The role of listening effort during degraded speech recognition: A comparison of the dual-task and pupillometry paradigms

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Introduction

Listening Effort: Deliberate allocation of cognitive resources towards successful speech perception

- Speech perception in normal hearing individuals is automatic, listening effort only engaged in challenging listening situations
- Unclear relationship between construct of listening effort and methods of measurement

Two common ways to investigate listening effort

1) Dual task: compare performance in a non-linguistic task with and without a concurrent speech task.
   - Key Question: does speech perception use domain general resources?
   - E.g., Older adults show larger detriment to performance in visual monitoring task when simultaneously presented with noise vocoded sentences (Ward et al., 2017)
2) Pupillometry: task-evoked changes to pupil size can reflect cognitive effort
   - Susceptible to task difficulty, task engagement, reward
   - E.g., Hearing impaired listeners show larger peak pupil dilation across various SNRs compared to normal hearing listeners (Ohlenforst et al., 2017)

Research Questions

What is the relationship between the dual-task paradigm and pupillometry?

What is the relationship between performance recognizing noise-vocoded speech and listening effort?

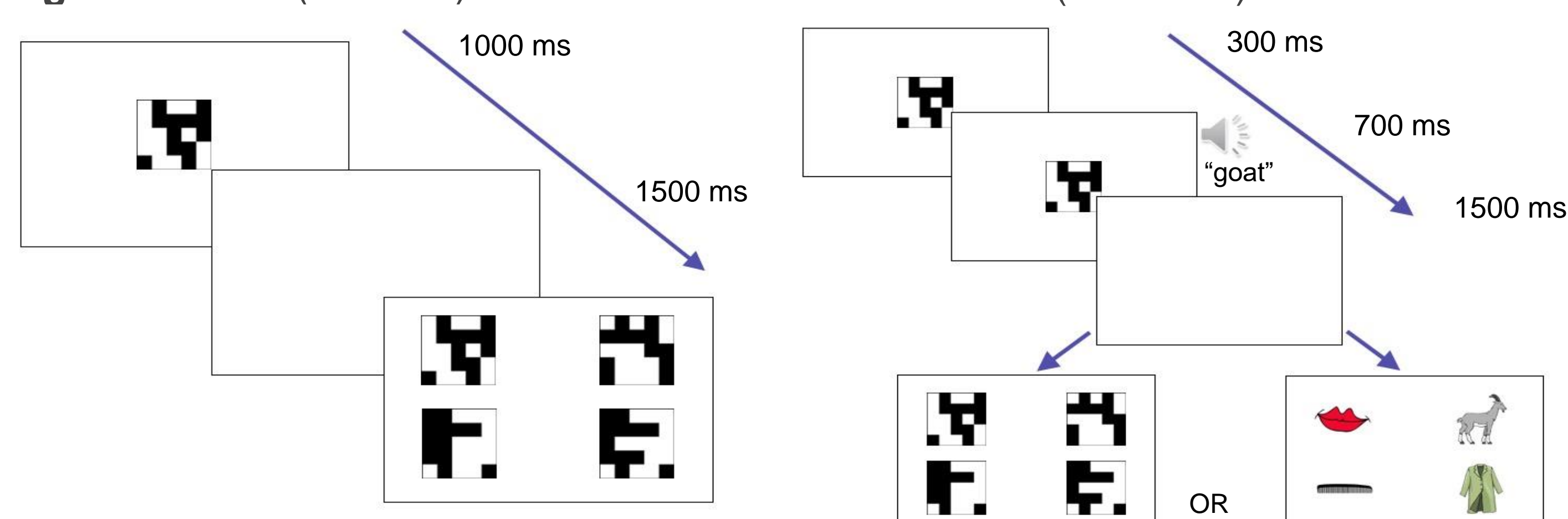## Experimental Tasks

Dual Task

Task 1: Visual Match to Sample: Select the grid that matches the preview
Task 2: Spoken Word Recognition: Select the picture that matches the spoken word
Difference between single-task accuracy and dual-task accuracy indicates recruitment of cognitive resources
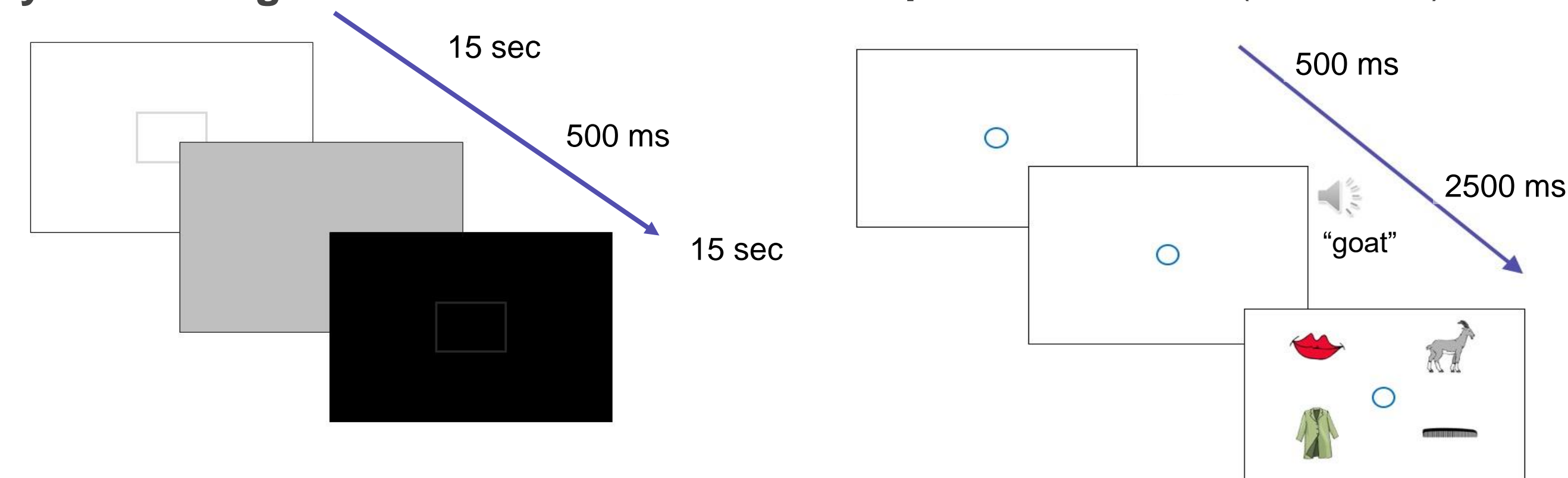

Pupillometry

Participants click on the picture that matches the spoken word while change in pupil size is measured
Increase in pupil size reflects increased cognitive effort (including task engagement, difficulty)
Pupil size scaled to each individual's dynamic range, then baselined to 500ms preceding audio on each trial
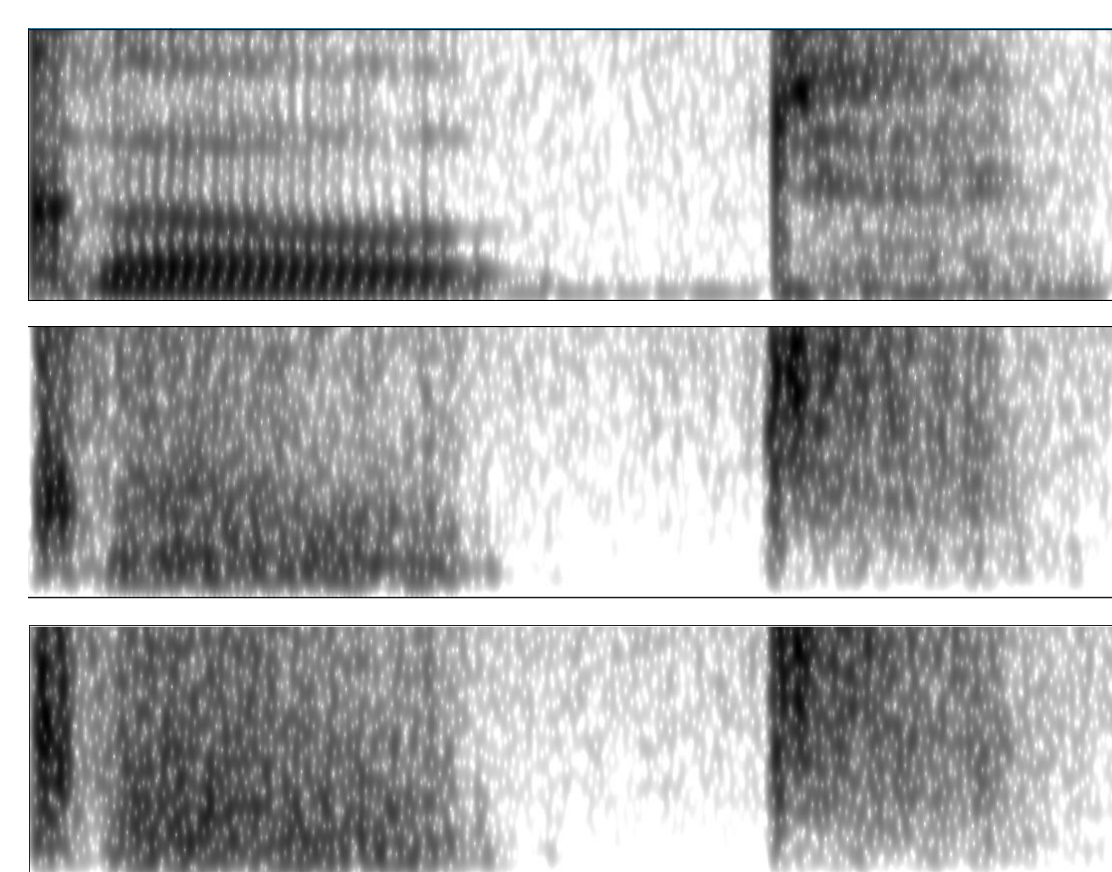

Stimuli

80 words in isolation presented naturally and vocoded at 2 different levels of difficulty

Noise vocoding:
- Maintains temporal information, blurs spectral information
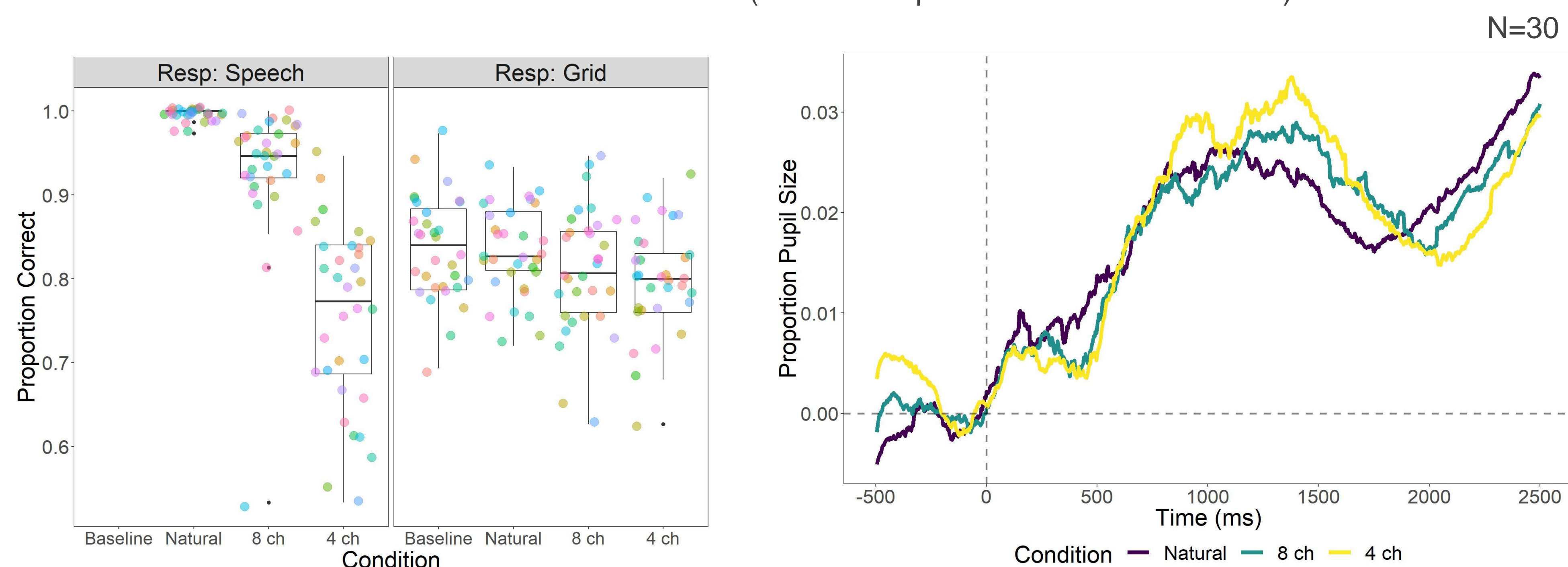- Simulates experience of cochlear implant users

Experiment 1

Participants completed the dual task and pupillometry task one week apart
Received feedback on each trial (whether response was correct/incorrect)

N=30

Grid matching performance is significantly worse when presented alongside 4- and 8-channel vocoding
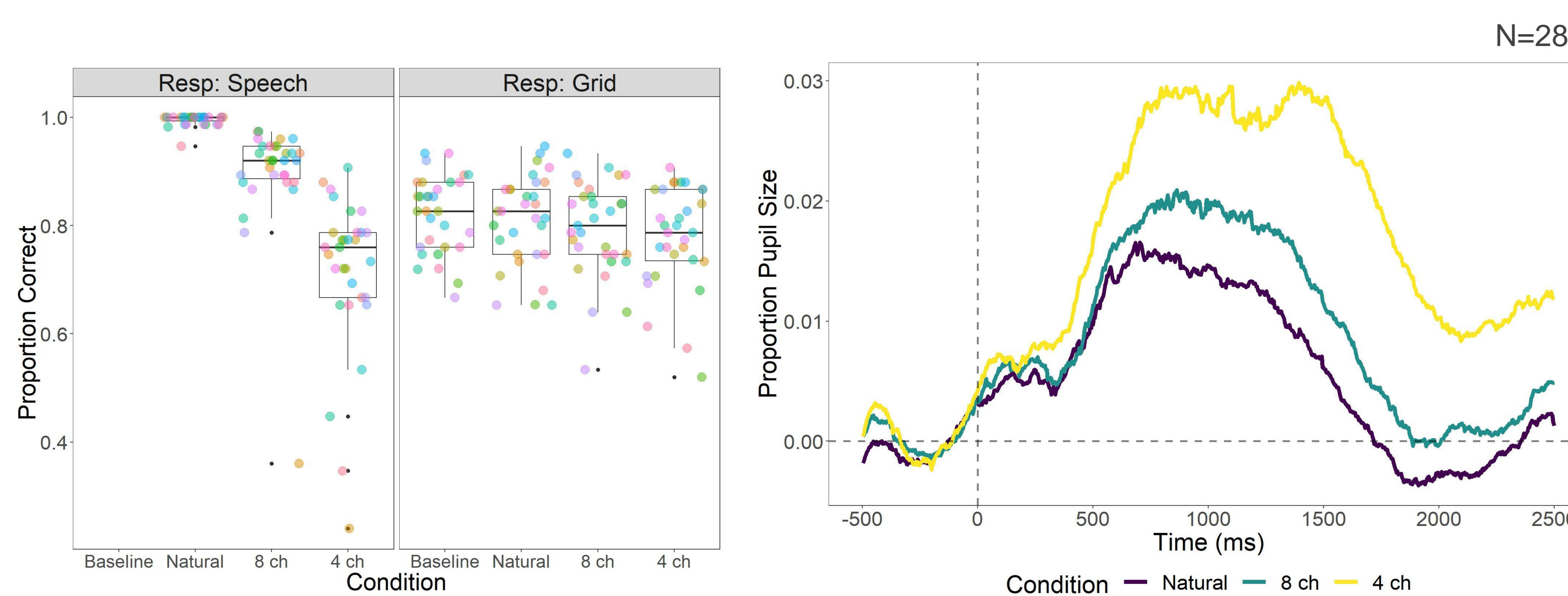
Level of degradation does not predict max pupil size
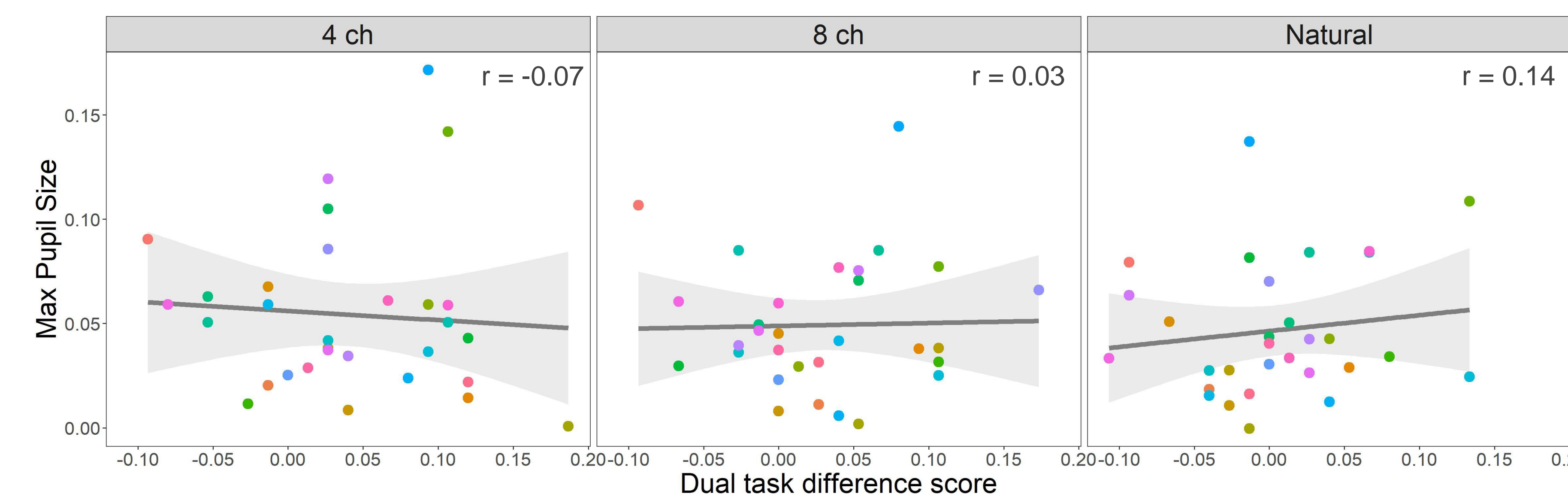
No correlation between max pupil size and difference score on the dual task at any level of degradation

Experiment 3

Participants completed the dual task (Exp 1) and pupillometry task (Exp 2) one week apart
Received feedback in the dual task, no feedback in the pupillometry task

N=28

Grid matching performance is significantly worse when presented simultaneously with 4-channel vocoding

Max pupil size is significantly larger under increasingly difficult levels of degradation
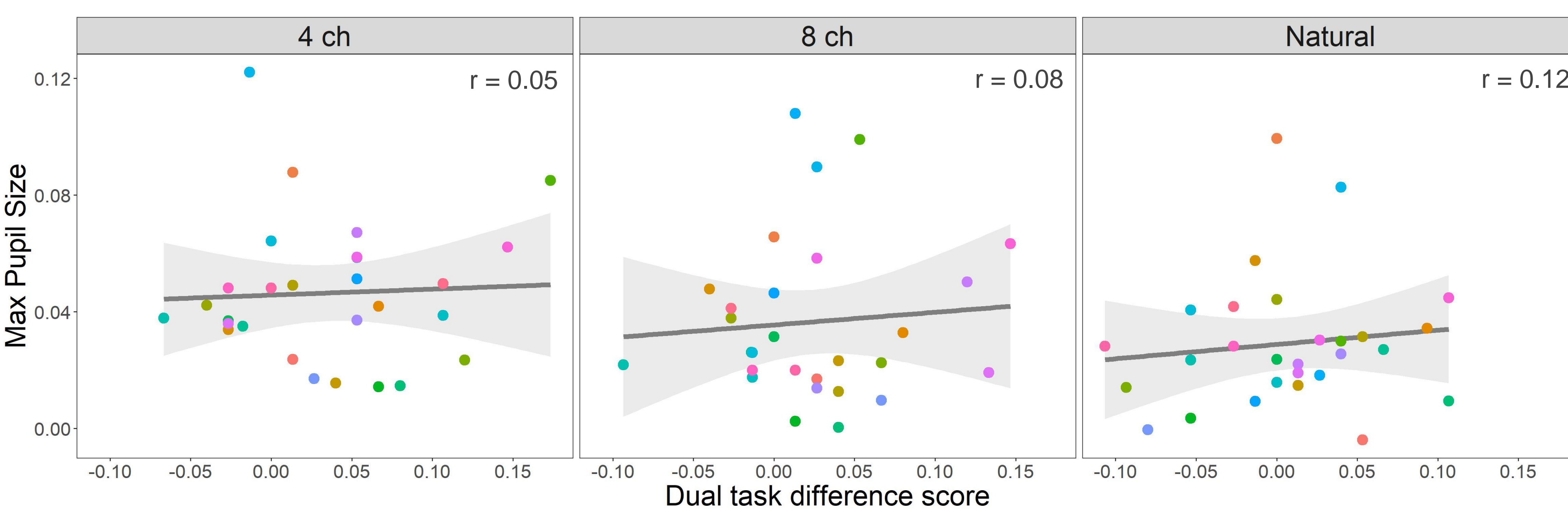
No correlation between max pupil size and difference score on the dual task at any level of degradation

Does level of degradation (condition) or overall accuracy uniquely predict effort in each task?

Dual Task

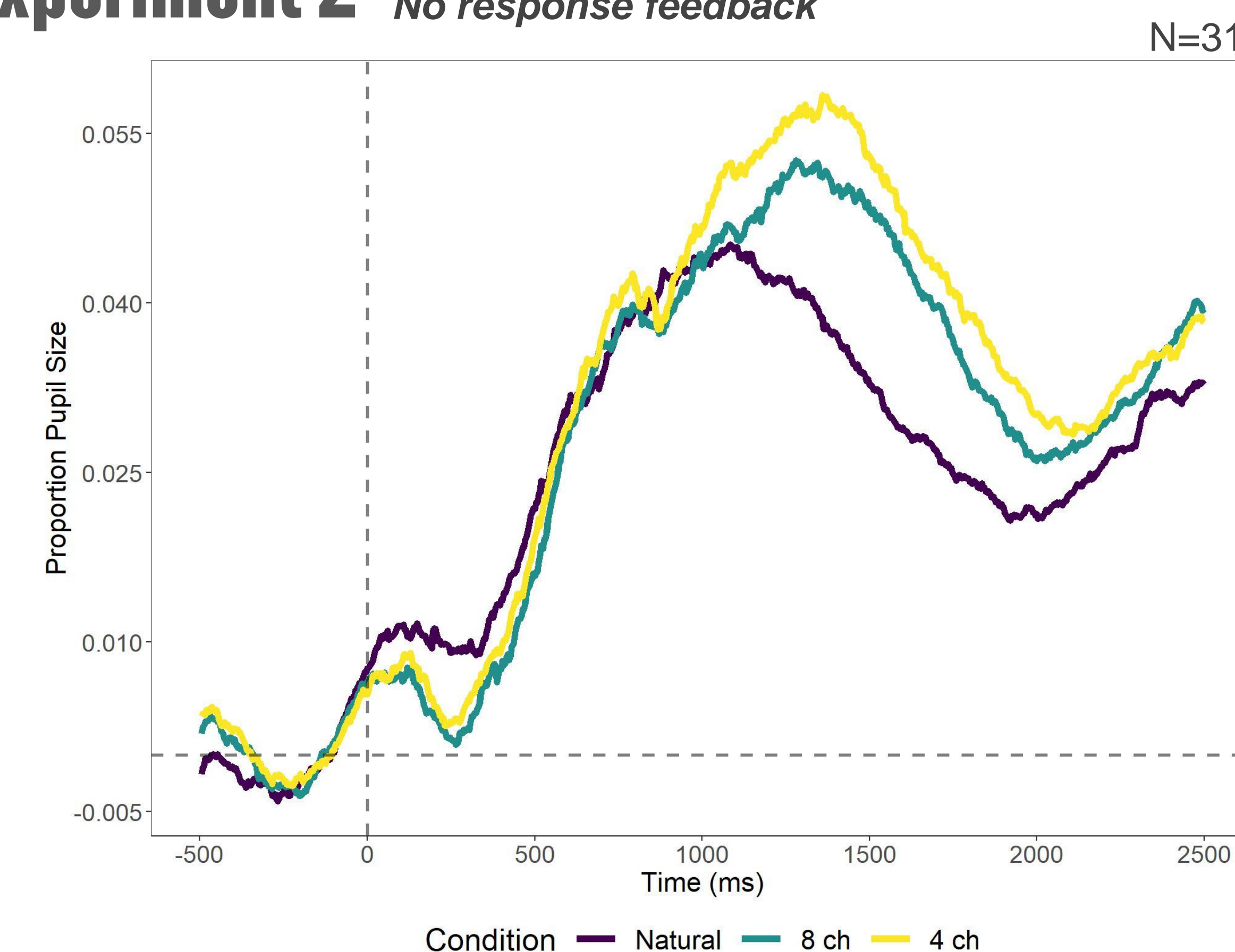|	Accuracy | Condition	Condition | Accuracy
1	Grid response ~ condition	Grid response ~ speech accuracy
2	Grid response ~ condition + speech accuracy	Grid response ~ speech accuracy + condition
χ^2	0.28 (df=1, n.s.)	5.81 (df=2, p=0.05)

Pupillometry

	Accuracy | Condition	Condition | Accuracy
1	Max pupil ~ condition	Max pupil ~ speech accuracy
2	Max pupil ~ condition + speech accuracy	Max pupil ~ speech accuracy + condition
χ^2	4.00 (df=1, p=0.04)	2.38 (df=2, n.s.)

Different factors predict unique variance across the two tasks: condition is important in the dual task, while accuracy is important in the pupil task

Experiment 2

Participants completed only the pupillometry task
No response feedback

N=31

Max pupil size is significantly larger under increasingly difficult levels of degradation

	Accuracy | Condition	Condition | Accuracy
1	Max pupil ~ condition	Max pupil ~ speech accuracy
2	Max pupil ~ condition + speech accuracy	Max pupil ~ speech accuracy + condition
χ^2	1.72 (df=1, n.s.)	6.7 (df=2, p=0.03)

Condition uniquely predicts variation in max pupil size, similar to the dual task from Experiment 1

Summary & Conclusions

Experiment 1 (Dual task & Pupillometry, with feedback)
- Different factors explain unique variance for the dual task and pupillometry
- Level of degradation is important for the dual task, while pupillometry is sensitive to individual accuracy

Experiment 2 (Pupillometry, no feedback)
- When feedback is removed from the pupillometry task, level of degradation now predicts unique variance (consistent with the dual task from Experiment 1)

Experiment 3 (Dual task, with feedback & Pupillometry, no feedback)
- Level of degradation predicts variation in both tasks
- Accuracy remains important for both tasks

Despite level of degradation predicting variance in both tasks of Experiment 3, we find no relationship between performance on the dual task and maximum pupil size from pupillometry

Pupillometry is sensitive to task design, including to error monitoring as a result of feedback
- Must carefully design tasks to isolate listening effort

References

Ohlenforst, B., Zekveld, A. A., Lunner, T., Wendt, D., Naylor, G., Wang, Y., ... Kramer, S. E. (2017). Impact of stimulus-related factors and hearing impairment on listening effort as indicated by pupil dilation. Hearing Research, 351, 68–79. https://doi.org/10.1016/j.heares.2017.05.012
Ward, K. M., Shen, J., Souza, P. E., & Grieco-Calub, T. M. (2017). Age-Related Differences in Listening Effort during Degraded Speech Recognition. Ear and Hearing, 38(1), 74–84. https://doi.org/10.1097/AUD.0000000000000355