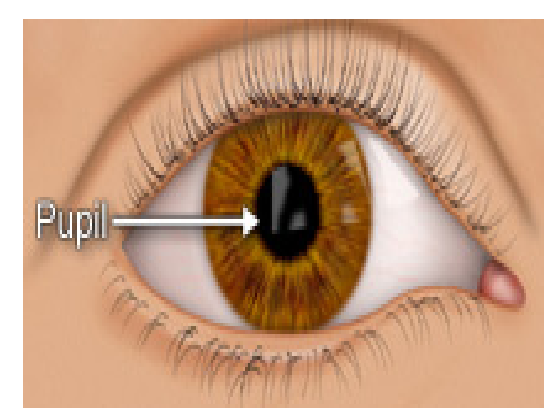


## BACKGROUND

- Pupil size widely used to investigate cognitive processing e.g., short-term memory (Kahnemann & Beatty, 1966), affective processing (Hess & Polt, 1960), and language processing (Just & Carpenter, 1993).



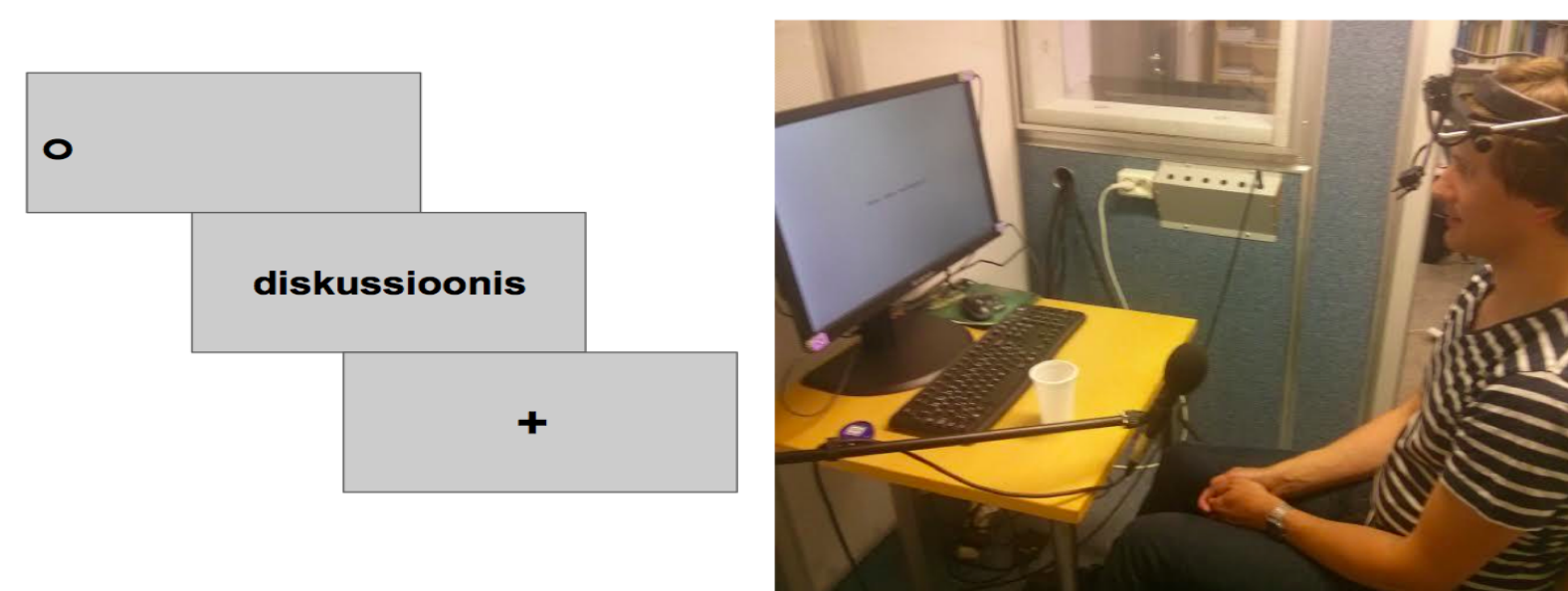
- The frequency of word occurrences a strong predictor of lexical processing across modalities and experimental paradigms (see e.g., references in Baayen et al. 2016).
- Only a few studies with pupillometry in lexical processing (Kuchinke et al. 2007 ==> infrequent words triggered stronger pupil responses).
- Most studies presuppose similar kind of effects on pupil response across all participants.

## RESEARCH QUESTIONS

- Does pupil size reflect lexical processing during a word naming task? If yes, what is the time-course of the frequency effect?
- Is the effect the same for each individual participant?

## METHODOLOGY

- Participants:** 31 speakers of Estonian (18 women; 22-69 years; mean age 38).
- Items:** 2,800 Estonian case-inflected nouns, 400 words in each list.
- Apparatus:** Table-top microphone, Eyelink II head-mounted eye tracker.

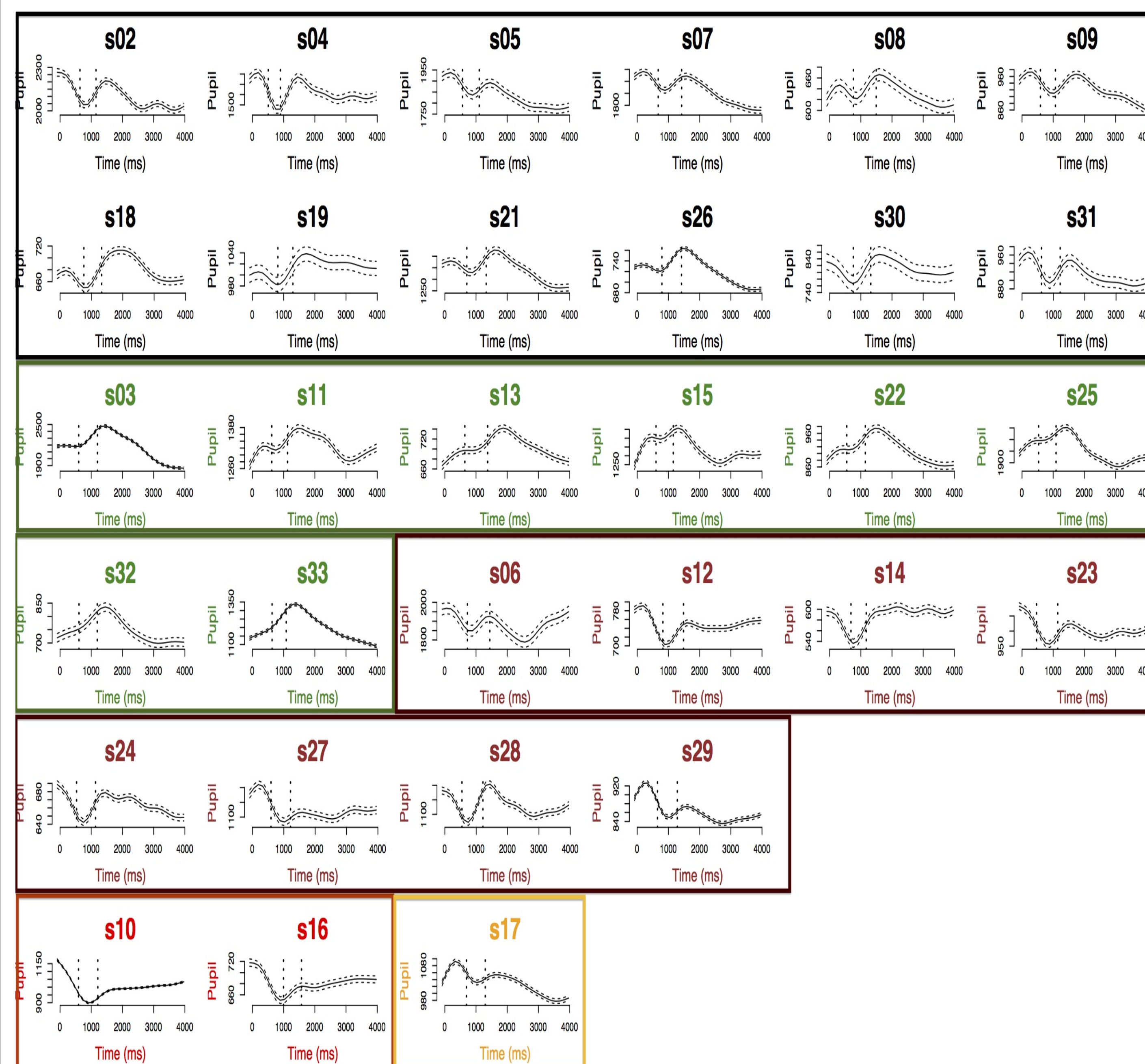


- Procedure:** Reading aloud single words appearing on the screen one by one.

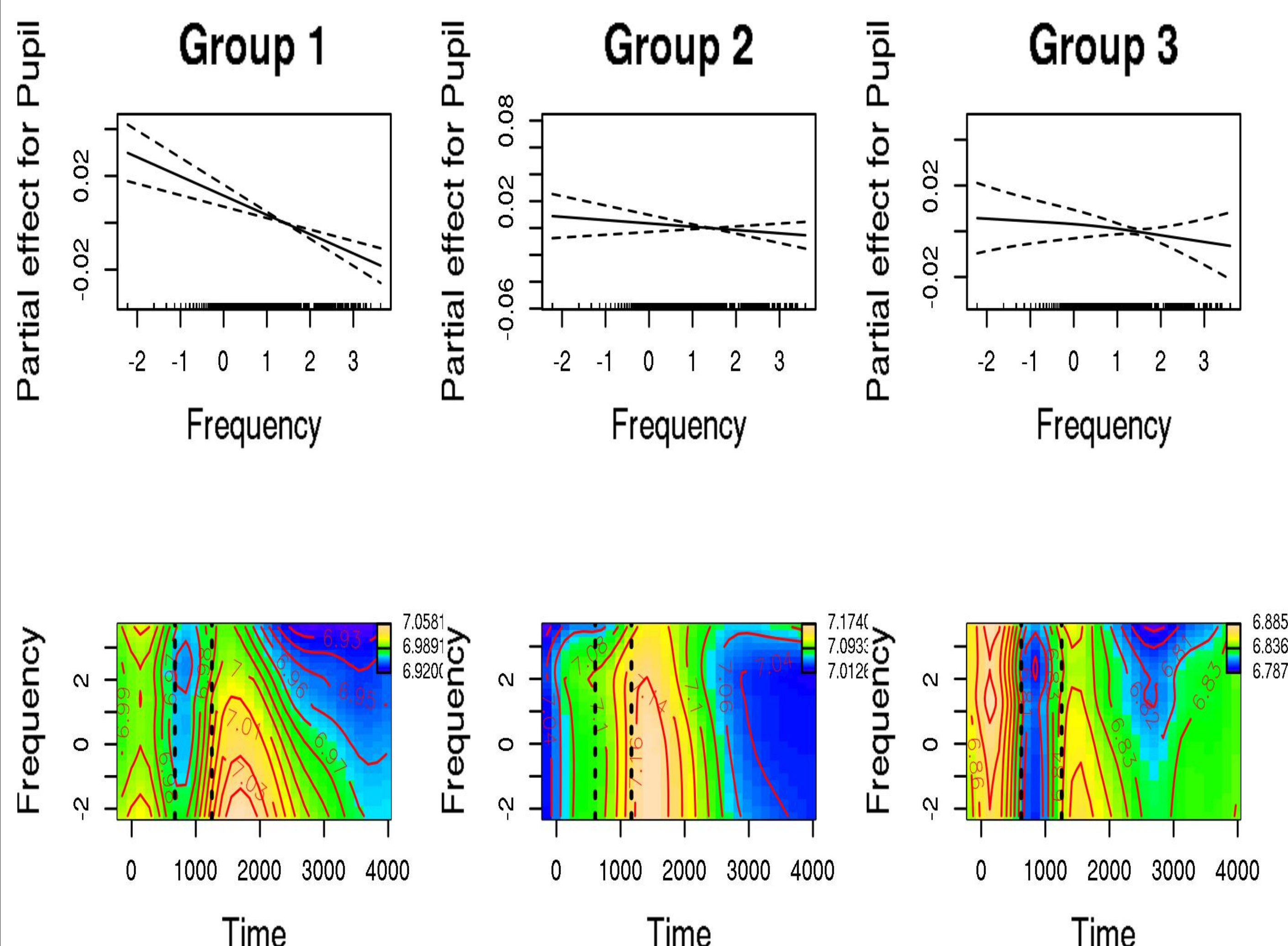
## ANALYSIS

- Generalized additive mixed effects regression modelling (GAMM, Wood 2006).
- For each participant, a GAMM to the 400 time series of the pupil values was fitted; a hierarchical clustering algorithm was developed to group participants (see Figure 1).
- For the three largest groups, a GAMM with Frequency as the main effect and Frequency and Time interaction was fitted (see Figure 2).

## RESULTS



**Figure 1:** Time smooths for 31 subjects (the first dotted vertical line indicates the median articulation onset; the second line the median articulation offset).



**Figure 2:** The partial effects of Frequency (the upper panels) and the tensor product smooth for Frequency and Time for three subject groups without random effects.

## RESULTS

- Key events reflected in group discrimination: **onset of stimulus; onset of articulation; offset of articulation.**
- Group 1** reveals early and late frequency effects; a **significant main effect** of Frequency ( $t(89884.6)=-4.93$ ;  $p$ -value < 0.0001) and a **nonlinear interaction** with Time ( $F(14.02, 896425.4)=8.72$ ;  $p$ -value<0.0001);
- Group 2** shows no frequency effects; **no main effect** of Frequency ( $F(1, 578743.7)=1.17$ ;  $p$ -value=0.28) and the vertical contour lines indicate that the **significant interaction** ( $F(15.034, 578743.7)= 9.90$ ;  $p$ -value <0.0001) is mostly modulated by Time.
- Group 3** shows only late frequency effects; also **no main effect** of Frequency ( $F(1.255, 591182.6)=8.95$ ;  $p$ -value=0.42), but a **significant nonlinear interaction** after the speech onset ( $F(14.388, 591182.6)=7.52$ ;  $p$ -value <0.0001).

## DISCUSSION

- Participants have various **reading strategies**: some processed words carefully before speaking them out, others only do it as they speak.
- Further research is needed to determine whether these individual differences in pupil responses might be due to **shallow reading** vs. **reading for meaning** (see e.g., Kuperman & Van Dyke 2011).

## CONCLUSIONS

- Pupil size is sensitive to lexical processing.**
- Participants are still **engaged** with the words long **after speech offset.**
- Looking at **individual/group pupil curves** as opposed to averaging across all participants offers interesting information on individual differences.

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