

The Mind-Writing Pupil

Sebastiaan Mathôt

s.mathot@cogsci.nl

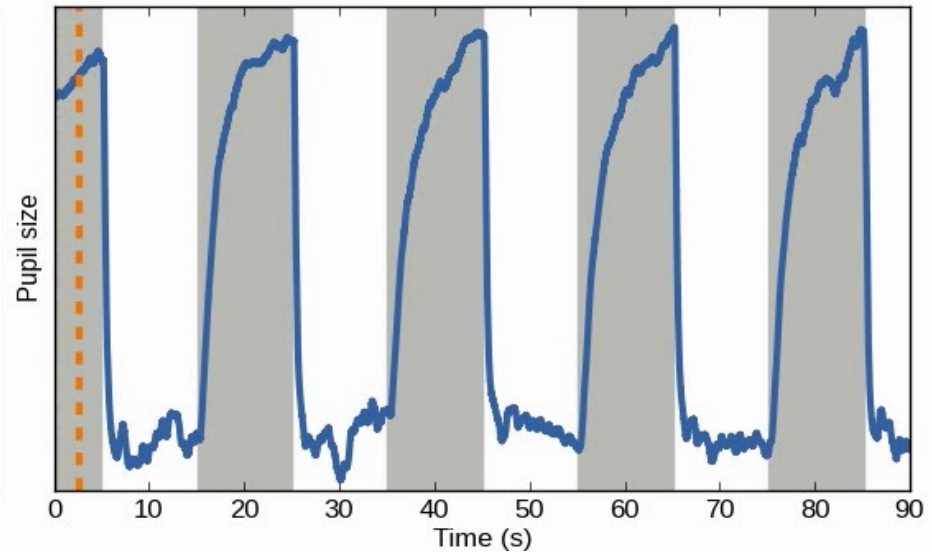
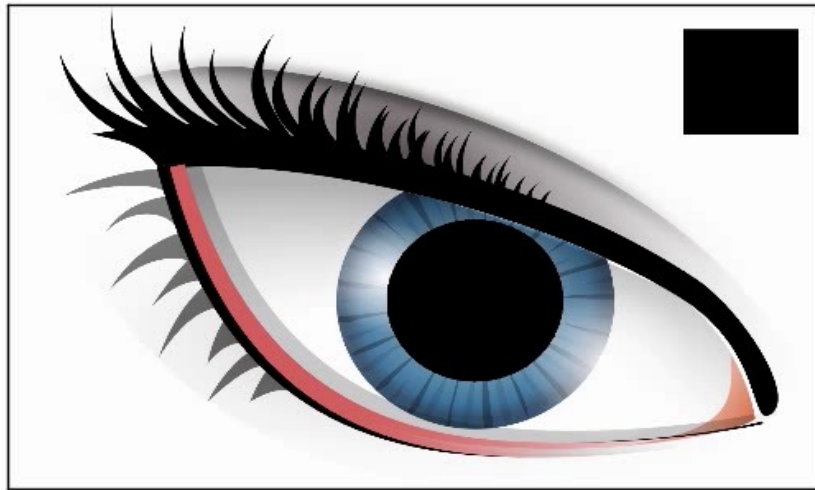
<http://www.cogsci.nl/smathot>

September 29, 2016, Université Lumière Lyon II, Lyon, France

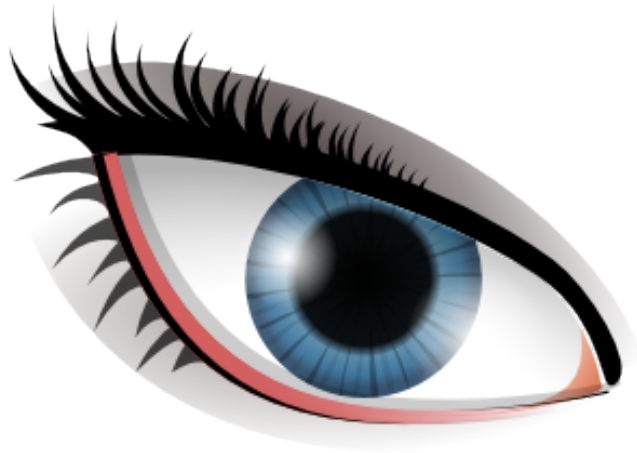
The research leading to these results has received funding from the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme (FP7/2007-2013) under REA grant agreement n° 622738.



The pupillary light response

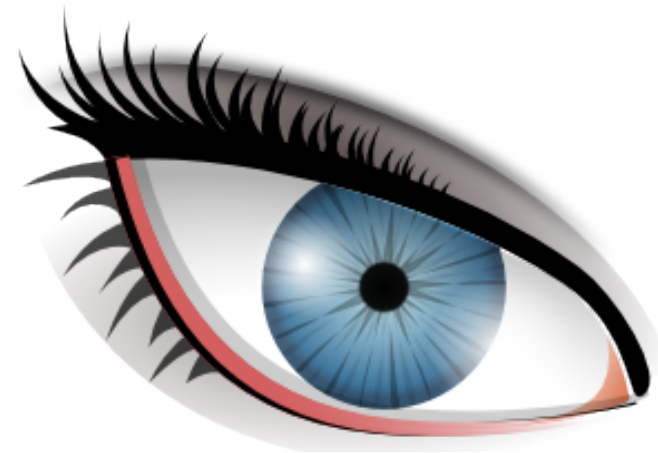


The pupillary light response



Captures lots of light

Has lots of optical distortions



Captures less light

Has less optical distortions

The pupillary light response

- The pupillary light response is traditionally considered a reflex
- Recent studies show cognitive influences[1]
- Today: The pupillary light response in
 - Part I: Visual attention
 - Part II: Visual working memory
 - Part III: Word comprehension
 - Part IV: A human-computer interface

The pupillary light response and visual attention



Mathôt, Dalmaijer, Grainger, & Van der Stigchel (2014)
<http://doi.org/10.1167/14.14.7>

Visual attention

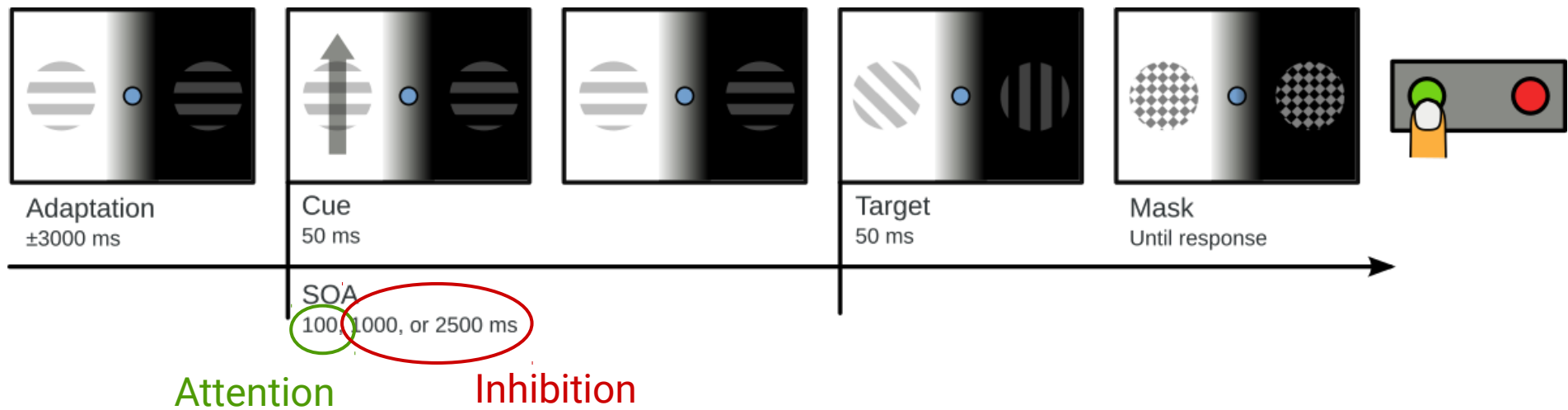
- If you attend to something, you see it more clearly
- Sudden visual events capture attention[1]
 - A light that is switched on
 - A sudden movement
- ... regardless of goals
 - It's reflexive
- ... and this can occur without eye movements
 - Covert visual attention

[1] Yantis & Jonides (1984)

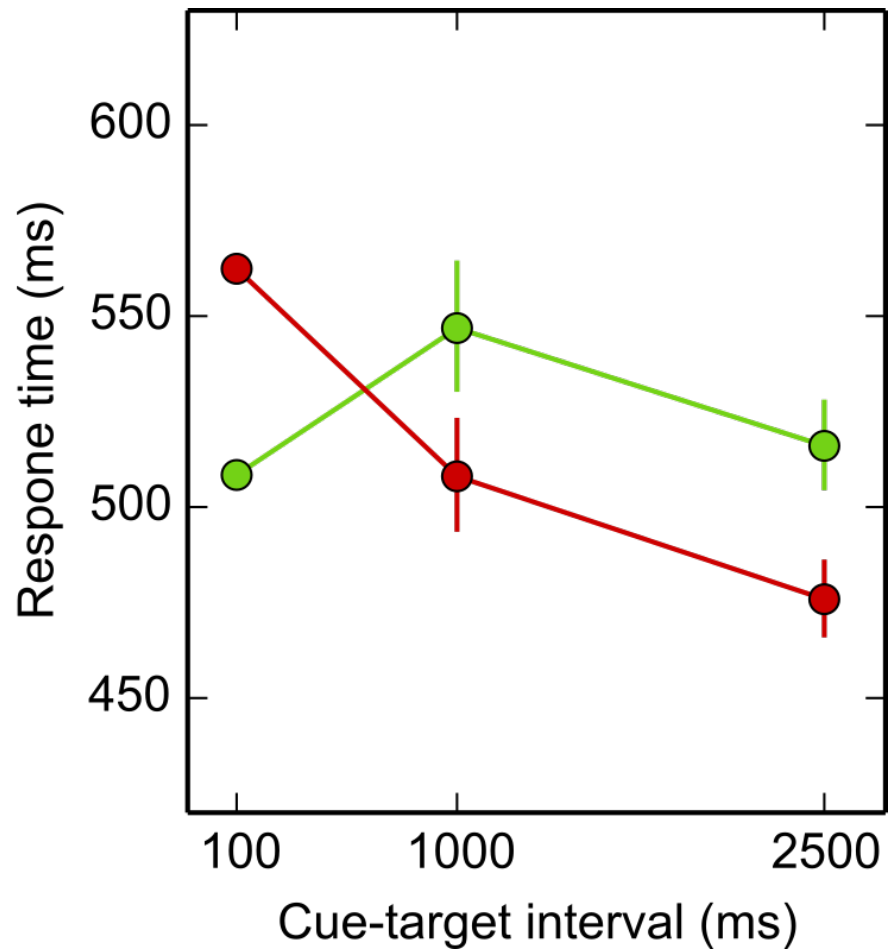
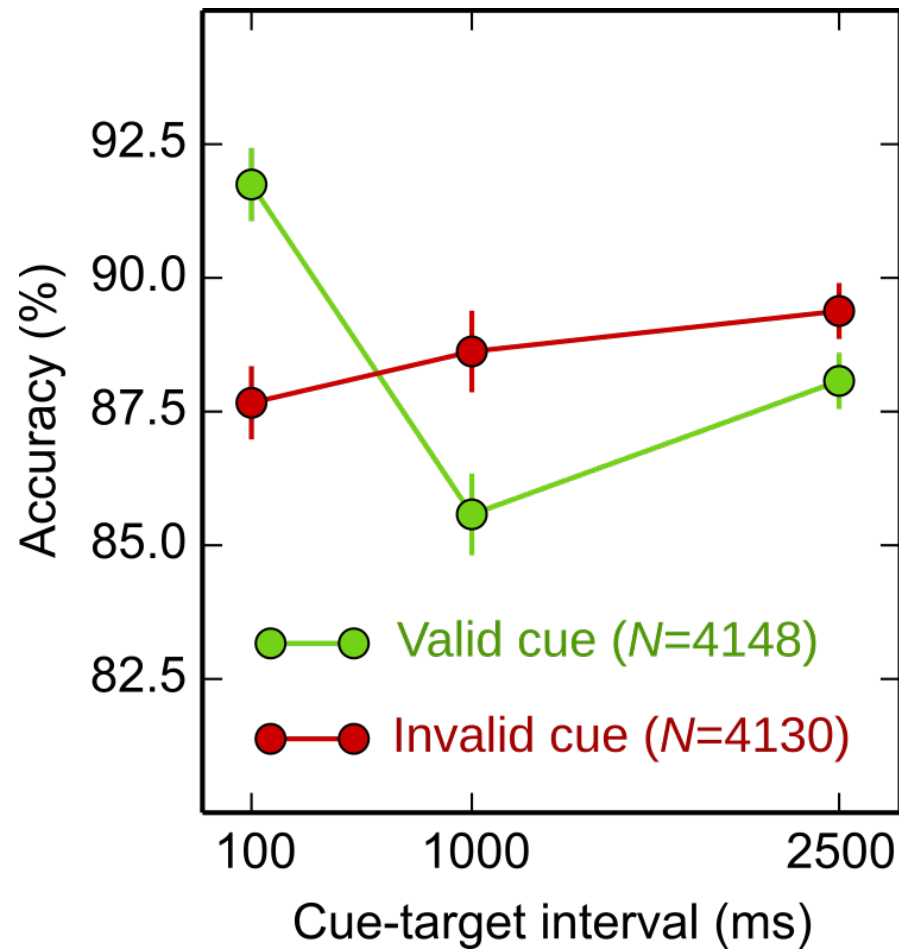
Visual attention

- Reflexive shifts of attention are brief
- ... and followed by inhibition (of return) [1]
- This prevents us from attending to the same things over and over again [2]
 - A been-there-done-that mechanism
- Does the light response reflect:
 - Reflexive attention?
 - Inhibition of return?

Methods



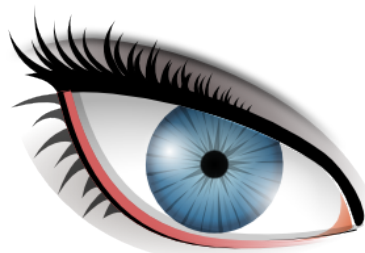
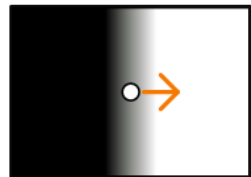
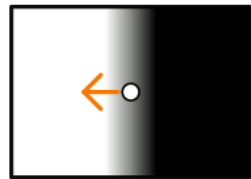
Results



Prediction

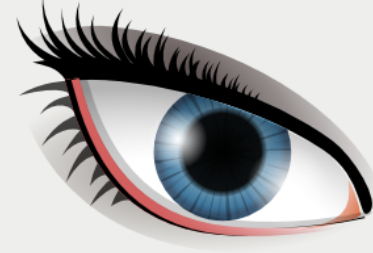
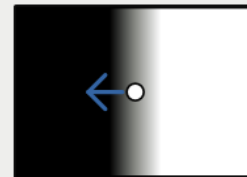
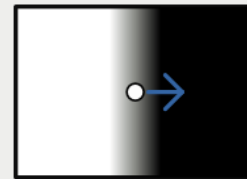
Attend bright

Small pupil



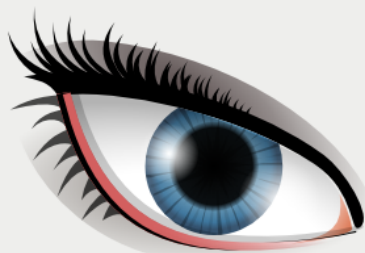
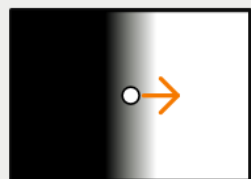
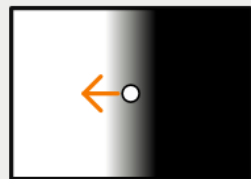
Attend dark

Large pupil



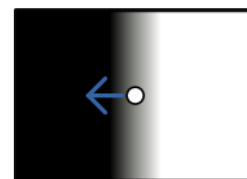
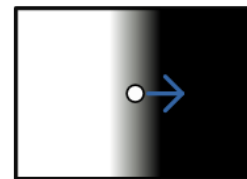
Inhibit bright

Large pupil



Inhibit dark

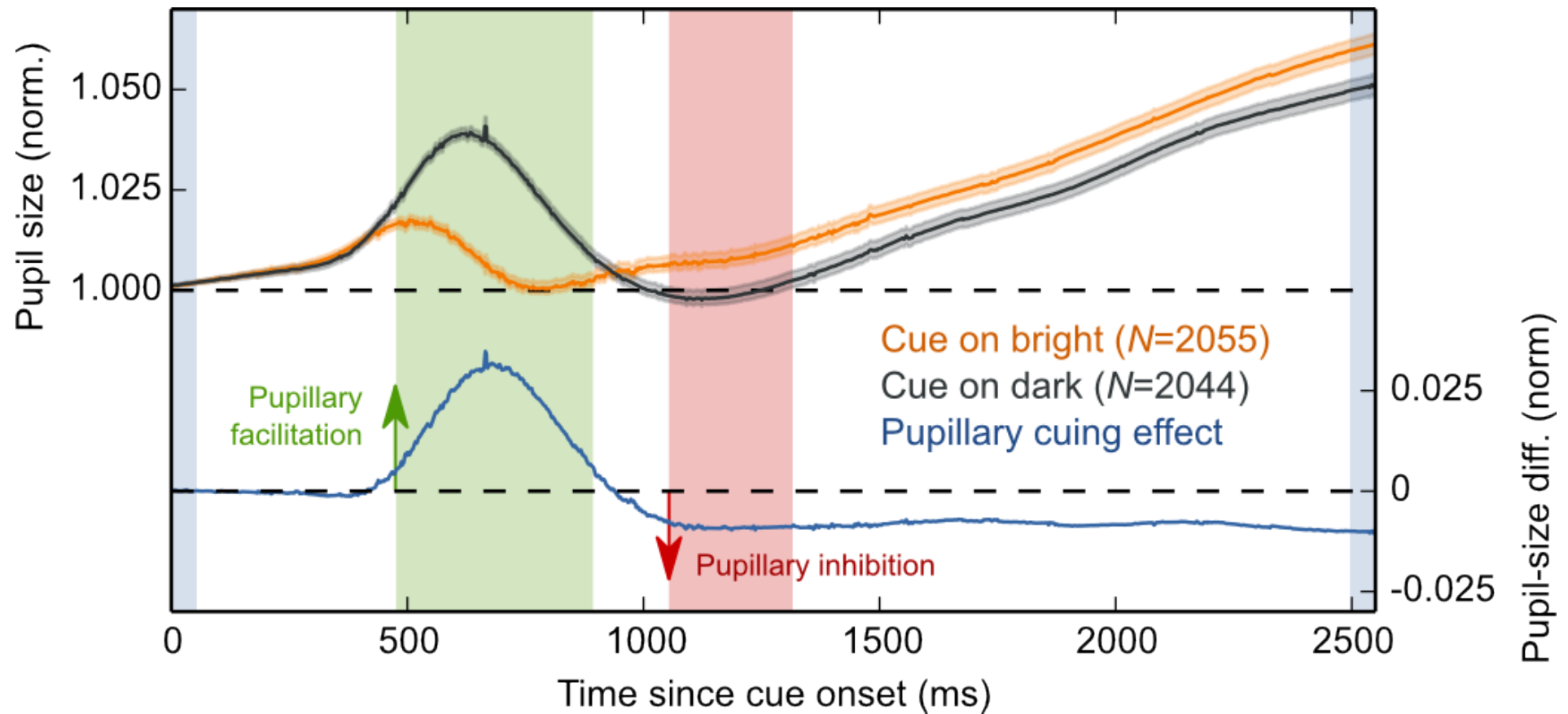
Small pupil



Shortly
After
cue

Longer
after
cue

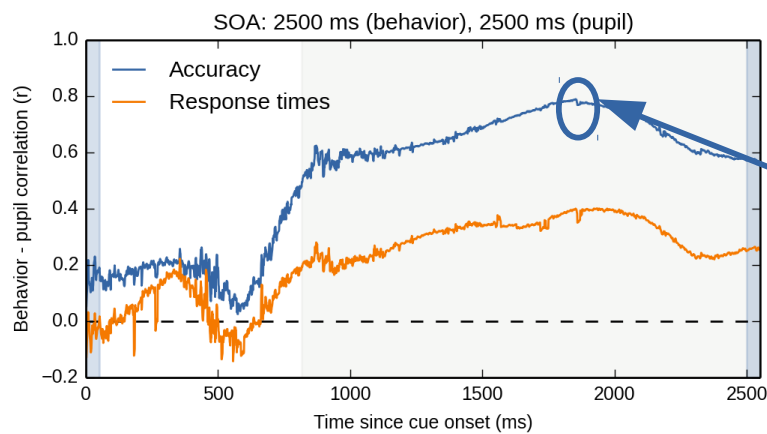
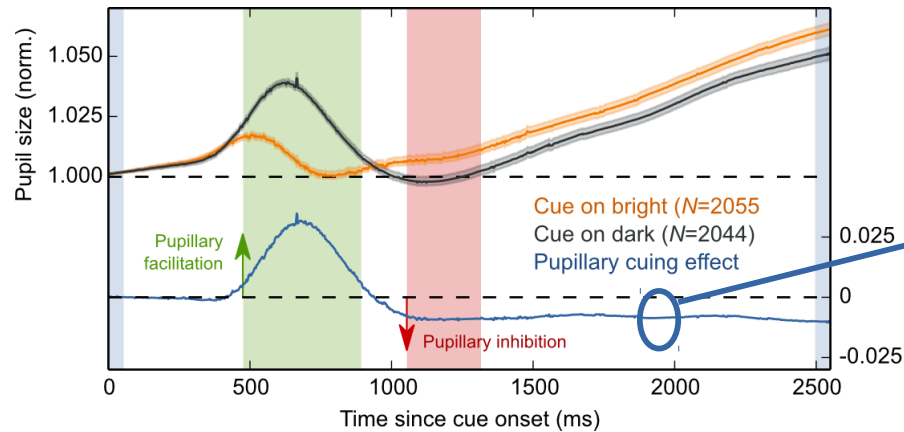
Results



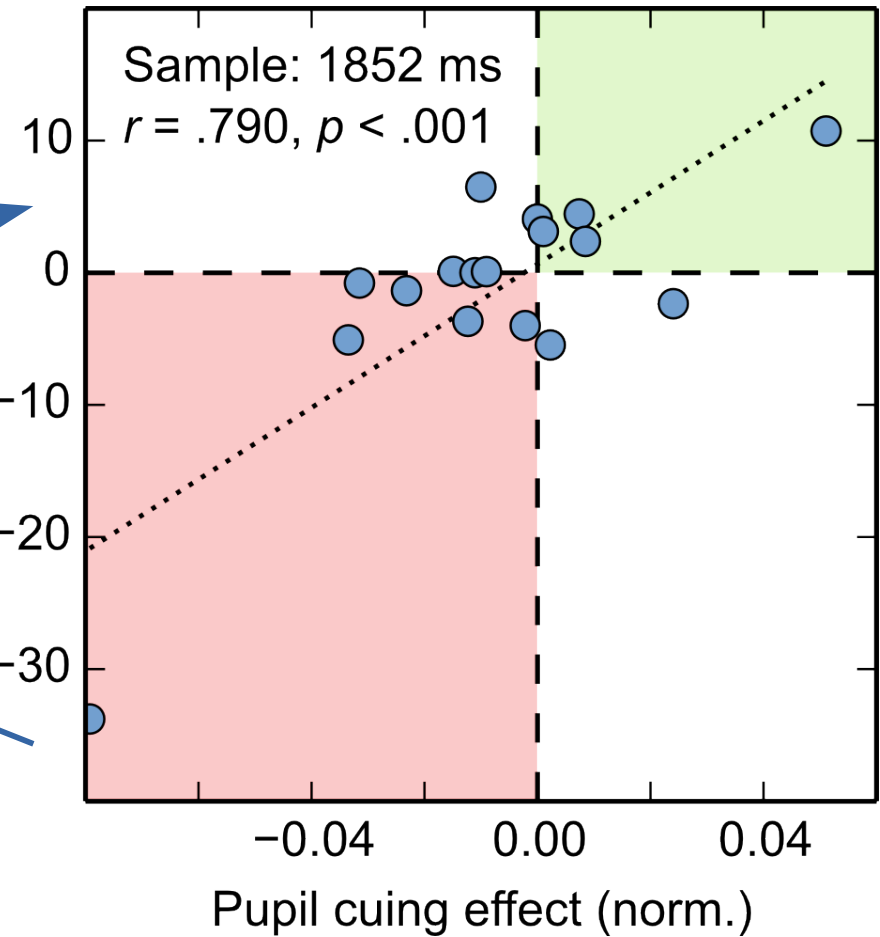
Interim discussion

- Pupil size reflects reflexive attention
... and subsequent inhibition of return
- Can we link this to behavior?
 - Strong behavioral effect → Strong pupillary effect

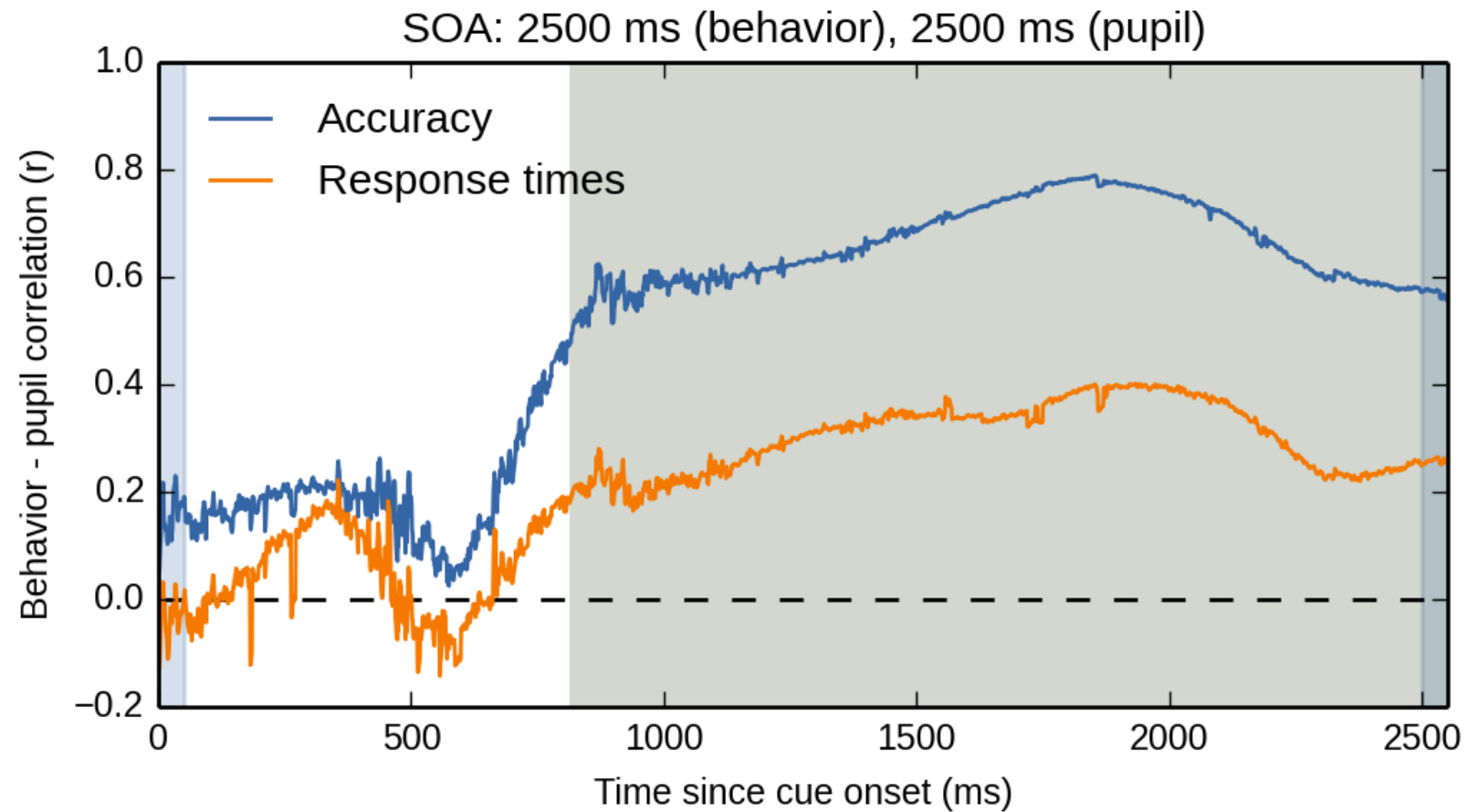
Results



Behav. cuing effect (%)



Results



Discussion

- Pupil inhibition is related to behavioral inhibition of return
... suggesting that both reflect the same mechanism
- The pupillary light response is a sensitive measure of visual attention and inhibition

The pupillary light response and visual working memory



Blom, Mathôt, Olivers, & Van der Stigchel (2016)
<http://dx.doi.org/10.1037/xhp0000252>

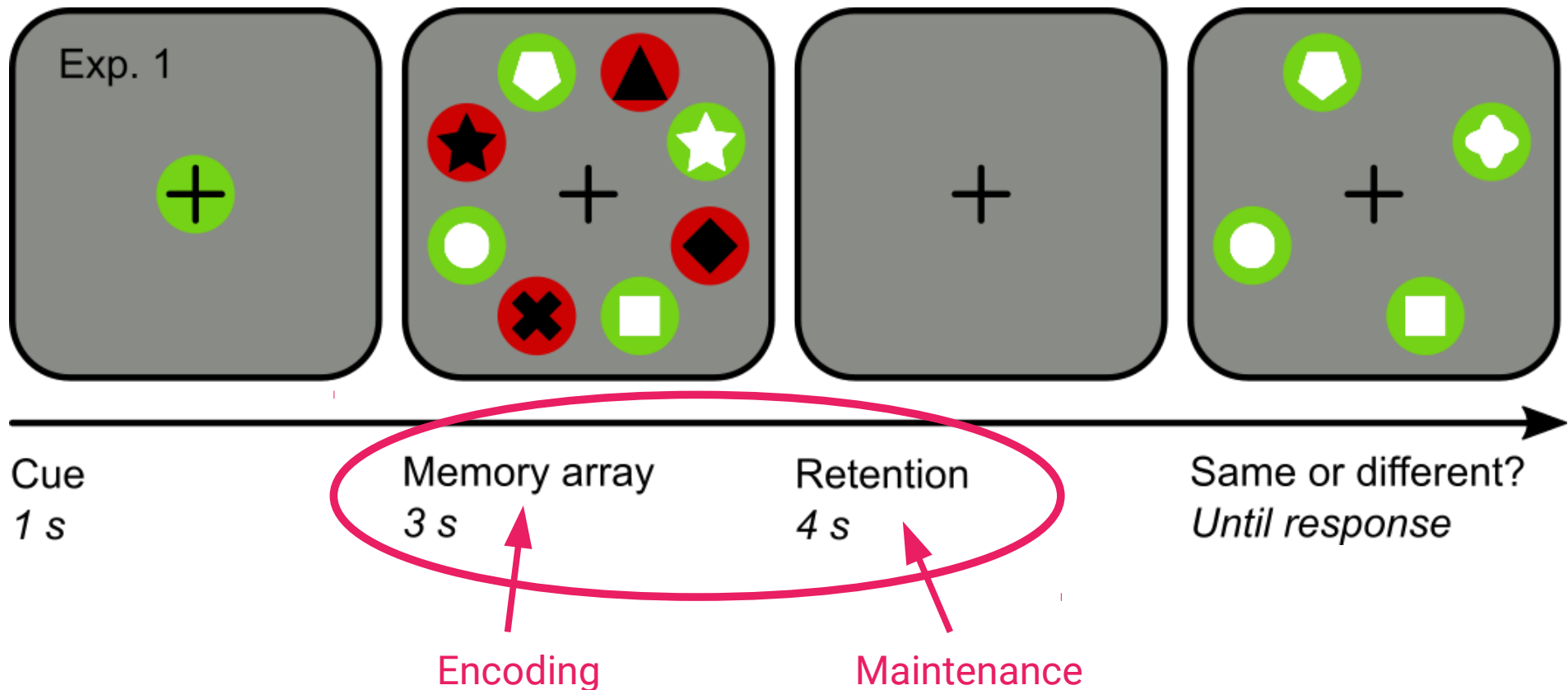
Attention and working memory

- Attention and working memory are linked
 - Things in working memory capture attention[1]
 - Attention disrupts working memory[2]
- General idea:
 - The same brain areas are used for:
 - Visual perception
 - Attention
 - Working memory
 - “Emergent properties”[3]

Attention and working memory

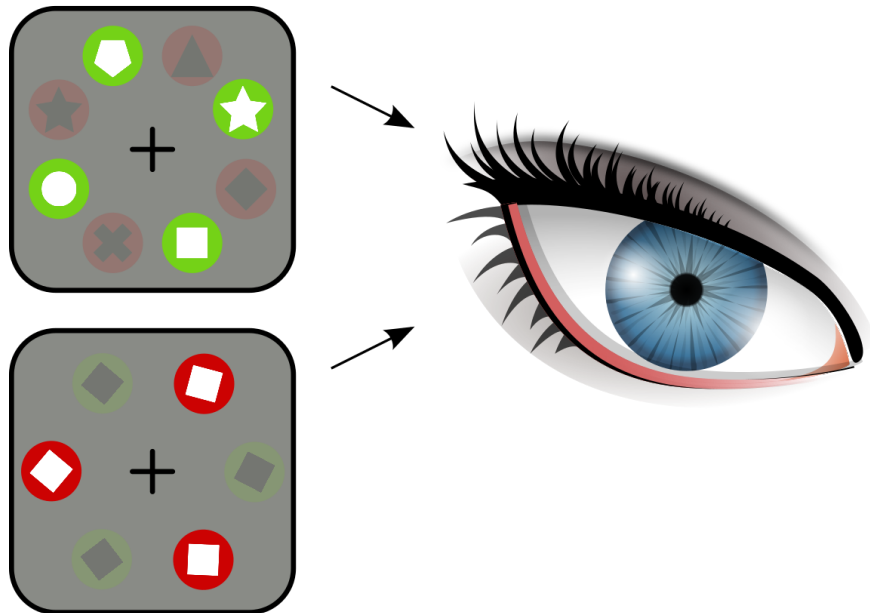
- Can we use the pupillary light response to track attention during a working memory task?
- Is there a difference between encoding (\approx attention) and maintenance of working memory?

Paradigm

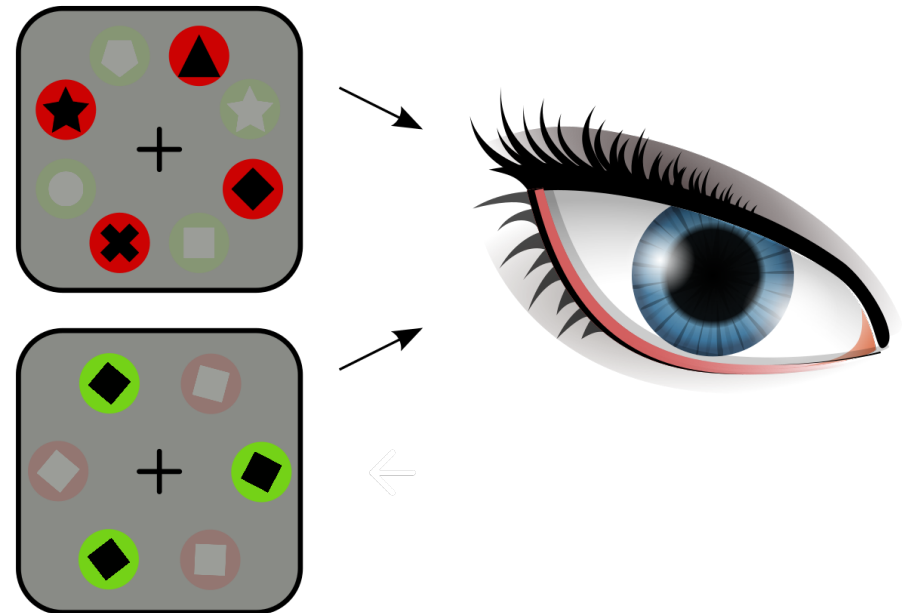


Prediction

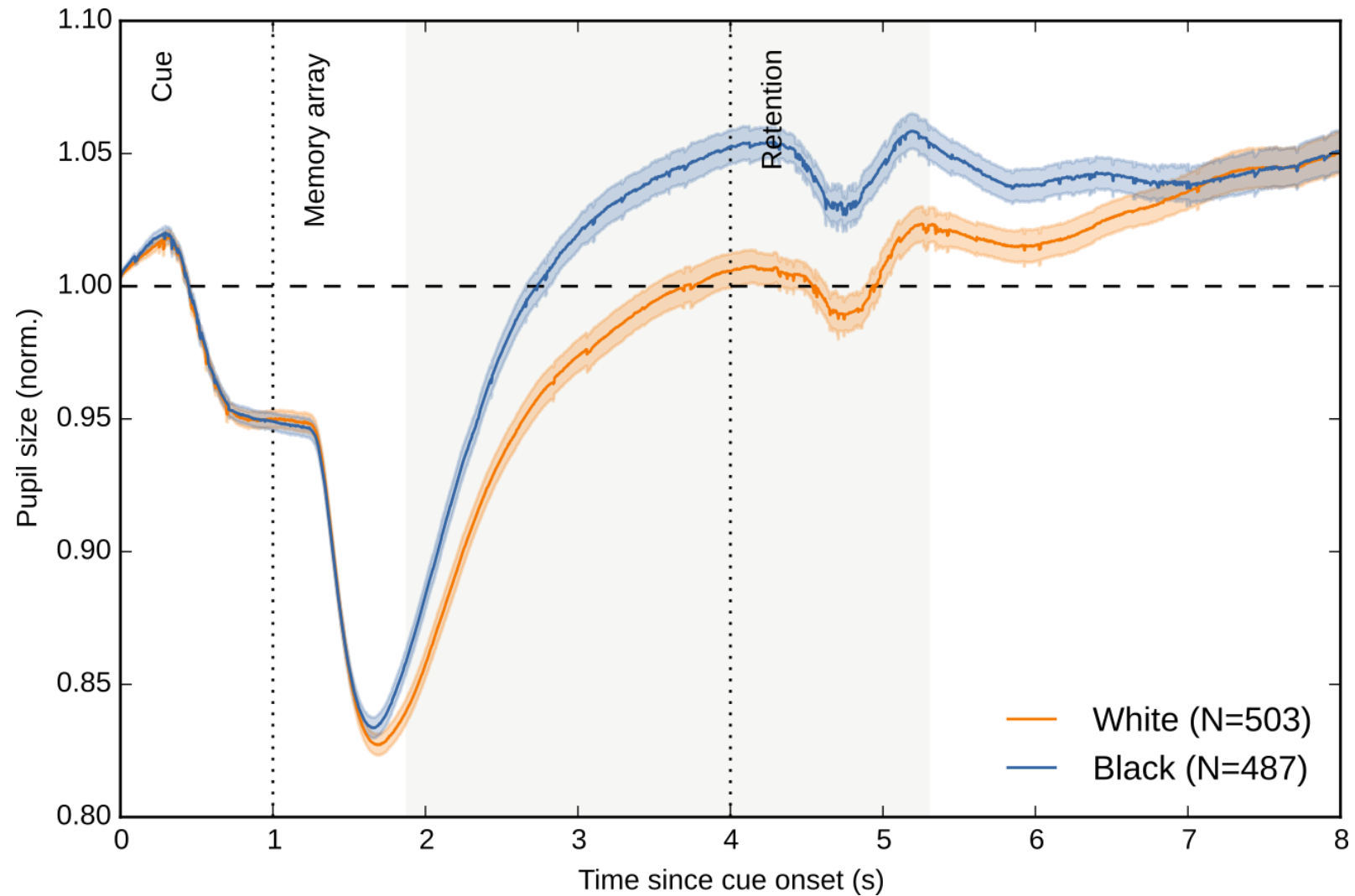
Memorize bright Small pupil



Memorize dark Large pupil



Results



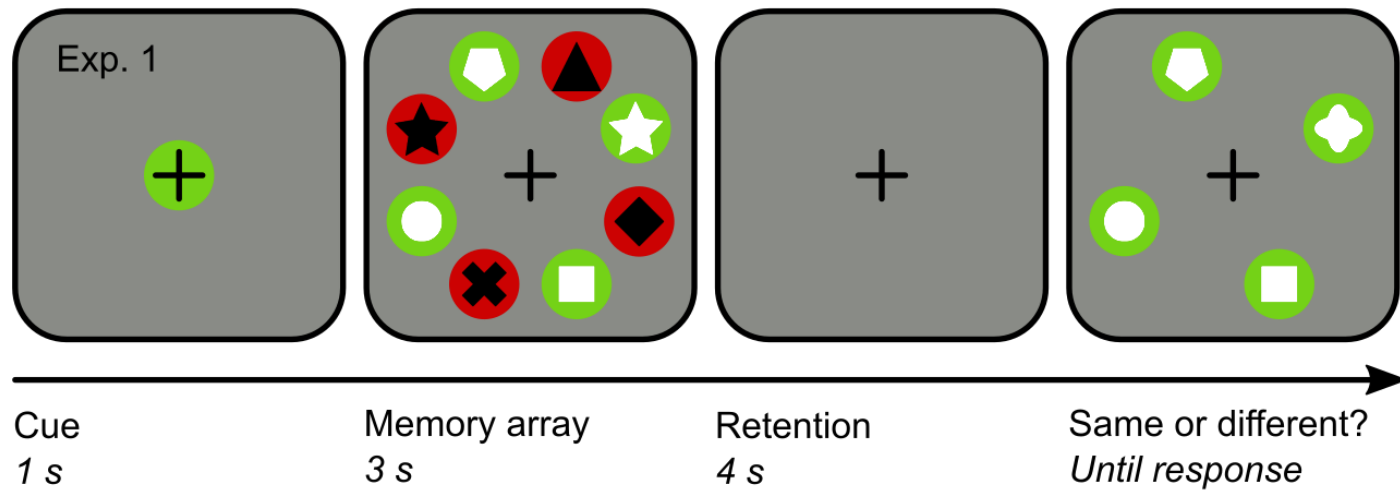
But first ...

... Let's compare this to an attention-only condition

Paradigm

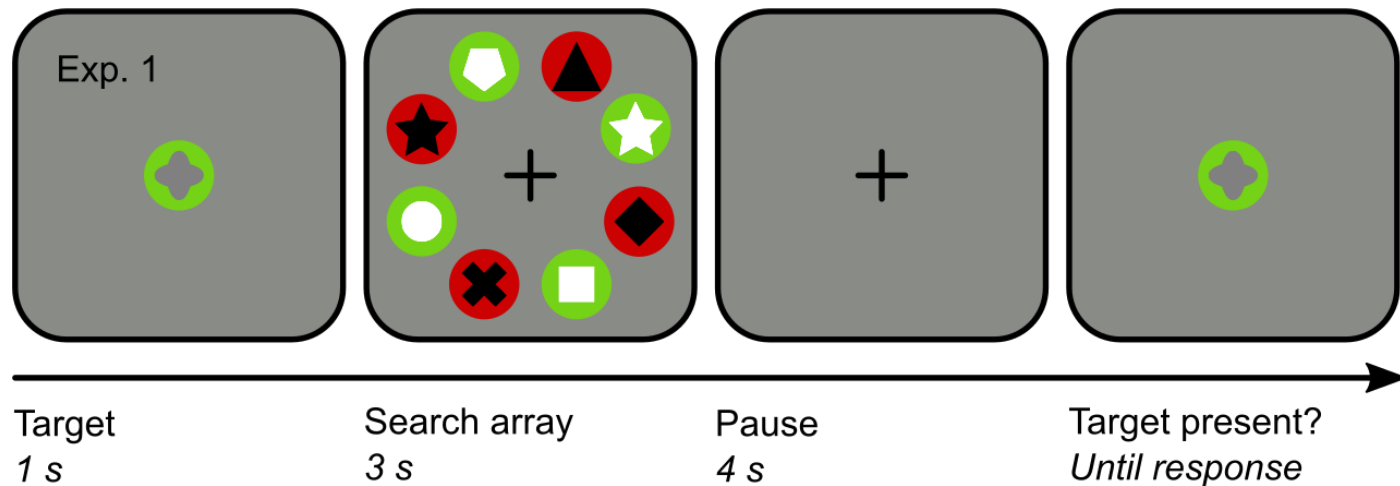
Working-memory condition

What you just saw →



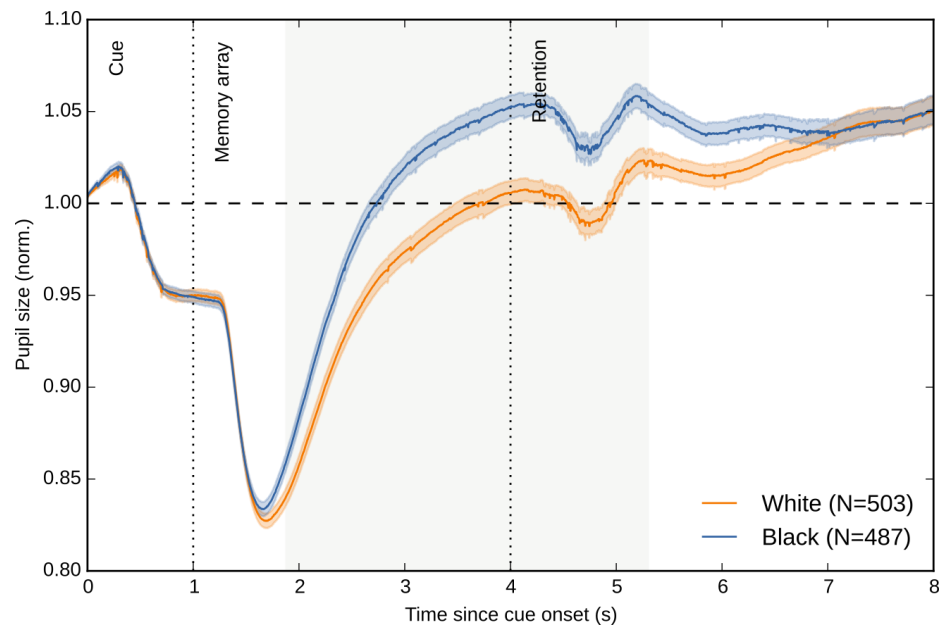
Attention condition

To see the effect of attention alone →

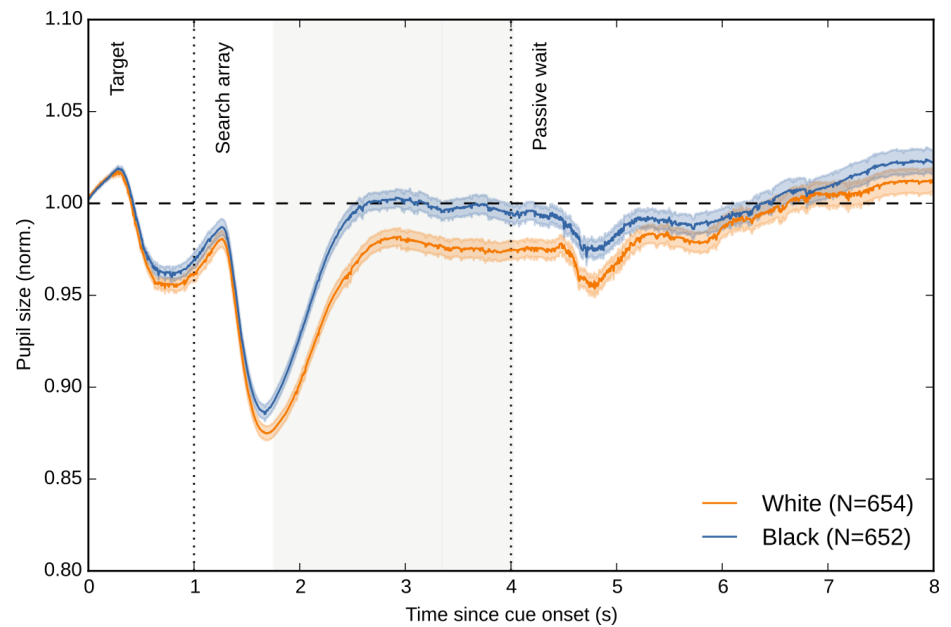


Results

The results that you just saw
(working-memory task)



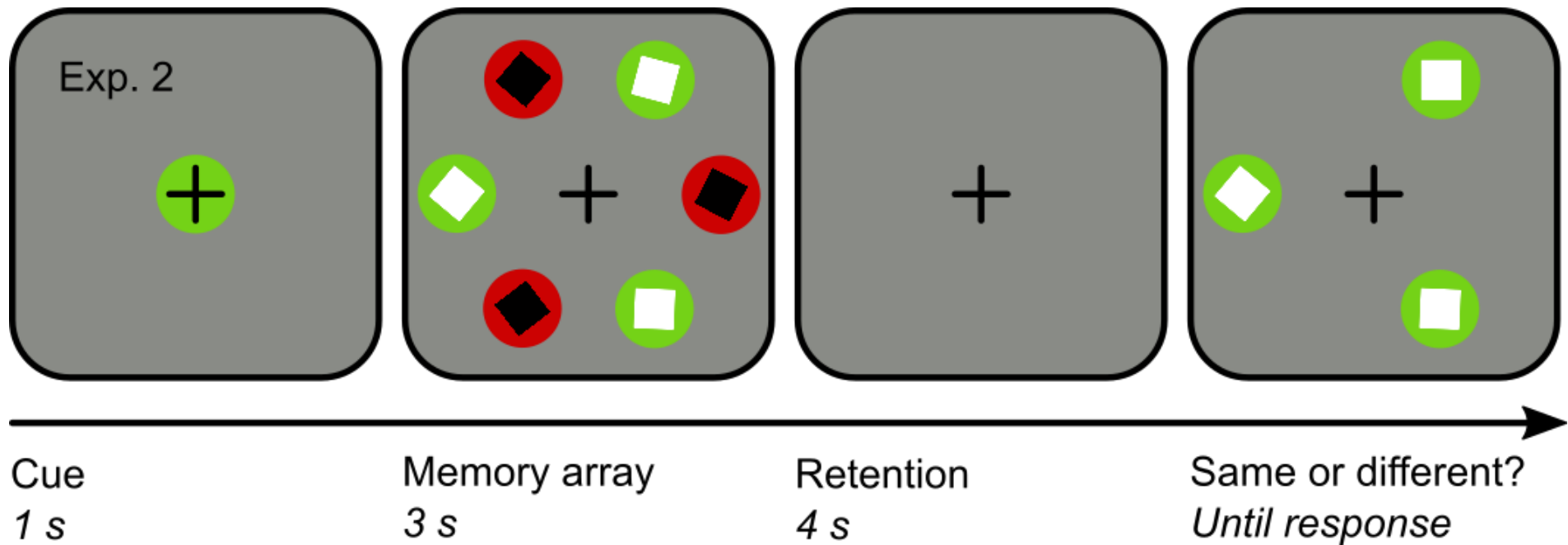
The effect of attention alone



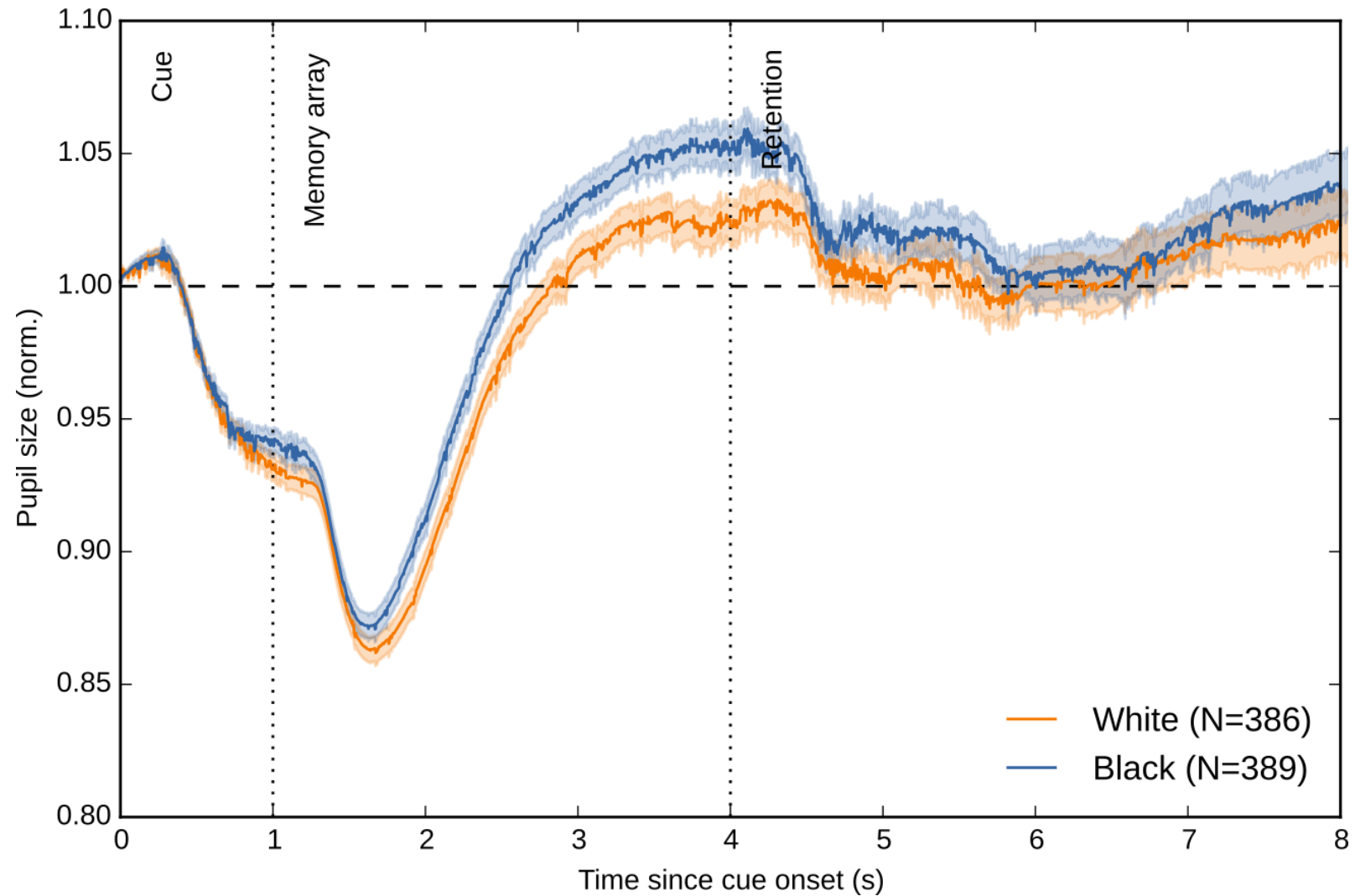
Results

- The pupillary light response reflects
 - Encoding of working memory (\approx attention)
 - But not maintenance of working memory
- Perhaps
 - Participants verbalized the stimuli?

Paradigm



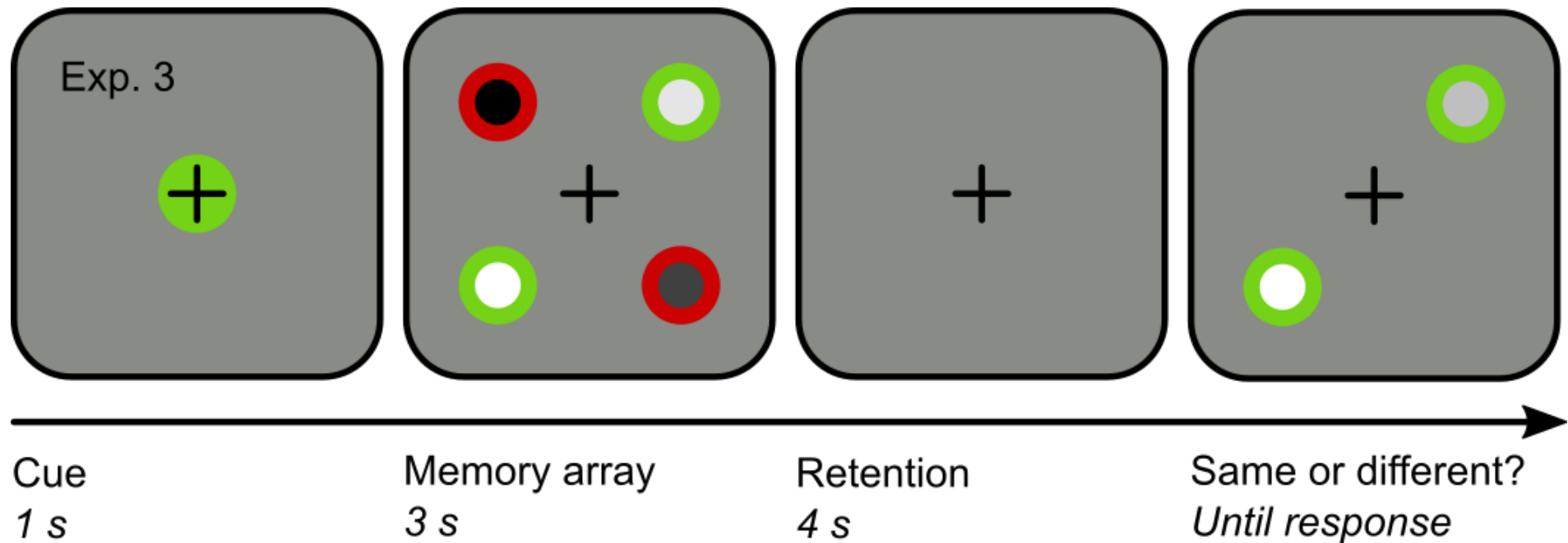
Results



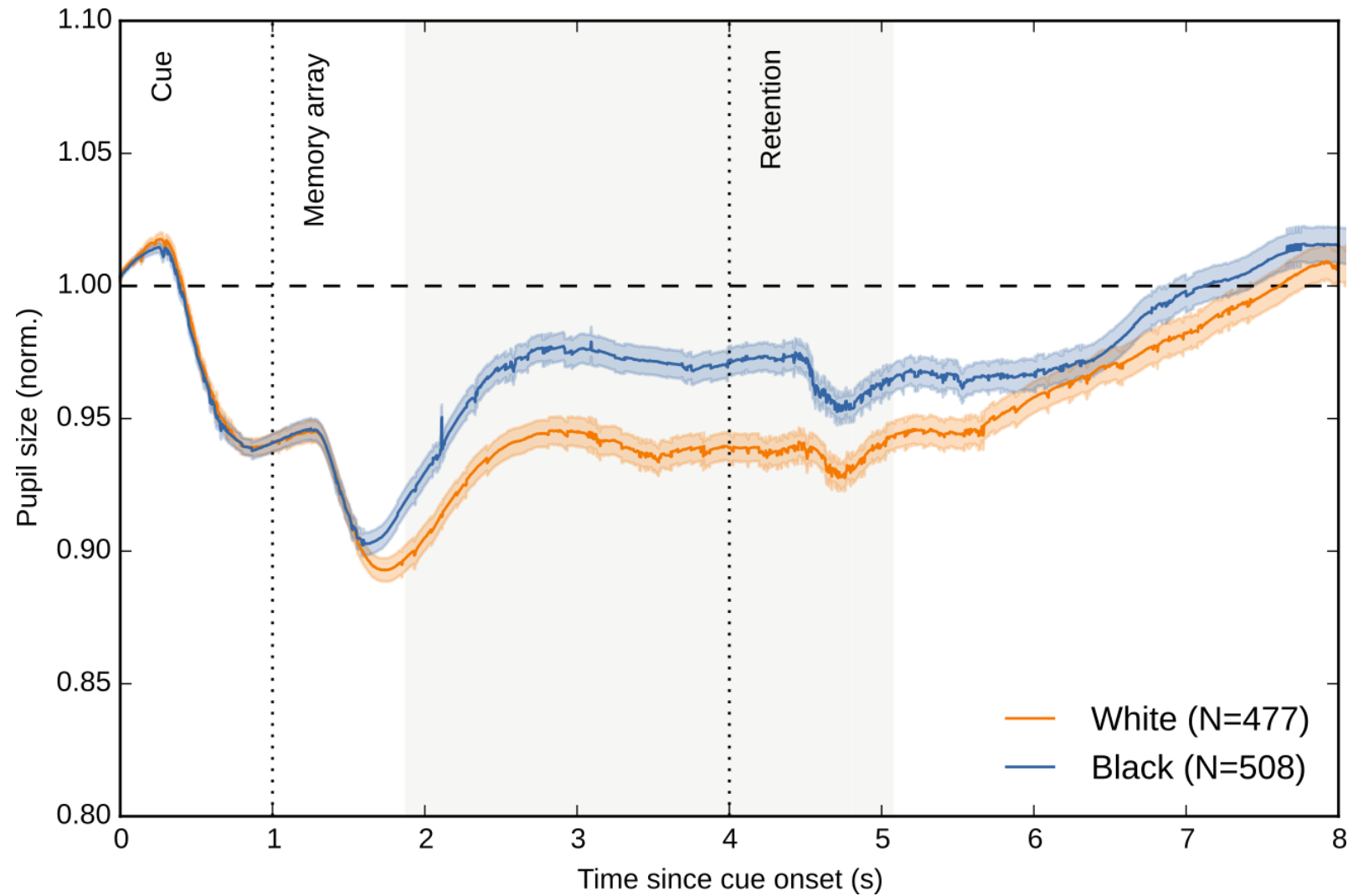
Results

- The pupillary light response reflects
 - Encoding of working memory (\approx attention)
 - But not maintenance of working memory
- Perhaps
 - ~~Participants verbalized the stimuli?~~
 - Only task-relevant features were encoded?

Paradigm



Results



Discussion

- The pupillary light response reflects
 - Encoding of working memory (\approx attention)
 - But not maintenance of working memory
- Perhaps
 - ~~Participants verbalized the stimuli?~~
 - ~~Only task-relevant features were encoded?~~
 - Working-memory maintenance and attention are qualitatively different?
 - An “accessory” memory state that does not interact with perception[1]

The pupillary light response and word comprehension

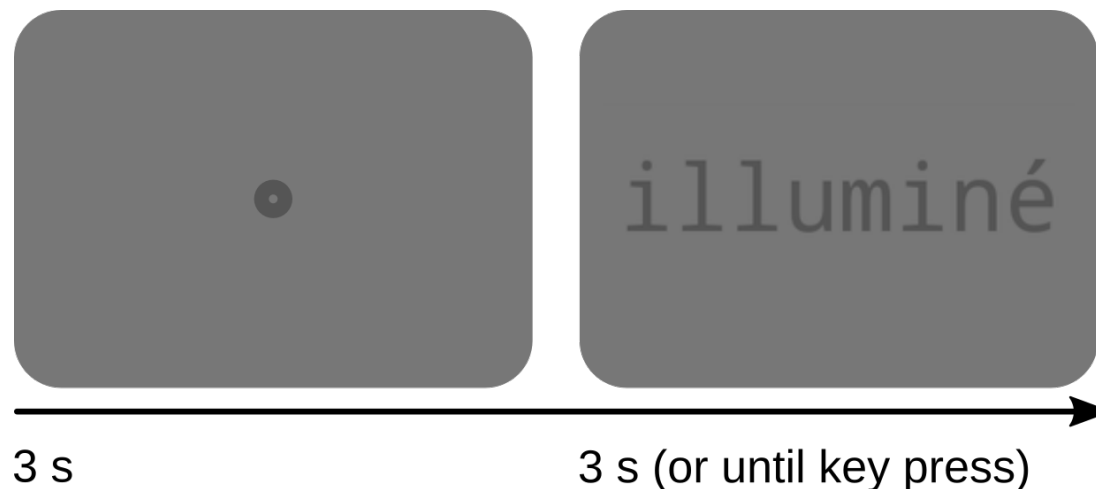


Embodied language

- When you read a word, you automatically[1]
 - Activate associated actions
 - Simulate associated sensory input
- Are these internally generated representations
 - Abstract?
 - Not involving early sensory and motor cortex
 - Or concrete?
 - Involving early sensory and motor cortex
- Can we test this using the pupillary light response?

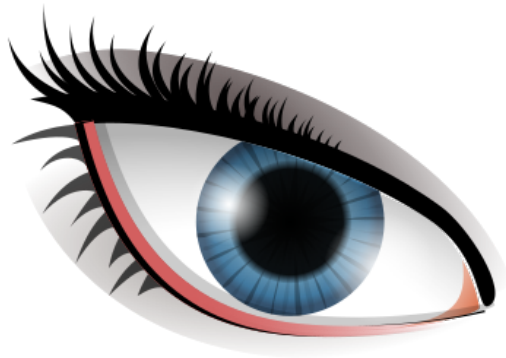
Methods

- Single word shown for 3 s
 - Brightness-conveying, darkness-conveying, neutral, and animal names
 - Matched on visual and lexical properties
- Press key for animal names

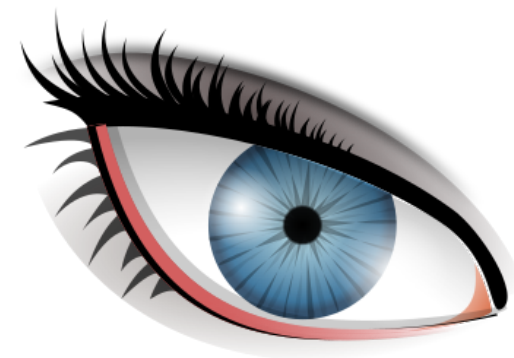


Predictions

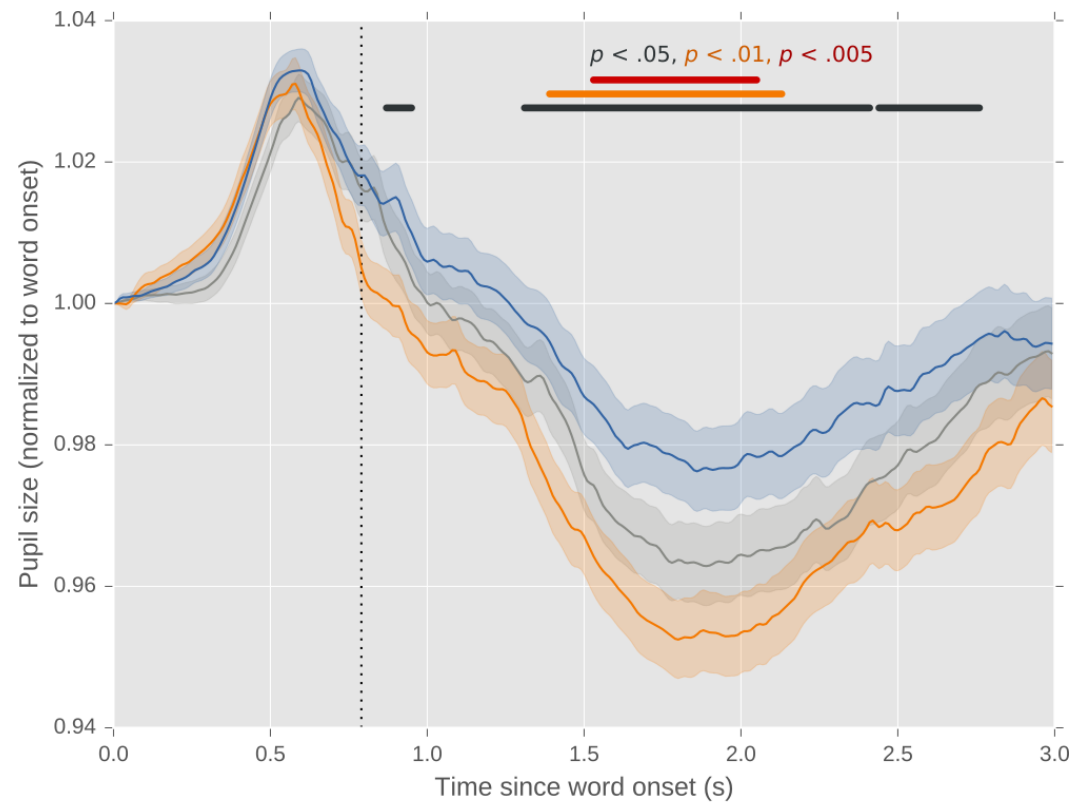
Darkness-conveying words



Brightness-conveying words



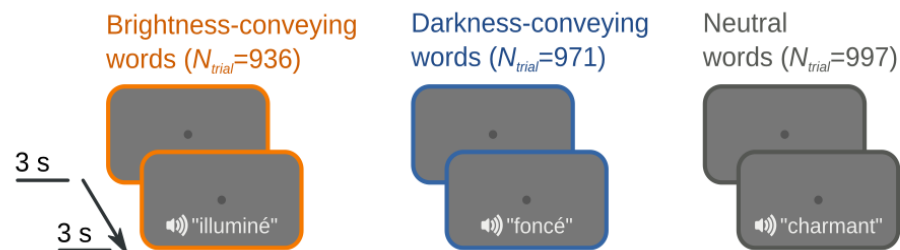
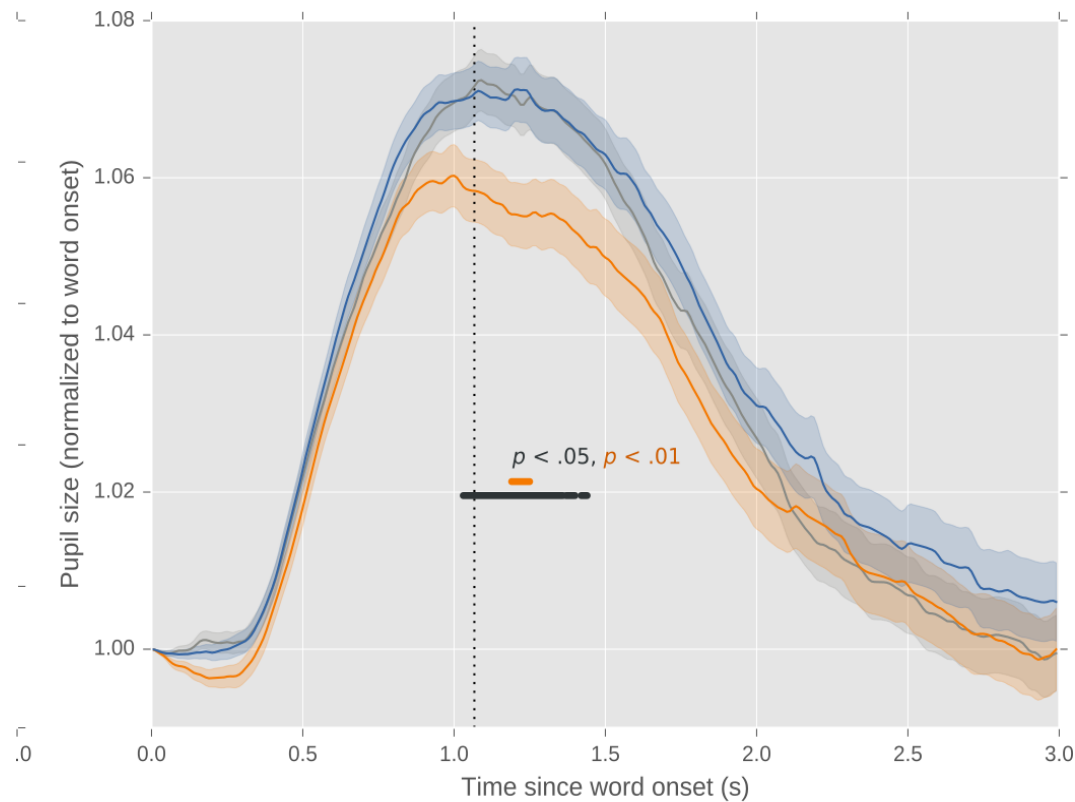
Results



Discussion

- Pupil size reflects semantic brightness
 - Read “sun” → small pupil
 - Read “night” → large pupil
- Does it also work with spoken words?

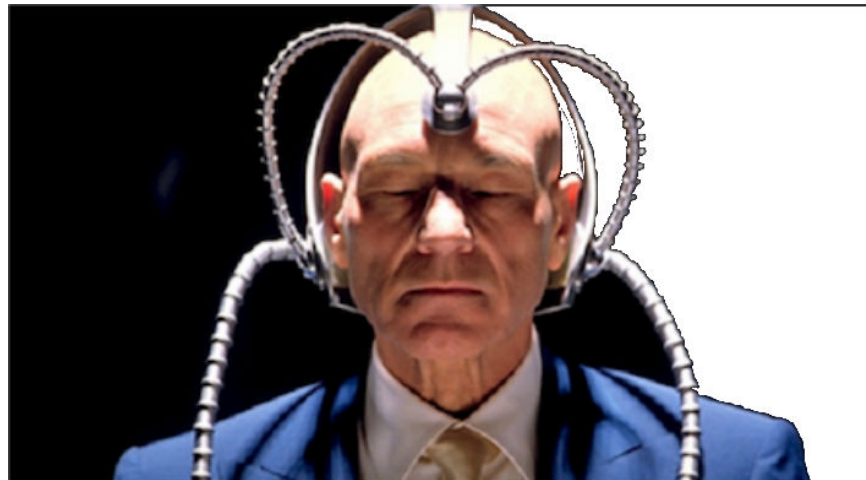
Results



Discussion

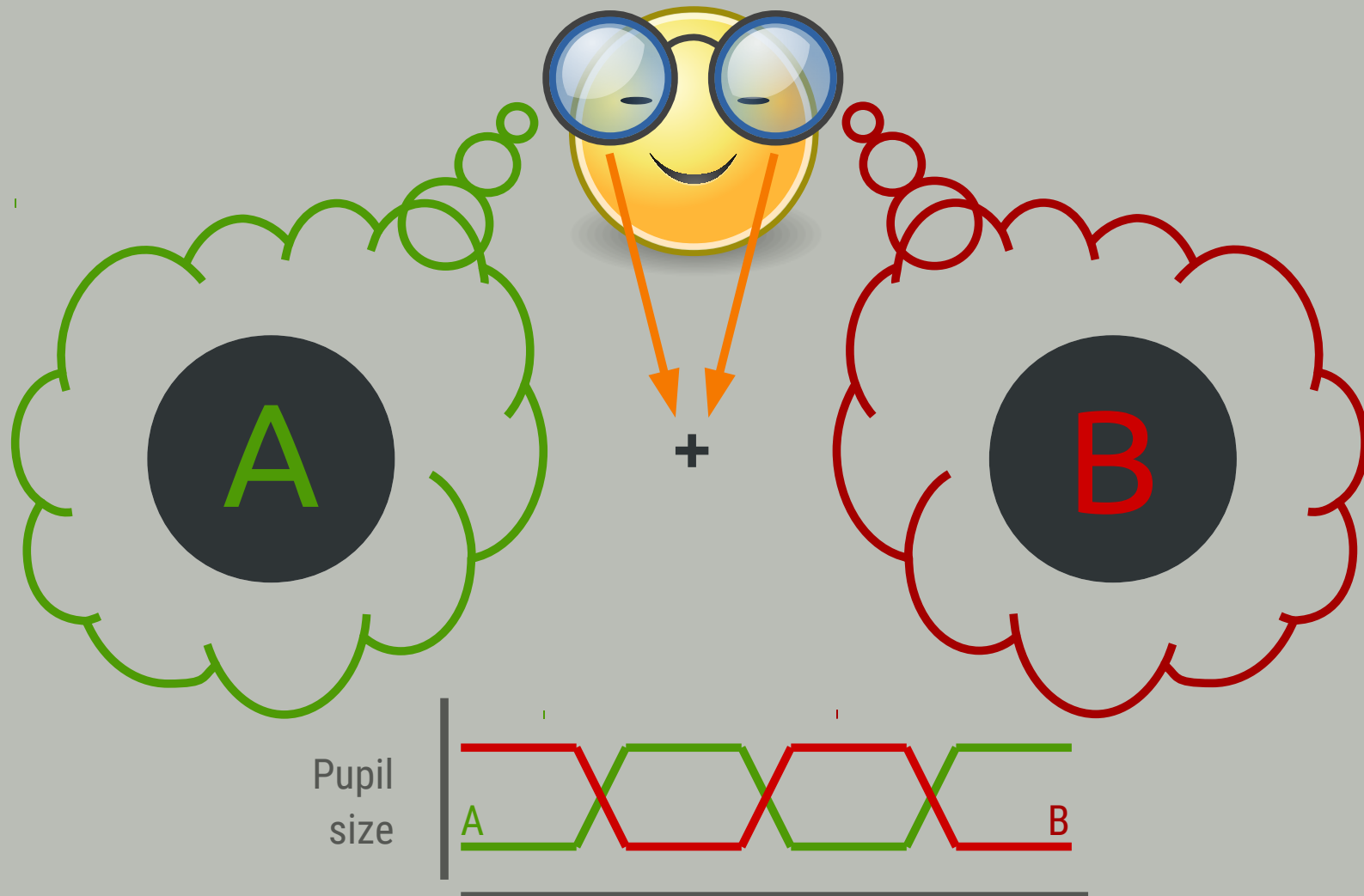
- Pupil size reflects semantic brightness
 - Read or hear “sun” → small pupil
 - Read or hear “night” → large pupil
- Word comprehension activates sensory representations (at least sometimes):
 - And these affect pupil size
 - Embodiment
 - “Internal attention”

The mind-writing pupil: A human-computer interface



Mathôt, Melmi, Van der Linden, & Van der Stigchel (2016)
<http://doi.org/10.1371/journal.pone.0148805>

PCI



PCI

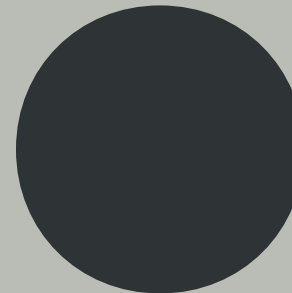


+

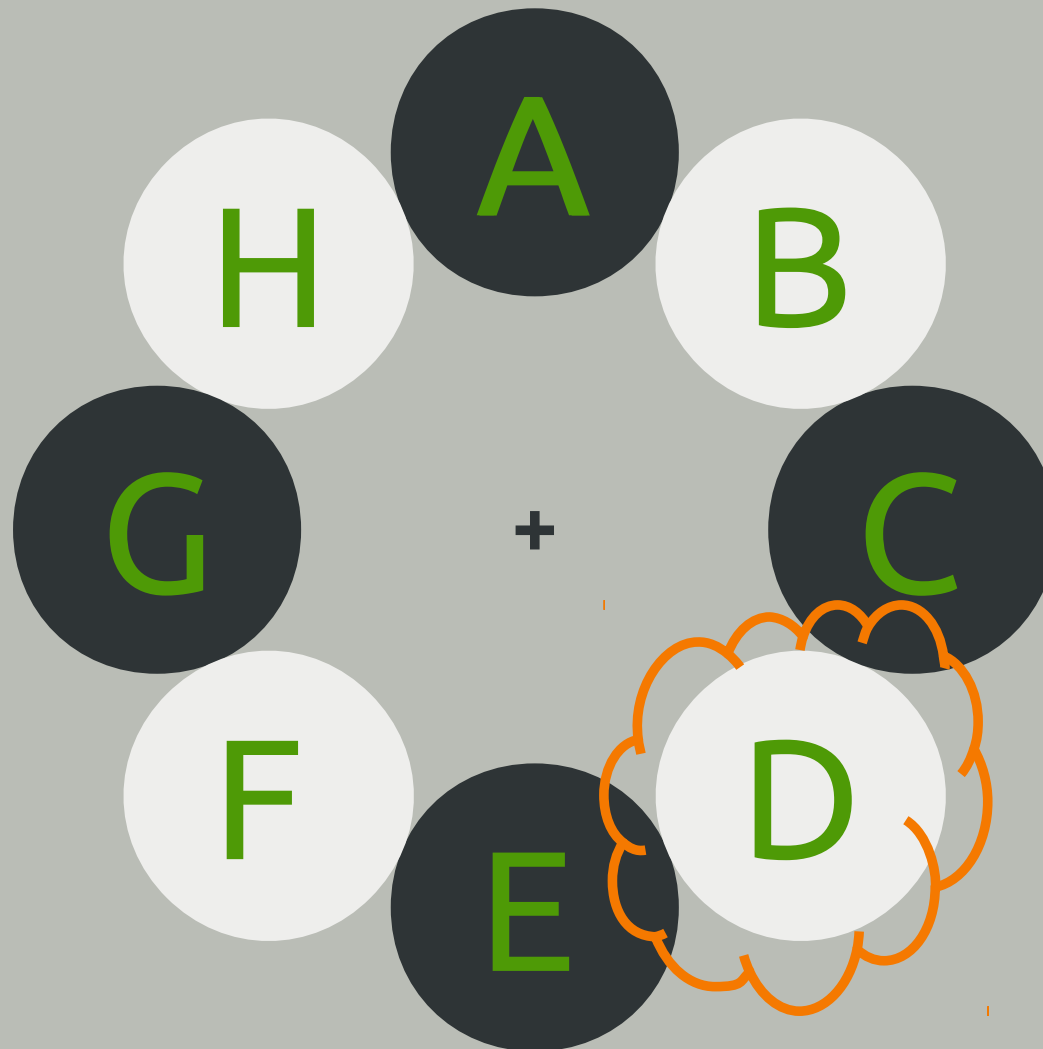
Stop when sufficiently sure!



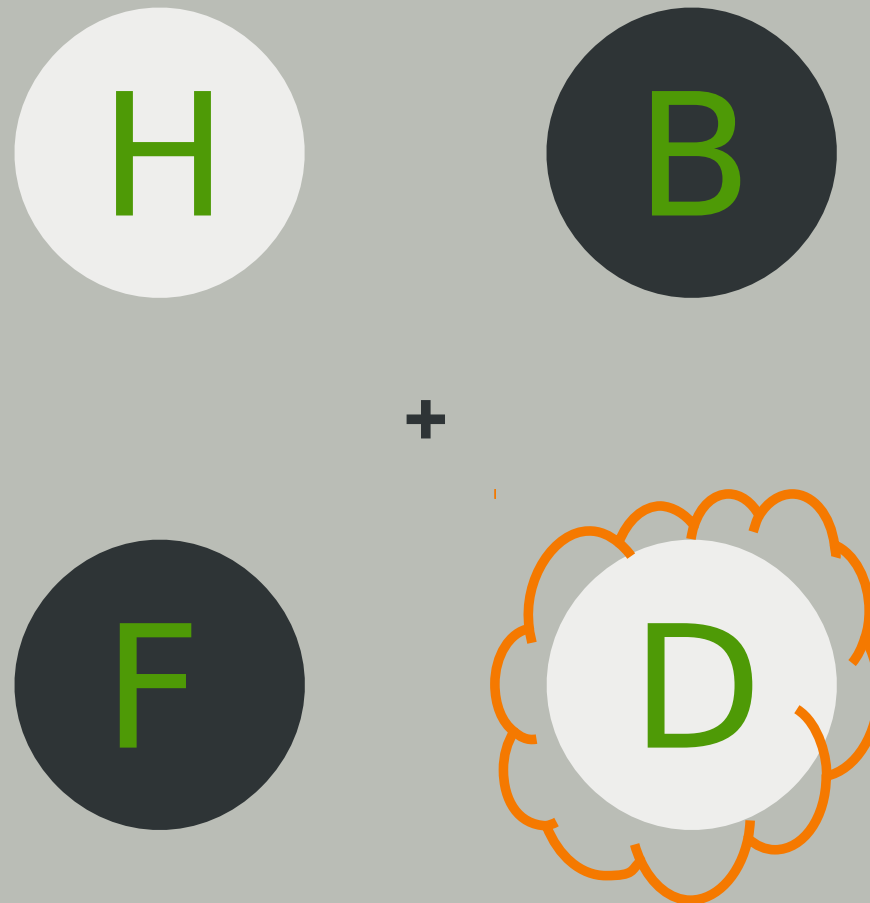
Biofeedback



PCI



PCI



PCI



+

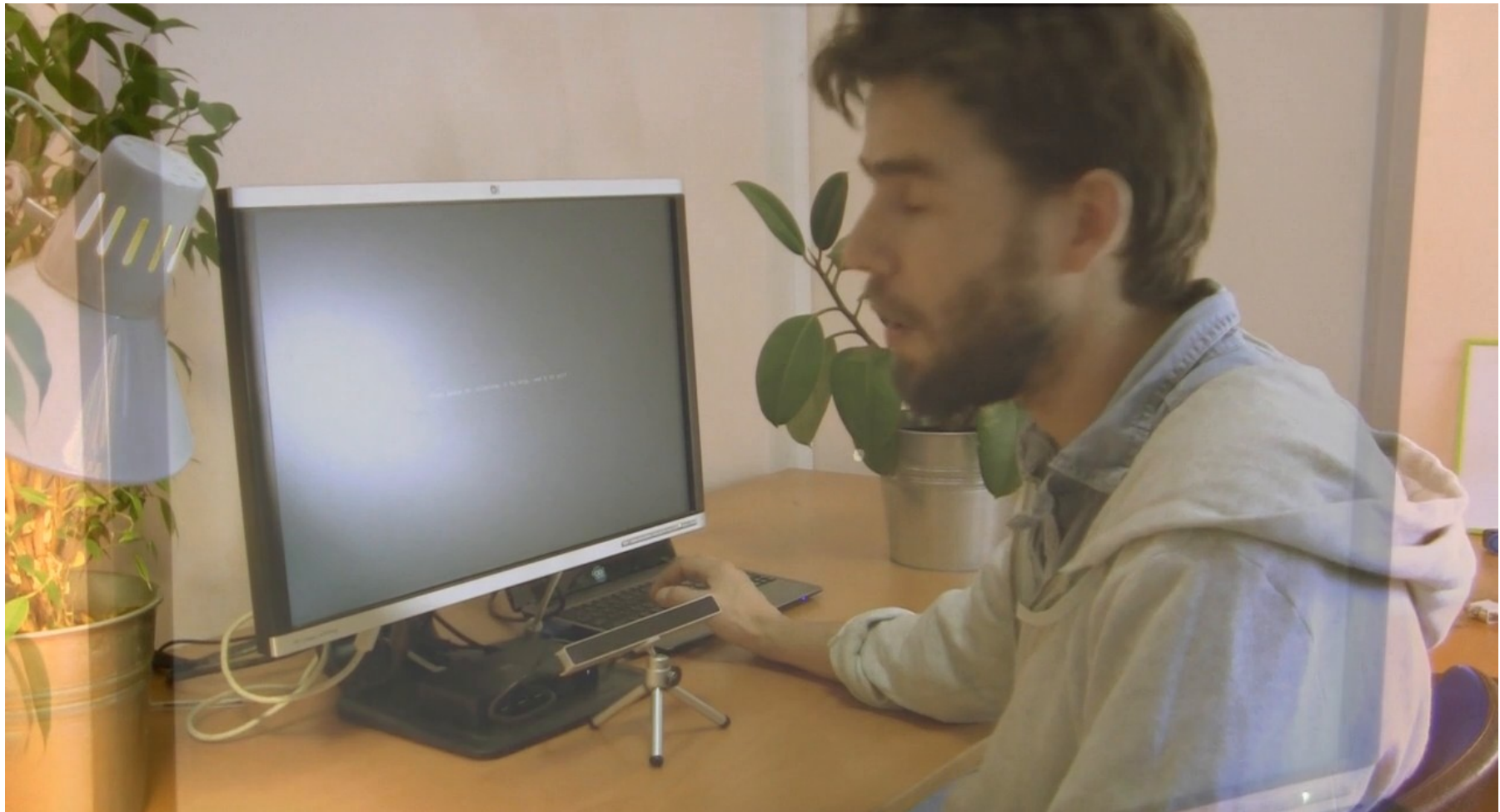


PCI

+



What it looks like ...



Methods

- Preregistered
 - <http://osf.io/s9j8z>
- 10 untrained participants
- 4 phases
 - Select target from 2, 4, and 8 options
 - Free writing with virtual keyboard
- Success criterion: > 80% selection accuracy
- Control for eye movements
 - Pause when fixation lost
 - Gaze-stabilization mode

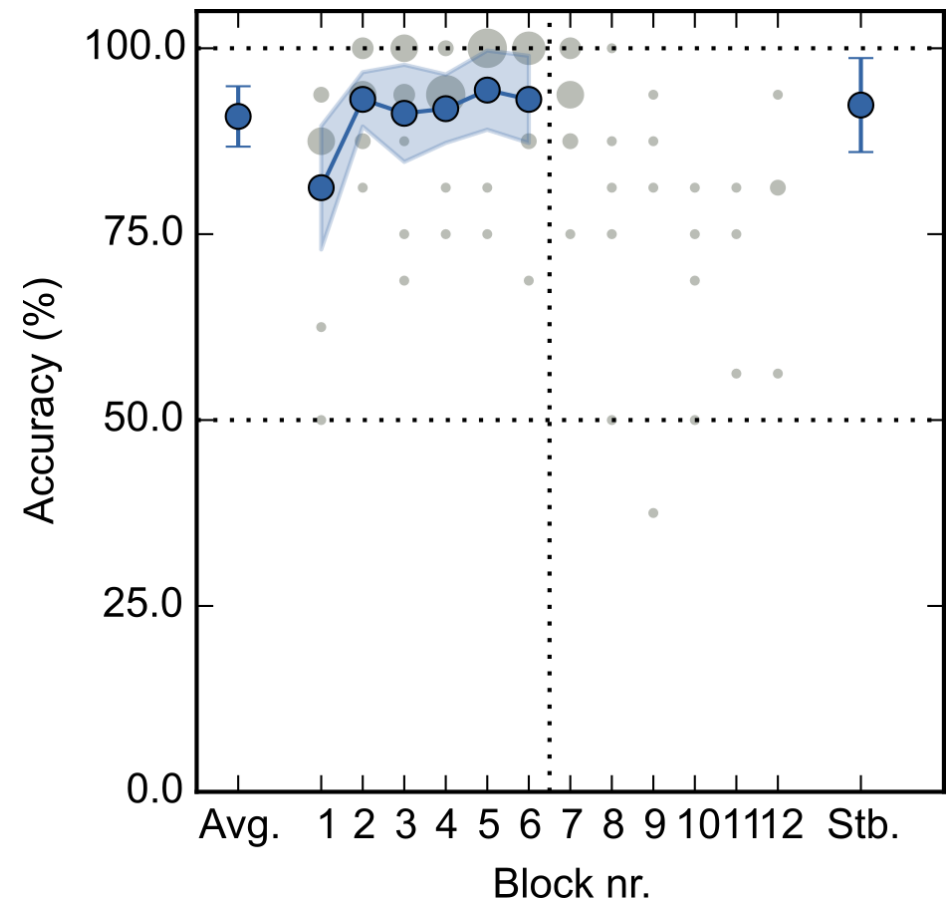
Two options



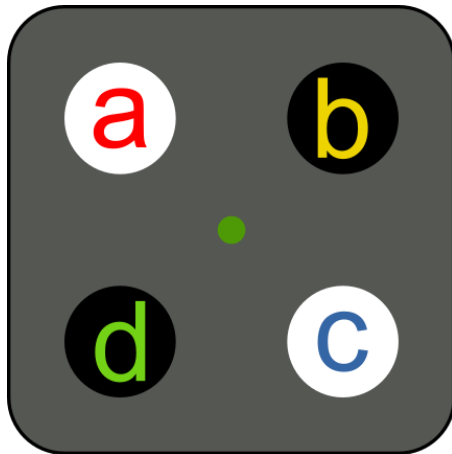
Accuracy: 91%

Selection time: 16 s

Success: 9/10 pp



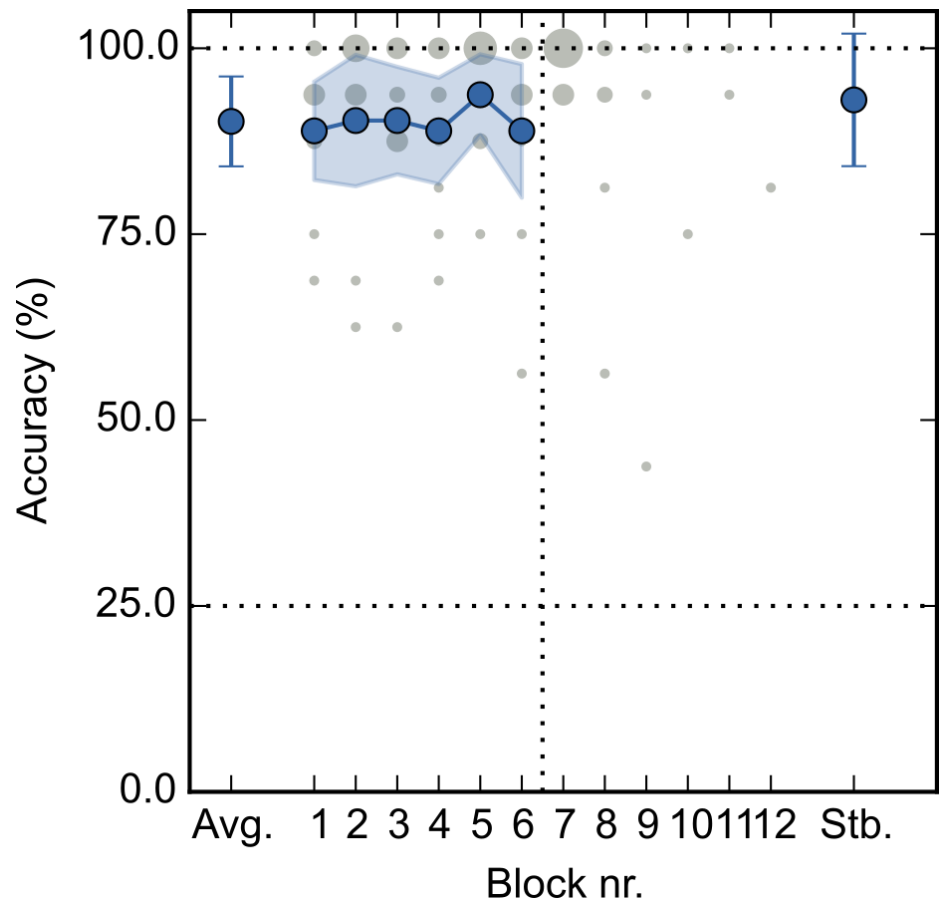
Four options



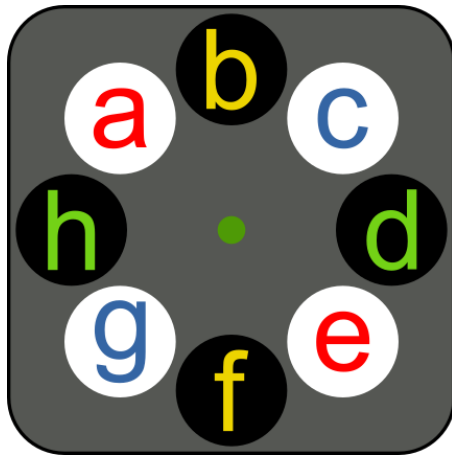
Accuracy: 90%

Selection time: 21 s

Success: 9/9 pp



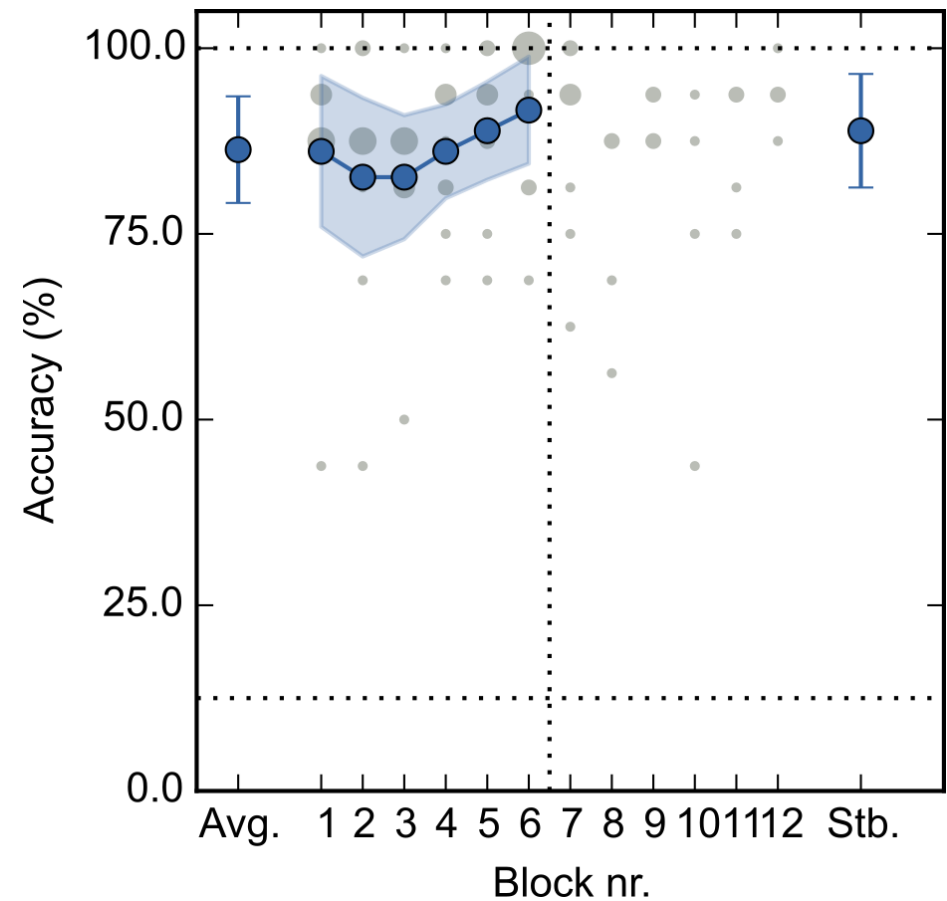
Eight options



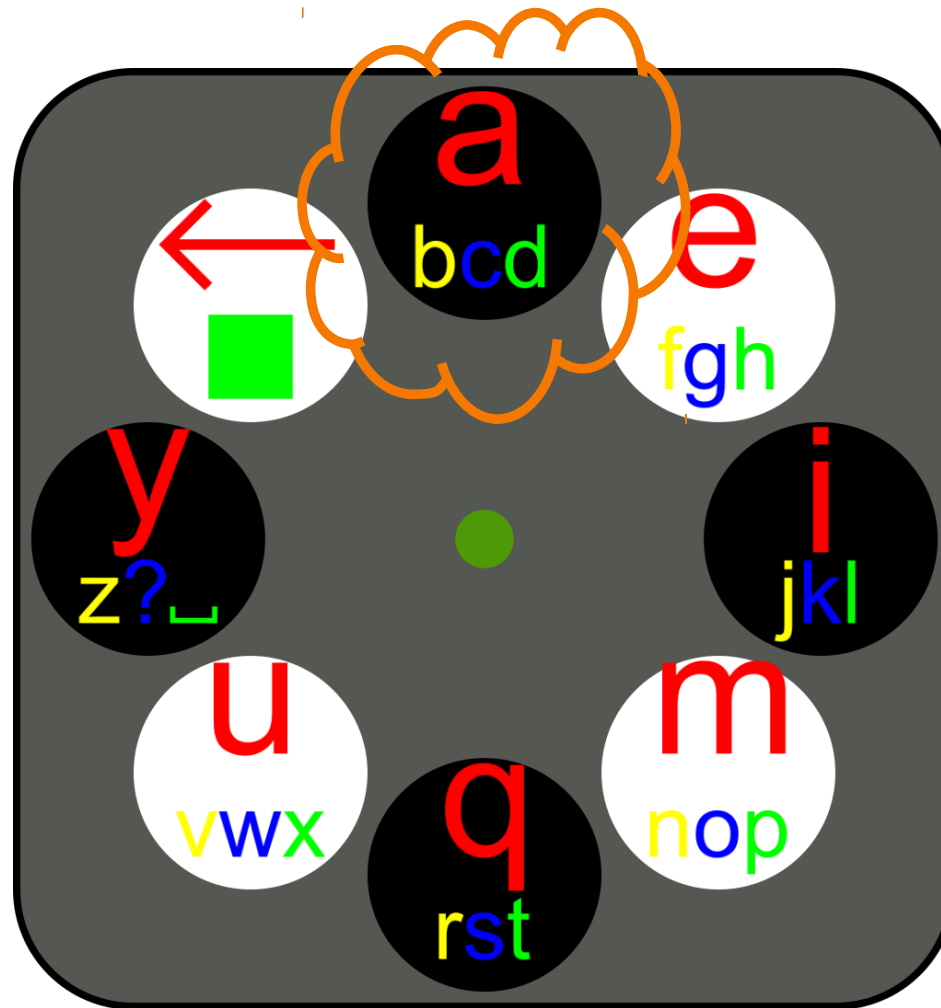
Accuracy: 86%

Selection time: 29 s

Success: 9/9 pp



Free writing



Free writing



Free writing

Enfin terminée
Finally done !

Je m'appelle *****
*My name is ******

Le chat dort
The cat sleeps

Je vais agrandir
I'm going to get bigger

Expérience terminée
Experiment finished

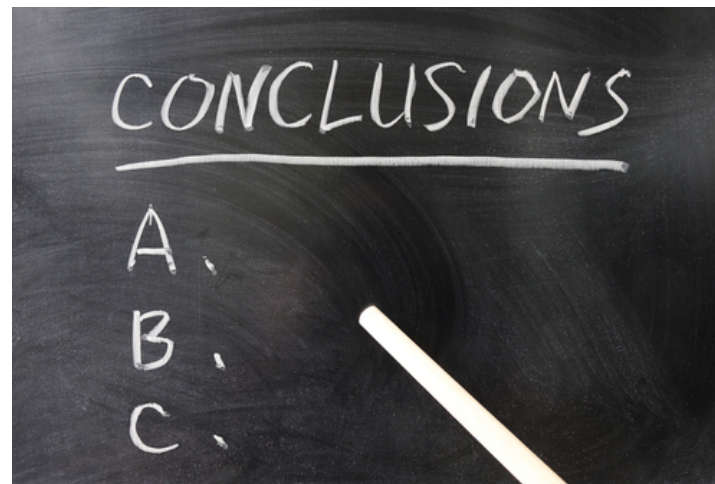
Je suis *****
*I am ******

Vive le poil ?
Live the fur?

Le chien boit
The dog drinks

Je ne suis pas si rapide que ça
I'm not all that fast

Conclusion



Conclusion

- Pupillary responses are not passive reflexes
... but are types of eye movements that reflect high-level visual processing
- “External attention”
 - Directing your attention to something out there
- “Internal attention”
 - Sensory representations without visual input
 - But where does working memory stand in this?
- Pupillometry has practical applications
... such as human-computer interfaces

Thank you!

For more info and slides
see cogsci.nl/smathot

References

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