



## The eye as a window to the listening brain

**Adriana Zekveld, Thomas Koelewijn, Dirk Heslenfeld, Barbara Shinn-Cunningham, Ingrid Johnsrude, Niek Versfeld and Sophia Kramer**

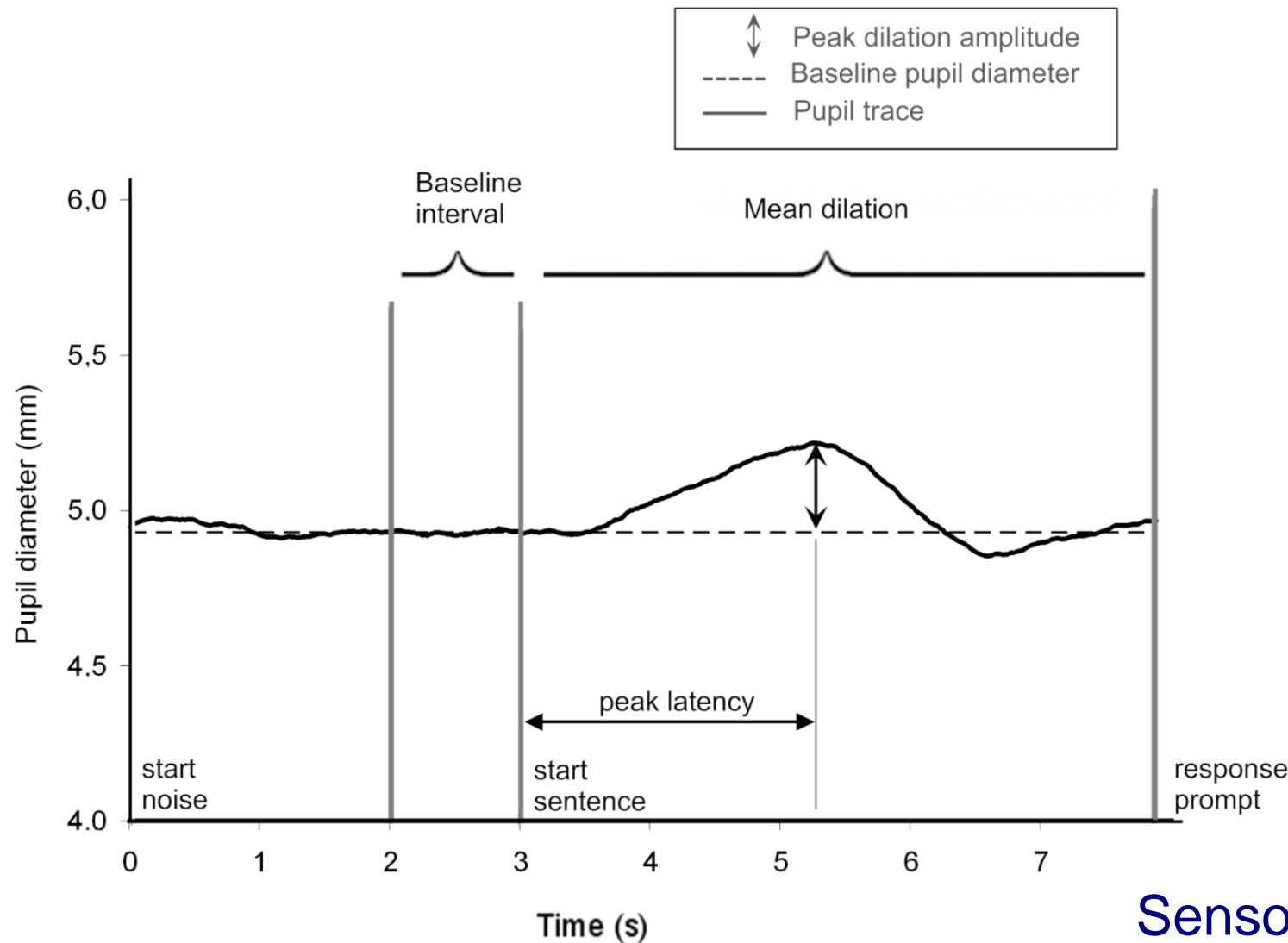
Section Ear & Hearing / dept. of Otolaryngology-Head and Neck Surgery & EMGO+ Institute for Health and Care Research, VU University medical center, Amsterdam, The Netherlands  
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Pupil dilation response: Cognitive resource allocation  
Neural basis: locus coeruleus in the brainstem

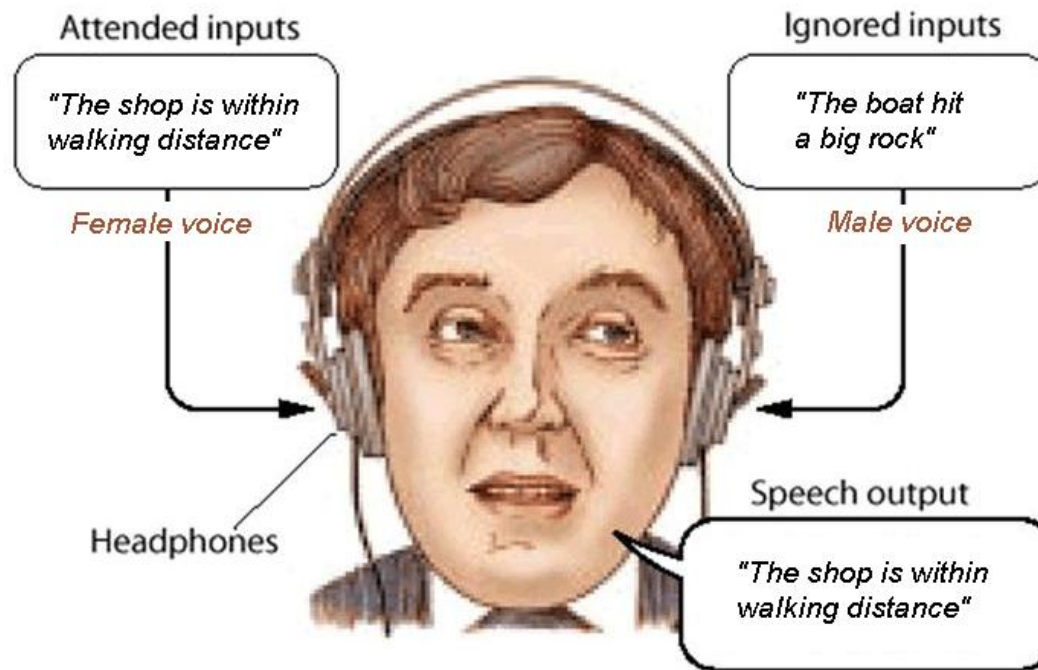
(Just, Carpenter & Miyake, 2003; Beatty & Lucero-Wagoner, 2000)

Increased processing load: larger pupil size (mm)



SensoMotoric Instruments  
eyetrackers

## 1) Focused versus divided attention



## 2) Neural correlates of pupil-dilation during speech comprehension



# Study 1: Focused vs. divided attention\*

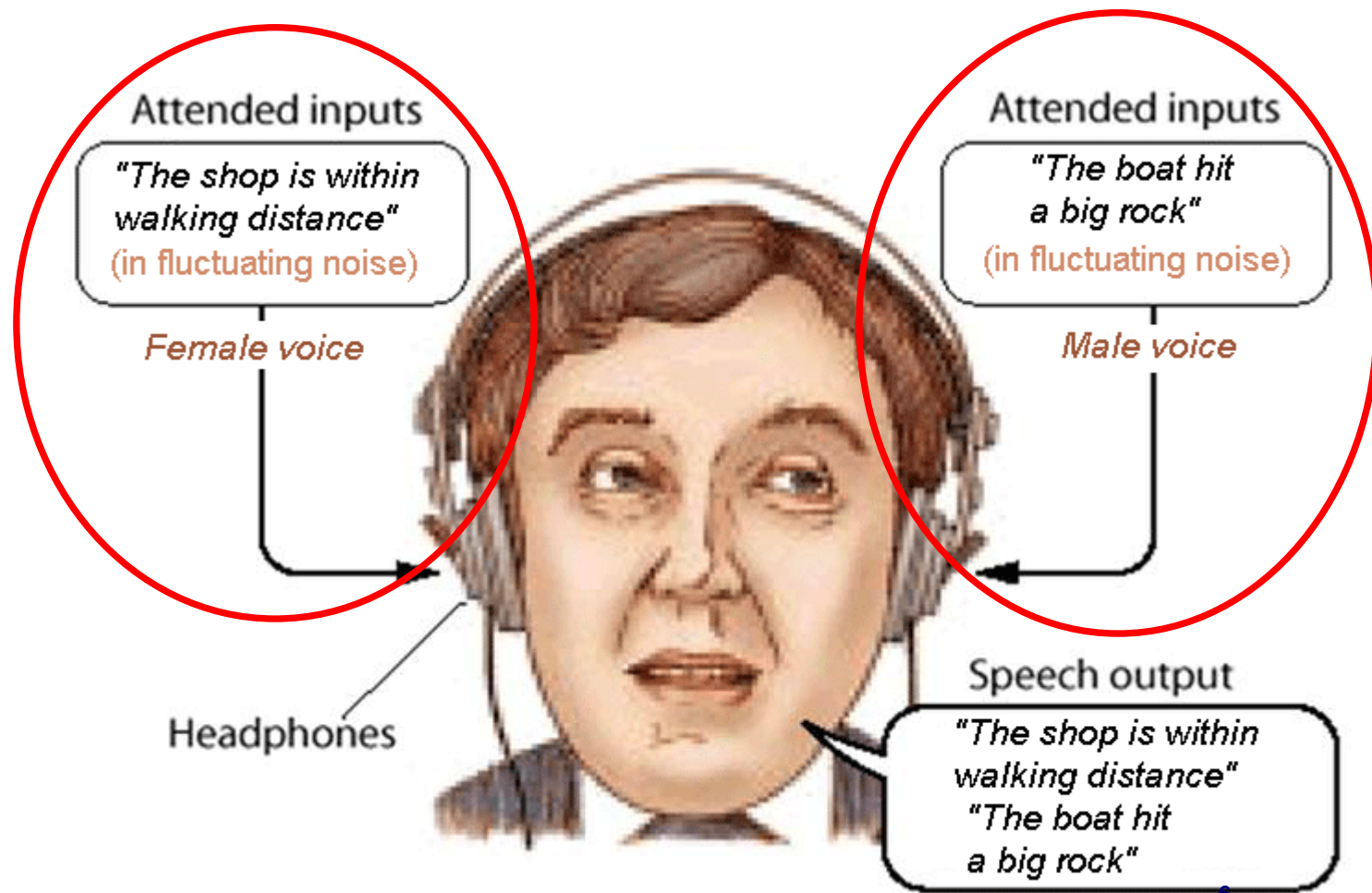
- 12 normal hearing young adults (mean 26 yrs.).
- Dichotic speech in noise task (Best et al. 2010):
- Sentence on one ear was uttered by a female talker and on the other ear by a male talker.
- Speech was masked by fluctuating noise: -9 dB, -3 dB, and 3 dB SNR.

Single-sentence task:

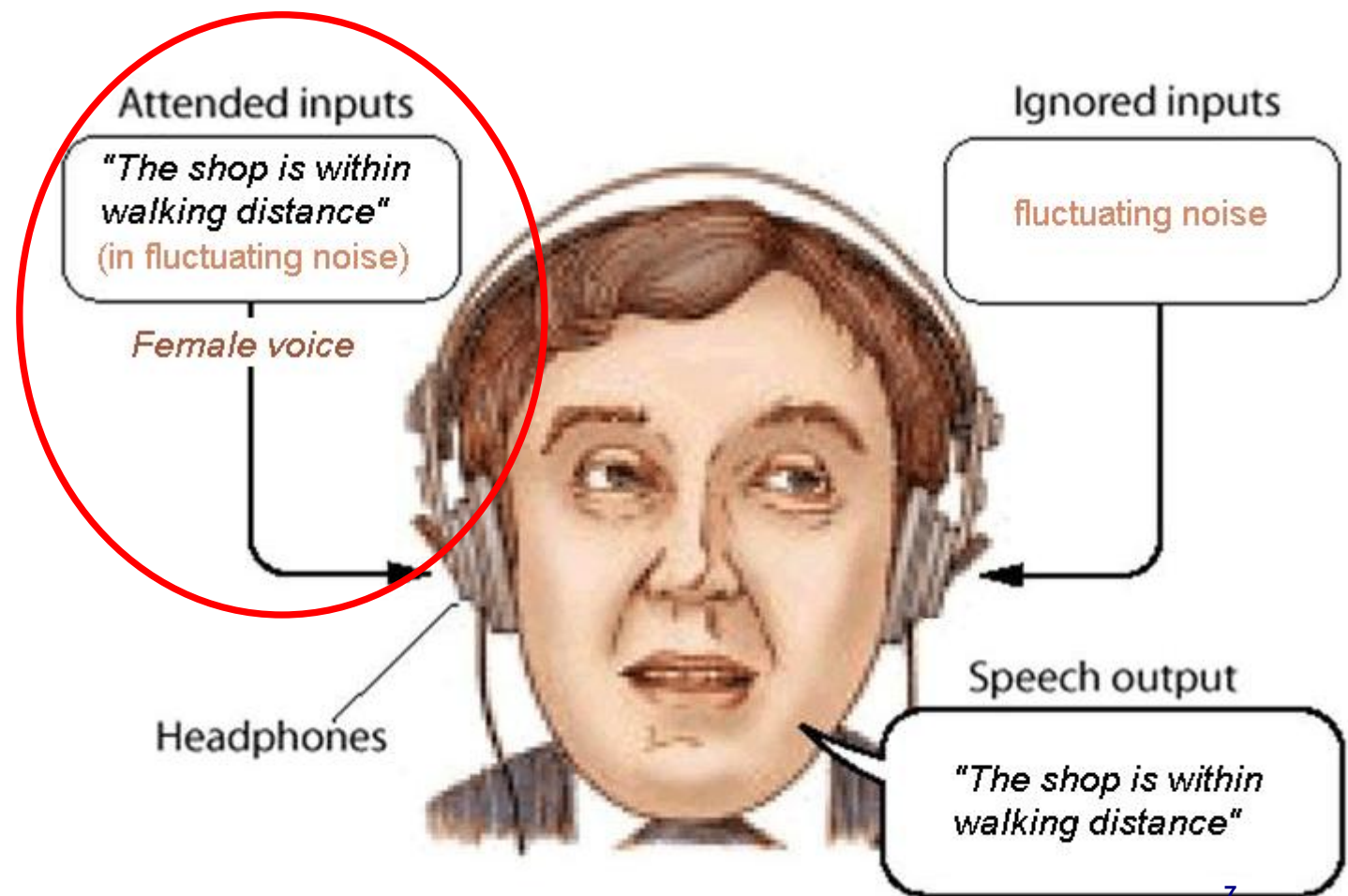


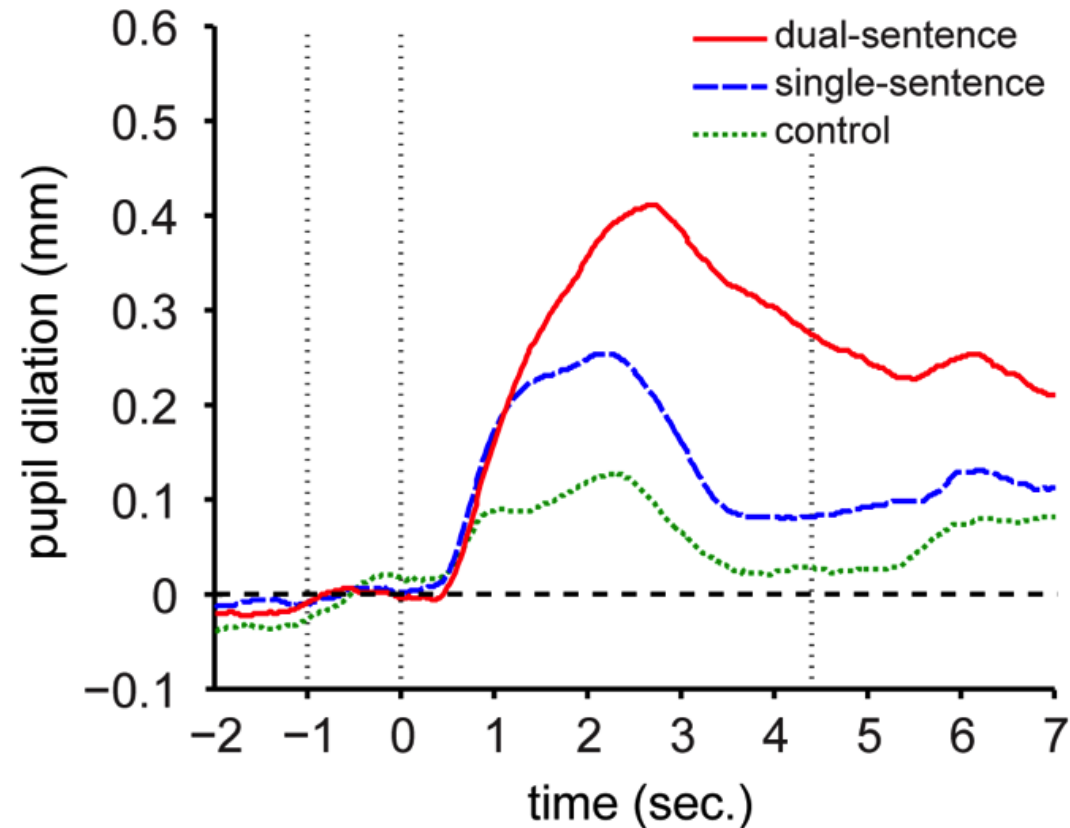
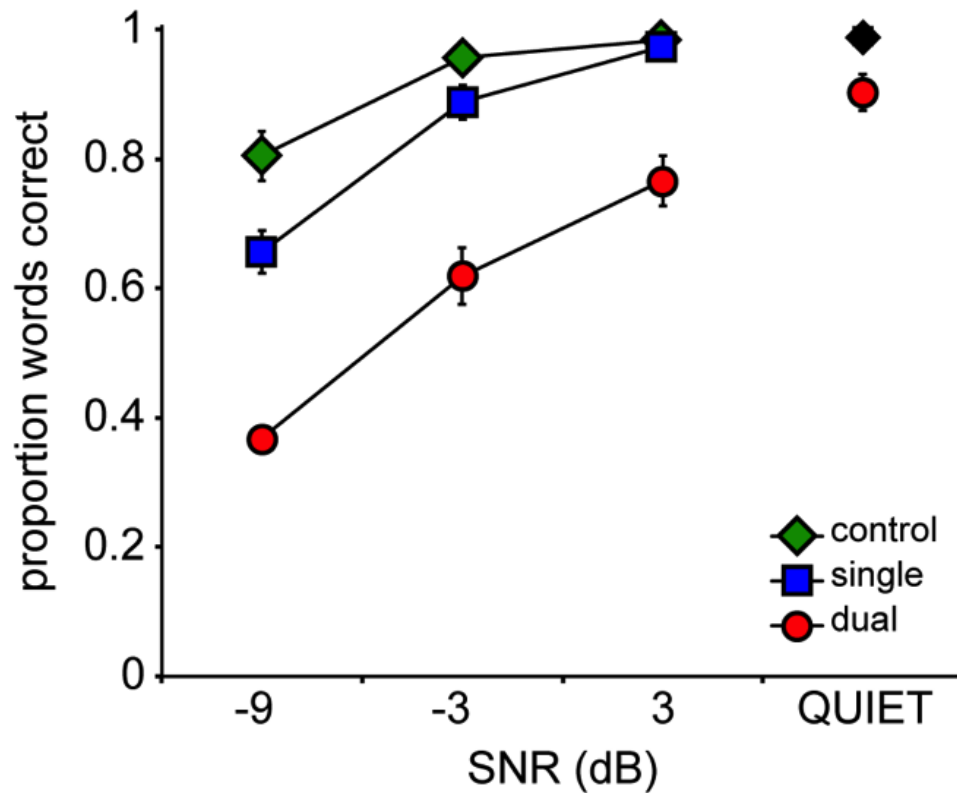
\*Koelewijn et al. (2014)

Dual-sentence task:



Control task:





Effects of attention on pupil response during listening

Other attentional effects (target onset, target location, target identity):  
..see poster of **Thomas Koelewijn (P2)**



Neural correlates of the pupil response during **speech perception**

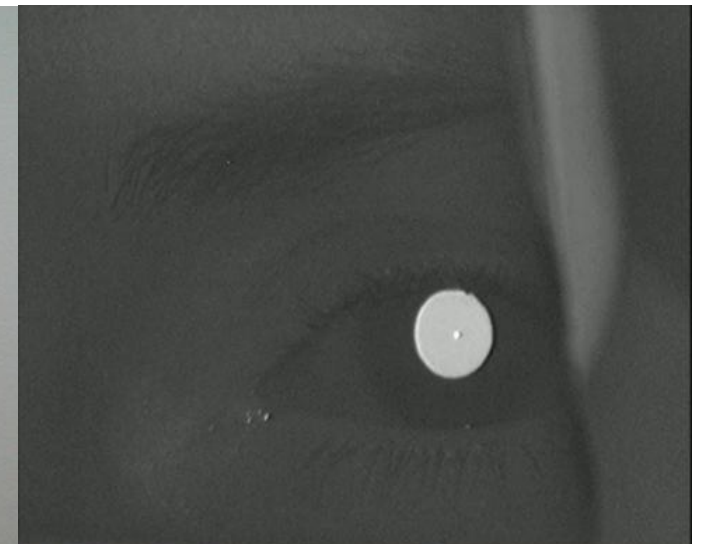
Methods:

- 17 young, normal hearing listeners
- Session 1: adaptive speech intelligibility tests (+ pupillometry)

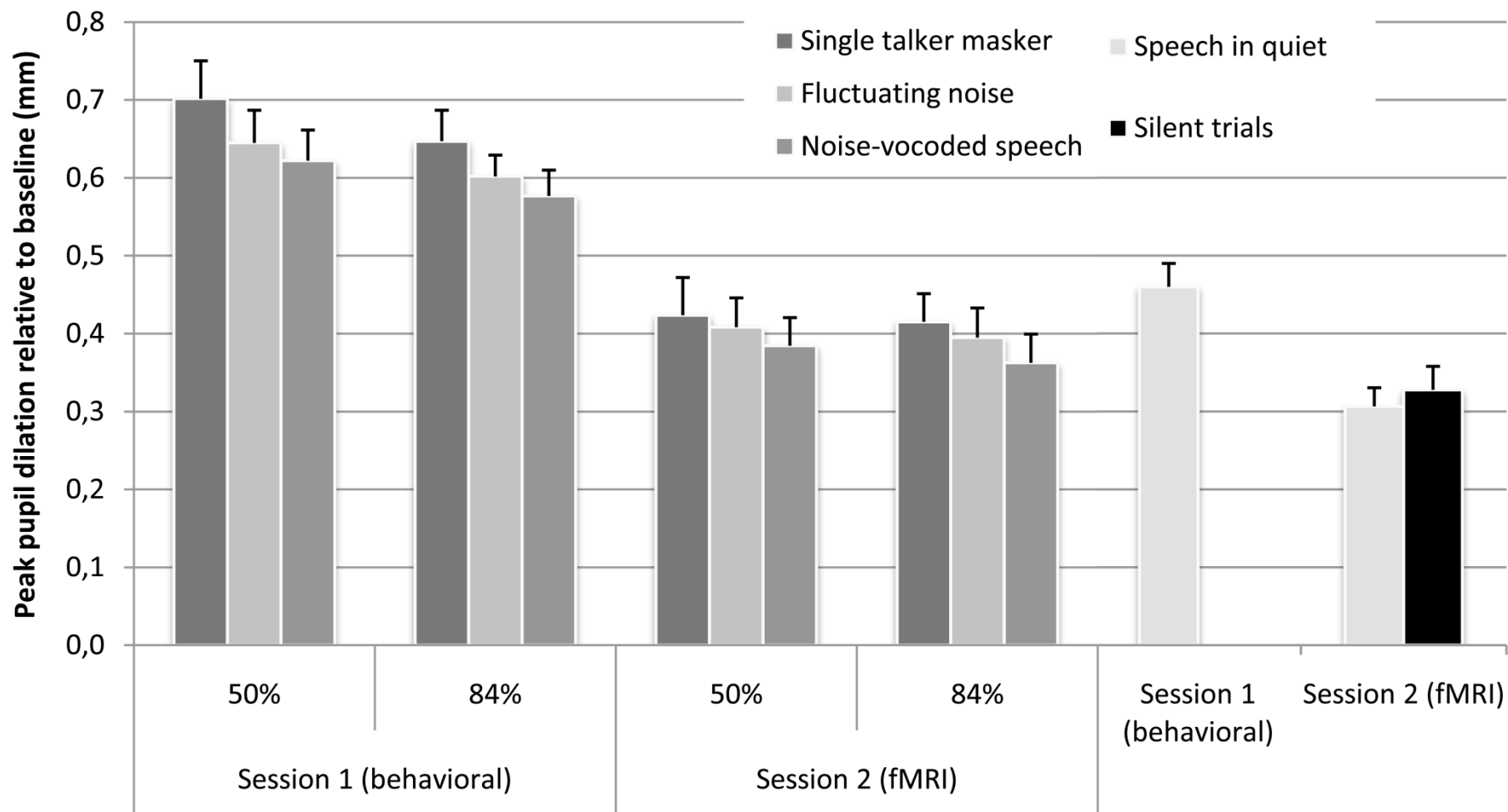
## Means (and SDs) of Speech Reception Thresholds

Sentence intelligibility	Degradation type		
	Single-talker masker	Fluctuating noise	Noise vocoded speech
50%	-3.9 (1.7) dB SNR	-3.9 (1.4) dB SNR	6.9 (0.8) bands
84%	0.4 (2.4) dB SNR	0.2 (1.5) dB SNR	9.8 (1.6) bands

- Session 2: functional Magnetic Resonance Imaging + pupillometry
  - same 2 (intelligibility) x 3 (degradation type) design
  - baseline conditions: *speech in quiet* and *silent* trials
  - Task: 1/9 of the trials: probe word recognition
  - Sparse sampling paradigm



# Results: peak pupil dilation



-Main effect *test session*: test session 1 > test session 2

-Main effect *intelligibility level*: 50% intelligibility > 84% intelligibility

-Main effect *degradation type*:

Single talker masker > fluctuating noise > noise-vocoded speech

## 1) Analysis of condition effects:

- Intelligibility (decreased speech quality)
- Degradation type (segregation demands)

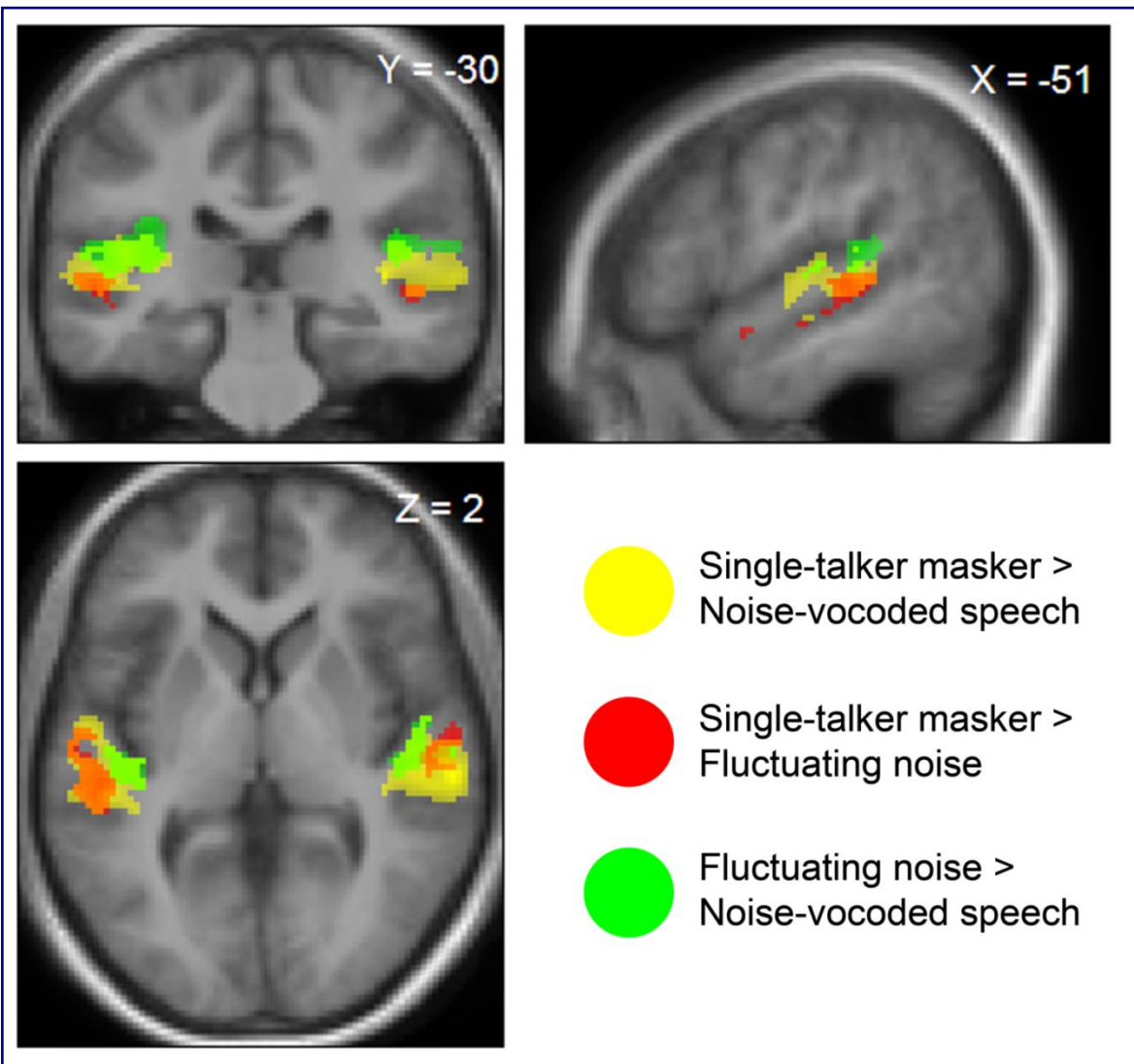
→ areas that reflect these **effortful speech perception processes**

## 2) Analysis of the relationship between BOLD and pupil dilation:

→ areas associated with **processes reflected by the pupil response**

## 3) Conjunction (overlap) between 1) and 2):

→ processes associated with: **effortful listening & reflected by pupil dilation**



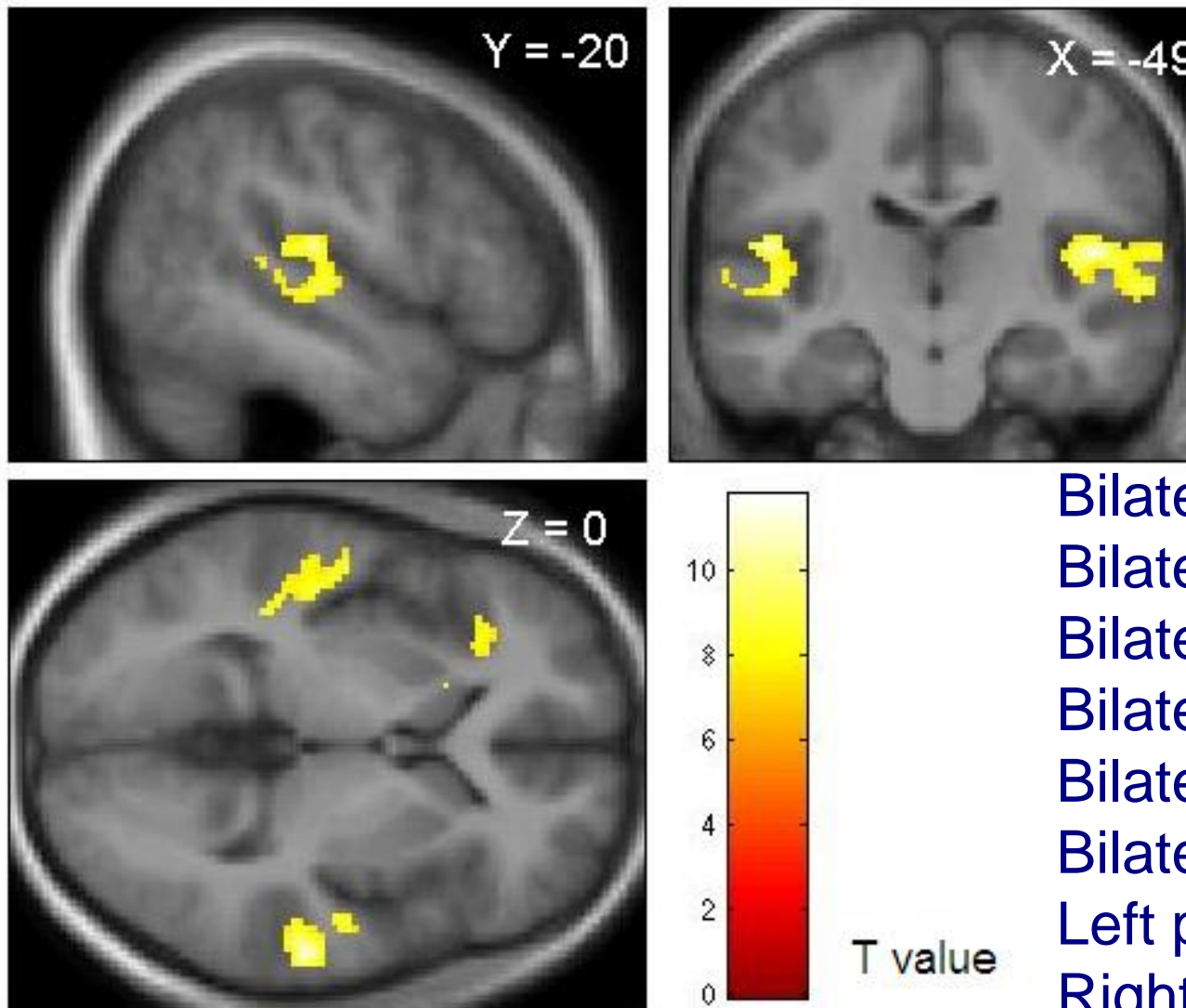
## ANOVA

*intelligibility level x degradation type*

- No effect of **intelligibility level**
- Main effect of **degradation type**: posterior superior (STG), middle temporal gyrus and sulcus bilaterally, left precentral gyrus

Same pattern of results as pupil data

- No negative association between BOLD (averaged over 6 degraded speech conditions) and peak pupil response.
- Positive association was observed in: (FWE corrected  $p < .05$ )

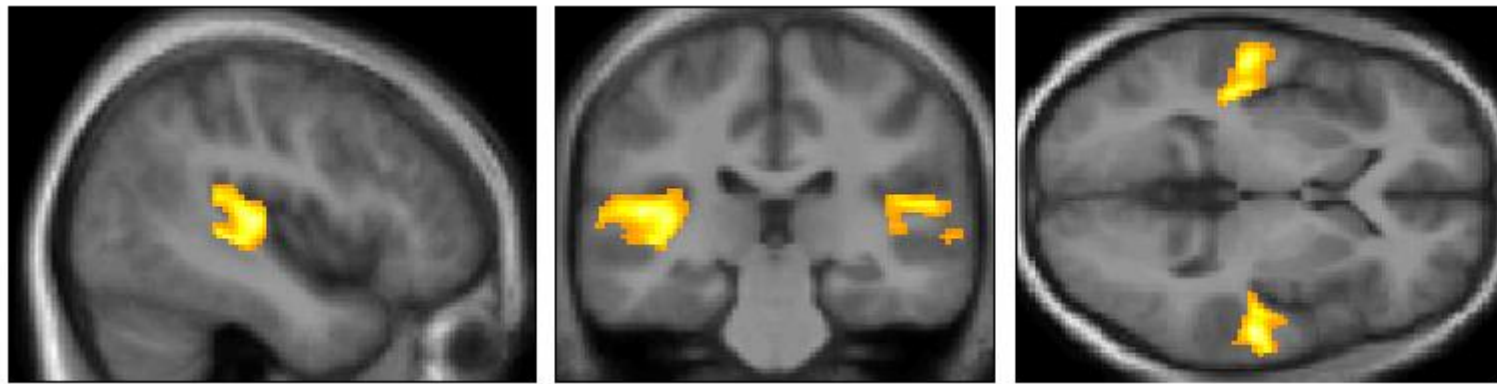


Bilateral STG / auditory cortex  
Bilateral anterior cingulate cortex  
Bilateral anterior cingulate gyrus  
Bilateral superior frontal gyrus  
Bilateral precentral gyrus  
Bilateral frontal operculum  
Left putamen  
Right inferior frontal gyrus



## Conjunction between condition effects and pupil-related areas

<p>Single-talker masker &gt; speech in quiet</p>	<p>Bilateral STG Bilateral middle temporal gyrus Bilateral auditory cortex</p>
<p>Fluctuating noise &gt; speech in quiet</p>	<p>Bilateral STG Left MTG, right auditory cortex Right anterior cingulate gyrus</p>
<p>Noise-vocoded speech &gt; speech in quiet</p>	<p><del>Left superior medial frontal gyrus</del> <del>Left STG</del> Left middle temporal gyrus</p>



- Bilateral STG, left MTG and right auditory cortex:
  - Effortful processes related to speech degradation
  - Speech segregation processes
  - Extraction of meaningful information from a noisy stimulus(Davis et al., 2011, Scott & McGeffigan, 2013)

**Pupil dilation reflects a summative measure\* of the brain activity associated with speech perception processes required by difficult conditions, such as attentional and segregation processes** (\*Siegle et al., 2003)

- Right dorsal anterior cingulate cortex: cognitive control processes; evaluation of "costs":
  - error processing,
  - task difficulty
  - conflicts

Same pattern of results in BOLD and pupil data, and overlap in activation associated with condition-effects and pupil



Thank you for your effortful attention!

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Research paper


**The pupil response is sensitive to divided attention during speech processing**

Thomas Koelewijn<sup>a,\*</sup>, Barbara G. Shinn-Cunningham<sup>b</sup>, Adriana A. Zekveld<sup>a,c</sup>, Sophia E. Kramer<sup>a</sup>

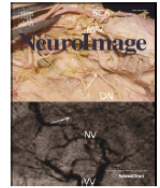
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NeuroImage 101 (2014) 76–86

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**The eye as a window to the listening brain: Neural correlates of pupil size as a measure of cognitive listening load**

Adriana A. Zekveld<sup>a,b,\*</sup>, Dirk J. Heslenfeld<sup>c</sup>, Ingrid S. Johnsrude<sup>b,d,e</sup>, Niek J. Versfeld<sup>a</sup>, Sophia E. Kramer<sup>a</sup>

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Pupillometry research @ VUmc Amsterdam:



Sophia Kramer



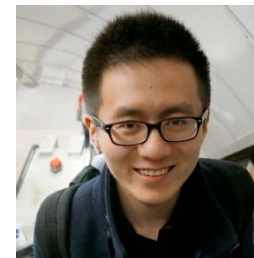
Adriana Zekveld



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Hans van Beek