UNIVERSITÀ DEGLI STUDI DI PADOVA

Elements of cognitive pupillometry

Data processing of pupillary diameter changes over time with the free software R

by
Giulia Calignano
Sofia Russo

January 5, 2023

AIM

disentangle the doubts about **cognitive** pupillometry
to fully understand the measure and
therefore avoid some **methodological mistakes**
when approaching this multifaceted measure

link to materials

Overview

PubMed.gov

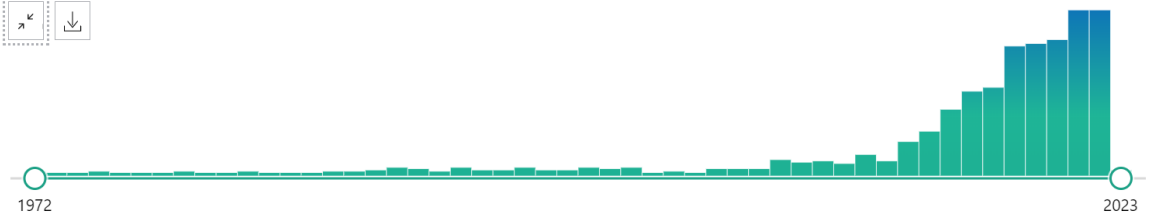
"pupillometry" OR "pupil size" AND "psychology" Search

Advanced Create alert Create RSS User Guide

Save Email Send to Sorted by: Best match Display options

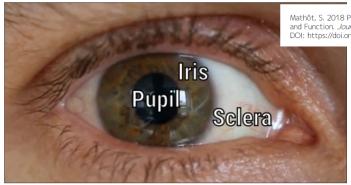
RESULTS BY YEAR

761 results Page 1 of 77



Physiology and Psychology of pupillometry

Physiology and Psychology of pupillometry



Mathôt, S. 2018 Pupillometry: Psychology, Physiology, and Function. *Journal of Cognition*, 1(1): 16, pp.1-23. DOI: https://doi.org/10.5334/joc.18

Figure 1: A photo of my own eye, showing the pupil, iris, and sclera.

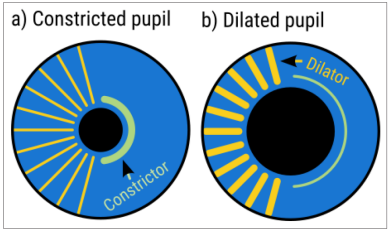


Figure 2: a) When the iris sphincter muscle (green) contracts, it tightens the inner side of the iris, thus causing the pupil to constrict. **b)** When the iris dilator muscle (yellow) contracts, it pulls the inner side of the iris outward, thus causing the pupil to dilate.

Physiology and Psychology of pupillometry

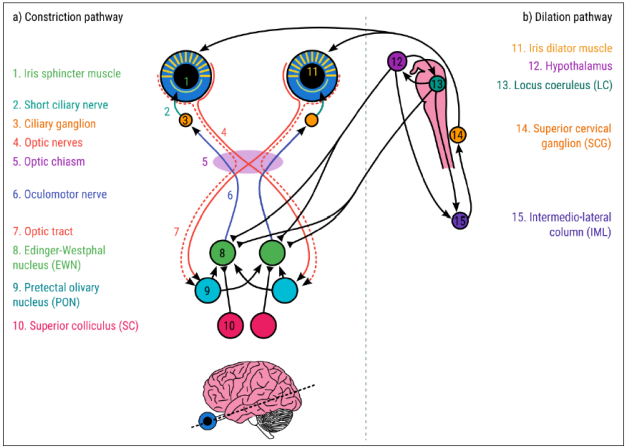


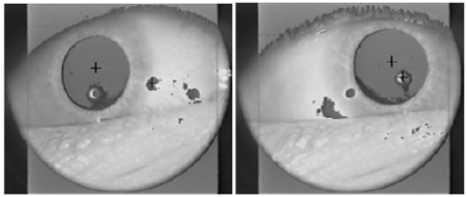
Figure 3: a) The pupil constriction pathway. **b)** the pupil dilation pathway. (Based on Kardon, 2005; McDougal & Gamlin, 2008; Samuels & Szabadi, 2008; Szabadi, 2012; C. Wang & Munoz, 2015).

Physiology and Psychology of pupillometry

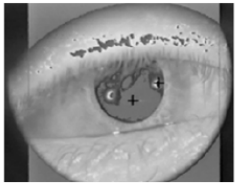
- The **dilator** muscle is under adrenergic control (**sympathetic system**) from the superior sympathetic ganglion.
- The **sphincter** pupillae innervated by cholinergic fibers of the **parasympathetic system**.
- Dilation = activation of the sympathetic system + a parallel inhibitory parasympathetic mechanism.
- Typical size: 3-5 mm(range: 1-9 mm) gets smaller by .04 per year
- In standard light conditions, pupil size is about 3 mm

(Beatty and Lucero-Wagoner 2000; Sirois and Brisson, 2014)

Physiology and Psychology of pupillometry



(a) Looking to upper-left. (b) Looking to upper-right.



Physiology and Psychology of pupillometry

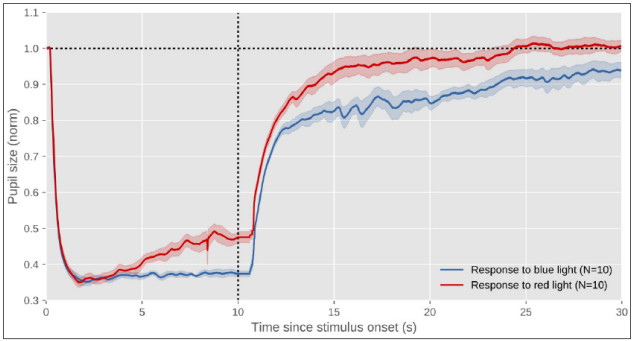


Figure 4: The profile of a typical pupil light response. This figure shows data of myself while I'm looking at red or blue full-screen colors on a computer display (N = 10 trials per color). The x axis indicates time since stimulus onset. The y axis indicates pupil size as a proportion of pre-stimulus pupil size. Errors bars reflect the standard error. All data shown in this figure and others is available through the URL provided at the end of the article.

Physiology and Psychology of pupillometry

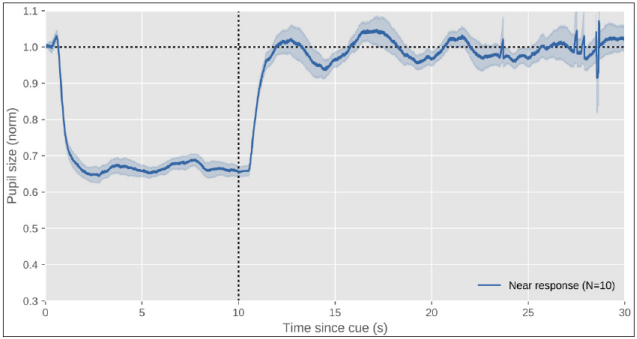


Figure 5: The profile of a typical pupil near response. This figure shows data of myself while I'm shifting gaze from a far-away to a nearby point (prompted by an auditory cue at 0 s) and back again (prompted by another auditory cue at 10 s; N = 10 trials). The x axis indicates time since the onset of the auditory cue to shift gaze. The y axis indicates pupil size as a proportion of pre-stimulus pupil size. Errors bars reflect the standard error. All data shown in this figure and others is available through the URL provided at the end of the article.

Physiology and Psychology of pupillometry

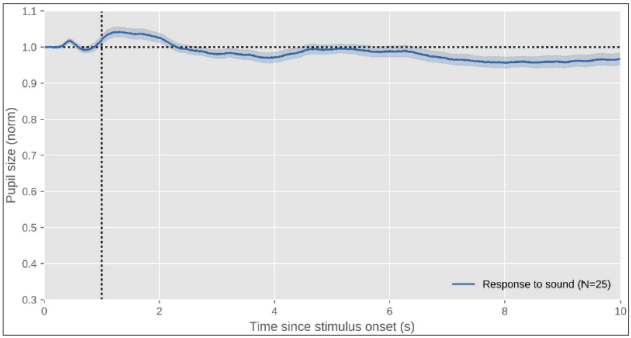


Figure 6: The profile of a typical psychosensory response to sound. This figure shows data of myself while hearing a 1 s burst of auditory white noise. Because the effect is small, this figure is based on more data than the previous figures (N = 25 trials). The x axis indicates time since stimulus onset. The y axis indicates pupil size as a proportion of pre-stimulus pupil size, and is intentionally kept identical to the other figures to illustrate the size of the effect. Errors bars reflect the standard error. All data shown in this figure and others is available through the URL provided at the end of the article.

Physiology and Psychology of pupillometry

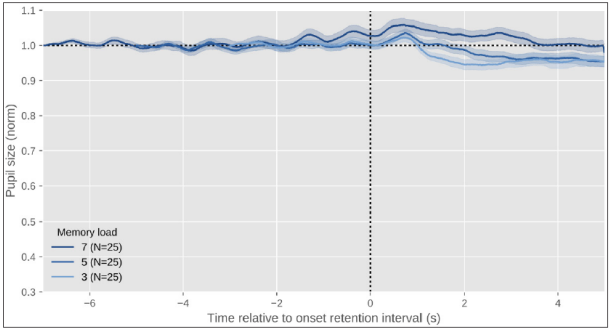


Figure 7: The profile of a typical psychosensory response during working-memory maintenance. This figure shows data of myself while I listen to 3, 5, or 7 digits (N = 25 trials for each set size) played back through a set of desktop speakers, followed by a 5 s retention interval during which I'm keeping the digits in working memory for later recall (recall phase not shown). The x axis indicates time since the onset of the retention interval. The y axis indicates pupil size as a proportion of pre-stimulus pupil size, and is intentionally kept identical to the other figures to illustrate the size of the effect. Errors bars reflect the standard error. All data shown in this figure and others is available through the URL provided at the end of the article.

Physiology and Psychology of pupillometry

- **Light reflex changes** in diameter to modulate the amount of light that reaches the retina, thus optimizing vision
- **Pupil diameter is modulated by attention**: sensitive to different components of attention the delay, speed, and length indexes various aspects of attention
  (Geva, et al., 2013)
- **Ideal for infant research** perceptual dynamics providing an alternative to looking time measures (Sirois and Jackson,2012).

Physiology and Psychology of pupillometry

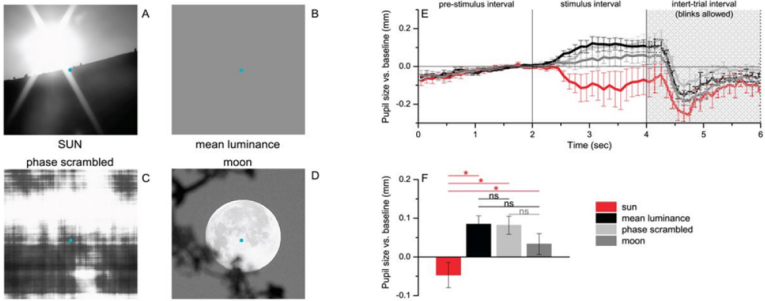
Two main activation profiles

- **Tonic state**: more efficient in sustained processing. This mode is associated with an elevated baseline firing rate in the LC. It promotes disengagement from the task and diffuse exploration
- **Phasic state**: firing rapidly to optimize performance during a specific task, to focus attention on an *exploitation mode*. This LC activation leads to rapid pupil dilation **= EVENT RELATED (~ 200 ms)**

Some examples of pupil dilation as an useful **event-related** measure in cognitive sciences

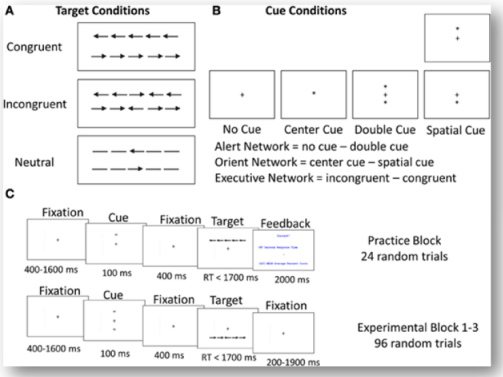
Physiology and Psychology of pupillometry

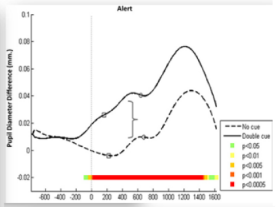
- Even luminance perception may be modulated by top-down processes (Binda, et al, 2013)
- high-level visual analysis (beyond the simple subcortical system mediating the pupillary response to light) can also induce pupillary constriction, with an effect size of about 0.1 mm

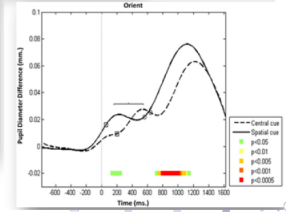


Physiology and Psychology of pupillometry

- Alerting,orienting or executive attention networks: differential patterns of pupil dilations (Geva et al.,2013)

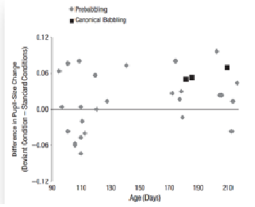


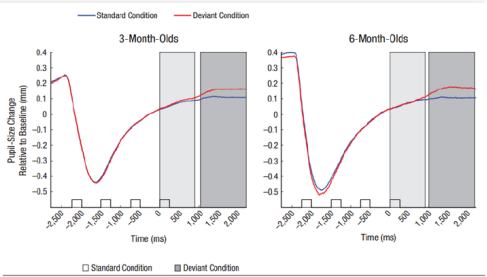




Physiology and Psychology of pupillometry

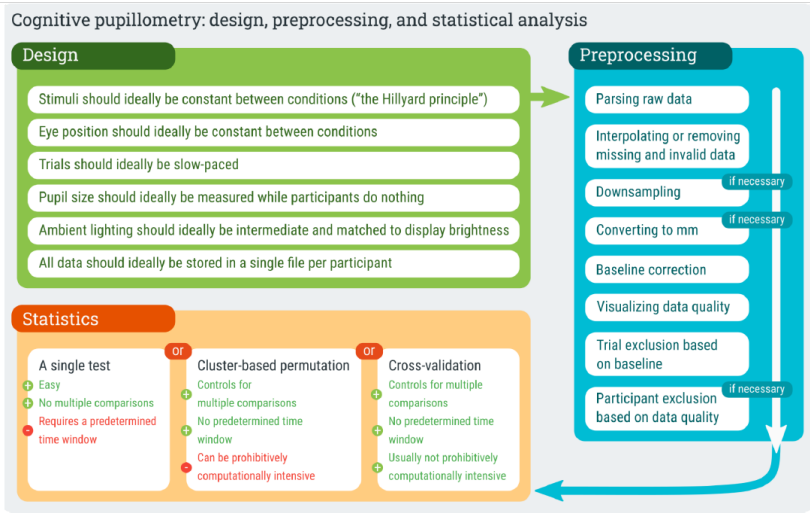
- the ability to perceive the same consonant in different syllables matching (Hochmann and Papeo,2014)
  3- and 6-month olds
  75 standard *ba-ba-ba-ba*
  25 deviant *ba-ba-ba-di*





Overview

Main sources of noise in Cognitive pupillometry



Main sources of noise in Cognitive pupillometry

best practice: the pre-processing steps should be selected before visualizing the data

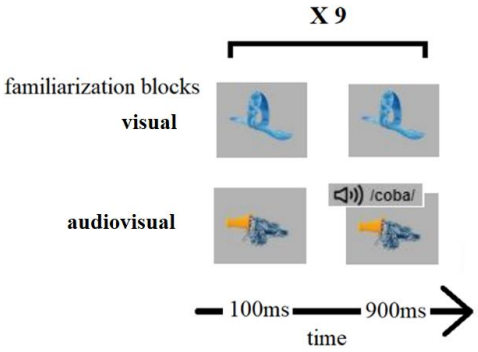
- data parsing
- sanity check to "weight" the main source of noise
  e.g. extreme values, area of interest
- missing data - interpolation **?**
- baseline correction
- model selection

...how many degrees of freedom in data management?
...give a look to Psicostat to embrace uncertainty ;)

Zoom meeting at Psicostat, let's collaborate:
giulia.calignano@unipd.it

Hands on pupillometry
Degrees of freedom in data pre-processing

Design: familiarization paradigm visual vs audiovisual stimuli



1. data dictionary (dataset_tutorial.csv)
2. a portion of the multiverse

Overview

Elements of functional interpretation of pupillometry

- Emotions
- Language processing
- Cognitive Effort
- Review on Cognitive Effort
- Psychopathology
- Infants - VOA

Tips for a safe trip in cognitive pupillometry

1. Define the **research question**
2. Choose a solid **design** (e.g., solid hypotheses on other complementary measures)
3. **Adapt** the design for a correct measurement of changes in pupil diameter over time
4. Select the degrees of freedom of **preprocessing** and **statistical analysis** based on the specific research question
5. Interpret the data by asking yourself these questions: what are the physiological **artifacts**? what are the **latency times** from stimulus onset to peak pupillary response? **when** does the effect emerge (early vs late effects)? what other **cognitive** processes or mechanisms am I measuring in addition to the one of interest?