Pupillometry and Auditory Attention Switching

Methods and Interpretations

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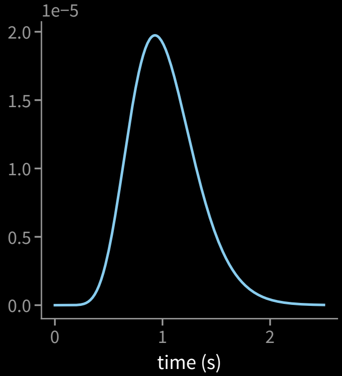
Overview

- Modeling the stereotypical pupil response
    - Hoeks & Levelt 1993
- Working backward from dilation to arousal / effort / load / attention
    - Weirda et al 2012; McCloy et al 2016
- The effort of auditory attention switching
    - McCloy et al 2017
- Attention switching and APD

Modeling the stereotypical pupillary response

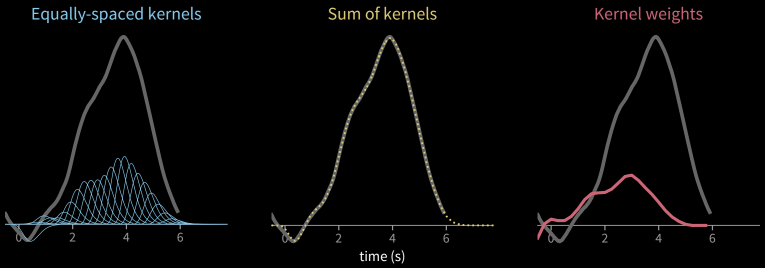
- Pupillary output = system impulse response $*$ attentional input
  - $y(t) = h * x(t)$
- System modeled as cascade of decaying exponentials (≈ neural relays)
  - Assumption: all relays have identical response properties (up to scaling factor) → Erlang
  - $h(t) = t^n e^{-nt/t_{max}}$ (for $t > 0$)
- Hoeks & Levelt's estimates of free parameters:
  - number of relays ("shape"): $n = 10.1$
  - latency of peak ("scale"): $t_{max} = 0.930$ s



Hoeks & Levelt (**1993**). "Pupillary dilation as a measure of attention: A quantitative system analysis," *Behavior Research Methods, Instruments, & Computers*, **25**, 16–26. doi:10.3758/BF03204445

Working backward from dilation to attention

- stipulate temporal locations of “attentional pulses”
- fit linear sum of pupil impulse responses at those times



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Problem encountered

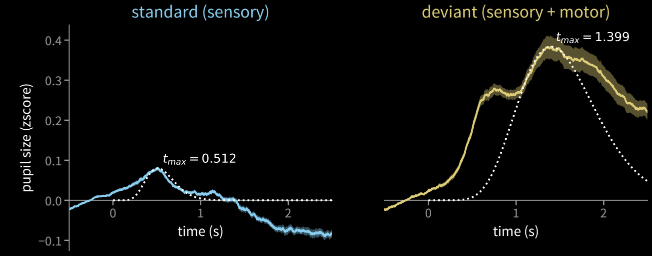
- Hoeks & Levelt (1993) estimated t_{max} using button-press trials
  - ~70% of pupillary response is button-press (Hupé et al 2009)
  - Estimate of t_{max} too large → acausal deconvolution results

Hoeks & Levelt (**1993**). "Pupillary dilation as a measure of attention: A quantitative system analysis," *Behavior Research Methods, Instruments, & Computers*, **25**, 16–26. doi:10.3758/BF03204445

Hupé, Lamirel, & Lorenceau (**2009**). "Pupil dynamics during bistable motion perception," *Journal of Vision*, **9**, article 10. doi:10.1167/9.7.10

Problem solved?

- Auditory deviant detection task (100 ms tone pips)
  - Our lab's estimate: $t_{max} = 0.512$ seconds
  - N=10 adults, aged 21-35



McCloy, Larson, Lau, & Lee (**2016**). "Temporal alignment of pupillary response with stimulus events via deconvolution," *The Journal of the Acoustical Society of America*, **139**, EL57–EL62. doi:10.1121/1.4943787

Methods summary: pupillary deconvolution

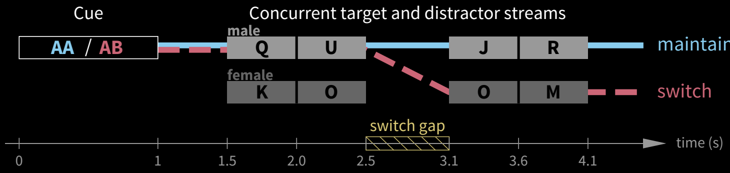
- Estimates of t_{max} not necessarily stable across tasks
  - Maybe re-estimate for each study type
  - Range across subjects: 0.397 to 0.607 s
- How problematic are button presses for event-related analyses?

The effort of attention switching

- Is attention switching the kind of cognitive event that manifests in the pupil?
  - If so, when does it show up?
  - Is it bigger than the response due to stimulus degradations?
  - Does it tell us anything that behavioral measures can’t?
- 3 experiments:
  - 2 concurrent streams of spoken letters
  - Detect target “O” and press button
  - Pre-trial “maintain” or “switch” cue

The effort of attention switching

- Experiment 1: ±45° spatially separated streams
  - *Stimulus degradation*: anechoic vs. reverberant
  - *Stream segregation*: 2 ♂ voices vs. 1 ♂ 1 ♀ voice
  - *Attention*: report same talker throughout trial, or switch halfway



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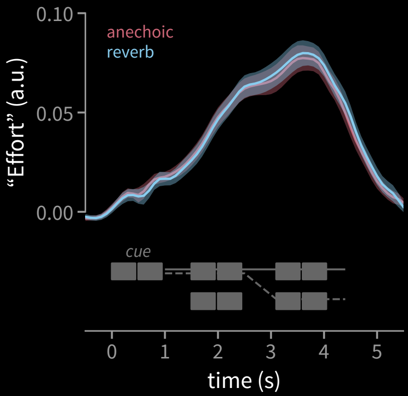
The effort of attention switching

- Stimulus degradation (reverb)
    - Significant differences in d′ and reaction time
    - No difference in pupillary response



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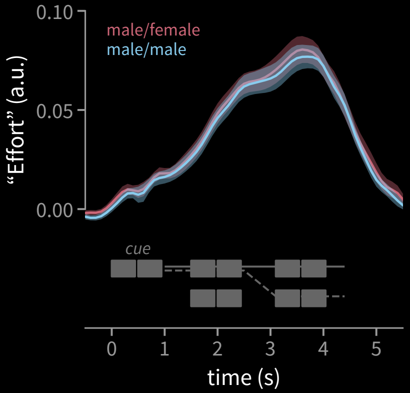
The effort of attention switching

- Stream separability (talker gender)
    - Significant differences in d′ and reaction time
    - No difference in pupillary response



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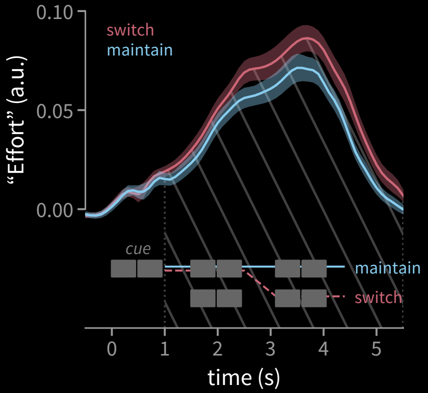
The effort of attention switching

- Attention (maintain/switch)
  - Significant differences in d′ and reaction time
  - Pupil sizes larger on “switch” trials, *as soon as cue is heard*



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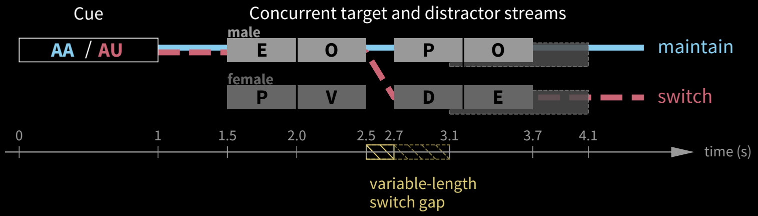
The effort of attention switching

- Experiment 2
  - *Stimulus degradation*: 10- vs. 20-band noise vocoder
  - Short- vs. long-duration mid-trial gap
  - *Attention*: maintain vs. switch (same as Exp. 1)



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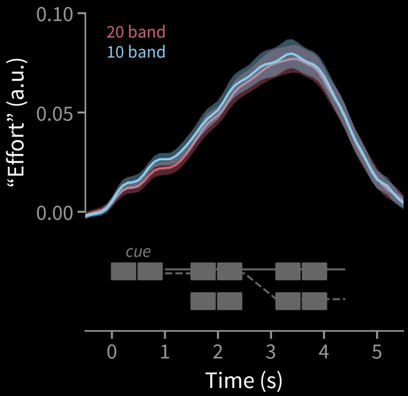
The effort of attention switching

- Stimulus degradation (# vocoder bands)
  - Significant differences in d′ and reaction time
  - No difference in pupillary response



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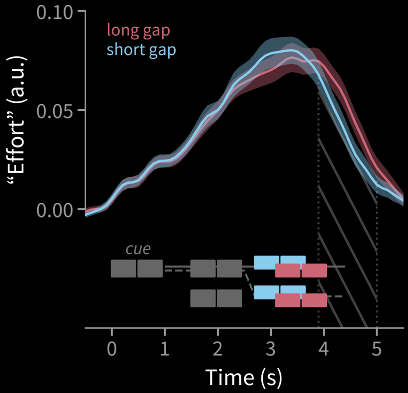
The effort of attention switching

- Length of switching gap
  - Significant differences in d′ and reaction time
  - Difference in pupil: latency, not magnitude



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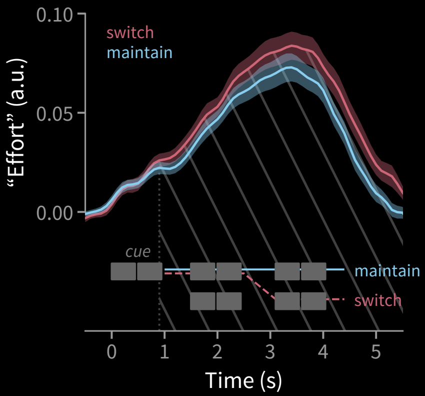
The effort of attention switching

- Attention (maintain/switch)
  - Significant difference in d'
  - Pupil sizes larger on “switch” trials, as soon as cue is heard



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Summary: spatial and non-spatial attention switching

- Pupillometry provides different information from either d′ or reaction time
    - Our interpretation: “listener effort, but only when it makes a difference”
- Same pattern of pupillary response for spatial switches (reverb exp.) and non-spatial switches (vocoder exp.)

Attention switching and APD

- Same paradigm, no stimulus degradation this time
- Switching between talkers
  - **spatial** (same voice, different locations)
  - **non-spatial** (different voices, same location)
  - **mixed** (different voices and different locations)
- Population contrast: self-reported APD
  - "Do you have difficulty understanding speech in the presence of background noise or in large rooms that echo?"
  - "Do you have difficulty determining where a sound came from without having to look?"

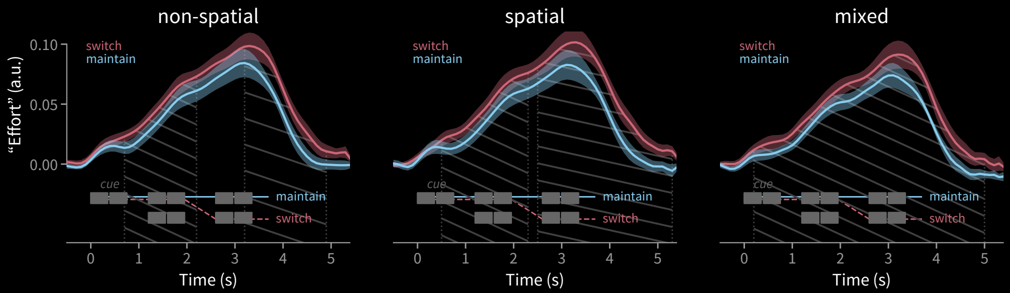
Gatehouse & Noble (**2004**). "The speech, spatial and qualities of hearing scale (SSQ)," *International Journal of Audiology*, **43**, 85–99. doi:10.1080/14992020400050014

Attention switching and APD

- Behavioral stats (APD vs. control)
  - No differences in performance between groups in any condition
- Behavioral stats (“maintain” vs. “switch”)
  - **spatial**: difference in d′ for both populations
  - **non-spatial**: difference in d′ for both populations
  - **mixed**: no difference in d′ for either population

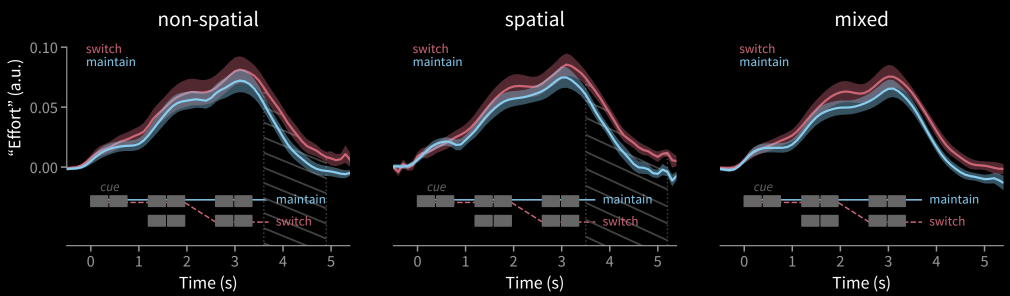
Attention switching and APD

- Self-reported APD listeners (*N*=12, aged 21-66)



Attention switching and APD

- Age-matched control listeners (*N*=12, aged 21-66)



Summary: Attention switching and APD

- Pupillometry reflects listener self-report (at least to some degree)
    - Doesn't seem to be error-monitoring (performance not different for APD / controls)
    - Trying harder to achieve same result? (cf. "listening effort")
    - Just nervous?
- Acausality after deconvolution
    - Wrong t_{max}? (older listeners → *shorter* latency?)
    - Experimentally blocked trials?

Discussion

- How to interpret results of deconvolved pupil size generally?
  - “Attentional processes”? (Wierda et al 2012)
  - “Cognitive load”?
  - “Arousal”?
  - Input to locus coeruleus?
  - Something the listener does to improve performance (“Effort”)?
- Interpretation depends on experiment design, and *perhaps even depends on what point in the trial listener is at*

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References

[1] Hoeks & Levelt (**1993**). “Pupillary dilation as a measure of attention: A quantitative system analysis,” *Behavior Research Methods, Instruments, & Computers*, **25**, 16–26. doi:10.3758/BF03204445

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