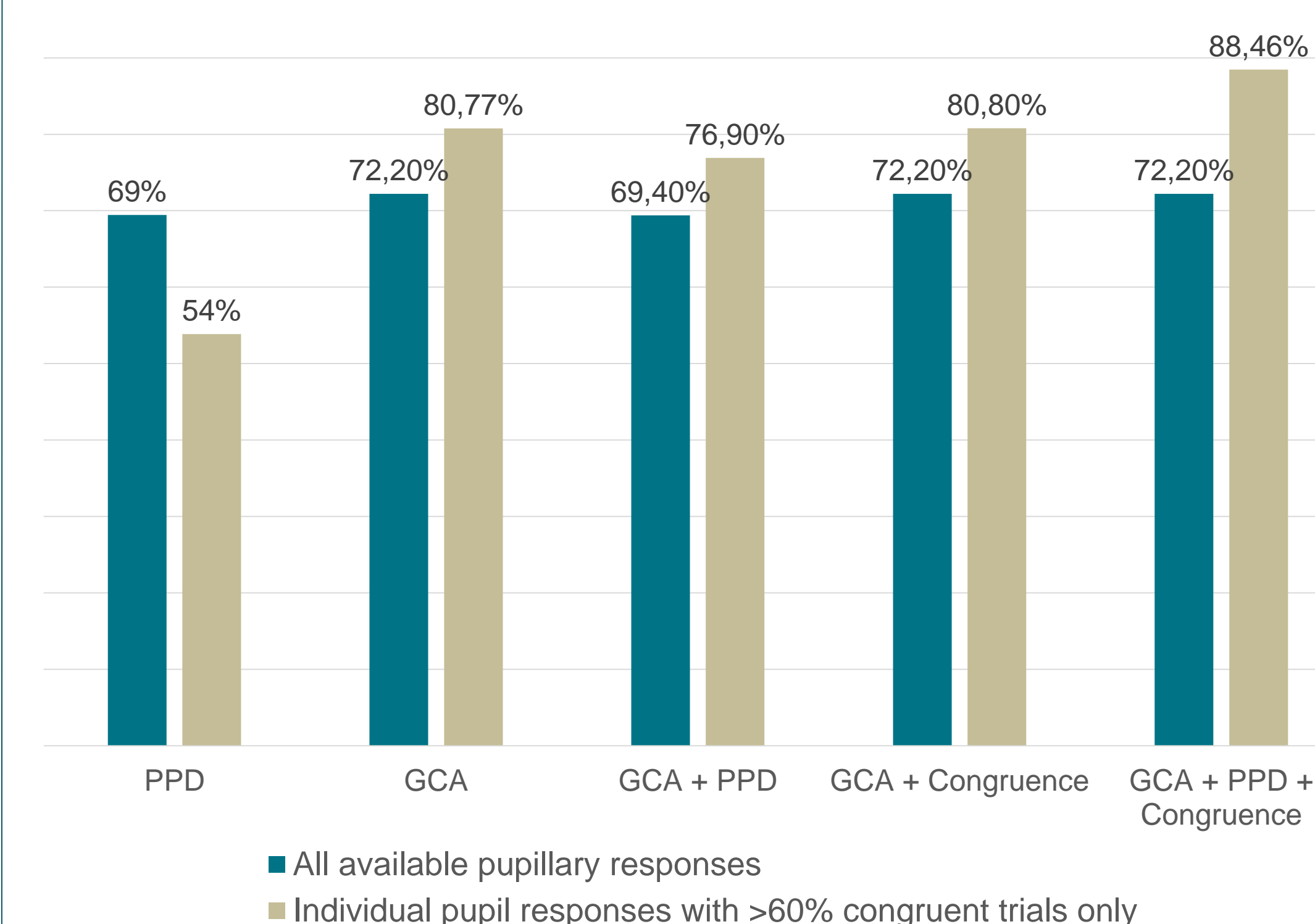
Classification Facts

1. Input: Pupil features – GCA, PPD, Congruence, Condition.
2. Output: Classification of the high/low effort pupil responses.
3. Performance Measure: Accuracy, Confusion Matrix
4. Classifiers: Decision Trees (DTs) trained on D1 and tested on D2.
5. Quality Assurance: Congruence was tested at the sentence level, where high/low effort examples were excluded from classification for <60% congruent trials. Thus, modified data sets were:
 - Training (D1m) – 17 listeners,
 - Test (D2m) – 14 listeners.

Results

Classification accuracy in detection high/low individual listening effort based on the pupillary responses.

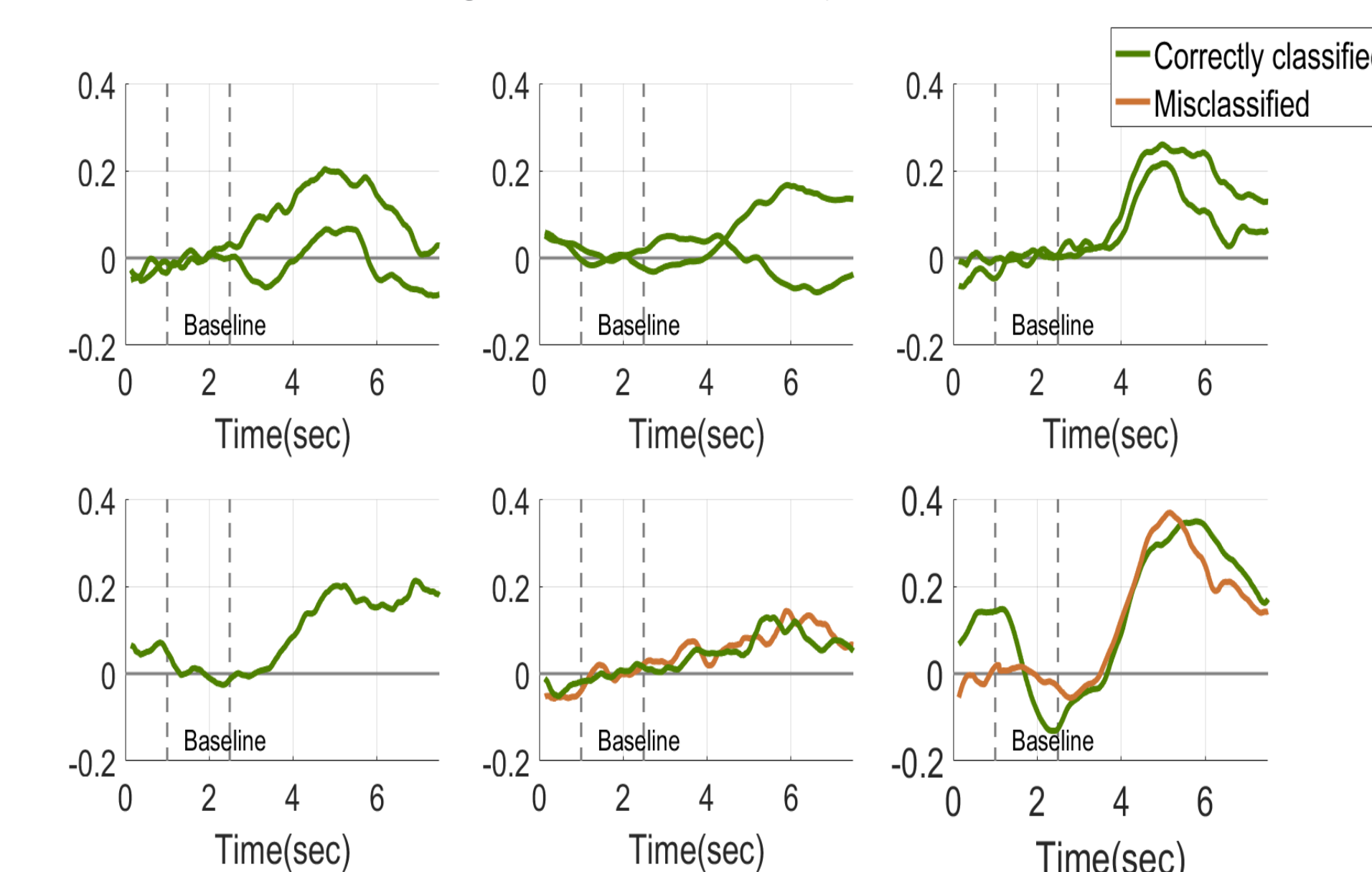
Accuracy of the Individual Low/High Effort Detection Based on Pupil Responses During Speech Perception in Noise Test



Most relevant pupil features are extracted with GCA. When combined with the additional features, DT correctly classifies 88.5% of the tested high/low effort examples. Figure shows a positive effect of the congruency analysis, which noticeably enhances classification accuracy.

| Example of → Classified as ↓ | High Effort | Low Effort |
|------------------------------|-------------|------------|
| High Effort | 15 (13) | 7 (2) |
| Low Effort | 3 (1) | 11 (10) |

Confusion matrix for the highest accurate classifier. () marks the classification results for pupil responses with >60% of the congruent trials only (D2m).



Examples of the classified pupil responses (D2m) with >60% congruent trials in the best tested scenario: GCA + Congruence + PPD. One of the removed in the congruence analysis responses is shown in the lower left plot. Misclassified examples are in here due to the indifferent pupil response in both condition as in the lower middle plot or the opposite pattern in the dilation per condition like it is shown in the lower right plot.

Conclusions

- GCA features are effective in quantifying individual listening effort during speech perception in noise task.
- Combined with the other pupil features, they classified 88.5% of the high/low effort examples correctly.
- Congruence analysis improves high/low individual listening effort classification up to 17%.

References

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- ⁶Kuchcziński, S. E., Ahlstrom, J., Jr, K. V., Cüte, S., Hulmes, L. E., Dubino, J., and Eckert, M. (2013). Pupil size varies with word listening and response selection difficulty in older adults with hearing loss. *Psychophysiology*, 50:pp. 23–34.
- ⁷Książek, P. (2017). Statistical Modelling of Pupil Curves to Quantify Differences in Processing Effort on Group- and Individual- Level. Master Thesis supervised by Wendt D., Lunner T., Technical University of Denmark. Available on request.



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