



**Assessing listening effort (processing load)
during speech perception in noise,
using the method of pupillometry**

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An individual's attempts to compensate and communicate optimally require vigilance: a constant effort to hear and pay attention (Demorest and Erdman, 1986)



Netherlands Longitudinal Study on Hearing (NL-SH) * **Need for Recovery (NfR) (cohort of 1000 employees)**

- Degree to which employee recovers from stressful work activities
- Acute, short-term reaction
- Predictor of health complaints and sick-leave in the long term

“It’s difficult to concentrate in the hours after working”

“I find it difficult to relax at the end of a working day”

With every dB increase in hearing loss, NfR increased with percent points

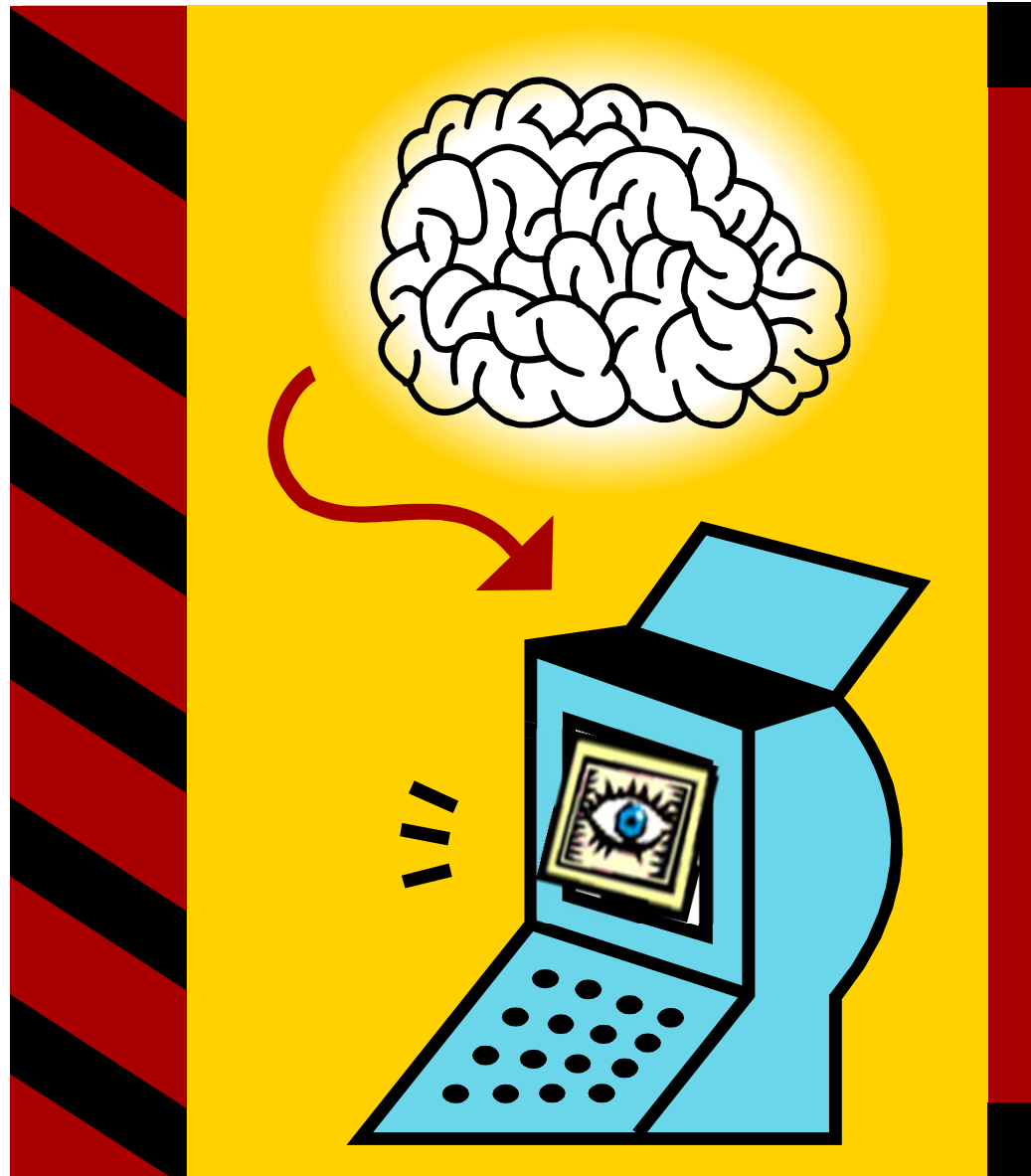
Hearing loss & sick-leave in a sample of 210 employees) (Kramer et al., 2006)

Employees with hearing loss more likely to report sick leave due to mental distress

Self-reported hearing problems & long-term stress (Hasson et al., 2009)

Negative relationship ability to recover from stress & self-reported hearing difficulty

* (Nachtegaal et al., 2009)



Task evoked pupil dilation is a sensitive measure of cognitive processing load

- Digit list recall (Granholm et al., 1996)
- Recall of lists in reversed order (Taylor, 1981)
- Arithmetic test complexity (Ahern & Beatty, 1981)
- Syntactic complexity sentences (Piquado et al., 2010)



Cognitive processing → frontal activation → reticular formation → pupil dilatation (parasympathetic & sympathetic system) (Siegle et al., 2004; Recarte et al., 2008)

Speech Reception Threshold (SRT) in noise test (Plomp & Mimpen, 1979)

Intelligibility level

- Adaptively estimate the Speech-to-Noise Ratio (SNR) required for: 50% correct, 71% correct, 84% correct

Type of background noise

- Stationary noise, fluctuating noise, or interfering speaker

Task demand

- Word identification (in stationary noise, 79% correct)
- Noise-burst-in-stationary-noise detection (79% correct)
- No demand, just listening to noise alone, with/without responding

Test modality

- Auditory versus visual

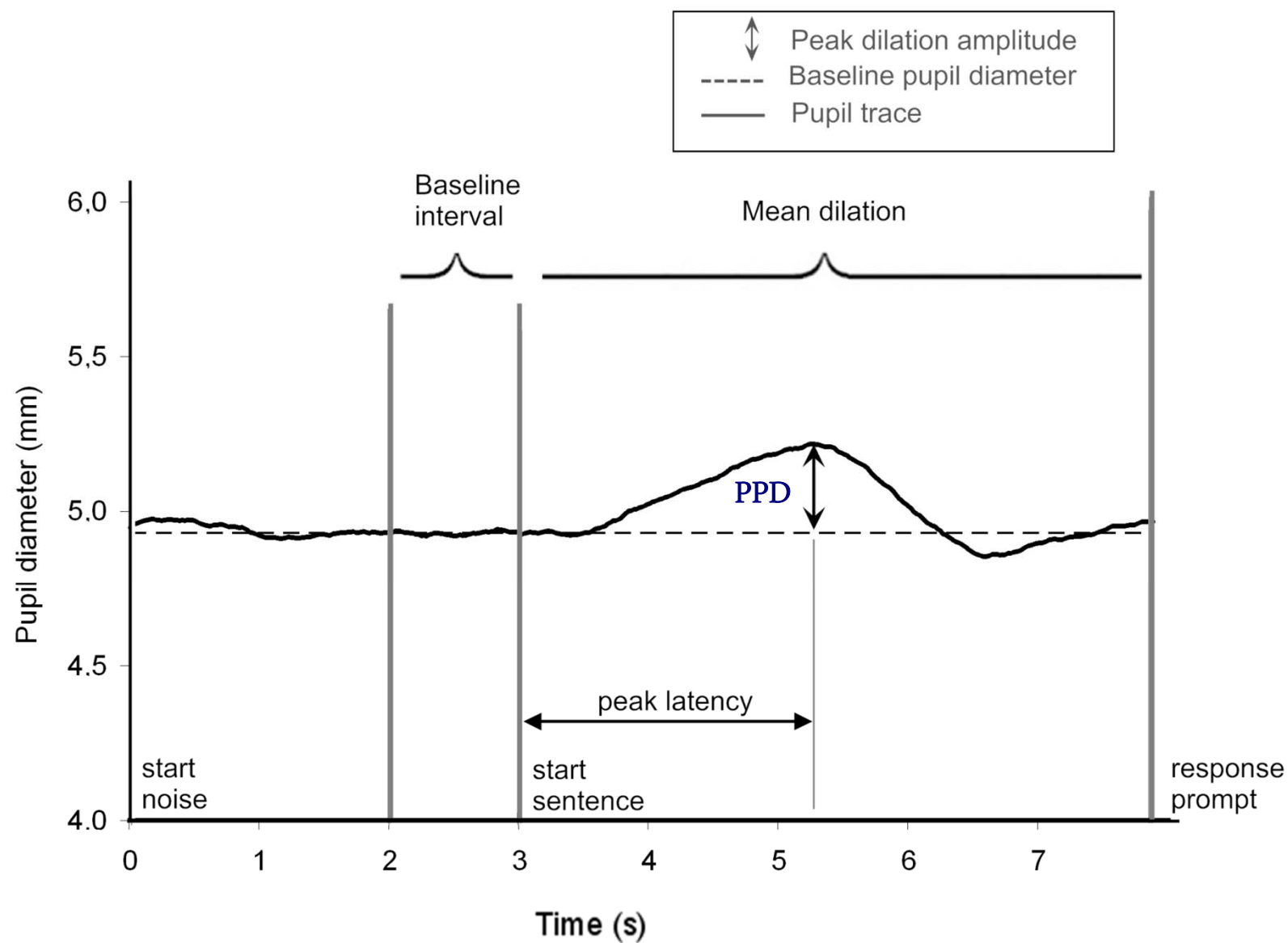
Relation to self-report

- Subjective effort ratings after each test

Hearing impaired vs. Normal hearing

Pupil dilation is recorded during the tests



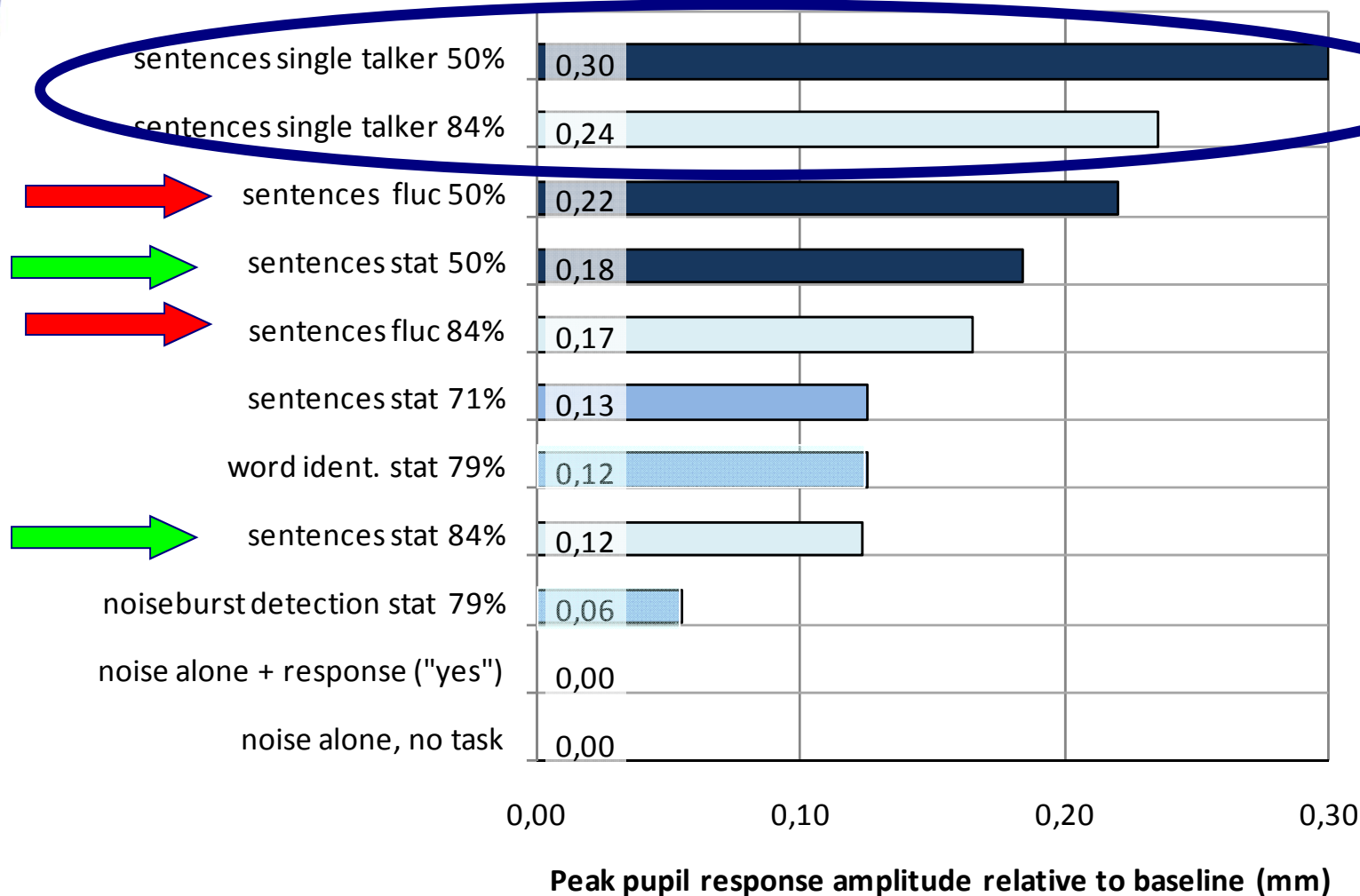


Overview of the results of 4 published studies:

Intelligibility, background noise, task demand

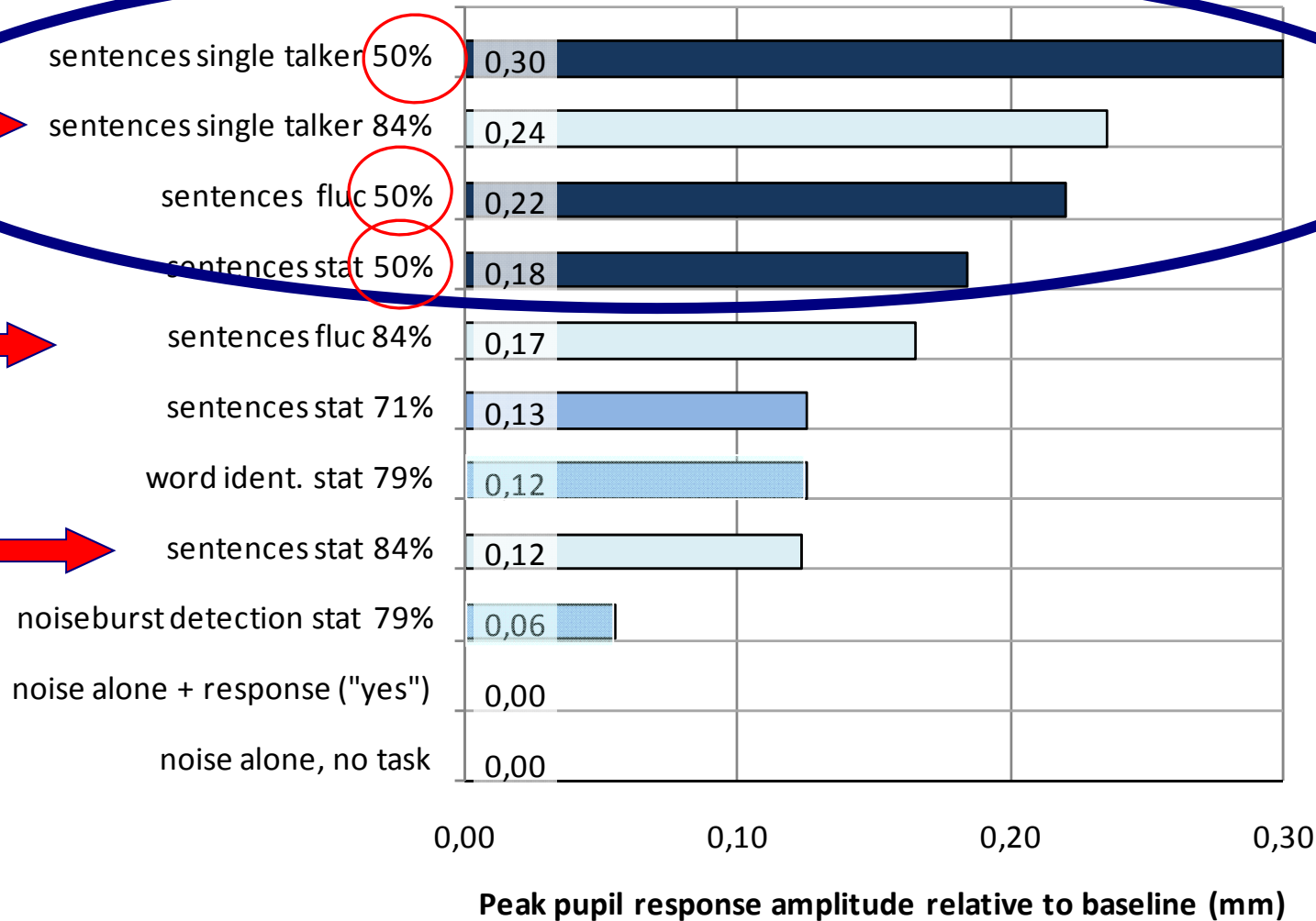
Normally hearing adults

Intelligibility effect

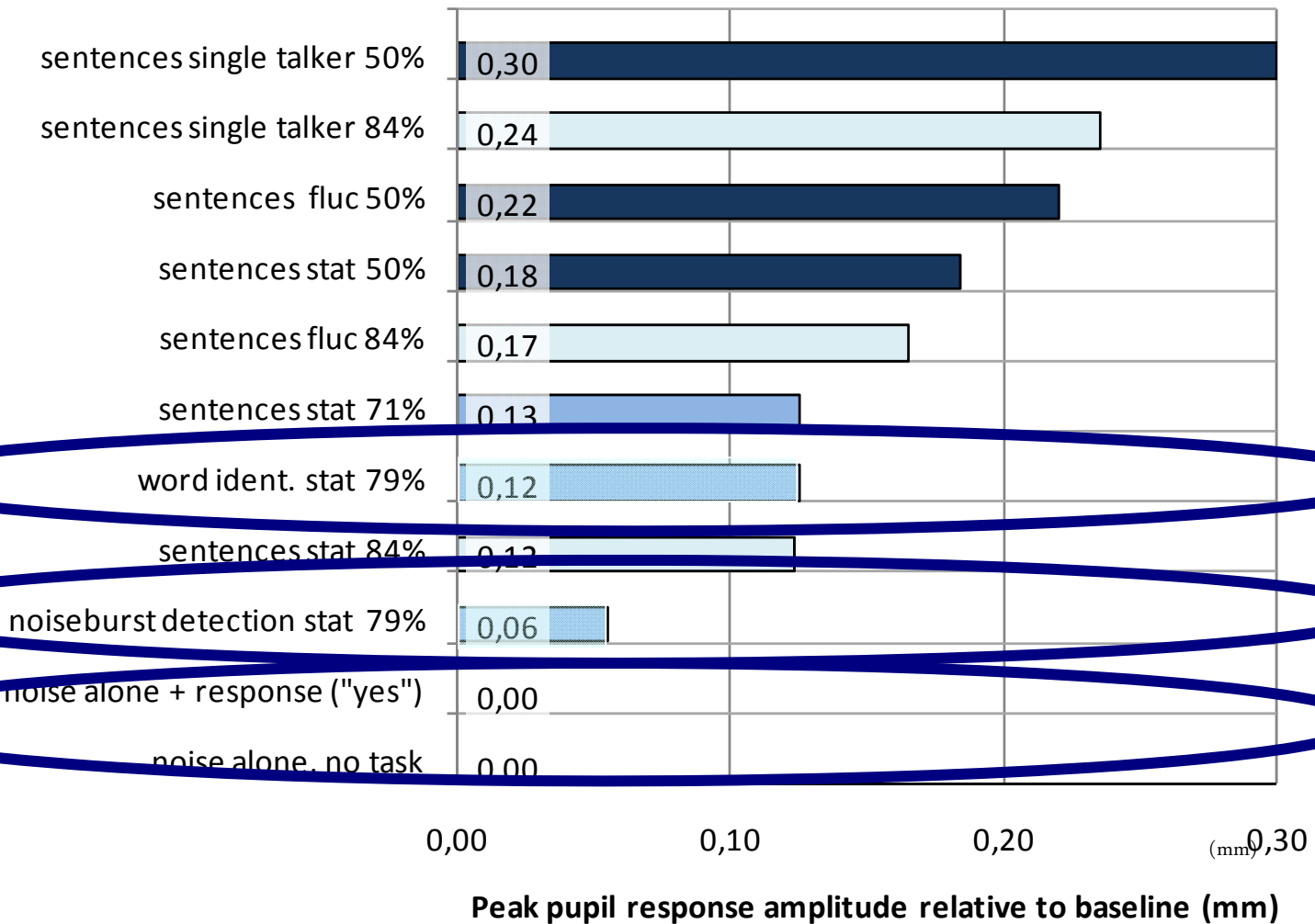


- Zekveld et al. (2010), Ear and Hearing 31
- Zekveld et al. (2011), Ear and Hearing 32
- Kramer et al. (2012), J Lang Cogn Processes, in press
- Koelewijn et al. (2012), Ear and Hearing 33

Noise effect (dark bars)

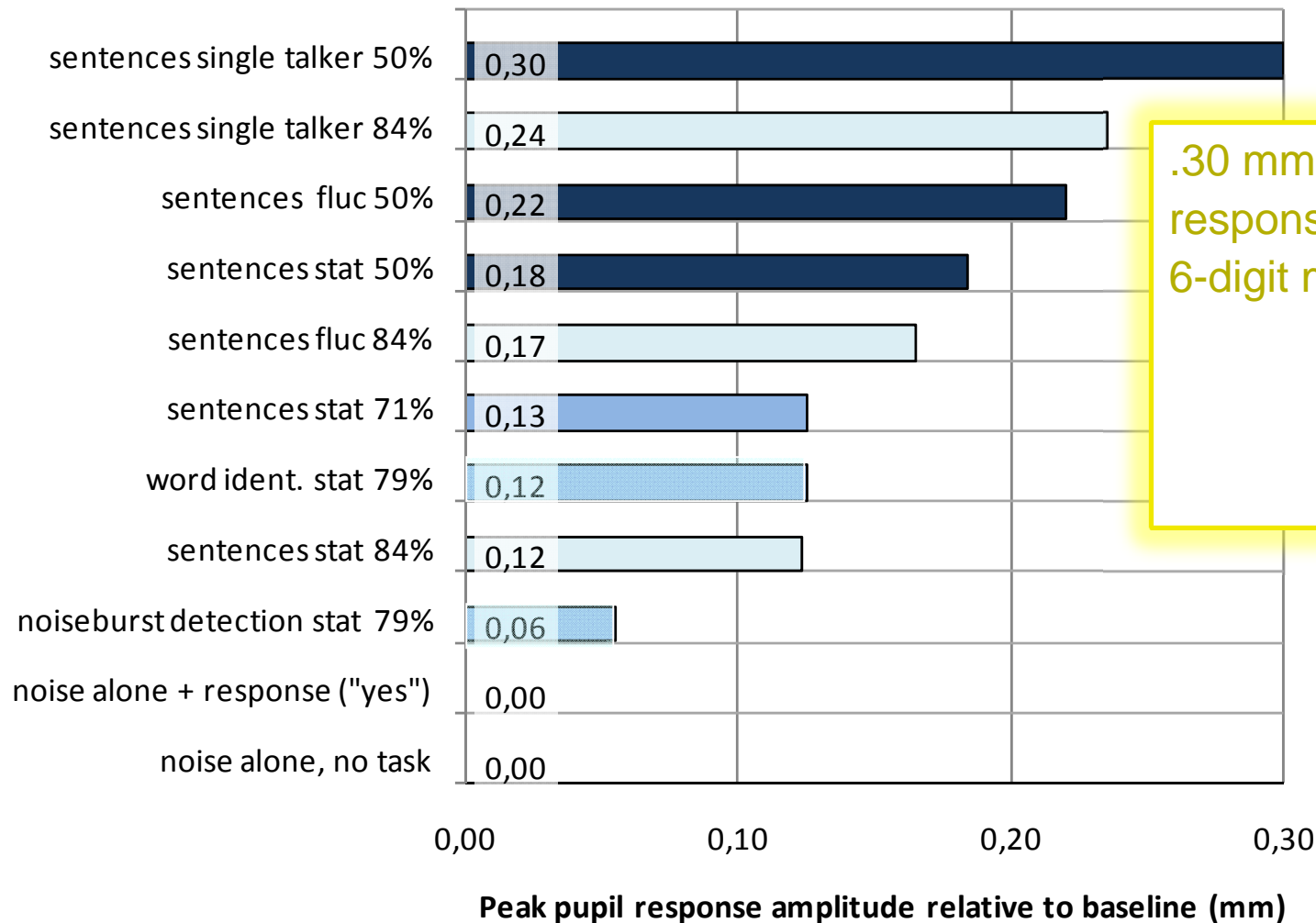


- Zekveld et al. (2010), Ear and Hearing 31
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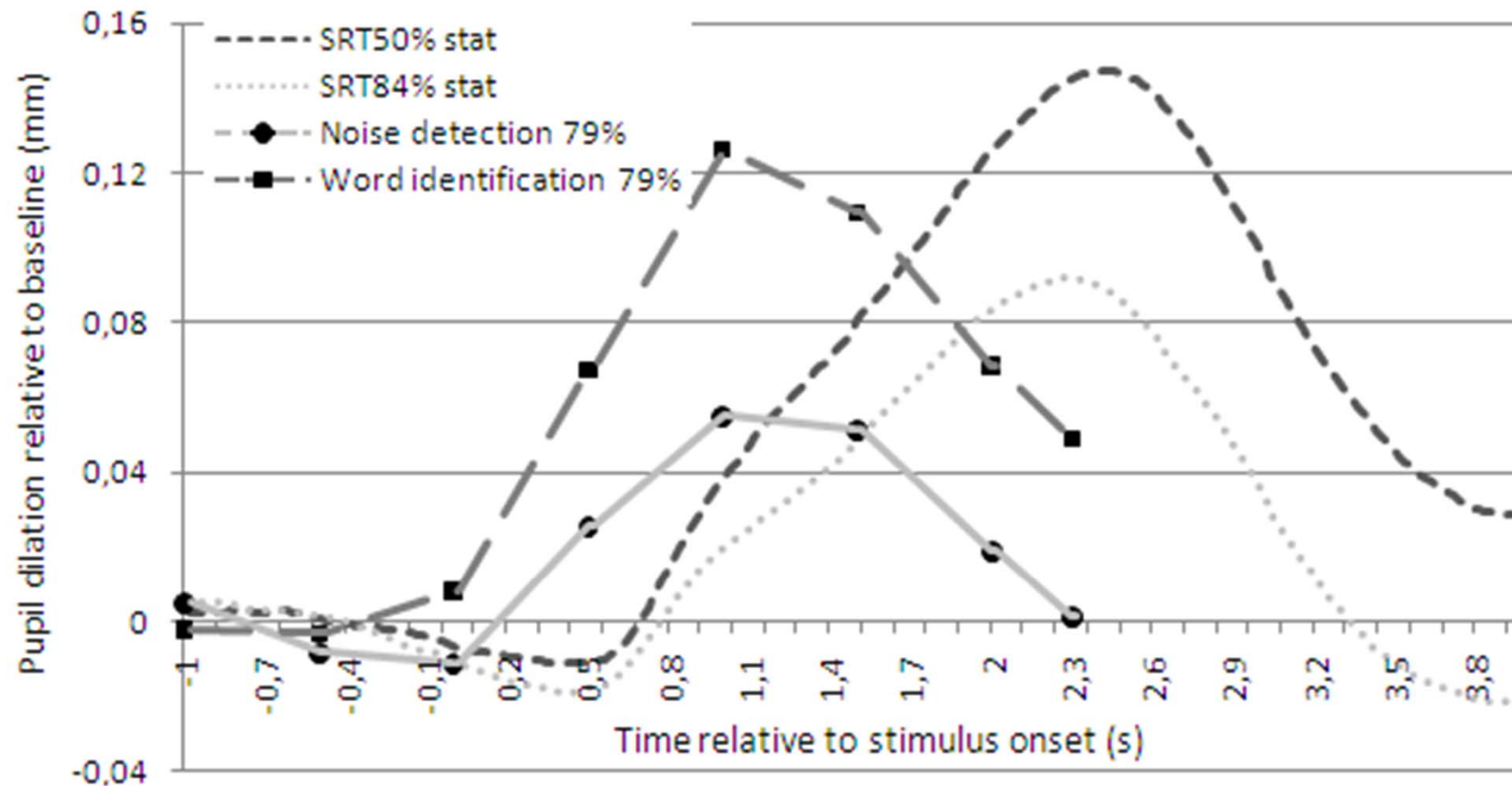
Task effect

- Zekveld et al. (2010), Ear and Hearing 31
- Zekveld et al. (2011), Ear and Hearing 32
- Kramer et al. (2012), J Lang Cogn Processes, in press
- Koelewijn et al. (2012), Ear and Hearing 33

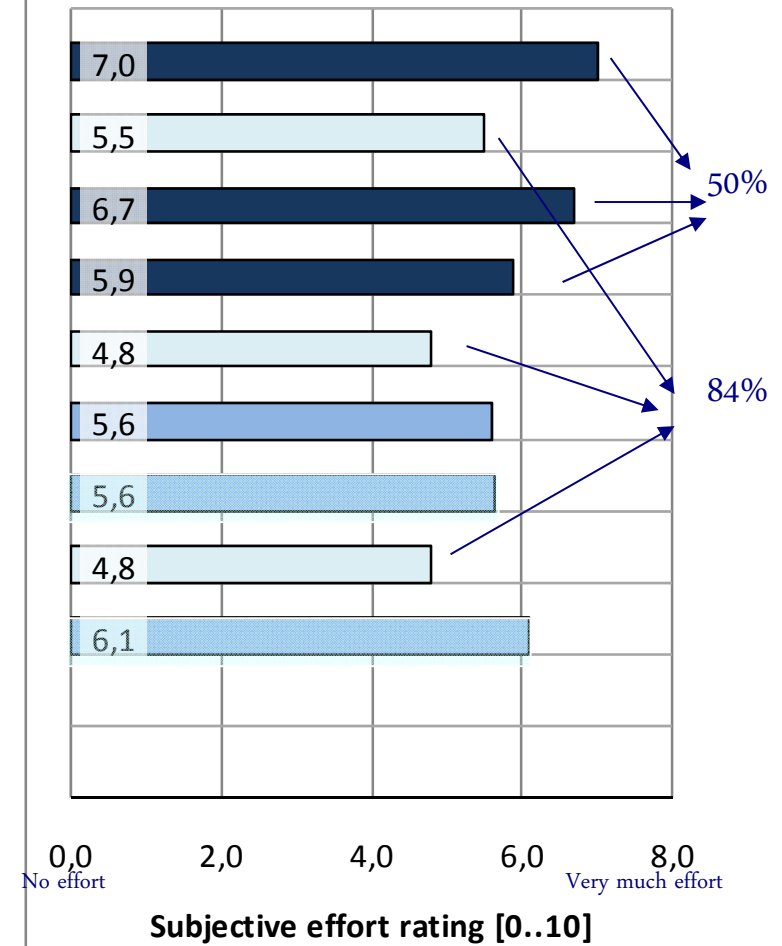
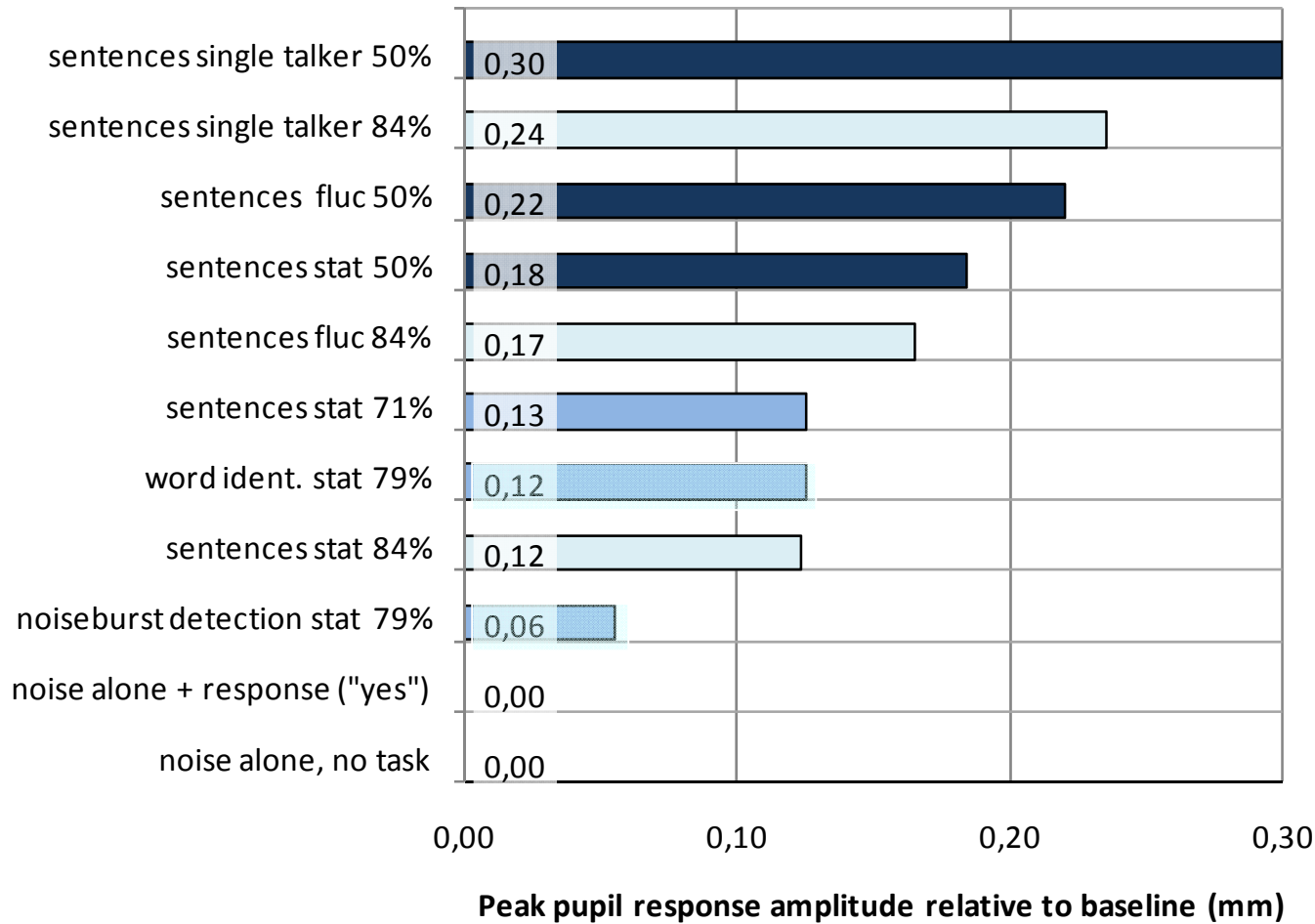


.30 mm: corresponds to pupil response during 6-digit memory task

- Zekveld et al. (2010), Ear and Hearing 31
- Zekveld et al. (2011), Ear and Hearing 32
- Kramer et al. (2012), J Lang Cogn Processes, in press
- Koelewijn et al. (2012), Ear and Hearing 33



Mean pupil trace in four listening conditions. SRT = speech reception threshold. Data are from Zekveld et al.2010, 2011 and Koelewijn et al.2012(SRT conditions) and from Kramer et al. In press (noise detection and word identification conditions).

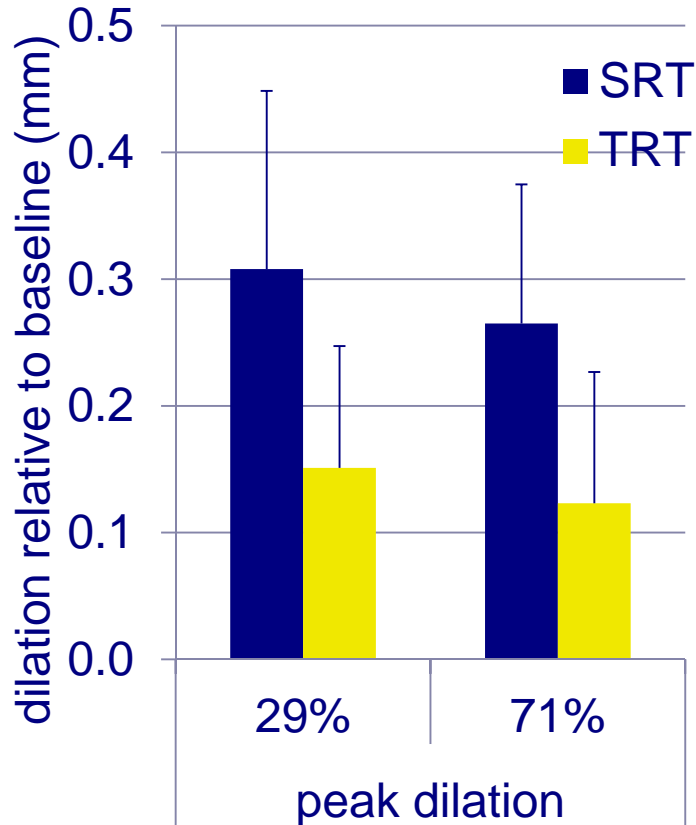


Pattern of results of pupillometric data and effort ratings differ
 Relatively small range in effort ratings



the driver looks at this with

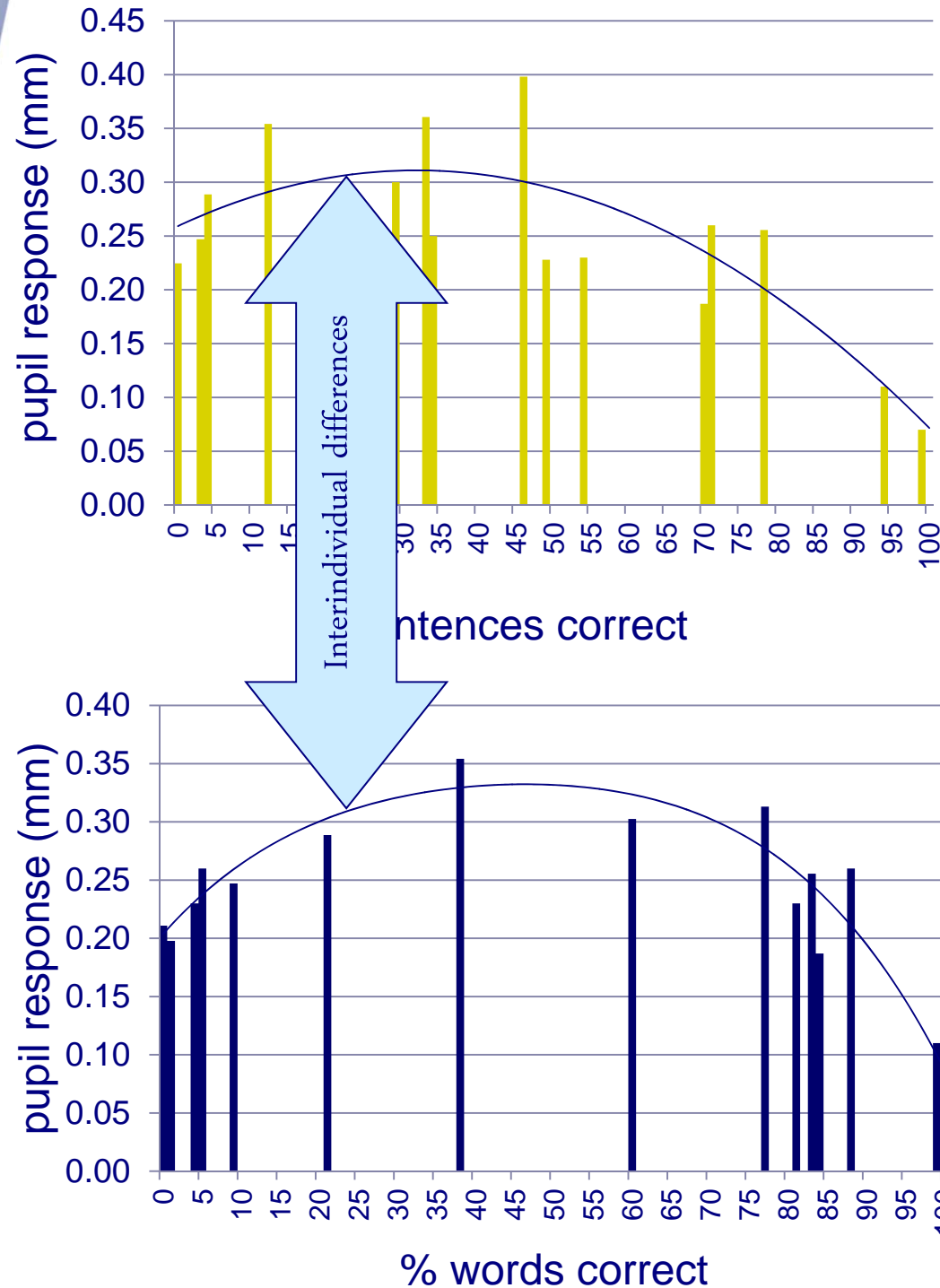
Text Reception Threshold test
Zekveld et al. (2007)



Main effects of test modality ($p < 0.001$)
and difficulty level ($p < 0.05$),
No interaction effect

Zekveld, Festen, Kramer (2012), under review

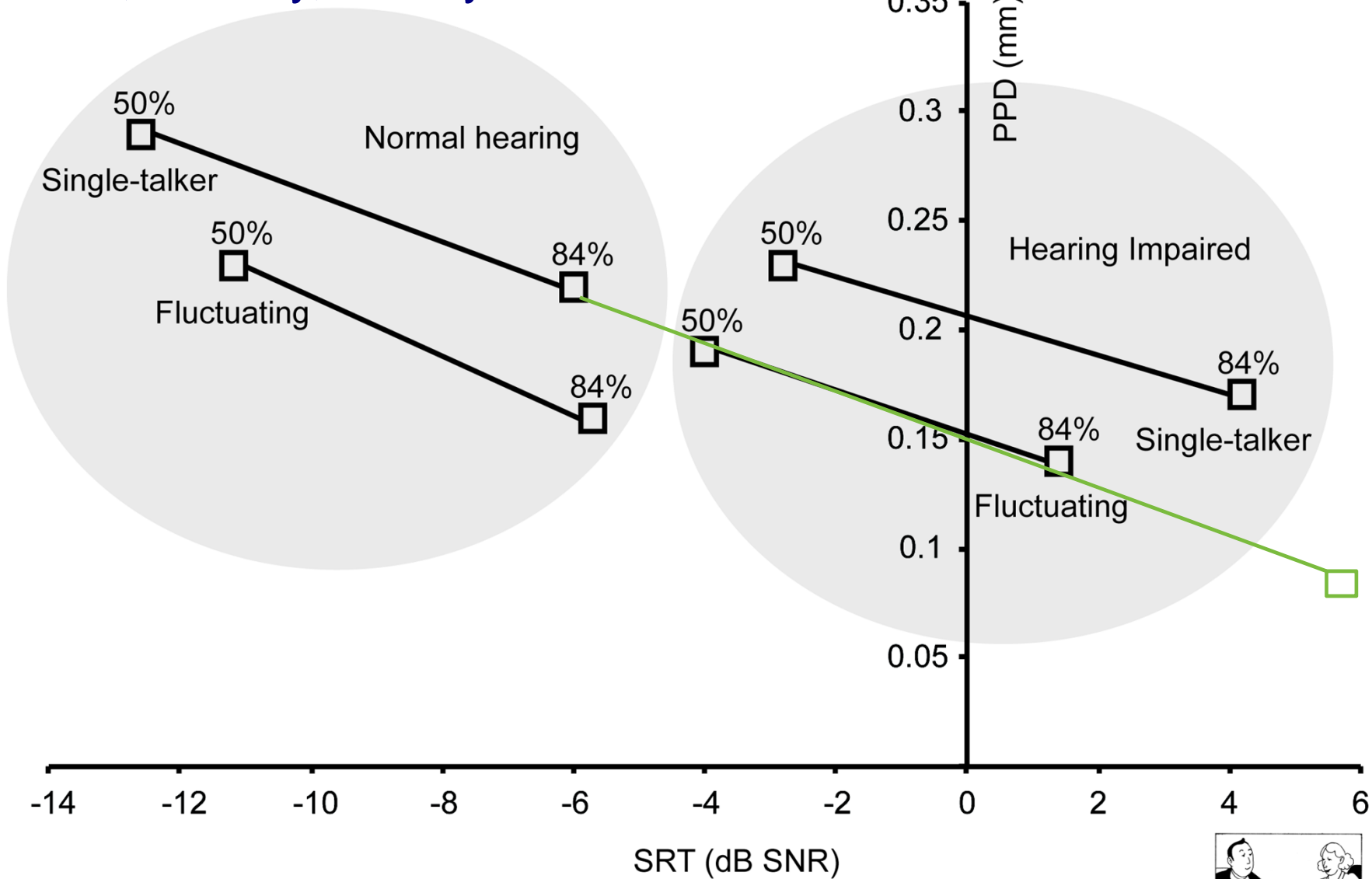
Similar performance differences in the visual and auditory modality affected the pupil response similarly!



- Speech masked by single-talker
- < 50% overload conditions?

N = 32, 31-76 y, M 59 y

N = 24, 47-63 y, M 55 y



Evidence that the pupil response is a
promising, precise, robust objective measure of processing load

- results have been replicated
- hypotheses have been confirmed



... several questions remain.....

- Individual differences in the pupil response?

Partly explained by cognitive abilities

(Zekveld et al., 2011, 2012; Koelewijn et al., 2012)

- Effects of hearing loss: perhaps strategy differences, habituation?
- Relation with other physiological measures (fMRI)
- Age effects on pupil response?
- Translation of laboratory based pupil response to daily life stress

Original Article

Audiology 1997; 36:155-164

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Assessing Aspects of Auditory Handicap by Means of Pupil Dilatation

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Abstract
The demand on extra-
notorious handicapped
self-assessment studies.

Pupil Response as an Indication of Effortful Listening: The Influence of Sentence Intelligibility

Adriana A. Zekveld, Sophia E. Kramer, and Joost M. Festen

INTRODUCTION

Speech understanding is impaired by background noise. In hearing loss, speech comprehension becomes more difficult because of cognitive (explicit) working memory processes to fill in incomprehensible or missing information (Pichioro et al., 2003, 2006; Zekveld et al., 2007; Rönnberg et al., 2008; et al., 2009). Thus, the use of cognitive processes to listen by allowing the listener to complete parts of missing information. As such, it helps individuals to cope with speech perception difficulties. However, the

Cognitive Load During Speech Perception in Noise: The Influence of Age, Hearing Loss, and Cognition on the Pupil Response

Adriana A. Zekveld, Sophia E. Kramer, and Joost M. Festen

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Objectives: The aim of the current study was to evaluate the link of age, hearing loss, and cognitive ability on the cognitive process load during listening to speech presented in noise. Cognitive load was assessed by means of pupillometry (i.e., examination of pupil diameter) supplemented with subjective ratings.

Design: Two groups of subjects participated: 28 middle-aged participants (mean age = 55 yrs) with normal hearing and 36 middle-aged participants (mean age = 51 yrs) with hearing loss. Using three Speech Reception Threshold (SRT) in stationary noise tests, we estimate speech-to-noise ratios (SNRs) required for the correct repetition of 50%, 75%, or 84% of the sentences (SRT_{50%}, SRT_{75%}, and SRT_{84%} respectively). We examined the pupil response during listening: the amplitude, the peak latency, the mean dilation, and the pupil reset duration. For each condition, participants rated the experienced listening effort and estimated their performance level. Participants additionally

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Psychology Press
Taylor & Francis Group

Processing load during listening: The influence of task characteristics on the pupil response

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Pupil Dilatation Uncovers Extra Listening Effort in the Presence of a Single-Talker Masker

Thomas Koelewijn¹, Adriana A. Zekveld,^{1,2,3} Joost M. Festen,¹ and Sophia E. Kramer¹

Objectives: Recent research has demonstrated that pupil dilatation is a measure of mental effort (cognitive processing load), and is sensitive to differences in speech intelligibility. The present study extends this outcome by examining the effects of masker type and age on the speech reception threshold (SRT) and mental effort.

Design: In young and middle-aged adults, pupil dilatation was measured while they listened to a SRT task in which various sentence sources were used.

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Volume 2012, Article ID 648731, 11 pages
doi:10.1155/2012/648731

Research Article

Processing Load Induced by Informational Masking Is Related to Linguistic Abilities

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It is often assumed that the benefits of hearing aids is not primarily reflected in better speech performance, but that it is reflected in less effortful listening in the aided than in the unaided condition. Before being able to assess such a hearing aid benefit the present study examined how processing load while listening to masked speech relates to inter-individual differences in cognitive abilities relevant for language processing. Pupil dilatation was measured in thirty-two normal hearing participants while listening to sentences masked by fluctuating noise or interfering speech at either 50% and 84% intelligibility. Additionally, working memory capacity, inhibition of irrelevant information, and written text reception was tested. Pupil responses were larger during interfering speech as compared to fluctuating noise. This effect was independent of intelligibility level. Regression analysis revealed that high working memory capacity, better inhibition, and better text reception were related to better speech reception thresholds. Apart from a positive relation to speech recognition, better inhibition and better text reception are also positively related to larger pupil dilatation in the single-talker masker conditions. We conclude that better cognitive abilities not only relate to better speech perception, but also partly explain higher processing load in complex listening conditions.

1. Introduction

A major complaint of both hearing-impaired and normal hearing individuals is the high level of effort while following a conversation in a noisy situation. Although sensory hearing loss is considered the main cause of speech communication difficulties [1, 2], comprehension of speech in noise is not fully predicted by a pure-tone audiogram or other psycho-acoustical tests [3-6]. Research has shown that speech comprehension and related listening effort are not only based on sensory processes, but also on linguistic and working-memory-related cognitive abilities [2, 7, 8]. These insights were obtained as the result of two major areas of science

CHS research would be the examination of the interaction between use and benefit of devices like hearing aids, and individuals' cognitive abilities and mental effort [10, 11]. Attempts into that direction were made by Gohmert et al. [12, 13] who observed a relationship between an individual's cognitive abilities and candidature for a certain hearing aid fitting pattern. However, before these and other insights obtained within CHS can be applied to clinical practice (i.e., hearing aid fitting evaluation) we need to know more precisely what cognitive processes is associated with listening effort. Although it is often assumed that the involvement of cognitive functions in speech comprehension is responsible for the listening effort that people experience, it is not



Effortful listening: A strategy to assess processing load during listening conditions

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A measure of cognitive load while listening to speech is measurement of the pupil response. The reliability of pupillometry is discussed by combining and comparing the influence of speech perception difficulty (speech-to-noise ratio) and listening effort (speech-to-noise ratio). The results show consistently larger pupil dilatation in the single-talker masker conditions. Furthermore, the data indicate that the

Kramer et al. (1997) Audiology 36, 155-164

Zekveld et al. (2010) Ear and Hearing 31, 480-490

Zekveld et al. (2011) Ear and Hearing, 32, 498-510.

Kramer, et al. (2012). Lang Cogn Processes, in press (Epub available).

Koelewijn, et al. (2012). Ear and Hearing 32, 291-300.

Koelewijn, et al. (2012). Int J Otolaryng, in press.

Zekveld et al. (2012) INCE conference proceedings or: se kramer@vumc.nl

Thank you for your listening effort!

