Pupil dilation, as a continuous measure of listening effort during sustained attention to competing talkers

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1. Introduction

Communicating in realistic listening environments often requires people to continuously attend to a particular talker. When acoustic demands increase (e.g. at a crowded bar), listeners must exhibit greater effort to track a target talker *(Zekveld et al. 2018)*. Listening effort may furthermore be exacerbated in individuals that experience declines in auditory and cognitive function, such as older adults *(Zekveld et al. 2011)*.

Research aims and hypotheses:
We aimed to measure pupil dilation, which has been used as a physiological measure of effort *(Winn et al. 2018)*, to quantify listening effort during naturalistic speech processing in varying signal-to-noise ratios (SNR).

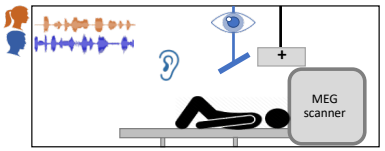
1. Pupil size ↓ when listening familiarity ↑ (e.g. repeated listening) to the same speech stimulus
2. Pupil size ↑ when task difficulty ↑
3. Pupil size ↑ for older versus younger (aging) individuals

2. Methods

Participants
- 19 younger adults (17-26 years); 16 older adults (65-78 years)
- Both groups have normal hearing (125-4000 Hz thresh. ≤ 25 dB HL)

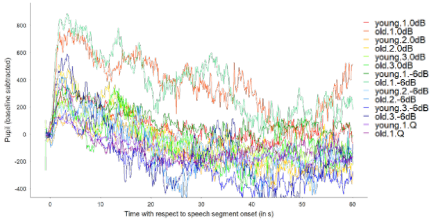
Task:
- Repeated listening of 60-s audiobook segments (trials), presented at 70 dB SPL
- Attend to male/female speaker (ignore the other one)
- Clean speech (1 trial); Mixed speech (3 trials, at each of two SNRs) (male vs female speaker: 0 dB, -6 dB)
- Randomized block design across participants

Set-up:
Pupillometry (EyeLink, 1kHz) and Magnetoencephalography
(visit poster 71 for MEG results)



Pupil analysis:
- Eyeblinks removed and then downsampled to 10 Hz
- Remove trials if
  - > 60% of baseline data missing
  - > 45% of task data is missing
- Baseline subtraction (median of 1 s before onset)

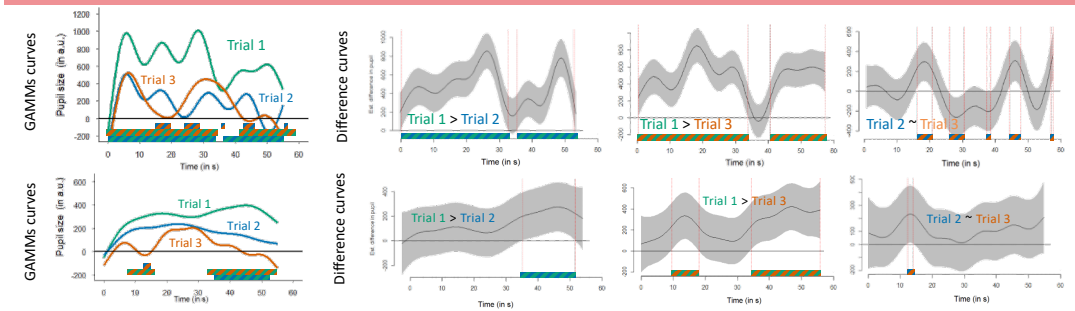
Raw pupil dilation curves for all conditions across time



General additive mixed models (GAMMs) have several advantages over linear mixed-effect models *(Soskuthy, 2017; van Rij et al., 2019; Wieling, 2018))*:
- model non-linear patterns without predefining the number of polynomials
- an Auto-Regressive model with immediately preceding value (AR1) can correct for the autocorrelation in the data
- allows a study of the significant time windows

3. Results

Pupil dilation across time - **Hypothesis 1: Repeated trials: pupil size ↓**

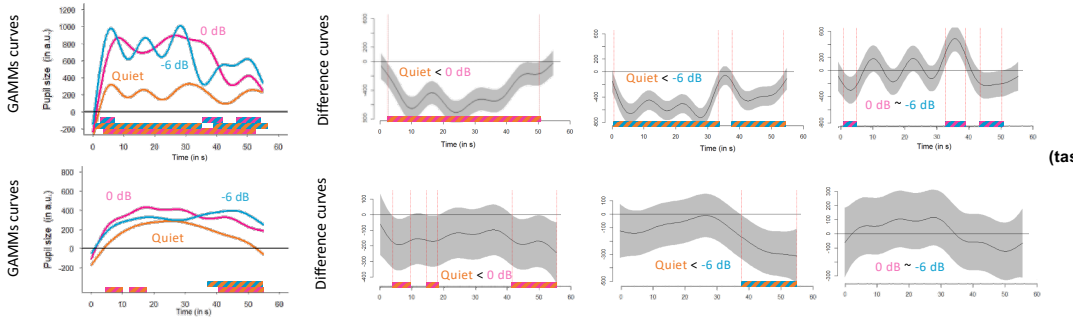


Younger adults / -6 dB
Trial 1 > Trial 2 & 3
Trial 2 ~ Trial 3

Pupil size ↓ with repeated listening (trial effect diminishes with age)

Older adults / -6 dB
Trial 1 > Trial 2 & 3
Trial 2 ~ Trial 3

Pupil dilation across time - **Hypothesis 2: Task difficulty: pupil size ↑**

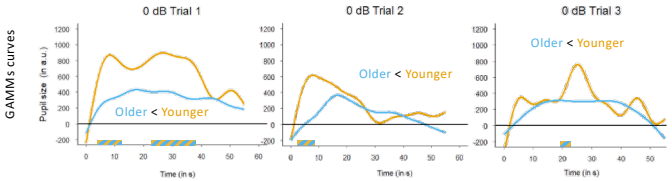


Younger adults / Trial 1
0 & -6 dB > Quiet
0 dB ~ -6 dB

Pupil size ↑ with increasing task difficulty (task difficulty effect diminishes with advancing age)

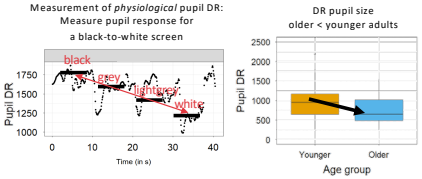
Older adults / Trial 1
0 & -6 dB > Quiet
0 dB ~ -6 dB

Pupil dilation across time - **Hypothesis 3: Pupil size ↑ for older vs younger adults (more effort)**



Pupil size of Older < Younger adults (age effect diminishes with advancing trial)

Possible explanation:
Age-related deterioration of the pupil's dynamic range (DR) => smaller pupil for older adults (despite baseline correction)



4. Discussion

- Measuring pupil size during long-duration speech segments is feasible in younger and older normal-hearing adults
- Pupil initially increases, then decreases over a long-duration time course (~ pupil response for short sentences)
- Long time course (60s) pupil size can be analyzed using general additive mixed models (GAMMs)
- Pupil size results indicate that:
  1. repeated listening leads to reduced effort or giving up? (trial 1 > 2 and 3) (will investigate this using simultaneously collected behavioral speech-in-noise and MEG data)
  2. task difficulty leads to increased effort (0 and -6 dB > quiet)
  3. no consistent effects of age (older < younger: opposite to listening effort hypothesis)

Remaining questions: Current results show the opposite of the following hypothesis: "Because older adults generally spend more effort during speech processing compared to younger adults, we hypothesize that the pupil size of older adults will be larger than those of younger adults. We found the opposite (older < younger) and this could be due to not taking the age-related changes in the pupil dynamic range into account *(Piquado et al. 2010)*. We used a black-to-white screen to measure a person's *physiological* pupil dynamic range (DR) but observed several problems: (1) non-reliable physiological DR measurement (2) mismatch between physiological pupil DR (screen) and task-evoked pupil DR (range of pupil size during audiobook listening). We could consider addressing the latter problem by measuring the pupil DR using a cognitive task. A particular cognitive task is, however, lacking (*Winn et al. 2018, Ayasse & Wingfield 2020)*.

5. Acknowledgements & References

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