Take another look: Pupillometry and cognitive processing demands

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Overview

• Eye-tracking technology
• Pupillometry
• Task evoked pupillary response (TEPR)
• Advantages, limitations
• TEPR measures and interpretations
• Methodological decisions

Eye-tracking technology

• Pupil Centre Corneal Reflection (PCCR) remote eye tracking technology

Source: (Tobii Technology, 2010)
PCCR

- Near infrared (IR) illumination creates reflection patterns on the cornea and pupil

- Image sensor captures eye images and IR reflection patterns

- Image processing algorithms + mathematical 3D model of eye: calculate eye and gaze position, and pupil diameter
Sampling rate and timing accuracy

- Eye tracking systems have different gaze data sampling rates
  - Number of gaze data points collected per second
- Image sensor in our T60 XL system
  - Mean rate of 60 Hz (0.0002 Hz SD)
  - 1 sample/16.67 ms
  - Processing latency < 17 ms
  - Total latency 27-33 ms
Pupillometry

- Measures that involve changes in the diameter of the pupil
- Pupil dilation (PD) is an involuntary, autonomic, motor reflex (lighting; emotion; cognitive effort)
- Parasympathetic (constriction) and sympathetic (dilation) innervation

- Circular muscles surround and constrict the pupil

- Radial muscles extend radially from pupil through iris, and dilate the pupil

- Light reflex vs. pupillary dilation reflex³
  - Light reflex: Pupil continually oscillates in response to steady light; not tied to other physiological systems (e.g., heart rate)
  - Pupillary dilation reflex: Radial muscles activate, while circular muscles are inhibited, resulting in large and momentary pupil dilation

Source: www.myprettypinkpearl.blogspot.com

Source: [image]
Task-evoked pupillary response (TEPR)

- Changes in pupil dilation linked to stimulus/task presentation
- Much smaller than light-driven responses
- Involuntary
- Studied by contrasting tonic and phasic PD
  - Tonic dilation: baseline (resting) pupil diameter under consistent light and processing conditions
  - Phasic dilation: changes in baseline diameter associated with stimulus presentation

TEPR as an index of mental activity

- Relationship of pupil dilation to cognition has been investigated for over 100 years

Every active intellectual process, every psychical effort, every exertion of attention, every active mental image, regardless of content, particularly affect just as truly produces pupil enlargement as does every sensory stimulus.

(Bumke, 1911, as cited by Beatty, 1982)

TEPR studies have involved diverse cognitive tasks

- Calculating math operations
- Processing & rehearsal of items for working memory
- Pitch discrimination
- Attentional control
- Analogical reasoning
- Lexical and syntactic processing
TEPR studies have involved diverse populations

- Infants and children
- Individuals with autism spectrum disorder
- Individuals with schizophrenia
- Individuals with Fragile-X syndrome
- Individuals with hearing impairment
- (Barn owls and other animals)

General patterns in TEPRs

- Pupil dilation increases in tandem with increases in processing demand and/or allocation of cognitive resources, e.g.,
  - number of items to be remembered
  - difficulty of problem solving
  - syntactic complexity
- Up to a point!
  - when processing demand exceeds capacity, PD declines

TEPRs and intelligence

- Some evidence suggests that people with relatively high IQs show relatively smaller TEPRs
- Often interpreted as reflecting larger overall processing capacity and/or increased cognitive efficiency
- But see Van der Meer et al. (2010) for a different perspective
Advantages of pupillometry

• Does not require volitional response
• Not controlled by conscious effort
• More sensitive and more reliable than other physiological measures (e.g., heart rate, GSR)
• Accessibility
• Feasibility

Disadvantages of pupillometry

• Low face validity
• Sensitive to variations in lighting conditions
• A “summative” measure²
  – may reflect the combined influences of any influences on cognitive arousal, e.g., anxiety, interest, incentives, age, fatigue, intelligence, illness, medication. . .

Balancing advantages and disadvantages

• Choice of TEPR measure
• Careful research design
• Rigorous research methods
Major TEPR measures

- Peak amplitude
- Average dilation (over some time window)
- Peak latency (latency to peak amplitude)
- Virtually all studies report TEPR in relation to pupils measured during a baseline period in which no systematic processing occurs

Klingner, Tversky & Hanrahan, 2011, p. 327

Baseline condition

- Period immediately preceding task/trial when pupils have accommodated to light
- Baseline durations have ranged from short (400 ms) to long (5 s)
- “Pure” baseline unlikely, as PD varies with fixation even without any task instructions
- Baseline PD increases gradually for challenging tasks; randomize task difficulty levels
Methodological Decisions

1. Testing situation
2. Tasks and stimuli
3. Data collection
4. Data reduction
5. Analyses

Testing situation decisions

• Ambient, screen, and stimulus lighting
• Instructions, esp. re: inhibiting blinks
• Demonstration and practice items
• Self-paced vs examiner/machine administration
• Opportunity for breaks

Task and stimulus decisions

• Active or passive
• Unimodal or bimodal
• Number and complexity of task conditions
Data collection

- Eye-tracking system and sampling rate
- Calibration routine
- Size, luminance and loudness of stimuli
- ISIs and other temporal features

Data reduction decisions

- Define, identify and deal with artifacts
  - Missing and/or extreme values
  - Interpolate or discard
- Define measures of interest
  - One pupil or two
  - Raw or smoothed pupil values
  - Adjusted or unadjusted for each participant’s dynamic range of PD values

Analyses

- Align relevant stimulus events
- Average baseline pupil values and subtract from averaged values during the relevant task segments
- Statistical approaches and safeguards
What’s next for TEPR

• PD interfaced with ERP^{21}
• PD interfaced with fMRI^{22}
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REFERENCES


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