

Pupillometry Remains Sensitive to SNR-based Manipulations Across Prolonged Experimental Sessions

update on an ongoing project (Oct. 2025)

Brady M. Chisholm & Juraj Mesik

GAMMs Club
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UNIVERSITY OF MINNESOTA

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Who We Are

- **Brady Chisholm:** U of MN Psychology B.S. August 2025, post-bacc researcher in Auditory Perception and Cognition Lab
- **Juraj Mesik:** Research Scientist at U of MN, predominantly interested in cortical processing of speech in challenging listening backgrounds (using TRF methods). Interested in the possible interplay of listening effort & cortical tracking of various speech features
- Both new to GAMMs, but learning more since Spring 2025 :)
- Working towards manuscript draft on fatigue... (more to come)

If you were a reviewer,
what's your verdict?  / 



Research Question

- Motivation: Pupillometry is a mainstream measurement

Citations of “Pupillometry” / 100,000 articles on Pubmed (Sperr, 2016)

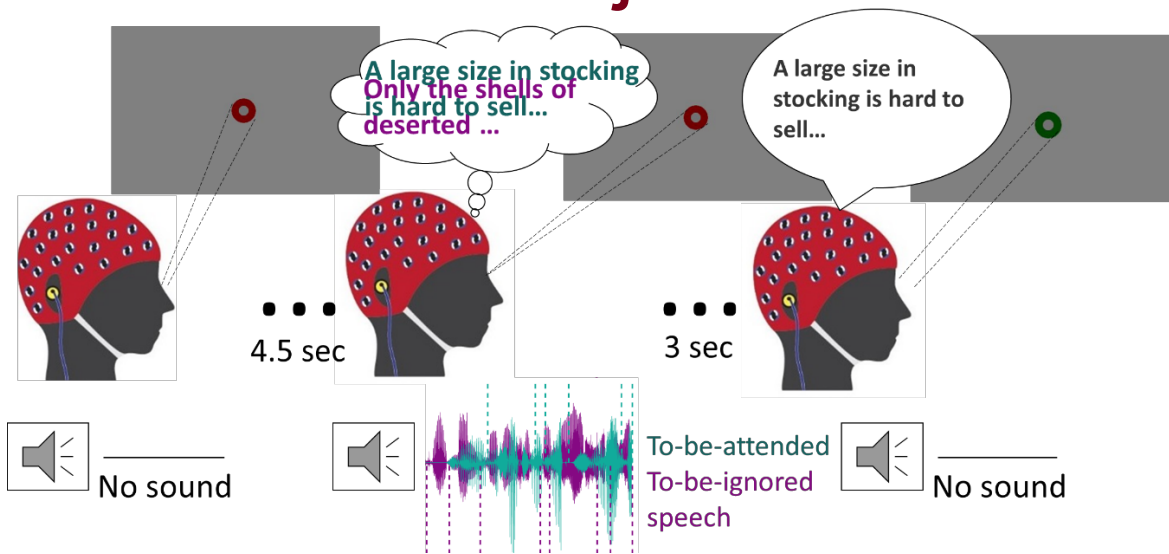
2015 = 7.23

2025 = 17.58

- Unclear if fatigue interacts with effect of LE manipulation
 - Presence of fatigue (in some form) is acknowledged in much of the literature discussing pupillometry
- Goal: Analyze existing dataset to assess whether fatigue and LE interact (or not...)
 - Accomplish by assessing how time x block x SNR interact



Present Project



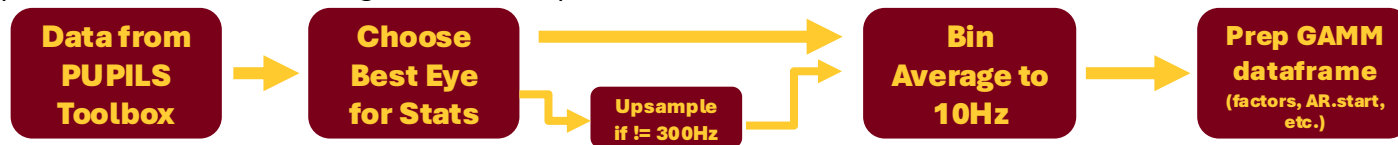
Paradigm: Diotic speech-in-speech recognition at four SNR levels (5, 0, -5, and -10 dB SNR) with 50 trials/condition, performed over 10 blocks of 20 trials. SNR varied on a trial-by-trial basis.

Stimuli: IEEE target sentences.

Distractor is simultaneous audiobook fixed at 65 dB SPL, and preceded target audio onset by 1 second each trial to facilitate streaming.

Pupillometry Data: Tobii Pro Spectrum tracking @ 300Hz

Load preprocessed pupillometry data from PUPILS Toolbox (Relaño-Iborra & Bækgaard, 2020) and then in R...



Pupil Data

Part of a larger study focusing on LE involving EEG, self-report, etc.

Pupil *mean* = 0.063; *sd* = 0.198

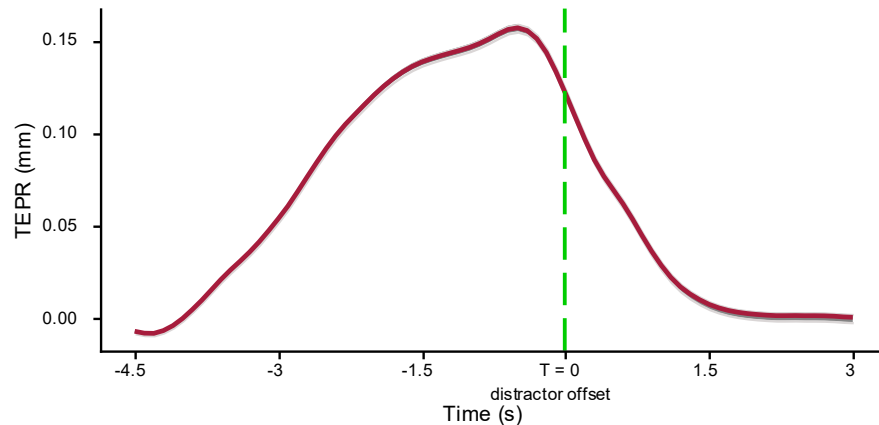
N = 62, Age *mean*: 47.6; *sd*: 17.65

- Assert effect of SNR on pupil
- **Offset aligned data**

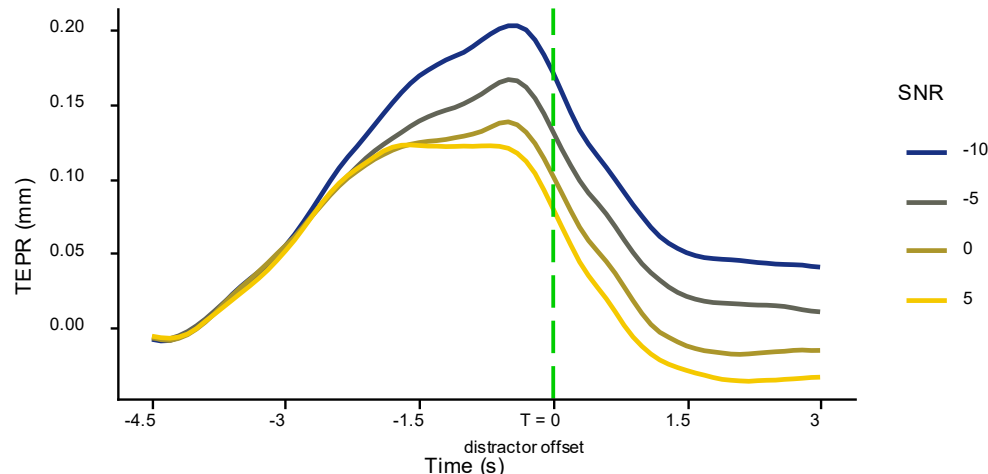
T = 0 is Distractor Offset

Target offset is -0.5s prior to T = 0

Average Pupil Response

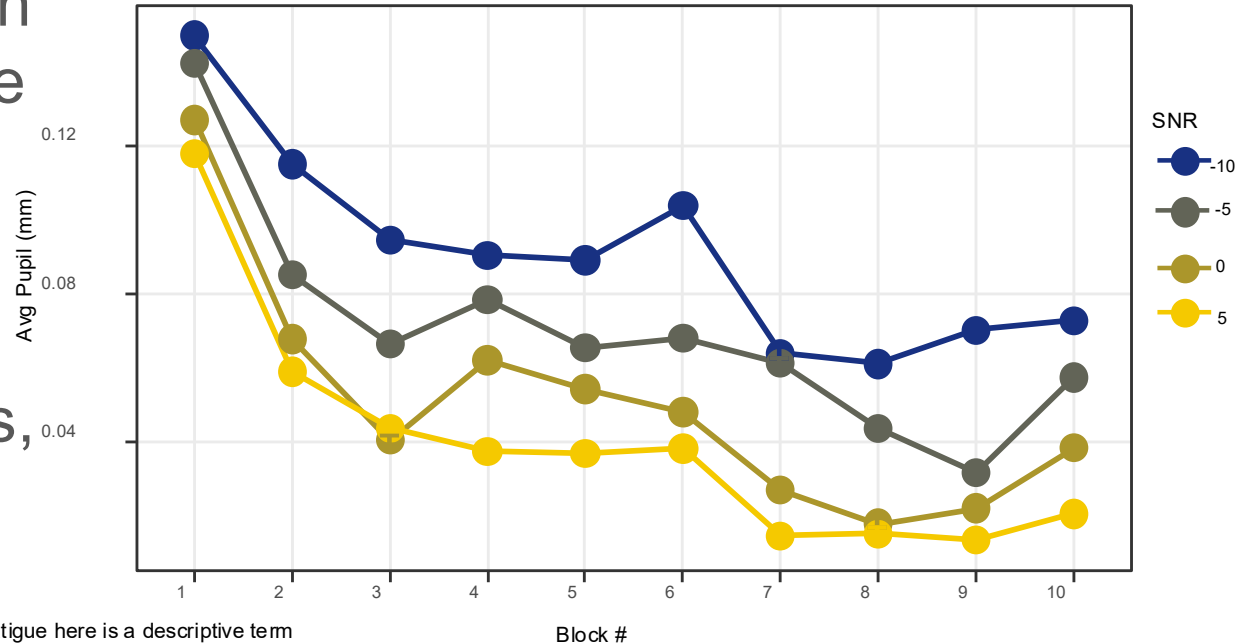


Average Pupil Response by SNR Condition



The Effect of Block (or...fatigue)

- Can observe fatigue in raw average response
- To most, weaker dilations over time is unwanted variance
- Effect of SNR persists, but does it interact with fatigue?



Note: *Pupillometric* fatigue here is a descriptive term for habituating pupil response. This is not the same as cognitive fatigue (in this presentation we are agnostic about the causes / contributing factors).



Previous Roadblocks

Issue

- Models failing to converge (endlessly running)
- Flat lines when plotting smooths using `itsadug`
- Exceeding memory capacity

Resolution

- Used offset aligned vs full time course
- Changed basis function
- Downsampled to 10Hz
- Bin averaging of data



How to Separate out Effects?

- Previous issue presented in Oct. 2025 meeting
 - Pursued binary predictors (such as Wieling et al., 2018; Johns et al., 2024; Smith et al., 2025)
- Believed with 10 blocks and 4 SNRs, would result in 9 (block main effects) + 3 (snr main effects) + 27 (block*snr interaction effects) = 39 binary predictors
- Also used ‘S Z’ smooths at the time



What We Actually Did

- Treated *only* SNR as an ordered factor variable
 - Excluded one level for reference treatment
 - Resulted in `isSNR_x` variables for each condition, modeled as parametrics
- Reference surfaces of `time` and `block`
- Differences surfaces of `block` by `isSNR_x`
- Interaction terms of `time` x `block` by `isSNR_x`
- `ti()` terms all the way...




Our Iterative Modeling Process

Model	Adj. R-sq	Dev. Explained
basicGAMM_noBlock_noAR1	0.291	23.7%
basicGAMM_noBlock_withAR1	0.282	22.8%
basicGAMM_noAR1	0.317	25.7%
basicGAMM_wAR1	0.307	24.8%
fullTensorGAMM	0.309	25.0%

Model of Interest

“Final” formula

- Use tp basis function
- 5.6 GB 

Term	k value
Time	50
Block	10
Random Effects	40

```
tensorGAMM_acf_and_rho_FULLData <- bam(pupil ~
# parametric main effects
  isSNR_m10 + isSNR_m5 + isSNR_0 +

# reference surfaces
ti(time, k = seconds_k, bs = "tp") +
ti(block, k = block_k, bs = "tp") +

# reference interaction
ti(time, block, k = c(seconds_k, block_k), bs = "tp") +

# differences surfaces of time by isSNR_x
ti(time, by = isSNR_m10, k = seconds_k, bs = "tp") +
ti(time, by = isSNR_m5, k = seconds_k, bs = "tp") +
ti(time, by = isSNR_0, k = seconds_k, bs = "tp") +

# difference surface of block by isSNR_x
ti(block, by = isSNR_m10, k = block_k, bs = "tp") +
ti(block, by = isSNR_m5, k = block_k, bs = "tp") +
ti(block, by = isSNR_0, k = block_k, bs = "tp") +

# --- INTERACTIONS ---
# discern time * block differences by SNR_x compared to reference of SNR 5
ti(time, block, by = isSNR_m10, k = c(seconds_k, block_k), bs = "tp") +
ti(time, block, by = isSNR_m5, k = c(seconds_k, block_k), bs = "tp") +
ti(time, block, by = isSNR_0, k = c(seconds_k, block_k), bs = "tp") +

# --- RNDM EFFECTS ---
s(time, subject, by = isSNR_m10, bs = "fs", m = 1, k = kRandom) +
s(time, subject, by = isSNR_m5, bs = "fs", m = 1, k = kRandom) +
s(time, subject, by = isSNR_0, bs = "fs", m = 1, k = kRandom) +
s(time, subject, bs = "fs", m = 1, k = kRandom),
```

Results

What to plot?

What matters?

- Start with summary
- Identify significant terms (what's wiggly?)
- Investigate further via plotting

Tensor Interaction Model Summary Statistics

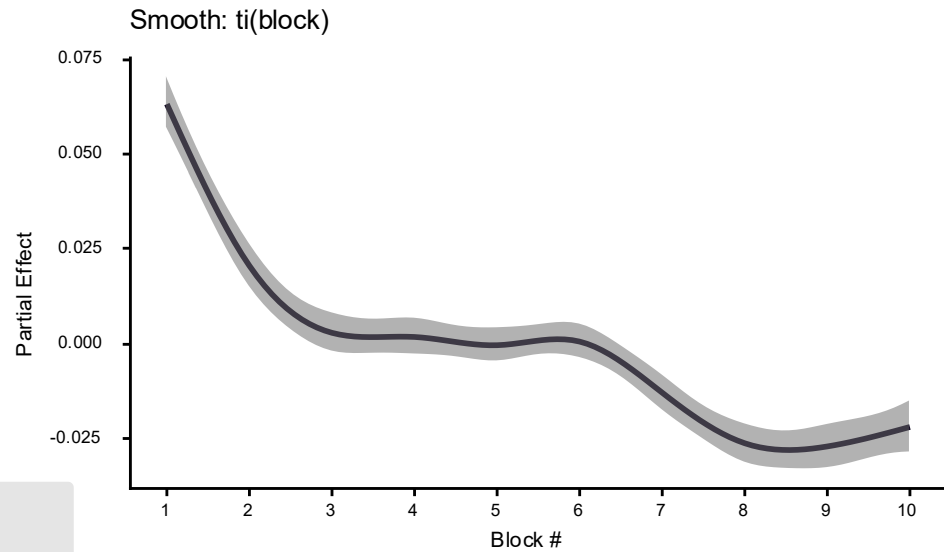
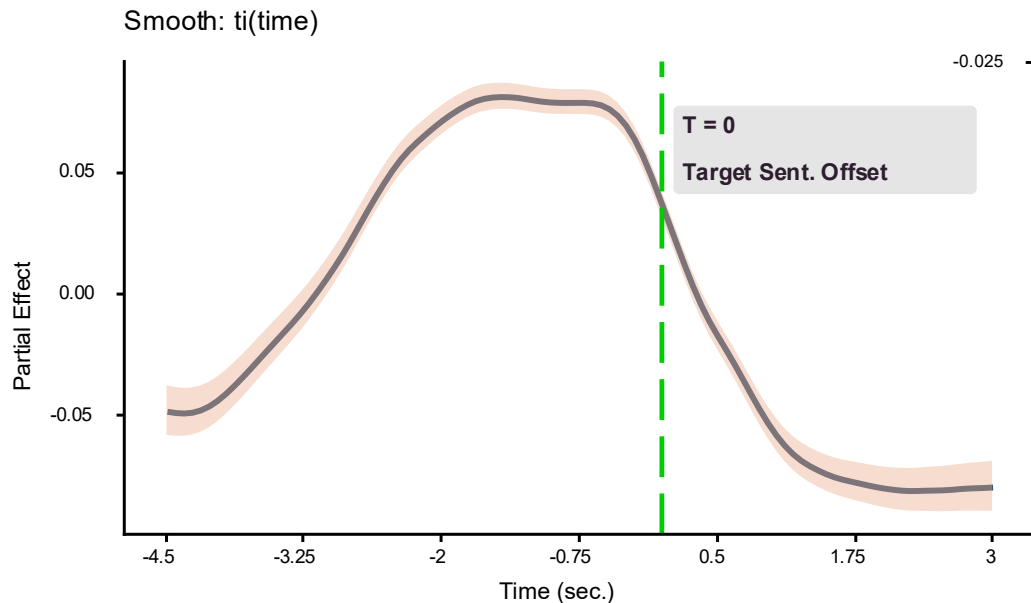
<i>Term</i>	<i>EDF</i>	<i>Ref.df</i>	<i>F</i>	<i>p</i>
Smooth terms				
time	34.49	36.60	47.72	< .001
block	7.41	8.39	46.36	< .001
block, time	216.10	282.20	4.08	< .001
time × is\$NR_m10TRUE	18.57	22.77	16.18	< .001
time × is\$NR_m5TRUE	14.79	18.94	9.42	< .001
time × is\$NR_0TRUE	10.94	14.11	3.27	< .001
block × is\$NR_m10TRUE	1.02	1.04	0.76	.390
block × is\$NR_m5TRUE	1.01	1.02	0.00	.997
block × is\$NR_0TRUE	1.03	1.06	0.07	.826
block, time × is\$NR_m10TRUE	66.91	108.59	0.61	.999
block, time × is\$NR_m5TRUE	87.69	138.86	0.72	.994
block, time × is\$NR_0TRUE	42.63	63.15	1.06	.345
Random smooths				
time, subject × is\$NR_m10TRUE	1215.56	2480.00	1.05	< .001
time, subject × is\$NR_m5TRUE	779.74	2480.00	0.47	< .001
time, subject × is\$NR_0TRUE	796.57	2479.00	0.49	< .001
time, subject	2158.47	2480.00	9.26	< .001

Adjusted R-squared = 0.309 | Deviance Explained = 25.0% | fREML = 282911.95



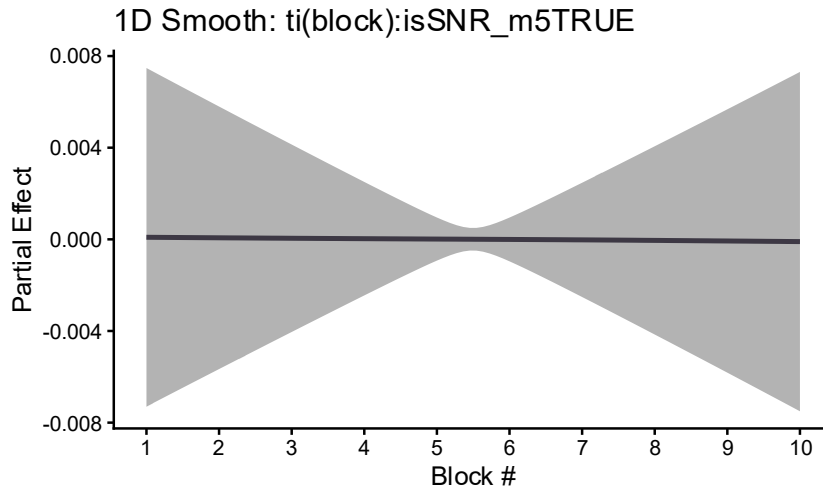
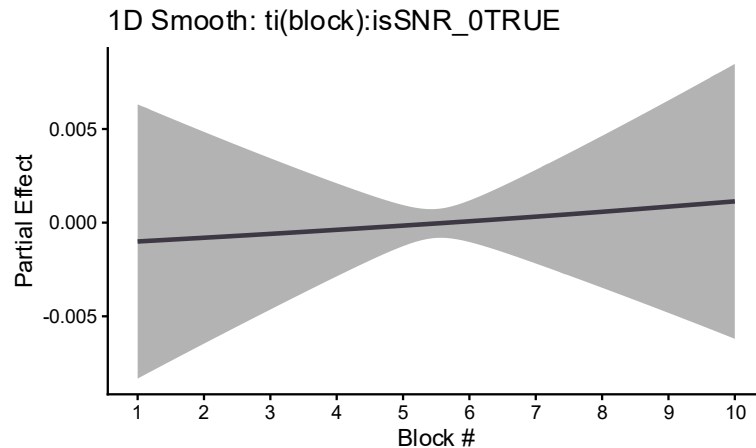
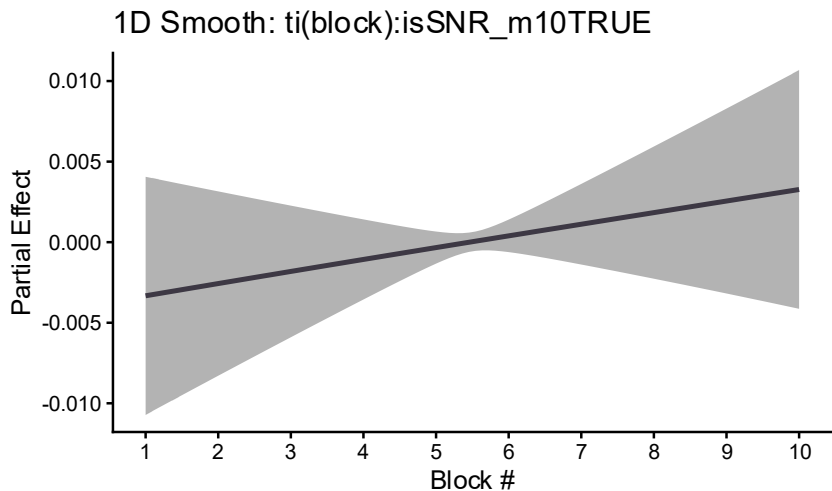
Results (cont.)

First inspect significant smooths of block and time



Results (cont.)

Also significant smooths of block x SNR, but unsure how to interpret... (and bowtie CIs!)

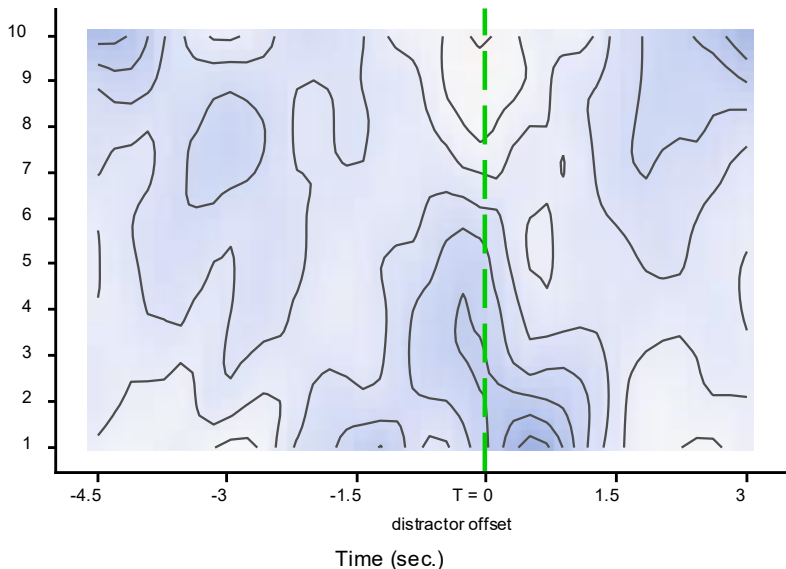


Results SNR -10

What does the interaction surface look like?

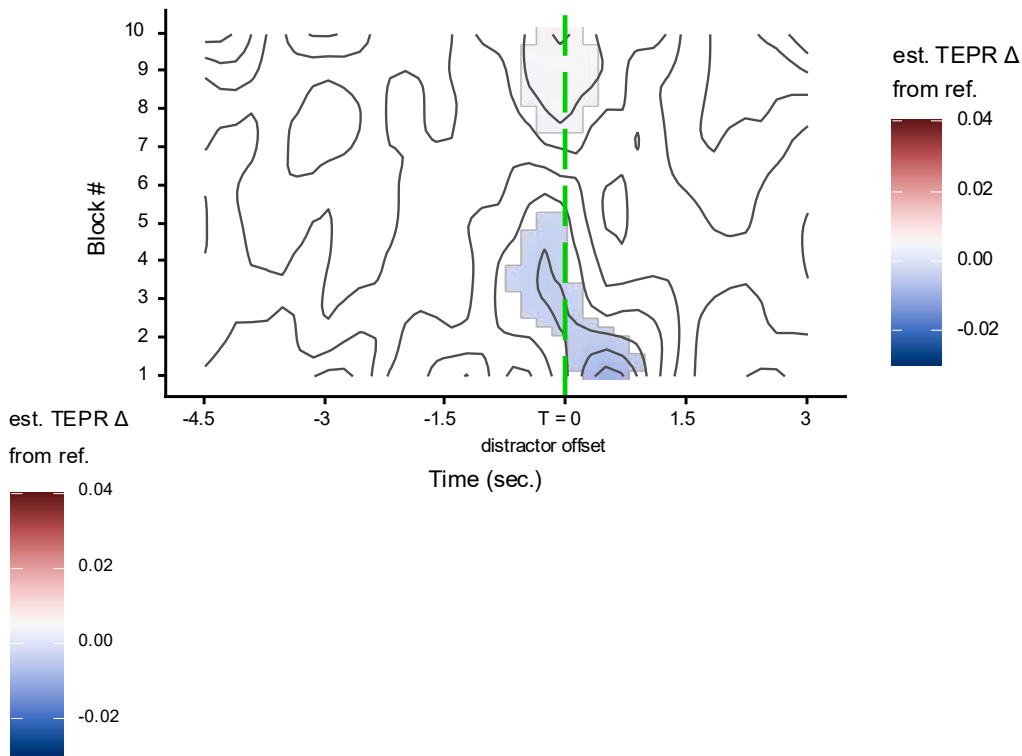
(with and w/o sig. test)

Interaction Surface $t_i(\text{block}, \text{time}): \text{isSNR_m10TRUE}$



Interaction Surface $t_i(\text{block}, \text{time}): \text{isSNR_m10TRUE}$

Colored regions sig. diff. from ref. ($p < 0.05$)

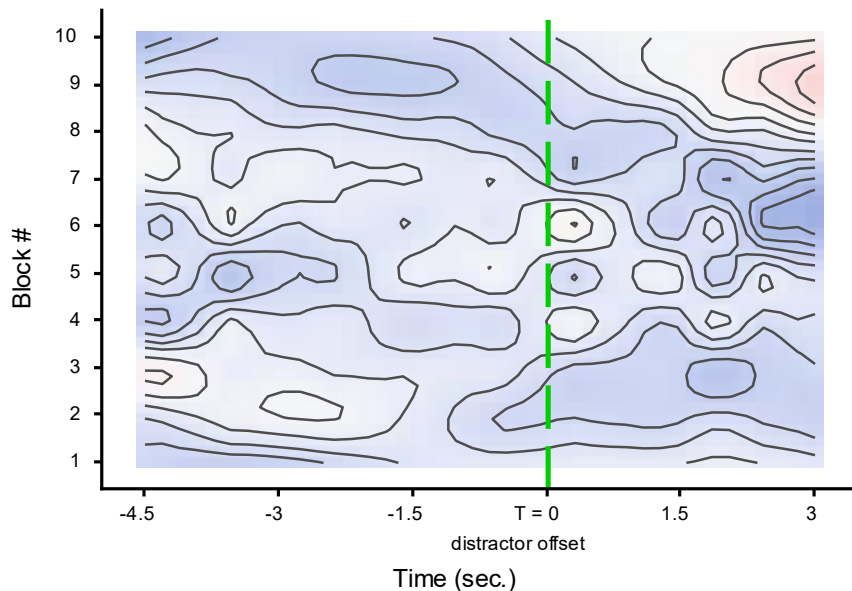


Results SNR 0

What does the interaction surface look like?

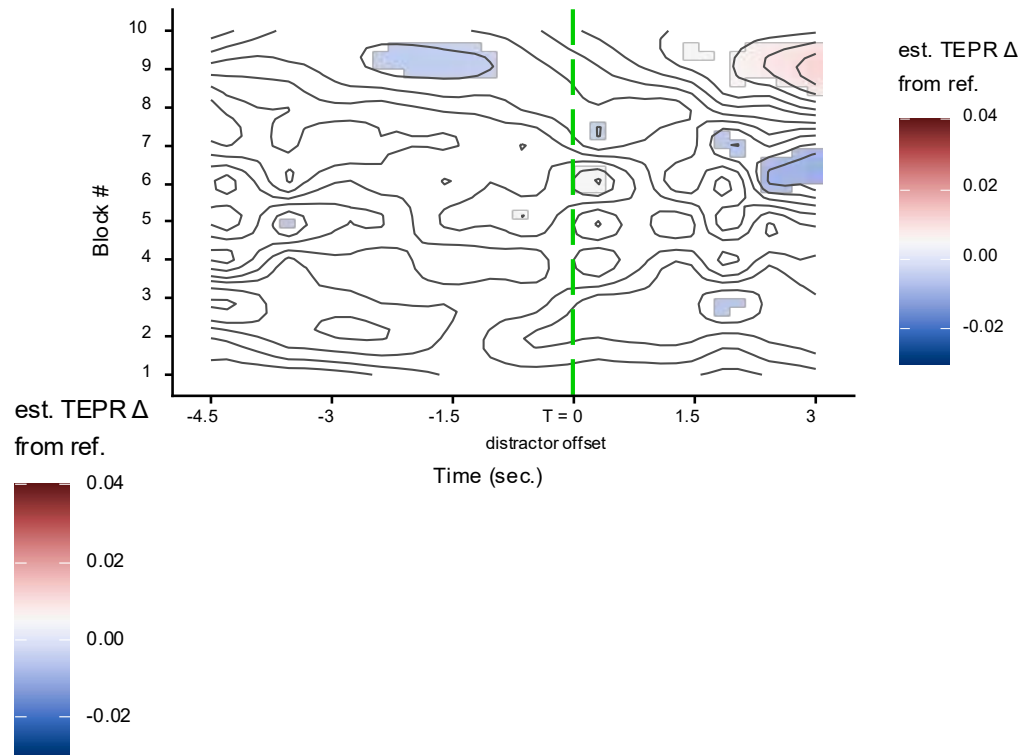
(with and w/o sig. test)

Interaction Surface $t_i(\text{block}, \text{time}): \text{isSNR_0TRUE}$



Interaction Surface $t_i(\text{block}, \text{time}): \text{isSNR_0TRUE}$

Colored regions sig. diff. from ref. ($p < 0.05$)

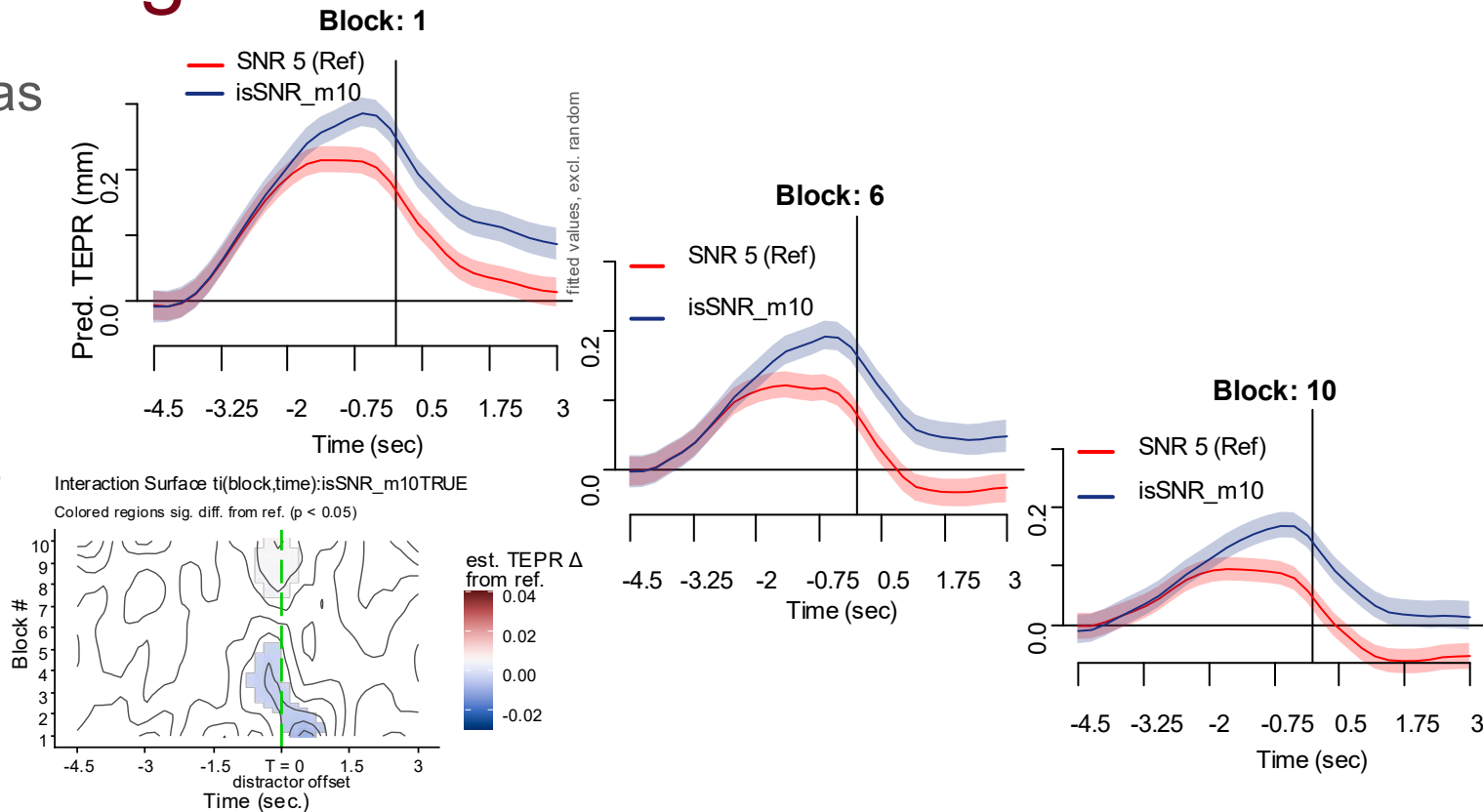


Comparing SNR over Block

Observed areas of significant difference are nearly nonexistent.

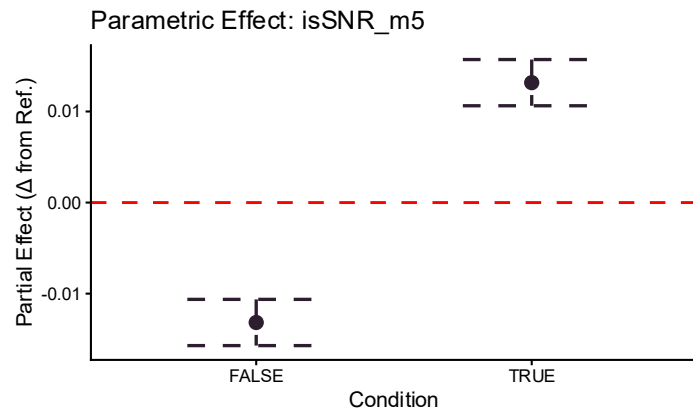
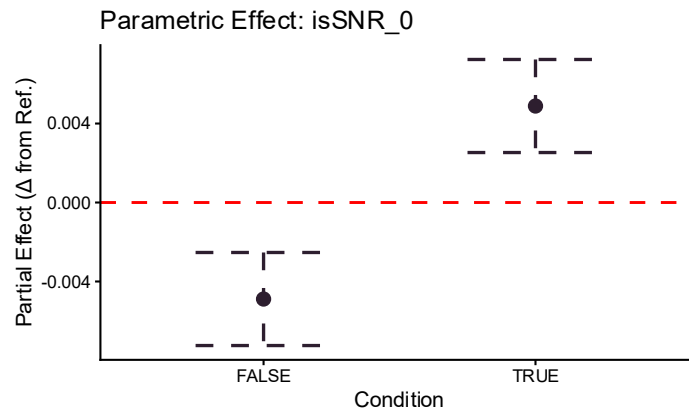
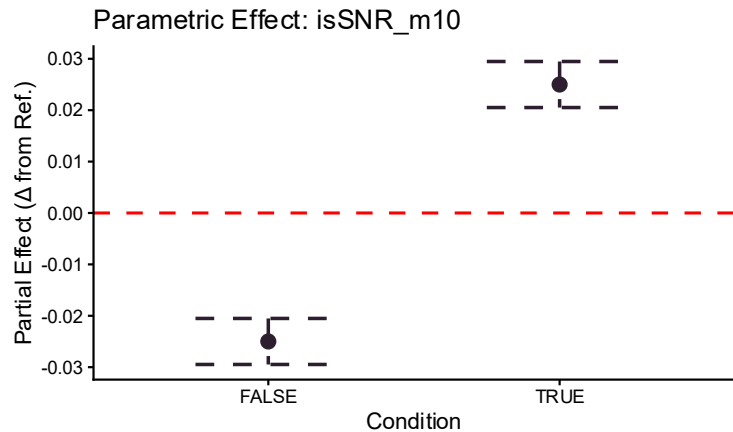
But what does the difference look like?

(itsadug plots)

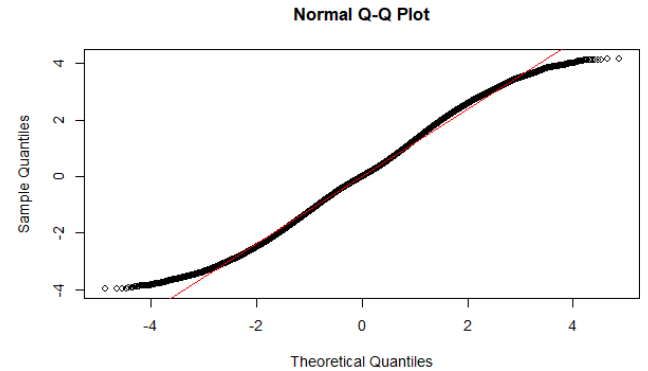
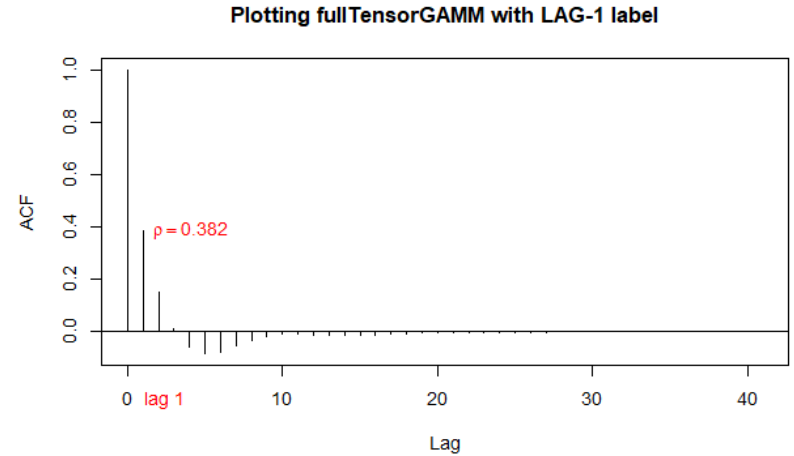
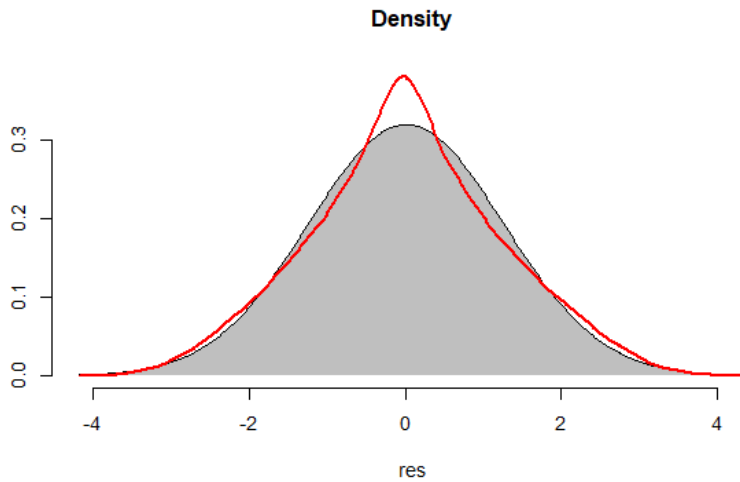


Results (cont.)

Parametrics






Critiquing our Model



Summary

- Fatigue does not interact with ***this*** manipulation of LE
- Uncertain how fatigue may behave in other paradigms
- Did model specifications, interpretation, figures make sense? What would help to see?
- If you were a reviewer...

Decision?
Accept 
Accept with revisions 
Rejected 

End slide



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