Pupillometry and Psychological Processes

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Overview

- Why pupillometry?
- Physiology of pupillometry
- History of pupillometry
- Methodological considerations
- Examples

Why pupillometry?

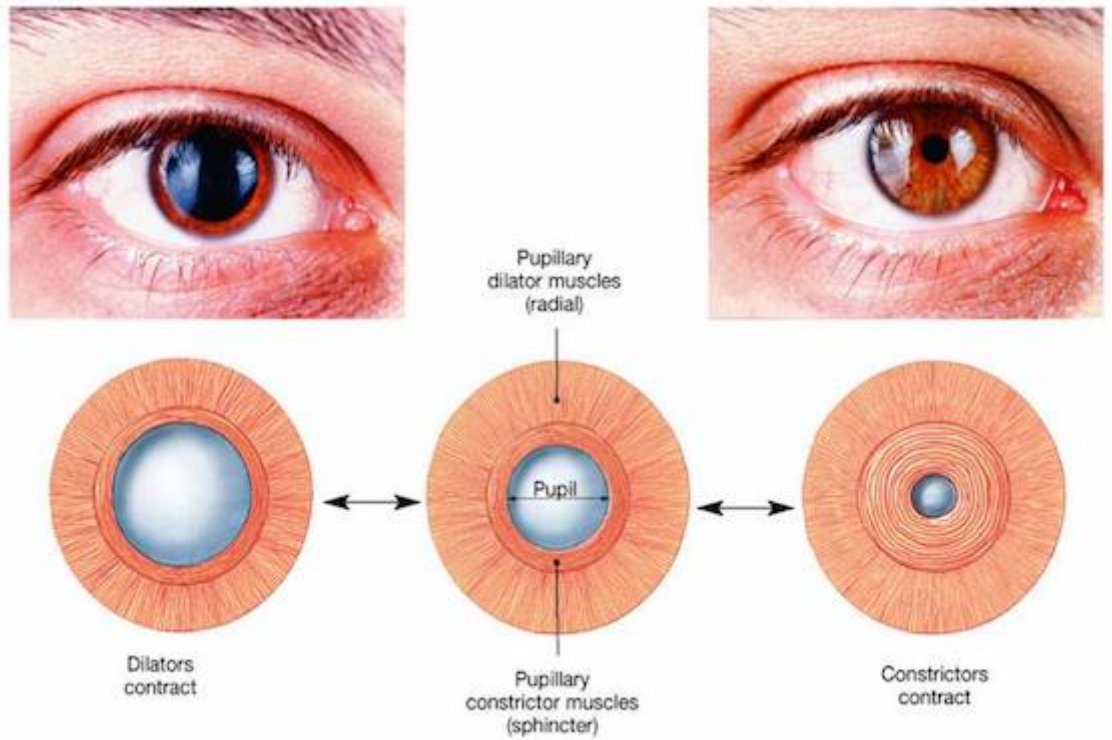
The measurement of pupil size (i.e., pupillometry) is:

- A reliable, consistent measure of psychological constructs
- A dynamic (online) measure of processing
- Non-invasive
- Easy to acquire

Physiology of pupillometry

The human eye

Pupil change



Large scale pupil changes

Caused by:

- Brightness (luminosity)
- Neurological issues
- Certain drugs (e.g., morphine)

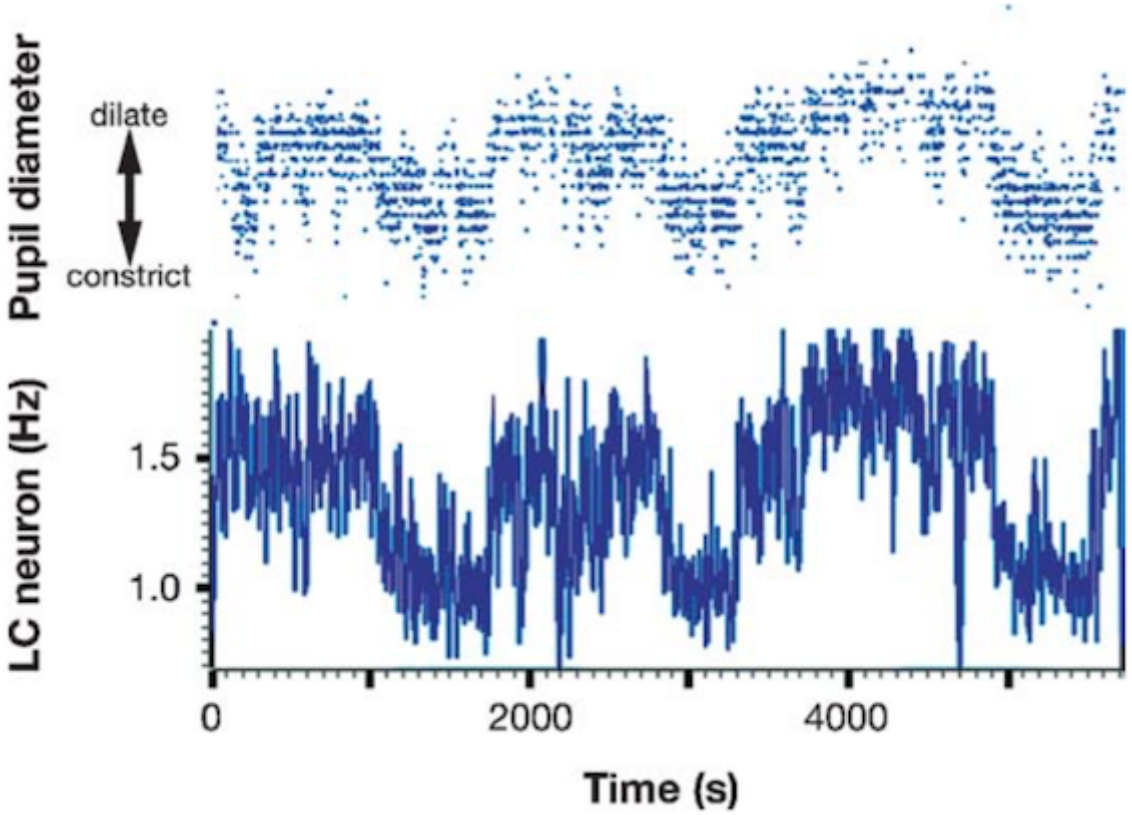
Not of interest to us as psychologists

Small scale pupil changes

- Tiny, visual fluctuations
- Less than 0.5 mm in size
- Related to affective and cognitive functioning (Beatty and Lucero-Wagoner 2000; B. Laeng, Sirois, and Gredeback 2012; S. Sirois and Brisson 2014)

Pupil-LC-NE link

Pupil appears to be tightly linked with locus coeruleus (LC) functioning (Aston-Jones and Cohen 2005)



Pupil-LC-NE link

The LC is responsible for the release of noradrenaline (NE) throughout the brain

- Related to a variety of processes, including stress responses, memory retrieval, or selective attention, the sleep-wake cycle, and general arousal

One popular interpretation is that the LC-NE is responsible for the trade-of between task engagement (exploitation) and task disengagement (exploration)

- **Task engagement:** Low baseline PD - Highly reactive PD
- **Task disengagement:** High baseline PD - Less reactive PD

History of pupillometry

History

- First discovered over 100 years ago (Schiff 1875; Heinrich 1896)

"Every active intellectual process, every psychical effort, every exertion of attention, every active mental image, regardless of content, particularly every affect just as truly produces pupil enlargement as does every sensory stimulus." **Oswald Bumke in 1911**
(Eckhard H Hess 1975, 23–24)

Re-discovery

- In the 60s by American researchers, particularly Hess and colleagues (Eckhard H Hess and Polt 1960; Eckhard H Hess and Polt 1964; Eckhard H Hess 1975)
- Up until the 80s, particularly Beatty and colleagues (Ahern and Beatty 1979; Ahern and Beatty 1981; Beatty and Lucero-Wagoner 1978; Beatty 1982; Jackson 1982; Kahneman and Beatty 1966; Kahneman and Beatty 1967; Richer and Beatty 1987)

Pupillometry as a proxy for psychological processes

- Arousal (Eckhard H Hess and Polt 1960; E H Hess 1965)
- Mental effort (Ahern and Beatty 1979; Ahern and Beatty 1981; Eckhard H Hess and Polt 1964; Kahneman and Beatty 1966)
- Memory retrieval (Kahneman and Beatty 1966)
- Language processing (Beatty and Lucero-Wagoner 1978; Schluroff 1982)

Pupillometry as a proxy for psychological processes

- Arousal (Margaret M. Bradley and Lang 2000; Margaret M Bradley et al. 2008; Partala and Surakka 2003)
- Cognitive conflict
  - Error (W. W. A. Sleegers, Proulx, and Beest 2015), surprise (Preuschoff, ’t Hart, and Einhäuser 2011), incongruence (Bruno Laeng et al. 2011; Proulx, Sleegers, and Tritt 2017)
- Pain (Connelly et al. 2014; Ellermeier and Westphal 1995; Höfle et al. 2008)
- Alertness (Smallwood et al. 2011)
- **Not** valence (Margaret M Bradley et al. 2008)

Methodology

Tobii T60 eye tracker

- 17” TFT monitor
- Infrared diodes to generate reflection patterns on the corneas of the user’s eyes, which are recorded by image sensors inside the monitor
- Measures gaze direction and pupil size

Strengths

Easy to calibrate

- Can measure the distance to the pupil
- Show immediate feedback
- Successful over 95% of the time

Non-intrusive

- No clamp or headrest needed

Raw data vs. manufacturer software

Manufacturer software:

- Expensive
- Easy to use
- Limited options
- Only available in the software package
- Hides your data
- Aimed at gaze direction

Raw data:

- Free
- Difficult to process
- Only limited by your ability
- Always available

4 challenges

1. Accommodation reflex and light reflex
2. No event-marked time variable
3. Messy data
4. Baseline differences

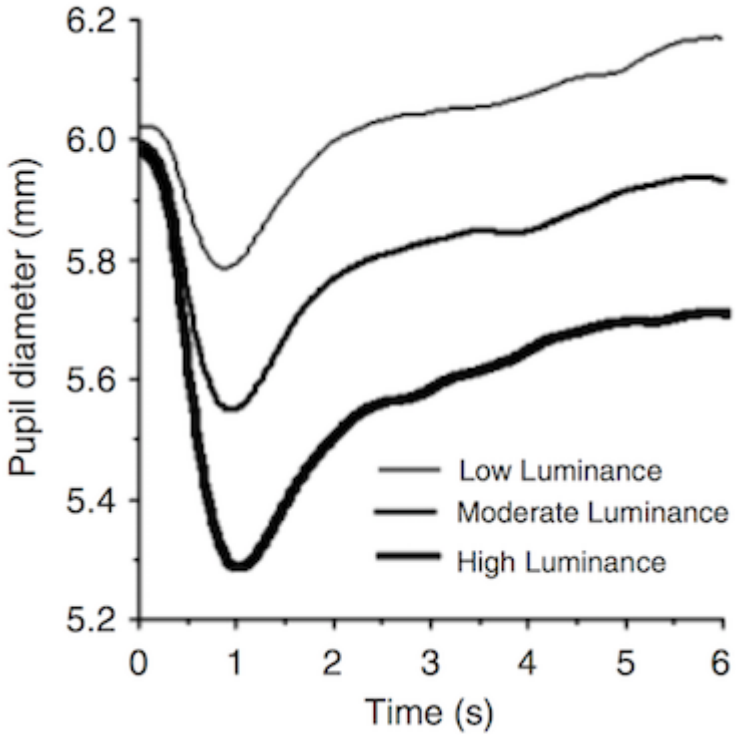
Challenge #1: Pupillary reflexes

Accommodation reflex: Change in pupil size due to focusing on objects at varying distances

- Generally not a problem in lab studies

Pupillary light reflex: Change in pupil size due to changes in luminosity

Challenge #1: Luminance



Challenge #1: Luminance

Solutions:

- Keep lighting constant in the room
- Keep the luminance of the stimuli constant
- Ignore pupil period immediately following stimulus presentation
- Use non-visual stimuli

Challenge #2: No time variable

Challenge #2: No time variable

```
# Create a new variable that shows the time only during the relevant period
raw_data$temp <- ifelse(raw_data$object == "Feedback", raw_data$TETTime, NA)

# Subtract the minimum time from each time stamp, per participant, per trial
raw_data %>%
    group_by(subject, trial) %>%
    mutate(
        temp = min(temp, na.rm = TRUE),
        time = TETTime - temp) -> raw_data
```

Challenge #2: No time variable

Challenge #3: Messy data

Show which trial?

1

Challenge #3: Messy data

Solutions:

- Extrapolate missing data
  - Linear interpolation
  - Regression based methods
- Replace data of one eye with the other eye
- Apply filters

```
# 'robfilter' package
dw.filter()
```

Challenge #3: Messy data

Filter:

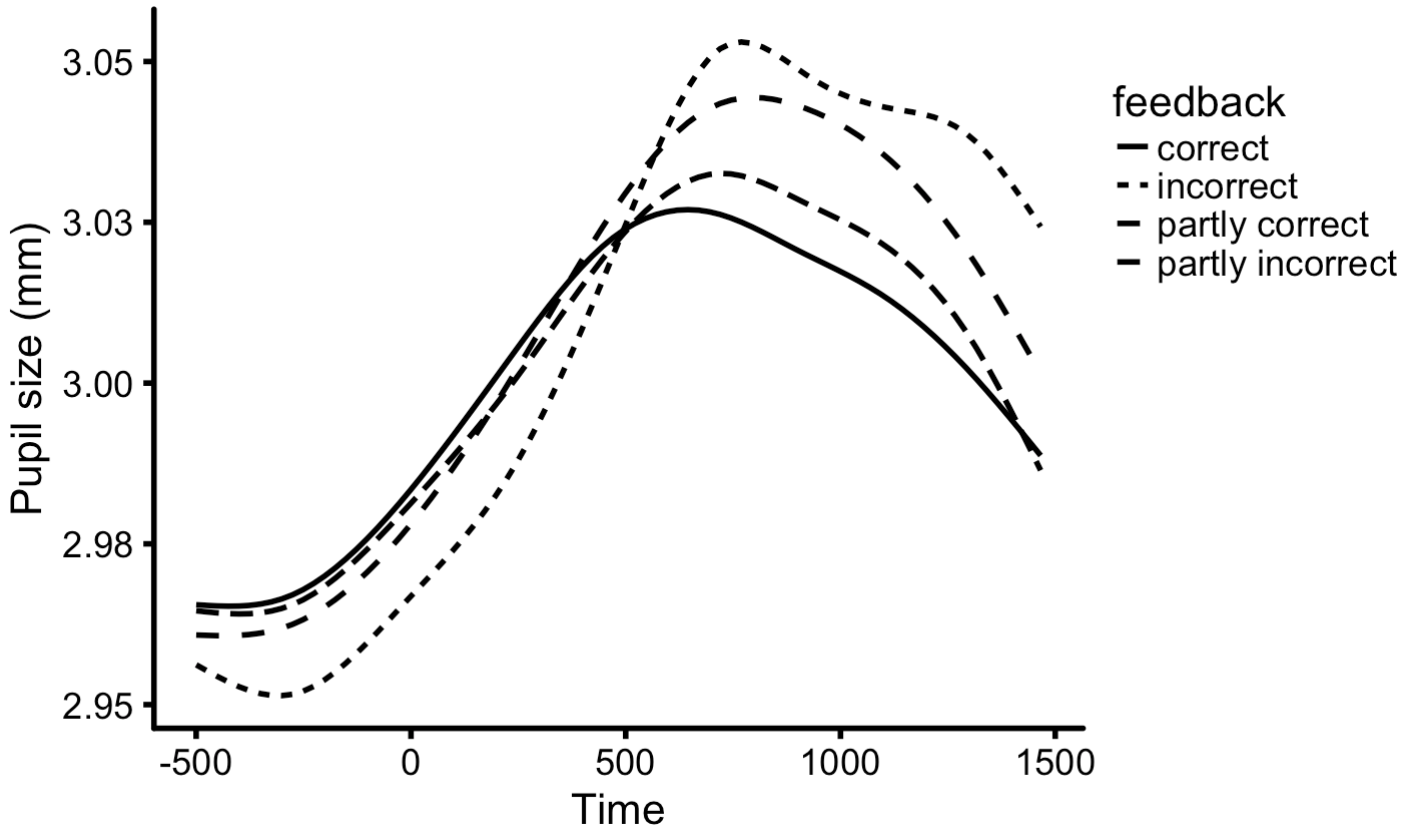
MED

Inner width:

15

Outer width:

Challenge #4: Baseline differences

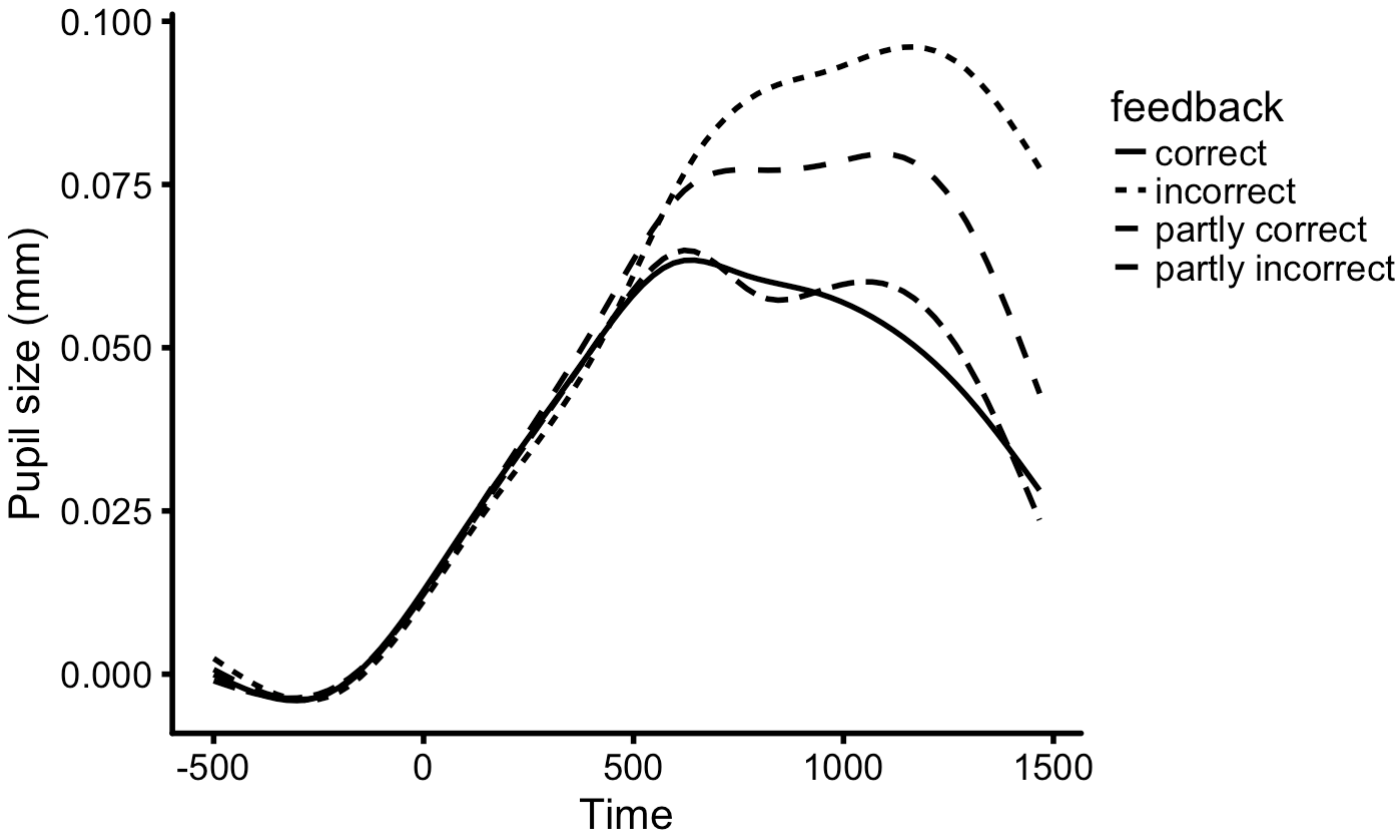


Challenge #4: Baseline differences

Solution:

- Calculate mean during a baseline period and subtract from subsequent measures

Challenge #4: Baseline differences



Data analysis

3 main DVs of interest:

- Mean pupil dilation
- Maximum pupil dilation
- Time until maximum pupil dilation

Data analysis

Alternatively, focus on baseline PD

- Tonic vs. phasic modes of processing
- **Task engagement**: Low baseline PD - Highly reactive PD
- **Task disengagement**: High baseline PD - Less reactive PD

Examples

My PhD work

Together with Travis Proulx and Ilja van Beest

Investigated pupillometric responses to:

- Belief feedback
- Perceptual anomalies
    - Reverse colored playing cards
    - Thatcherized faces
- Social exclusion

Belief feedback

Study 2:

Presented participants with misconceptions

- e.g., A chameleon changes its colors as a form of camouflage, Einstein was bad at math during high school, Eskimo's live in igloos

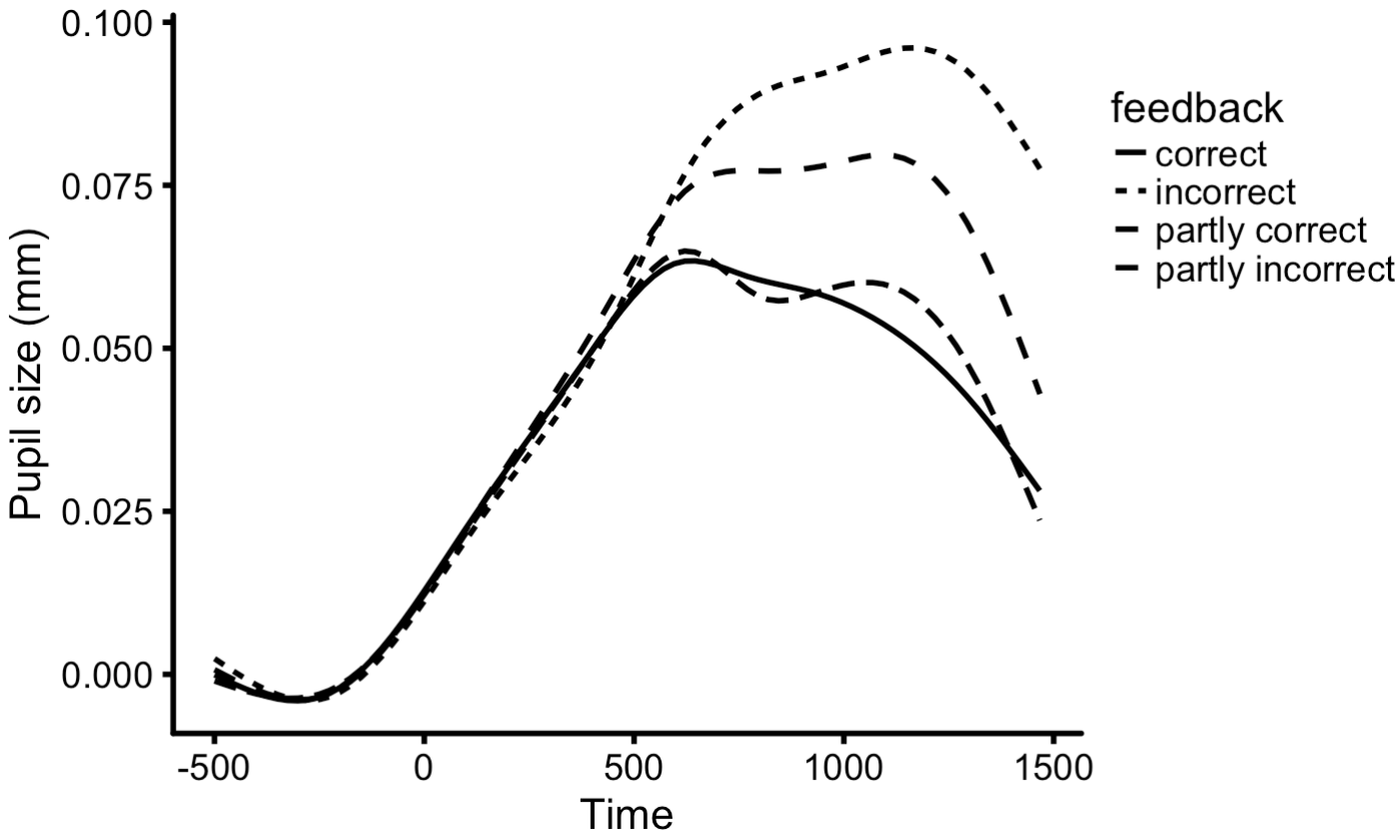
Response: True/False

Feedback:

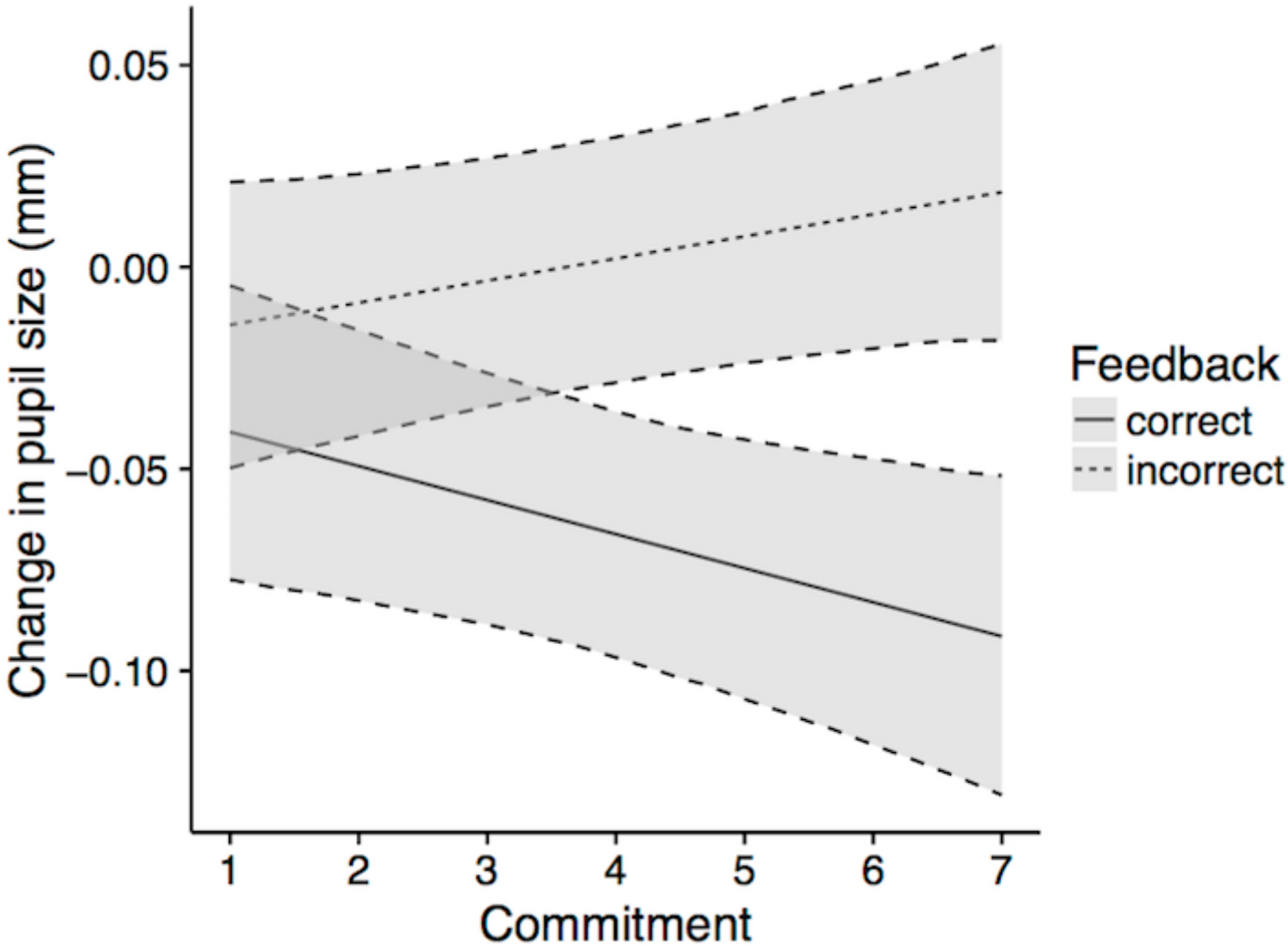
- **Clear feedback**: Correct/incorrect
- **Ambiguous feedback**: Partly correct/partly incorrect

Also measured commitment to each misconception

Belief feedback



Belief feedback moderation



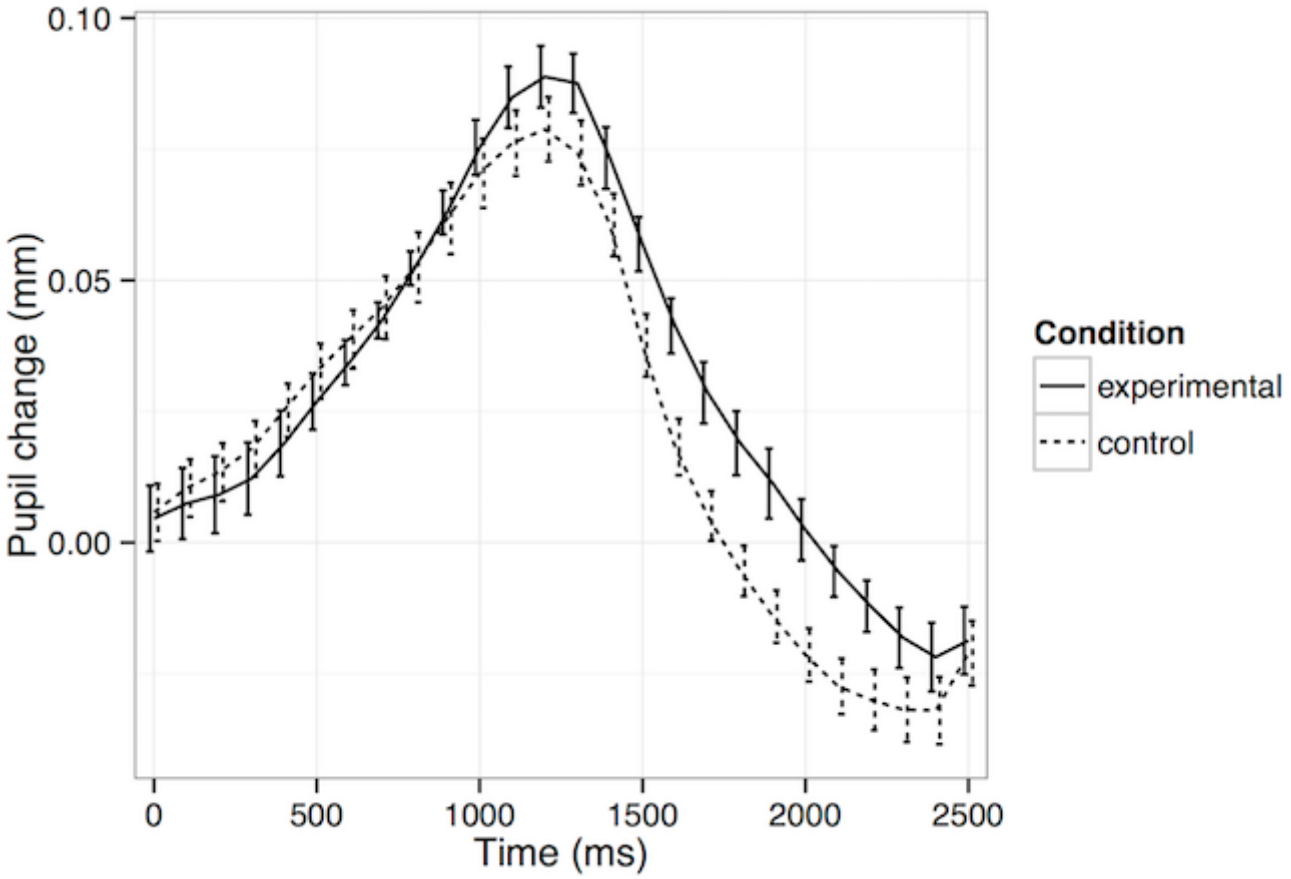
Perceptual anomalies: Playing cards

Reverse colored playing cards (W. W. A. Sleegers, Proulx, and Beest 2015)

Between-subjects design:

- Either saw only normal playing cards
- Or normal and reverse-colored playing cards

Perceptual anomalies: Playing cards

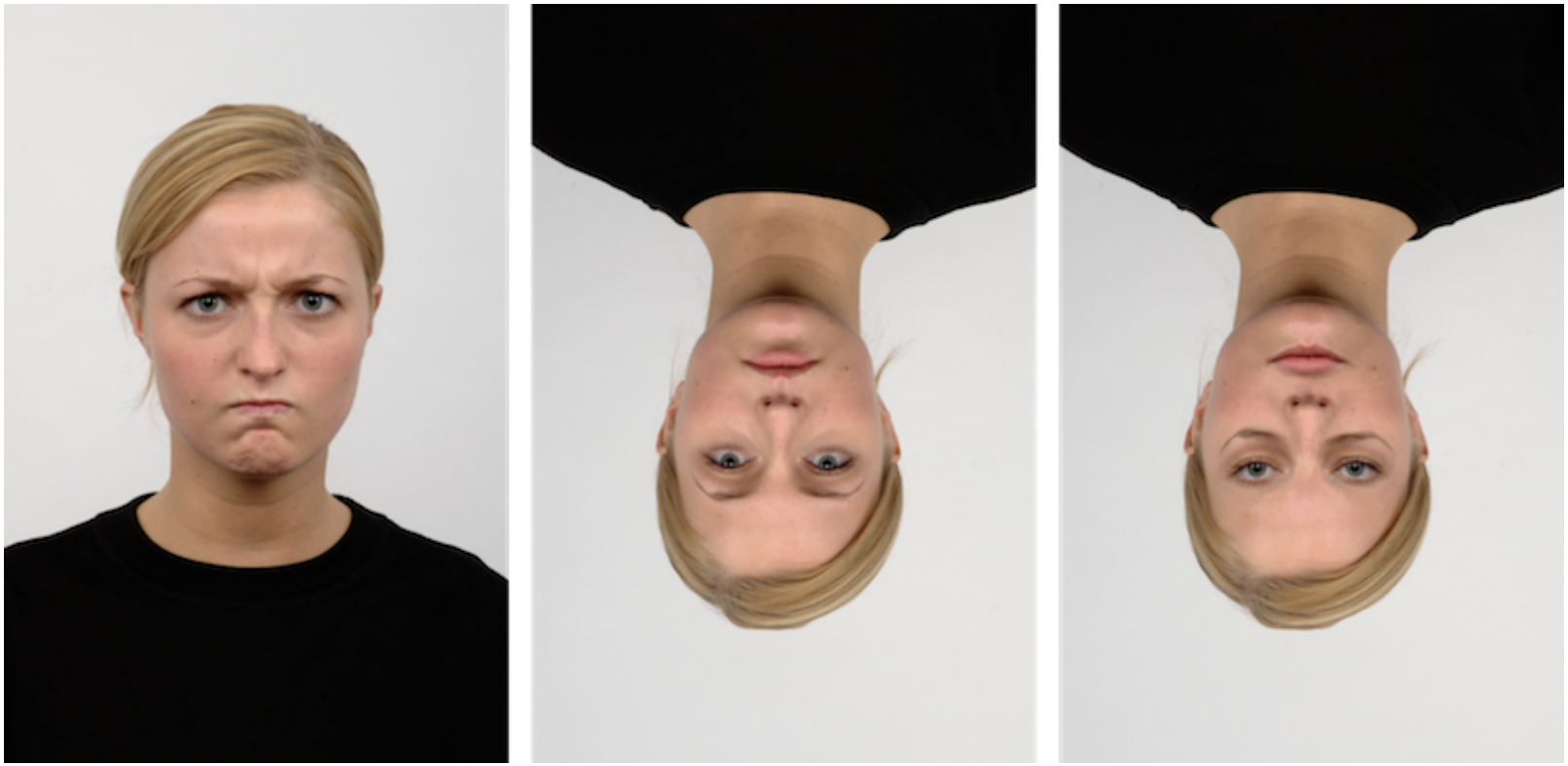


Perceptual anomalies: Faces

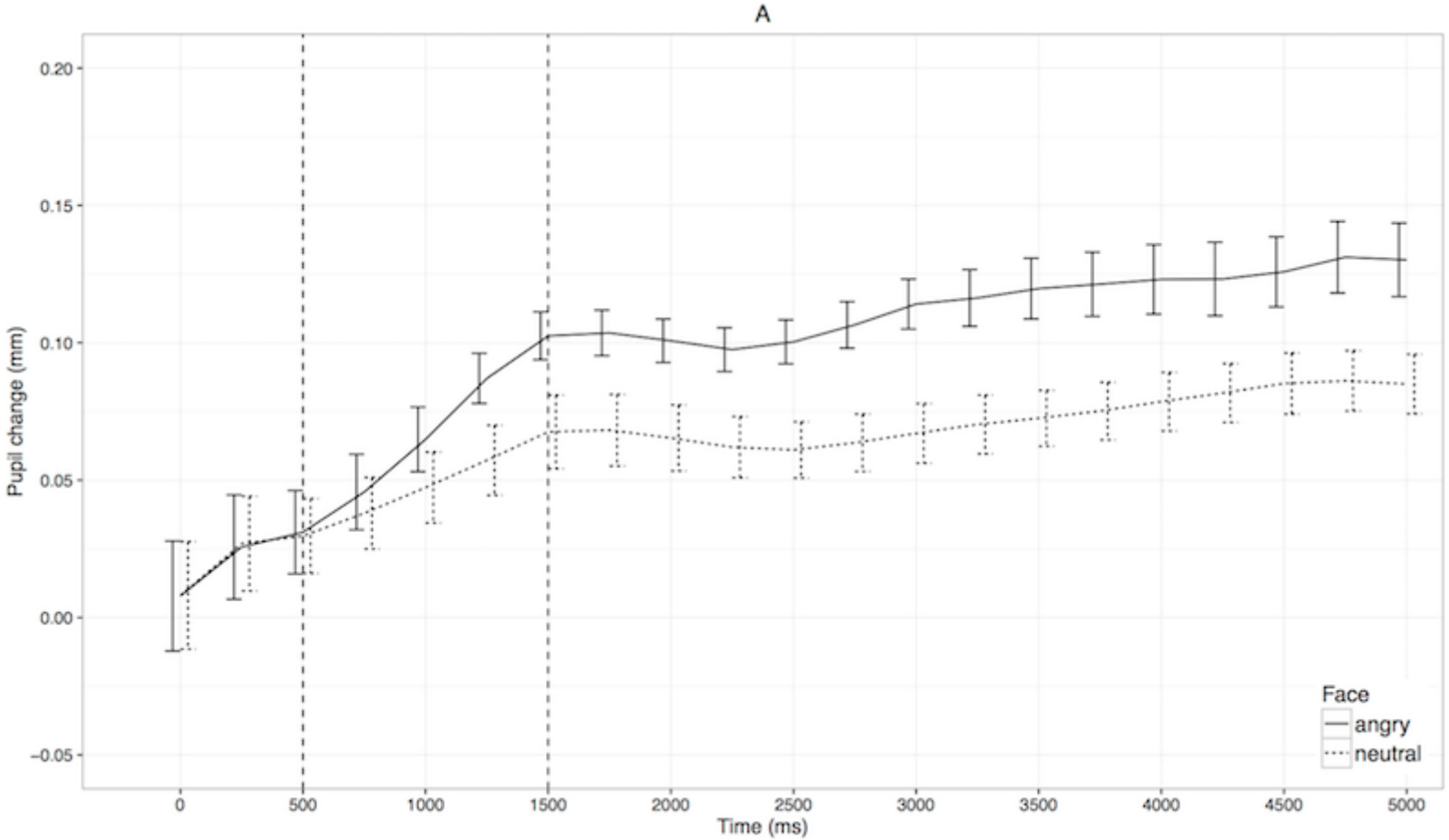
Presented participants with two sets of faces:

- Angry vs. neutral
- Thatcherized vs. neutral
- Thatcherized vs. upside-down faces

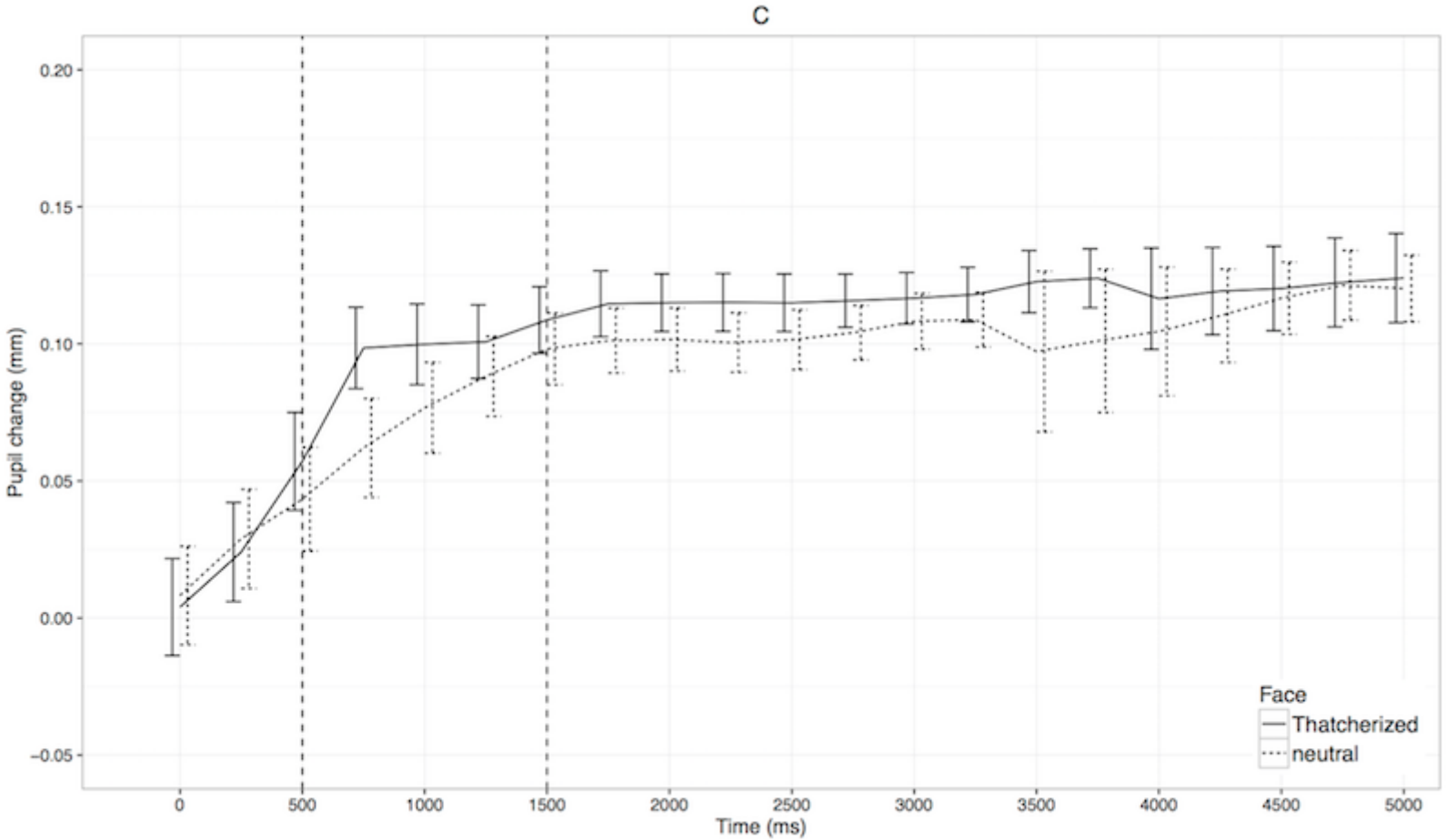
Perceptual anomalies: Faces



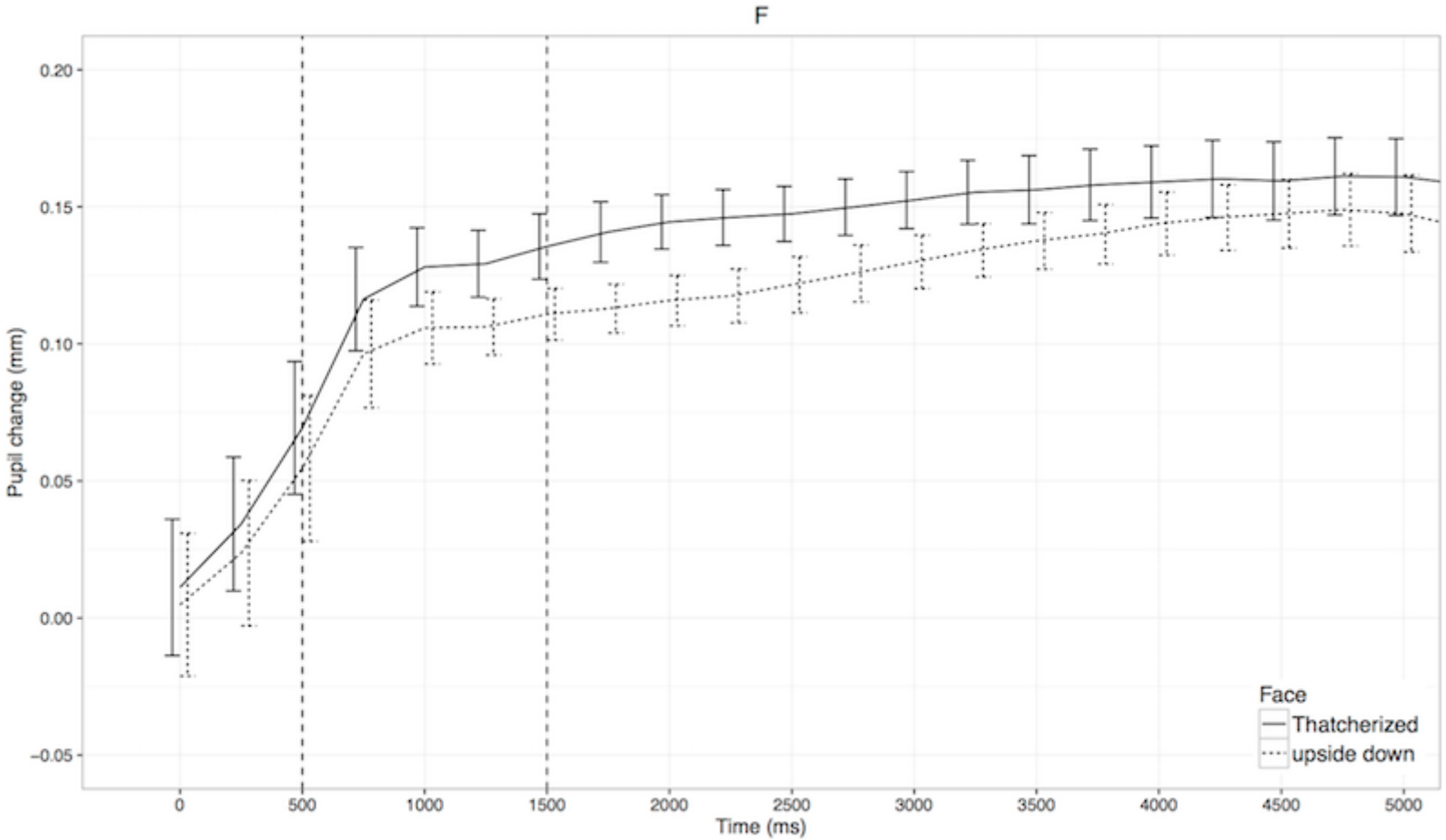
Perceptual anomalies: Faces



Perceptual anomalies: Faces



Perceptual anomalies: Faces



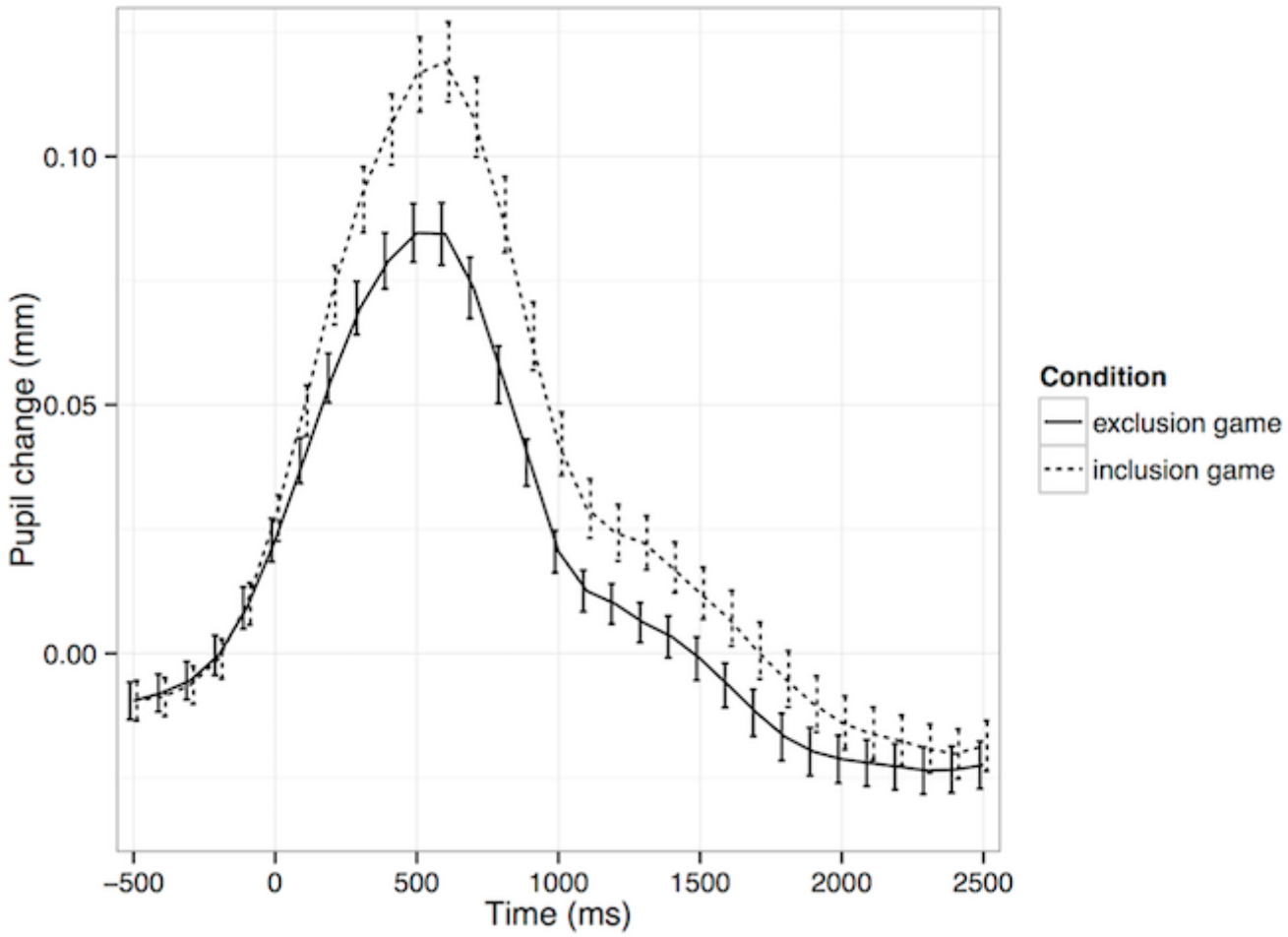
Social exclusion

Participants played two games of Cyberball:

- Inclusion game (receive 30 ball tosses)
- Exclusion game (receive 8 ball tosses)

Goal: Compare pupil size in response to not receiving a ball between both games

Social exclusion



Cardiff Specials

Faces:

- Our work
- Lot of facial recognition work
    - Autism

Mindfulness:

- Mindful vs. mindless reading (M. S. Franklin et al. 2013)
- Coupling and de-coupling of attention (Smallwood et al. 2011)

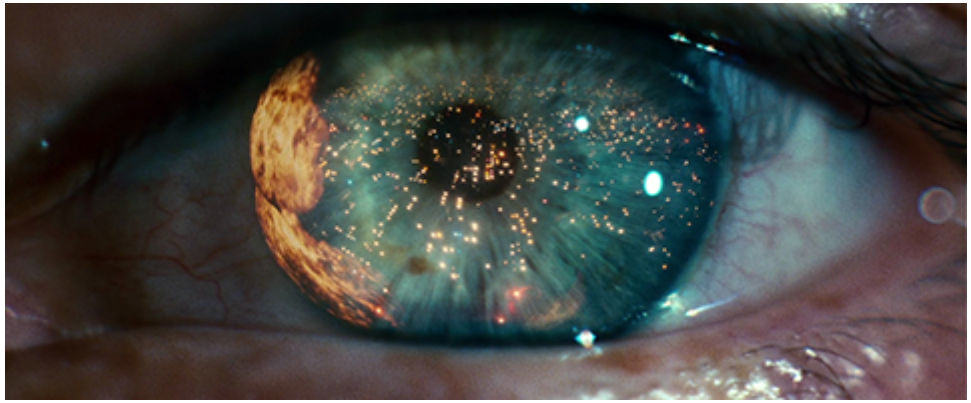
Happy to discuss further potential applications

Limitations

- Pupillometry assesses arousal, not valence
  - Valence can potentially be derived using different operationalizations (Steenbergen, Band, and Hommel 2011)
- Multiple trials needed

Conclusion

Pupillometry is a **noninvasive**, tool, capable of **dynamically** measuring a variety of **psychologically interesting constructs**, and **easy** to use.



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