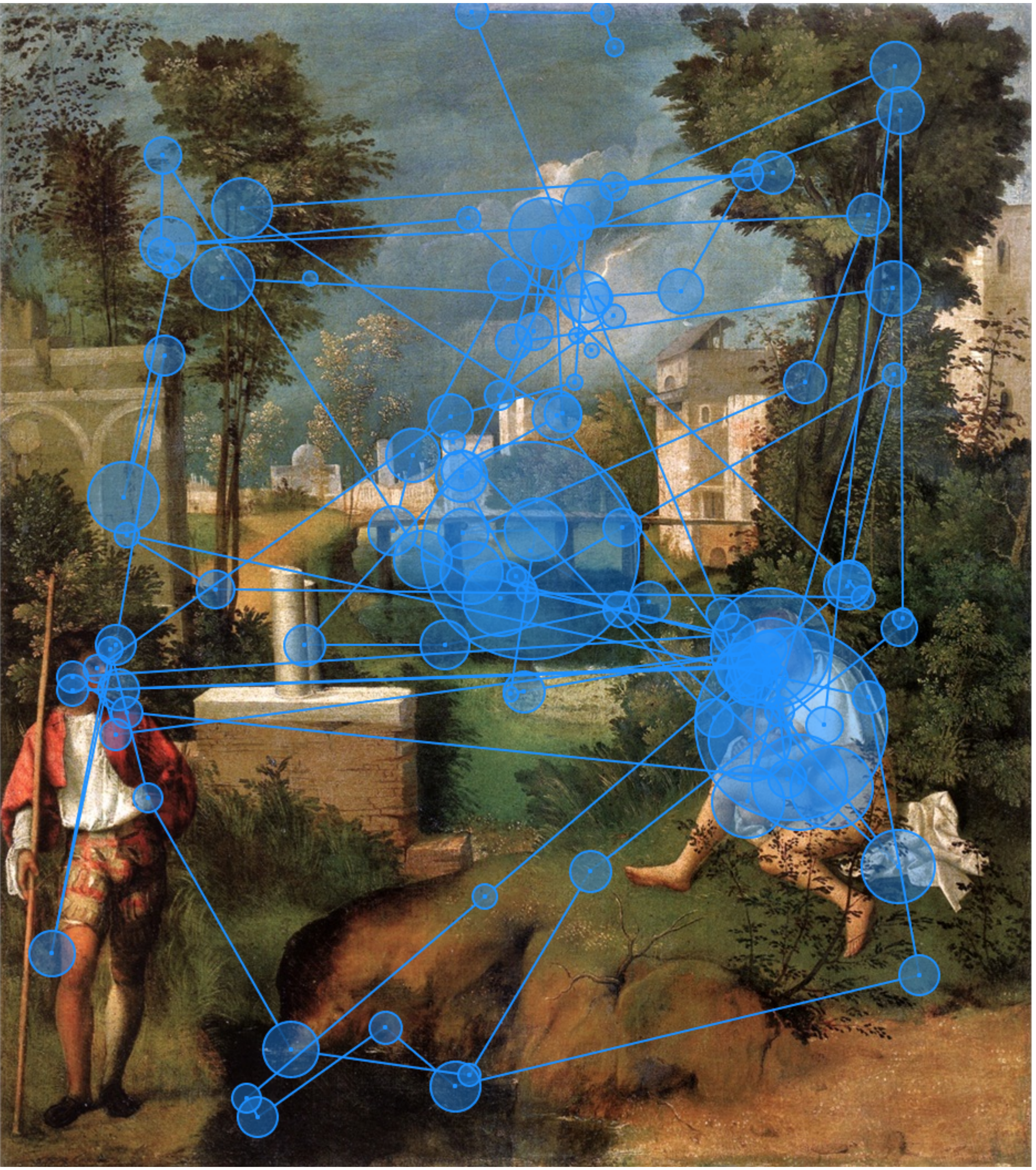
THE ROLE OF ATTENTION AND PERCEPTION DURING MULTIMEDIA LEARNING. A DYNAMICAL PERSPECTIVE

Krzysztof Krejtz

OUTLINE

- Visual information processing: two-stages models and their neuropsychological roots
- Two stages of attention reflected in eye movement characteristics
- Dynamics of attention fluctuations - a novel coefficient of ambient-focal eye movements patterns
- The role of focal information processing in multimedia learning
- Guiding attention location and its dynamics in multimedia learning environments
- Towards a novel, theoretical model of attention dynamics



VISUAL INFORMATION PROCESSING

- Visual exploration from eye movements perspective is a consecutive sequence of fixations and saccades
  - Fixations
    - stabilise image on retina
    - low spatial disparity
  - Saccades
    - moves eye towards a new location
    - high speed and amplitude

VISUAL INFORMATION PROCESSING DURING FIXATIONS

- eye-mind assumption (Just & Carpenter 1980)
  - viewers retain fixation on a certain object as long as it is processed
  - fixation duration is diagnostic for cognitive processing time (e.g., Rayner 1998)
- immediacy-of-processing assumption (e.g., Rayner 1977, 1998)
  - viewers interpret visual objects as they are encountered
- cognitive-lag assumption (Rayner 1977, 1978)
  - cognitive processing of previously fixated object may still occur while the eyes already have moved
    - during saccade execution no new visual information is acquired (*saccadic inhibition*)

TWO PATTERNS OF VISUAL PROCESSING

- Buswell (1935) distinguished two patterns of eye movements being an "unconscious adjustments to the demands of attention during a visual experience"
  - First "… consists of a series of relatively short pauses [fixations] over the main portions of the picture"
  - Second "… in which series of pauses, usually longer in duration, are concentrated over a small area of the picture"

DICHOTOMOUS MODELS OF VISUAL PROCESSING

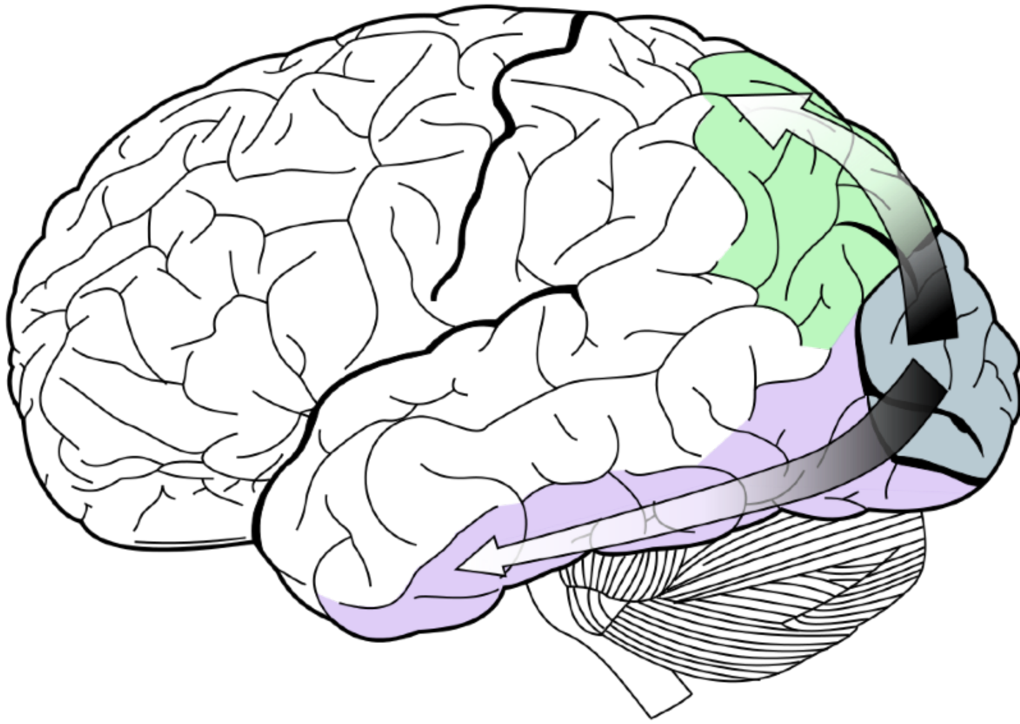
- Dichotomous models of visual information processing dominated the literature: orienting vs. scrutiny (Karpov, Luria & Yarbus 1968), orientation vs. evaluation (Ingle 1967), where vs. what (Schneider 1967)
- The models often relate to
  - pre-attentive processing: spatially parallel, computation of simple visual features, none or nearly none attentional costs
  - attentive processing: spatially serial, computation of complex visual representations (involving combinations of features), requires allocation of resources to specific locations or objects (e.g., Treisman & Gelade 1980)

NEUROPHYSIOLOGICAL ROOTS OF TWO-MODES OF VISUAL PROCESSING

- "anatomically distinct brain mechanisms" (ambient and focal) that serve parallel functions (Trevarthen 1968 in *Psychologische Forschung*)
- **subcortical DORSAL pathway (ambient)**
  - sends visual information to the posterior parietal cortex
  - processing mainly peripheral signals, low resolution, rapid
  - main functions: localisation, spatial orientation, recognition (Kveraga et al. 2007), attention shifting (Brown 2009)
  - related to covert attention - a mechanism for quickly scanning the visual field (Posner 1980)
- **cortical VENTRAL pathway (focal)**
  - sends information from the occipital lobes to the inferotemporal regions
  - processing mainly foveal signals, high resolution, relatively slow
  - main functions: visual identification, attentive processing (Bullier 2001, 2006)
  - related to overt attention - an act of selectively attending to an object (Posner 1980)

DORSAL PATHWAY

Spatial orientation



Visual identification

VENTRAL PATHWAY

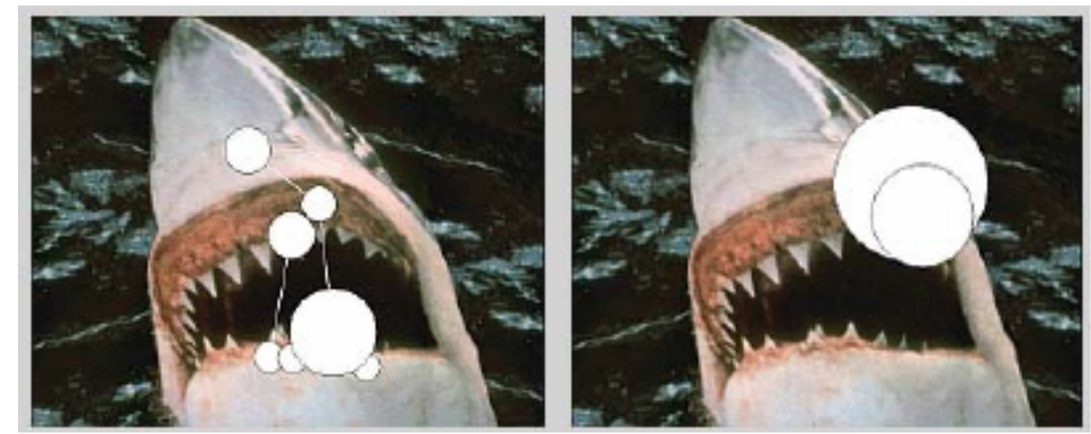
Image source: https://en.wikipedia.org/wiki/Two-streams_hypothesis#/media/File:Ventral-dorsal_streams.svg

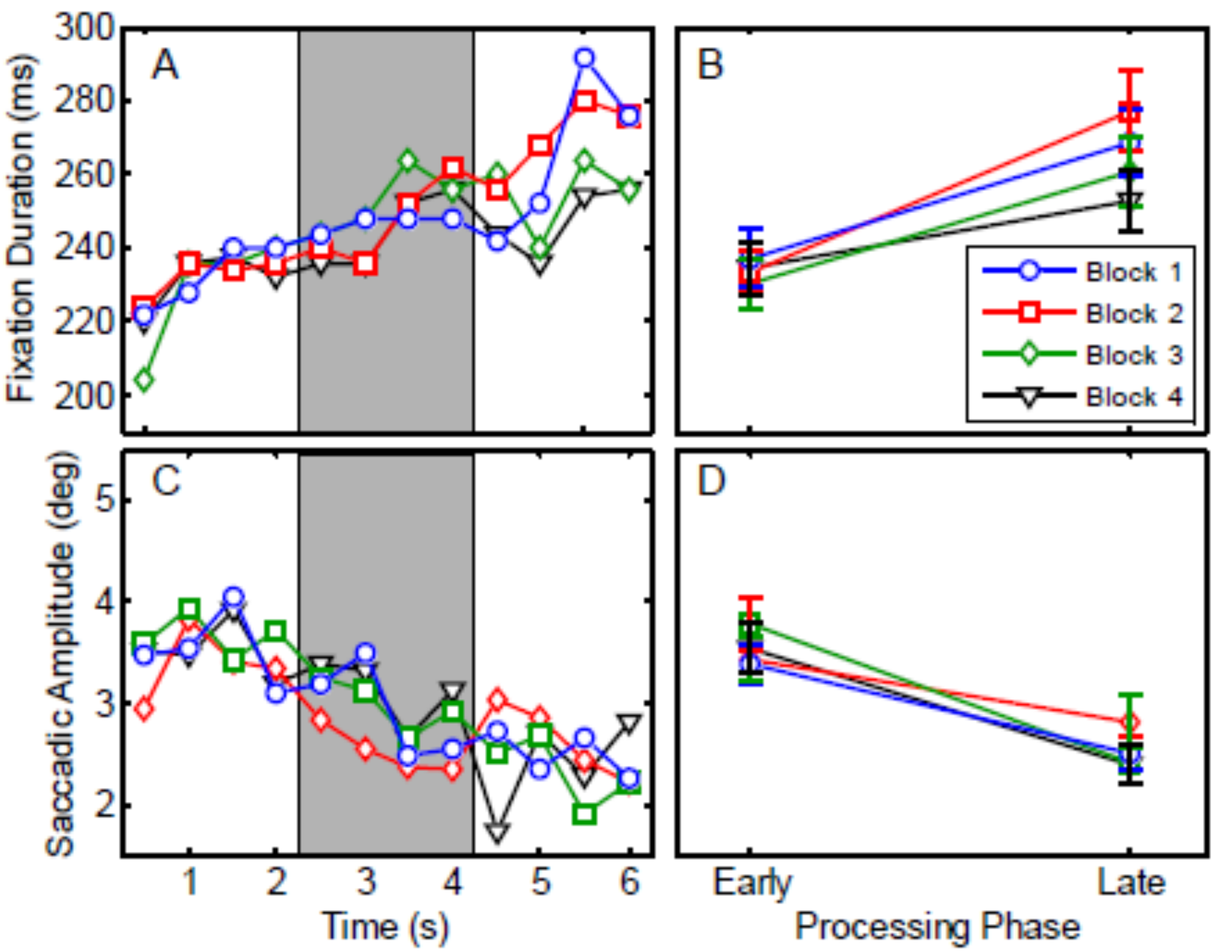
AMBIENT—FOCAL PROCESSING IN RELATION TO EYE MOVEMENS

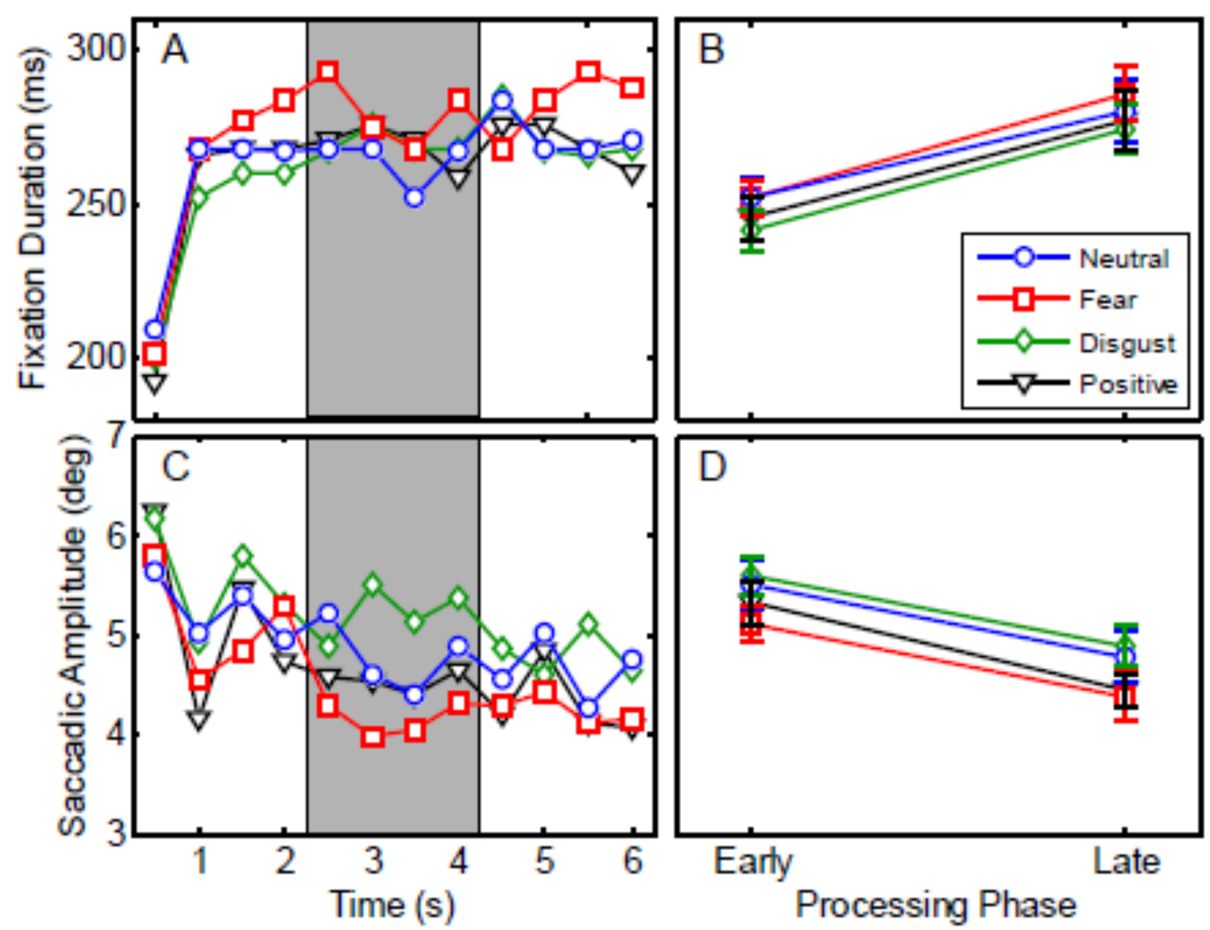
- **Attentional model of eye-movements control** (Henderson 1992, 1993)
  - Saccades are programmed on the basis of a weighted pre-attentive map of potential targets
  - Attention is allocated to the foveal information at the beginning of the fixation and when sufficient information is extracted, a reallocation of attention commends a new saccade execution
- Relationship between ambient—focal processing and eye movements characteristics (fixation duration and saccade amplitude) was demonstrated (e.g., Velichkovsky, Dornhoefer, Pannasch, & Unema 2000; Velichkovsky, Rothert, Kopf, Dornhoefer, & Joos 2002)
  - **ambient visual information processing**:
    - short fixations and long consecutive saccades
  - **focal visual information processing**:
    - long fixations and short consecutive saccades

AMBIENT - FOCAL EYE MOVEMENTS

FIXATION DURATION AND SACCADE AMPLITUDE AT EARLY AND LATE STAGE OF INFORMATION PROCESSING



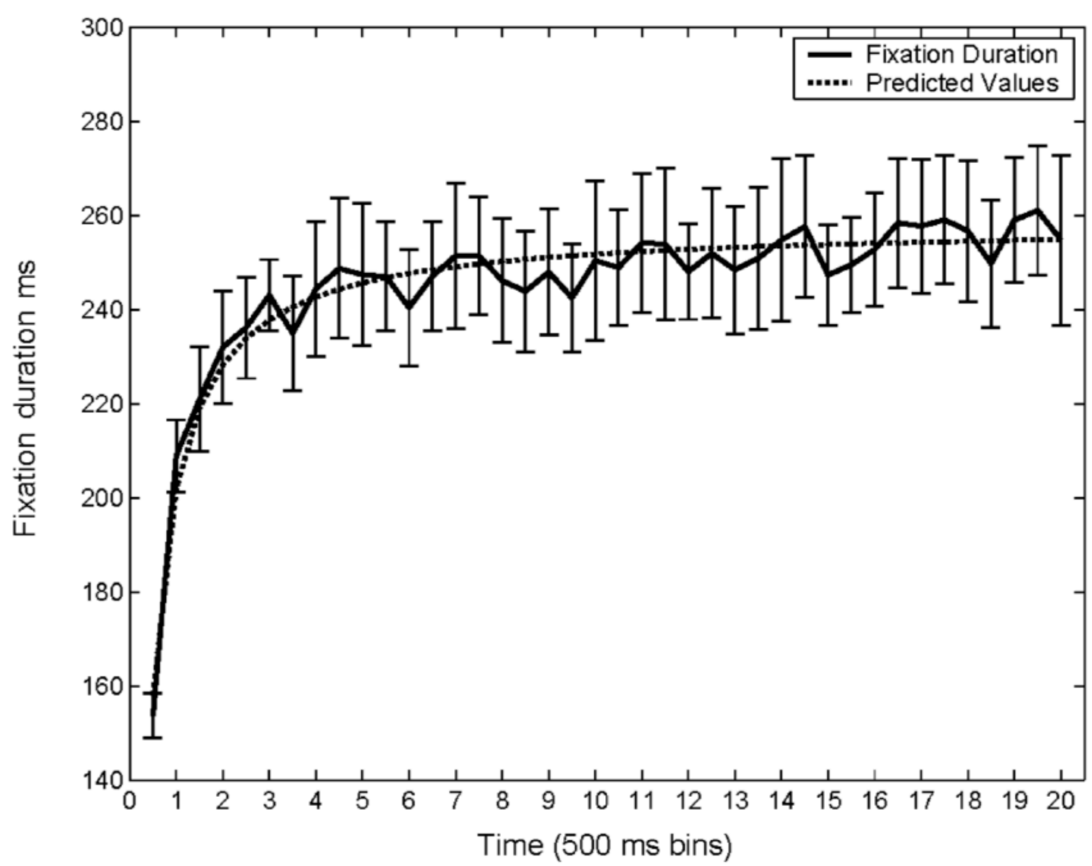


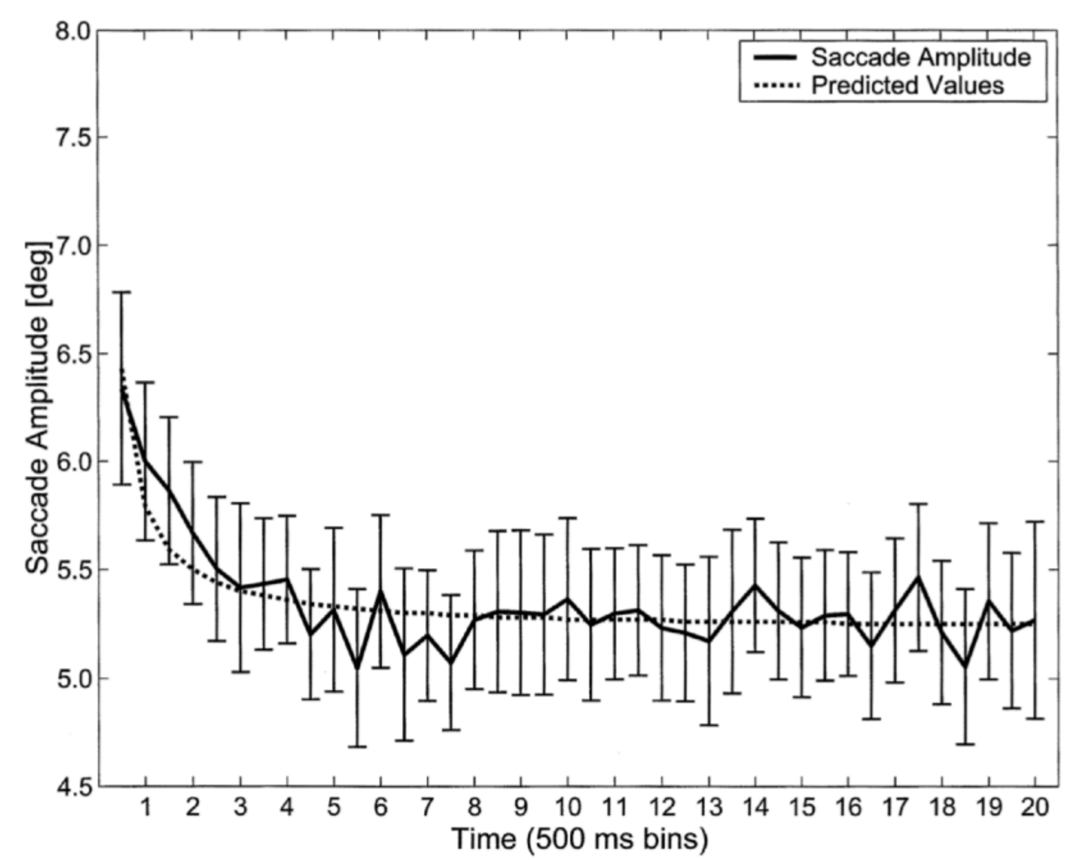


Images from: Velichkovsky et al. 2005

DYNAMICS OF FIXATION DURATION AND SACCADE AMPLITUDE

- Fixation duration gradually increases over time while at the same time saccadic amplitude decreased (Antes 1974)
- Increase of fixation duration and decrease of saccade amplitude in a visual search task should be considered as a strategic adaptation to the demands of the task (Scinto, Pillalamarri & Karsh 1986)





Images from: Unema, Panasch, Joos & Velichkovsky 2005

INTERPLAY OF AMBIENT AND FOCAL INFORMATION PROCESSING

- Neither dorsal nor ventral systems fully controls attentional processes in isolation at any stage (see Vossel, Geng & Fink 2015, Shomstein & Behrmann 2010)
  - Neuroanatomical studies established numerous connections between dorsal and ventral pathways (Cloutman 2013, Grafton 2010)
  - Flexible control between both systems enables the dynamic control of attention reflecting mutual influence of bottom-up and top-down processes
- Presumably increased functional interactions between two streams are needed as the task requires more complex visual processing (van Polanena & Davare 2015)
- Since visual processing of complex stimuli is a continuous interplay between ambient and focal processing, it should be conceptualised on a single continuous scale (Krejtz at al. 2012, 2016)

AMBIENT – FOCAL COEFFICIENT

$$\mathcal{K}_i = \frac{d_i - \mu_d}{\sigma_d} - \frac{a_{i+1} - \mu_a}{\sigma_a} \quad \text{such that} \quad \mathcal{K} = \frac{1}{n}\sum_n \mathcal{K}_i$$

$\boldsymbol{d_i}$ denotes i^{th} fixation duration; μ_d denotes average fixation duration; σ_d denotes fixations standard deviation

$\boldsymbol{a_i}$ denotes i^{th} saccade amplitude; μ_a denotes average saccade amplitude; σ_d denotes saccade amplitude standard deviation

- $\mathcal{K} > 0$ suggests **focal** viewing
- $\mathcal{K} < 0$ suggests **ambient** viewing

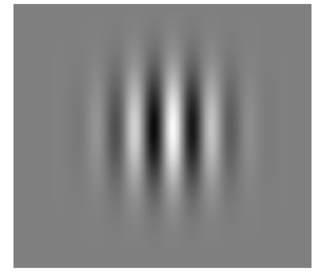
Krejtz et al. 2016

SEQUENTIAL (FOCAL) VS PARALLEL (AMBIENT) VISUAL SEARCH

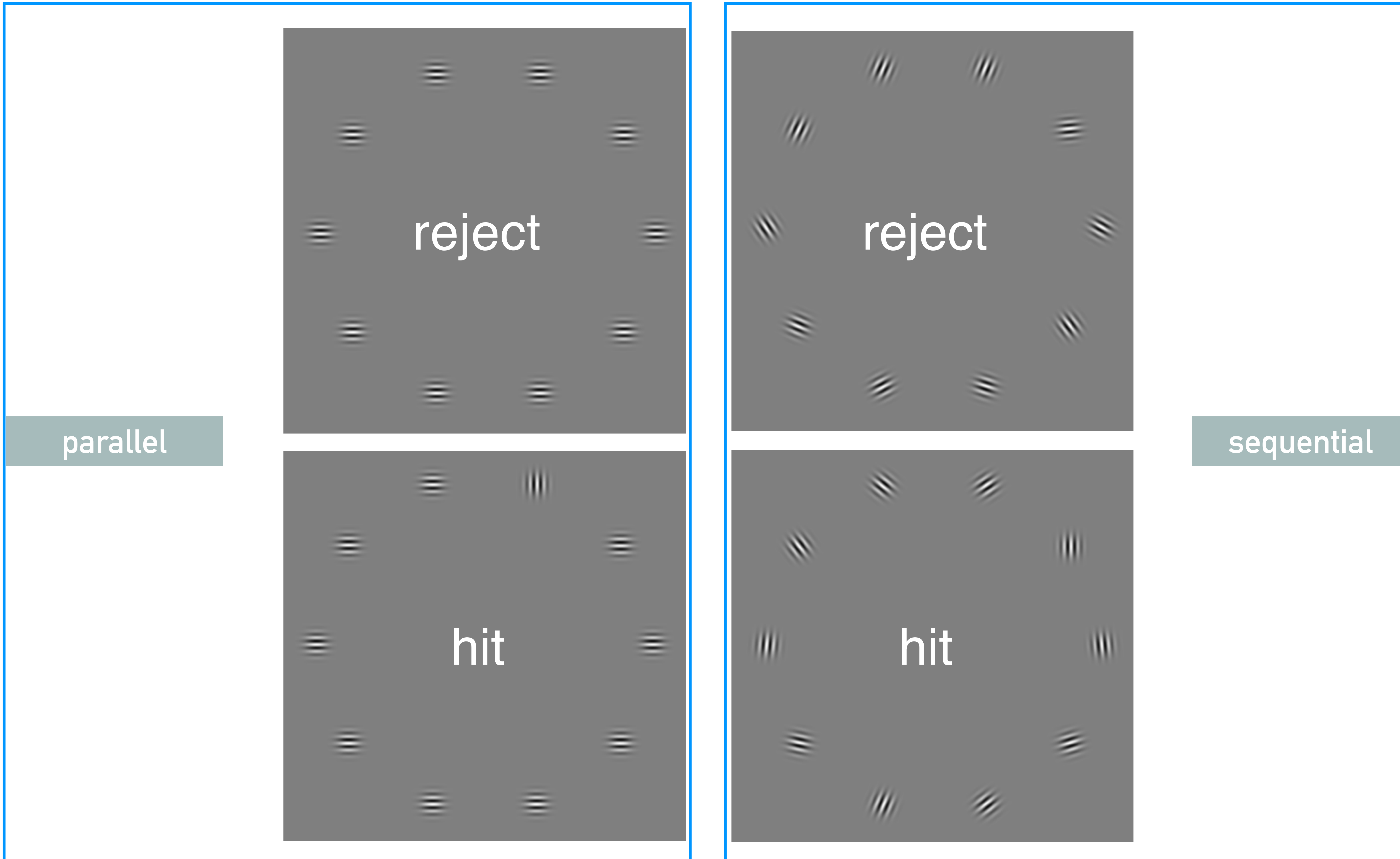
- **Assumption:** Ambient processing are related to parallel search and focal processing to sequential search (e.g., Nothdurft 1999)
- **Hypothesis**:
  - Sequential Visual Search Task (VST) will evoke focal eye movements while parallel VST will evoke ambient eye movements.
- **Design:**
  - within-subjects 2 (task: sequential vs. parrallel) x 2 (target: hit vs. reject) factorial design
- **Sample**:
  - *N* = 27 (male and female, 19-40 y.o.)
- **Equipment**:
  - Gaze Point 3 eye tracker (60 Hz), 17'' laptop screen

Krejtz et al. 2016

EXPERIMENTAL TASK

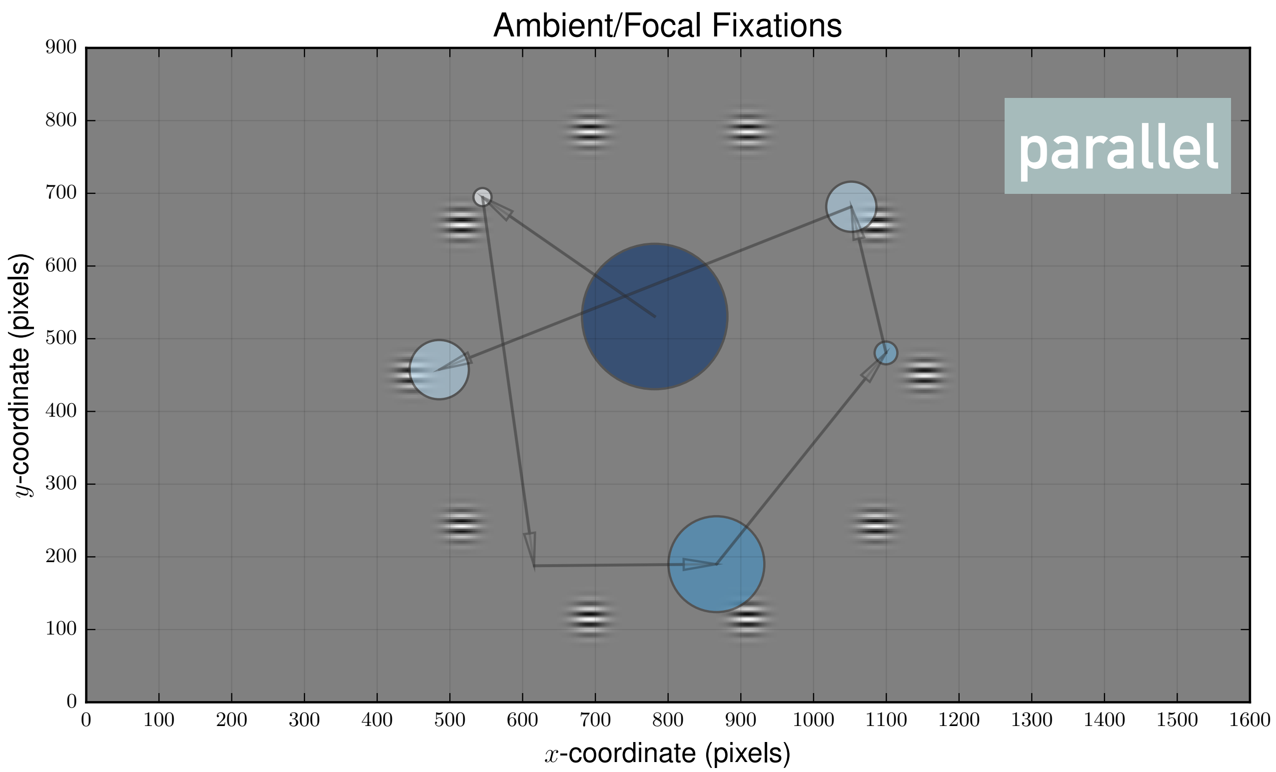


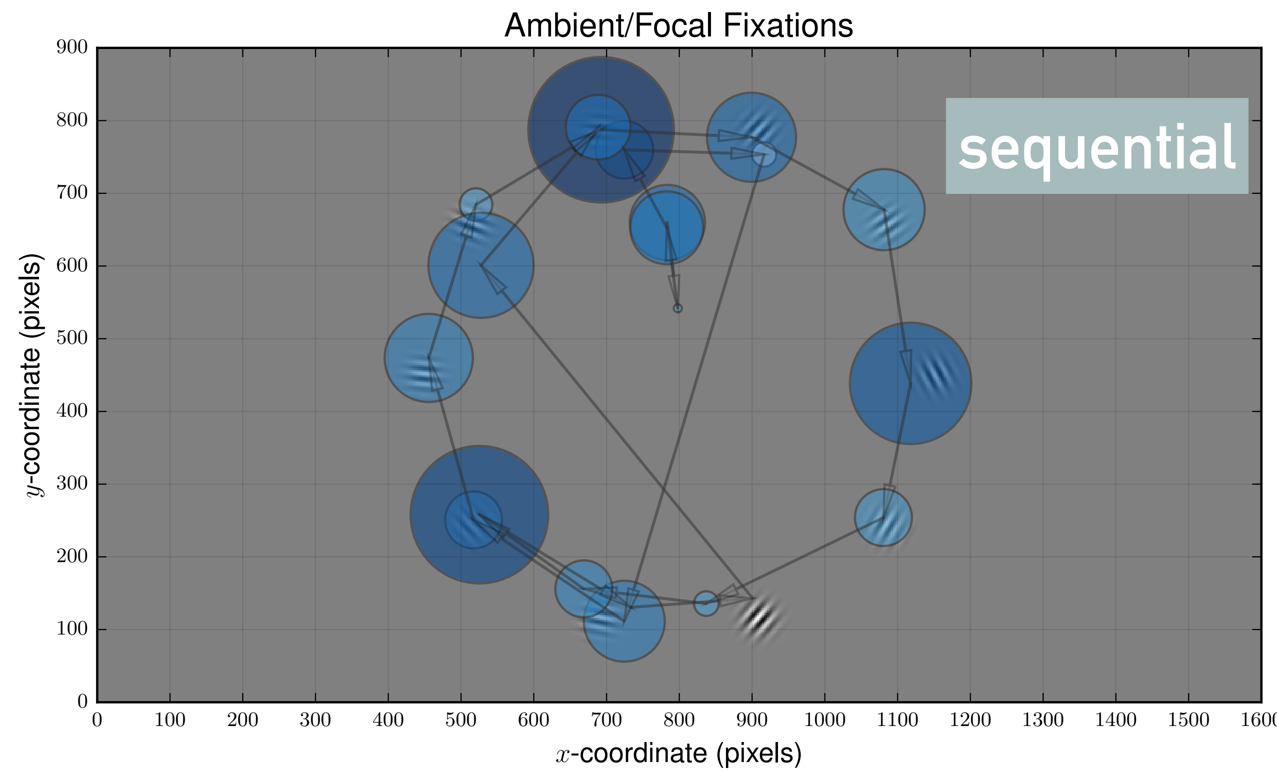
Find the target

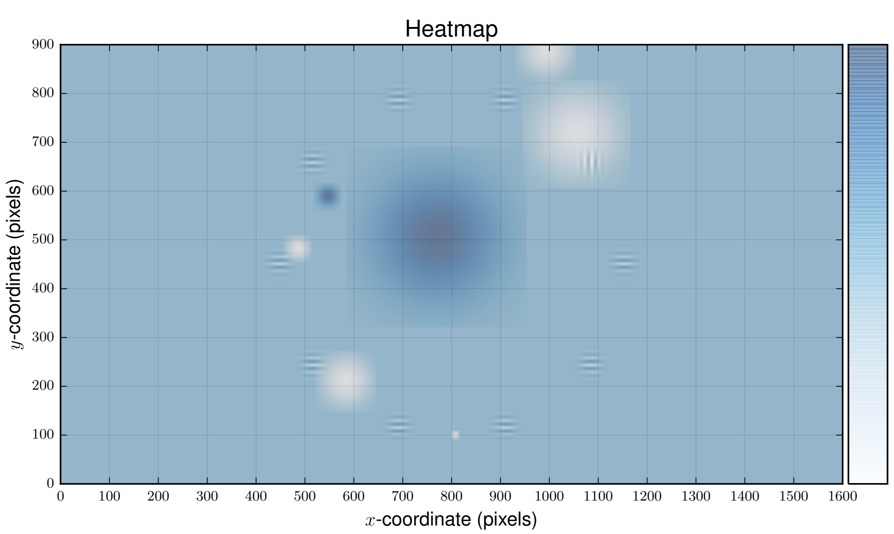


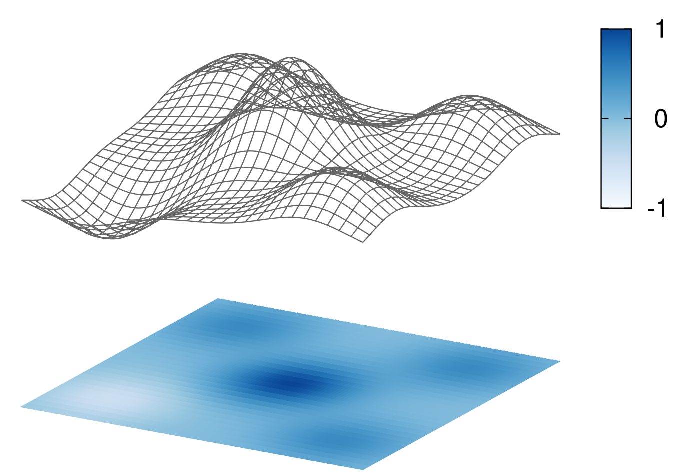
EXEMPLARY EYE MOVEMENTS VISUALISATIONS

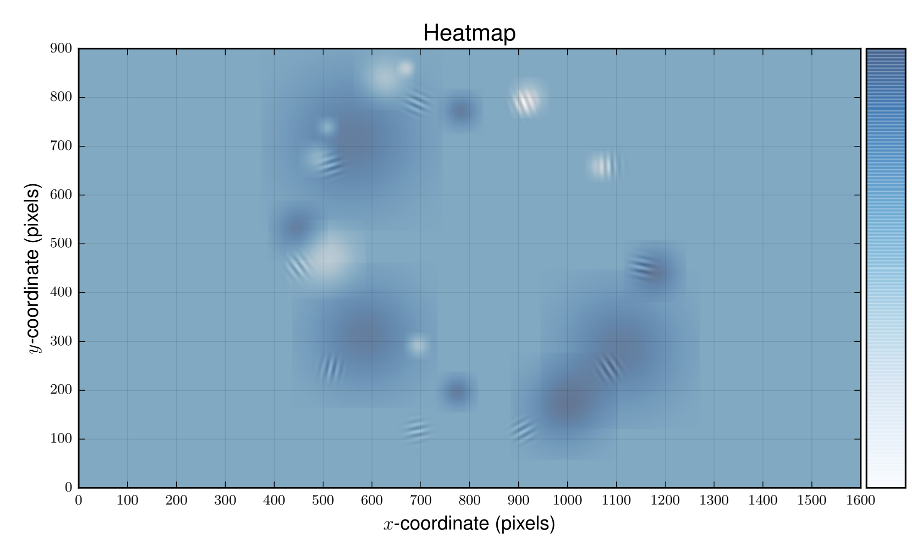
Krejtz et al., 2016





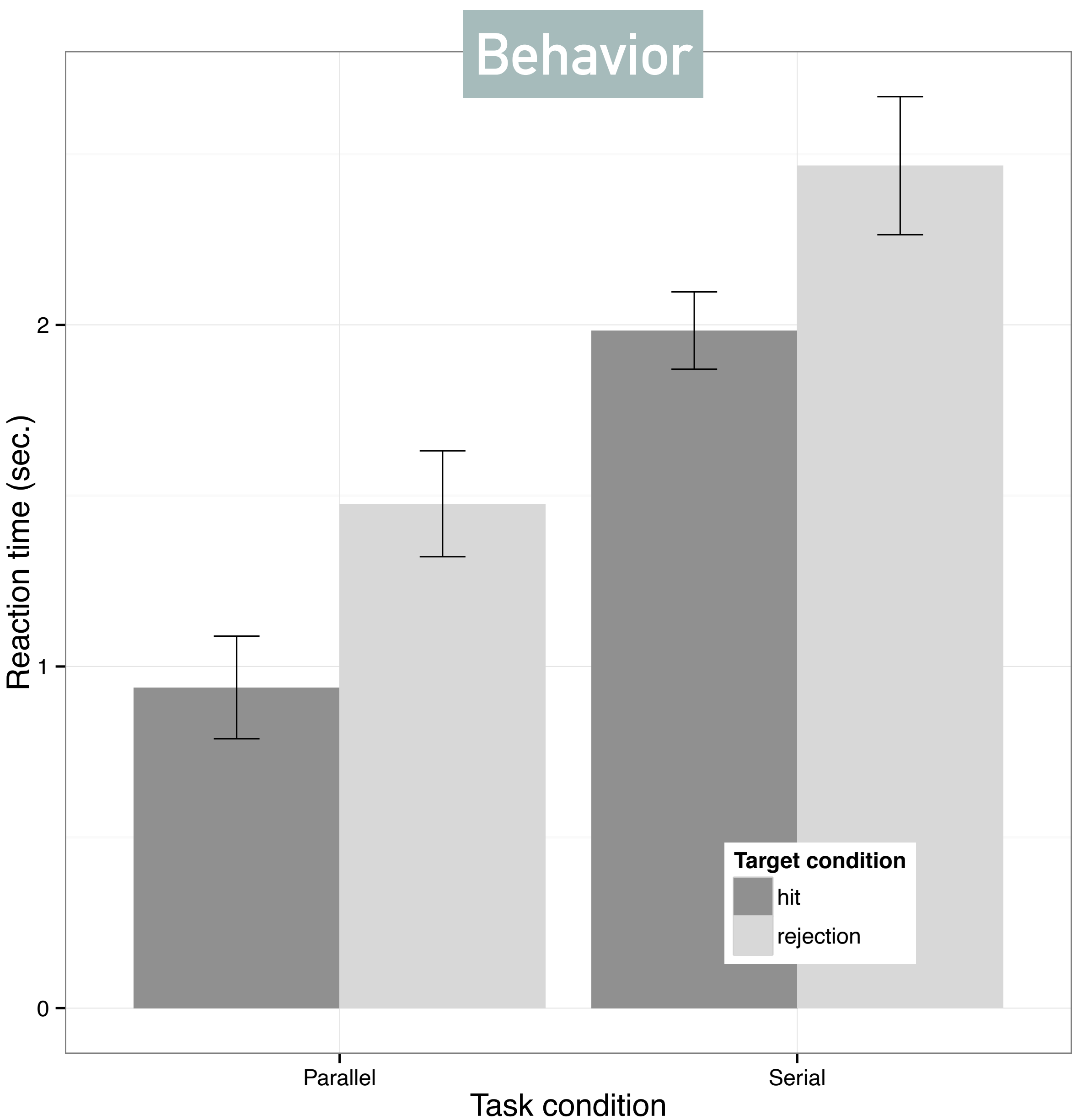


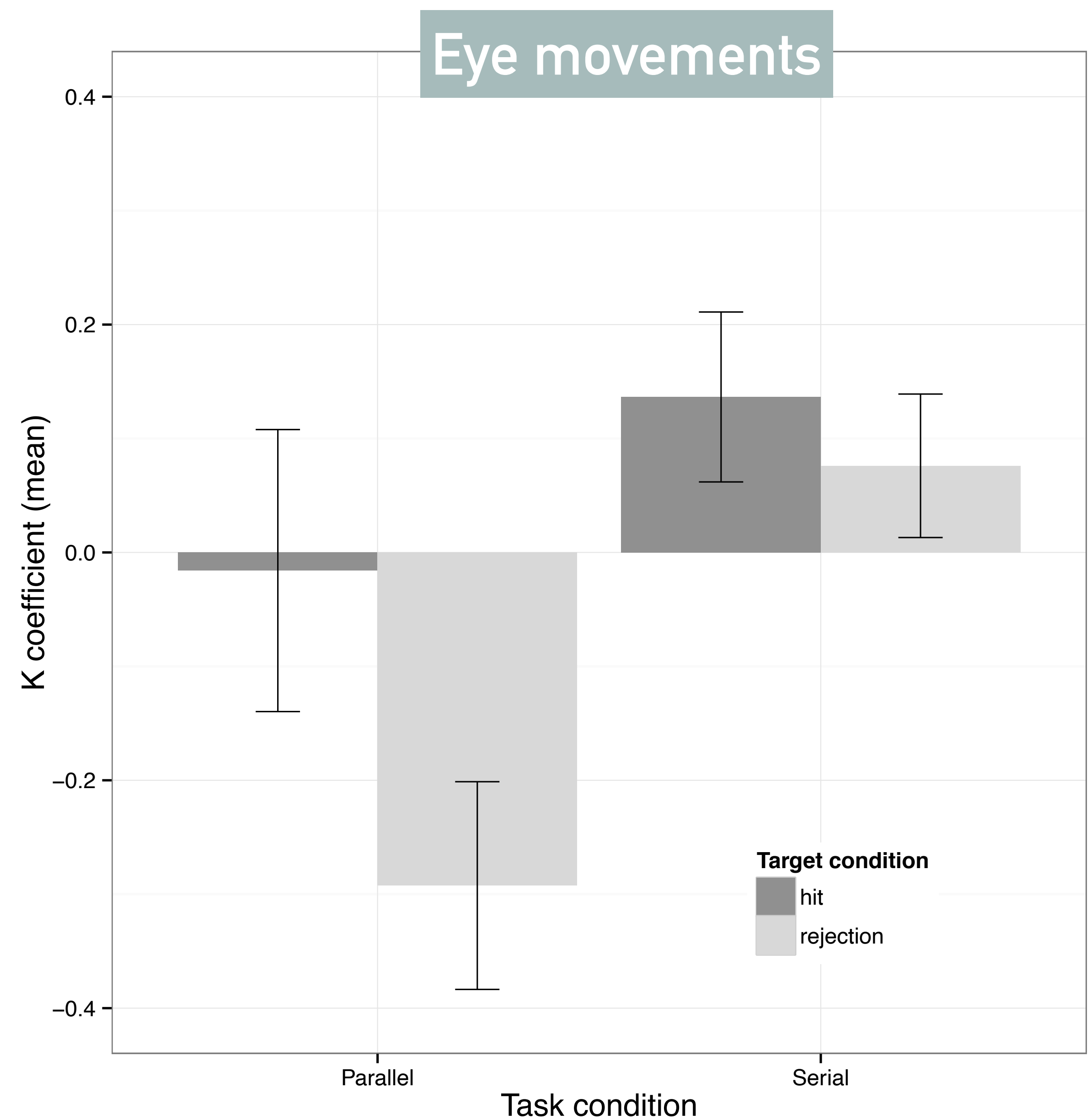




Duchowski & Krejtz, 2016

FASTER RT AND MORE AMBIENT EYE MOVEMENT DURING PARALLEL VISUAL SEARCH

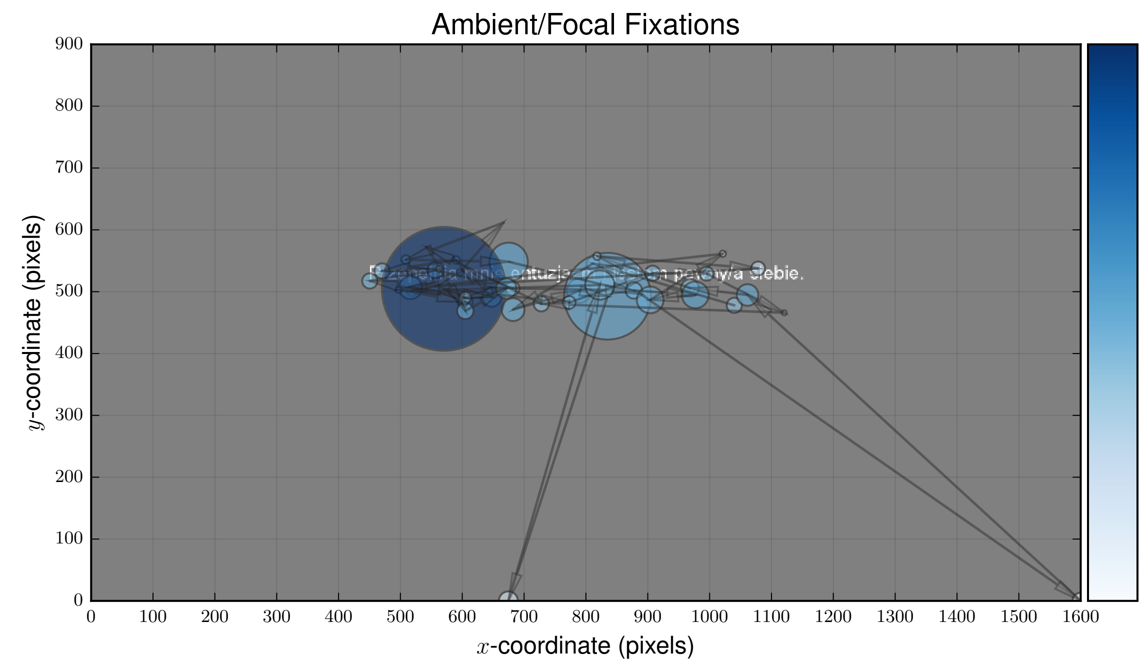


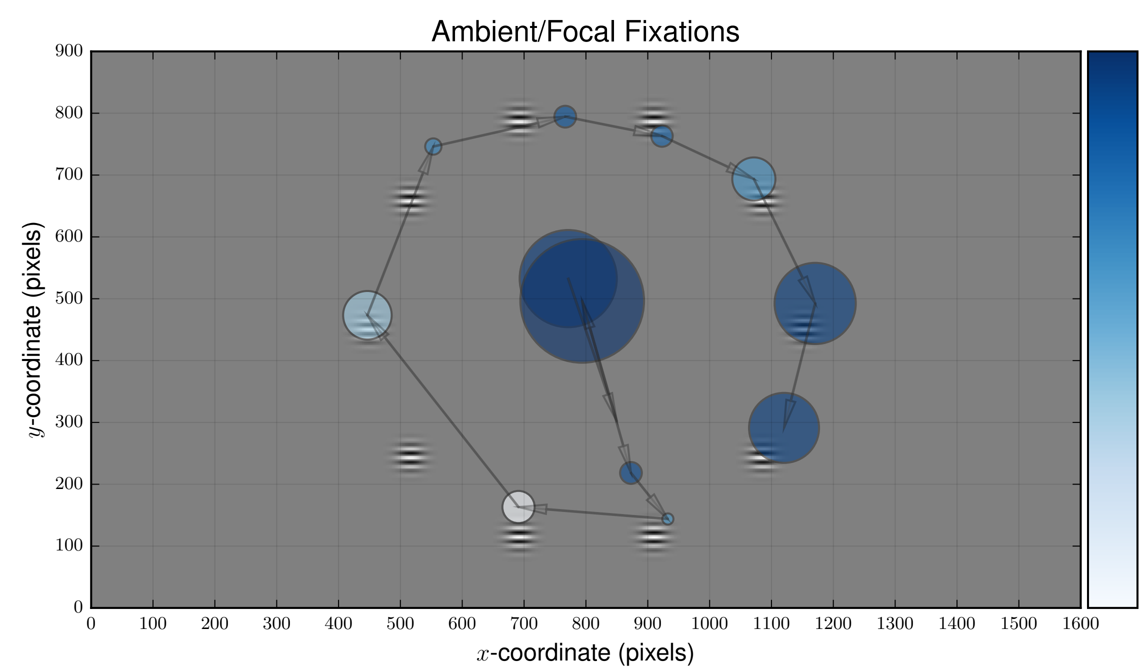


Krejtz et al., 2016

SEQUENTIAL (FOCAL) VS PARALLEL (AMBIENT) VISUAL SEARCH AFTER MOOD INDUCTION

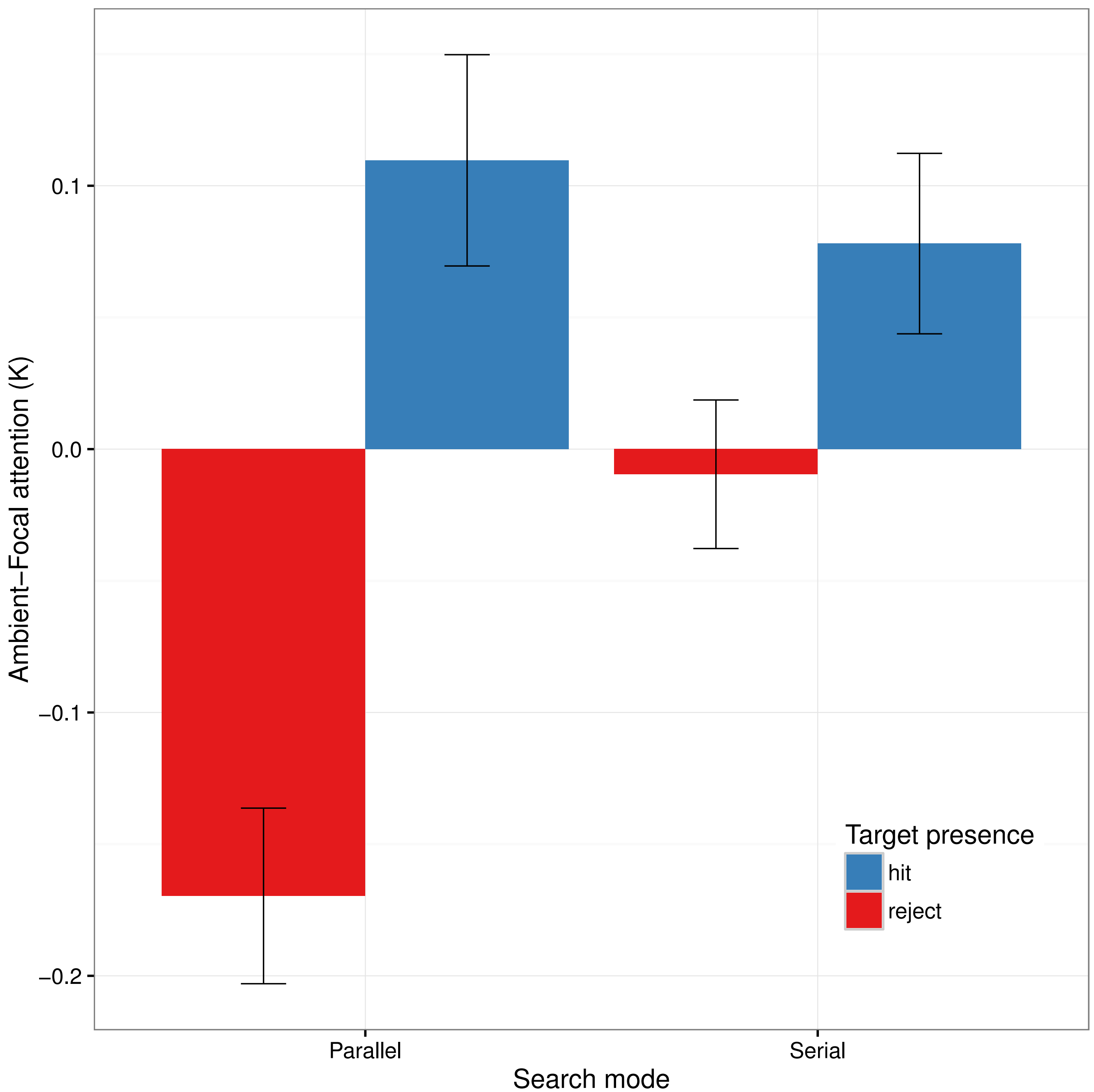
- **Hypothesis**:
  - Positive affect broadens visual field resulting in better recognition of stimuli presented in peripheral regions - fostering ambient mode
- **Sample**:
  - *N* = 81 (21 males and 60 female, 20 - 41 y.o.)
- **Equipment**:
  - Gaze Point 3 eye tracker (60 Hz), 17'' laptop screen
- **Procedure**:
  - Positive, negative or neutral mood induction (based on Velten 1968)
  - Visual Search Task (based on Nothdurf 1998 and Krejtz et al.2016)





Krejtz et al. (in preparation)

AMBIENT - FOCAL EYE MOVEMENTS



- Replication of Krejtz et al. (2016) behavioural and ambient - focal coefficient effects
- Contrary to predictions mood did not moderated ambient - focal eye movements patterns during simple visual search task
- Presumably need for more complex information processing task or stimuli

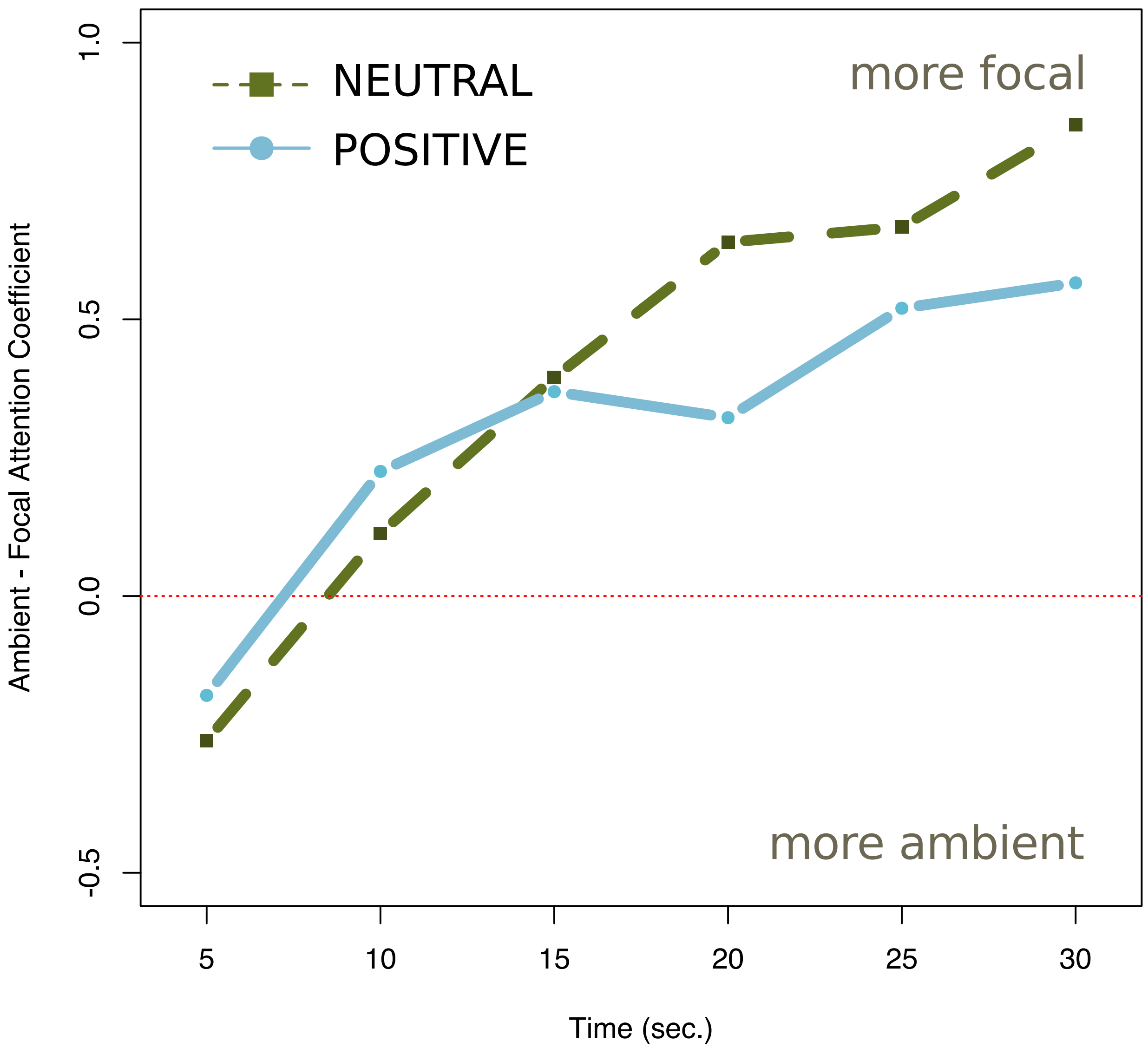
Krejtz et al. (in preparation)

AFFECT AND COMPLEX VISUAL EXPLORATION DYNAMICS

- **Hypothesis:**
  - during prolonged visual exploration of complex stimuli positive mood fosters more ambient visual information processing
- **Design:**
  - mixed 2 (mood) x 2 (art period)
- **Sample:**
  - *N* = 49 (18 female & 31 male)
- **Procedure:**
  - Positive or neutral mood induction procedure (based on Velten 1968)
  - Learning task of 6 art pieces from Impressionism and Bauhaus periods
- **Equipment:**
  - SMI RED 250Hz eye tracker

Krejtz et al. 2014

COMPLEX VISUAL EXPLORATION MODERATED BY MOOD

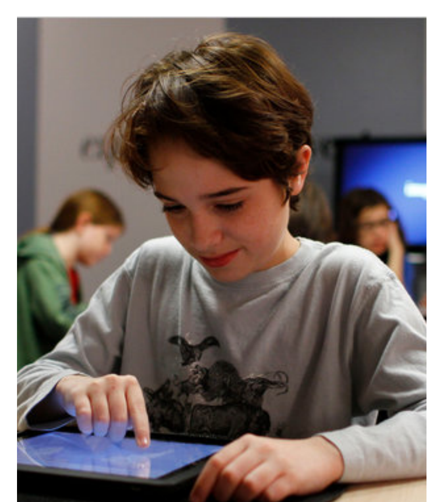


- Emotions may moderate the dynamics of visual exploration of **complex images during learning**
- Positive affect facilitates less focal scanning of complex visual stimuli comparing to control group
- Need for replication and negative mood effects test

Krejtz et al. (2014)

MULTIMEDIA LEARNING MATERIALS

- Multimedia learning materials are increasingly popular as teaching aids
- They incline high level of tasks and stimuli complexity
  - by definition engage at least two modalities audio and visual (Paivio 1986)
  - often with embed interaction defined as two-way communication between learner and learning material (Markus 1990)



MULTIMEDIA LEARNING EFFECTS

- Multimedia materials may foster learning outcomes
  - temporal contiguity effect - simultaneous activation of two modes of information (verbal and visual) foster learning effects (Baggett 1984, Mayer & Anderson 1991, 1992, Mayer & Sims 1994)
  - multimedia effect - learning is improved if learning materials contains verbal and visual elements (Mayer 2001)
- **Dual coding theory** predicts that storage and retrieval of information in both non-verbal and verbal forms fosters learning and recognition (Paivio 1986; Sadoski & Paivio 2001; Sadoski & Paivio 2004)
- Visual and auditory modalities has to be activated simultaneously in working memory, which has limited resources (Sweller 1999, Baddeley 1992)

COGNITIVE THEORY OF MULTIMEDIA LEARNING (MAYER 2001, 2005)

- Effective learning requires students to (Mayer & Moreno 2003, Moreno 2005)
  - first, attend to and select relevant information for further processing
  - second, organise the information into a coherent mental model and integrate with a prior knowledge
- When multimedia instructions are particularly complex, a student may be unable to
  - establish links between two sources / modes of information sufficiently quickly (Kalyuga 2012)
  - select important information for further processing (Krejtz et al. 2012)

ATTENTION GUIDANCE DURING MULTIMEDIA LEARNING

- Effectiveness of attention guidance during learning has been demonstrated (e.g., Jeung, Chandler, & Sweller 1997)
  - cueing means: pedagogical agent, colour changing, step-by-step presentation or progressive path cueing (Craig, Gholson & Driscoll 2002; Tabbers, Martens & van Merriënboer 2004, Grant & Spivey 2003, Boucheix & Lowe 2010)
- There is still an open question how to guide attention when learning with animated materials e.g. education movies or games without overloading working memory (Krejtz et al. 2012) or jeopardising instructional material design
- Furthermore, attention guidance may not only help in selecting important information but also keep longer active focal attention what in turns should lead to deeper information processing (Krejtz et al. 2012)

ATTENTION CUEING WITH AUDIO DESCRIPTION

- We exploited Audio Description (AD) an additional audio learning channel as an technique of visual attention cueing
- Audio Description is defined as
  - an assistive technology for the Blind
  - an additional audio track gives scene narrative
  - similar to subtitles used for the Deaf
- Audio Description fosters understanding of visual content for Blind or sight impaired participants (Frazier & Coutinhoo-Johnson 1995, Peli, Fine & Labianca 1996, Schmeidler & Kirchner 2001)

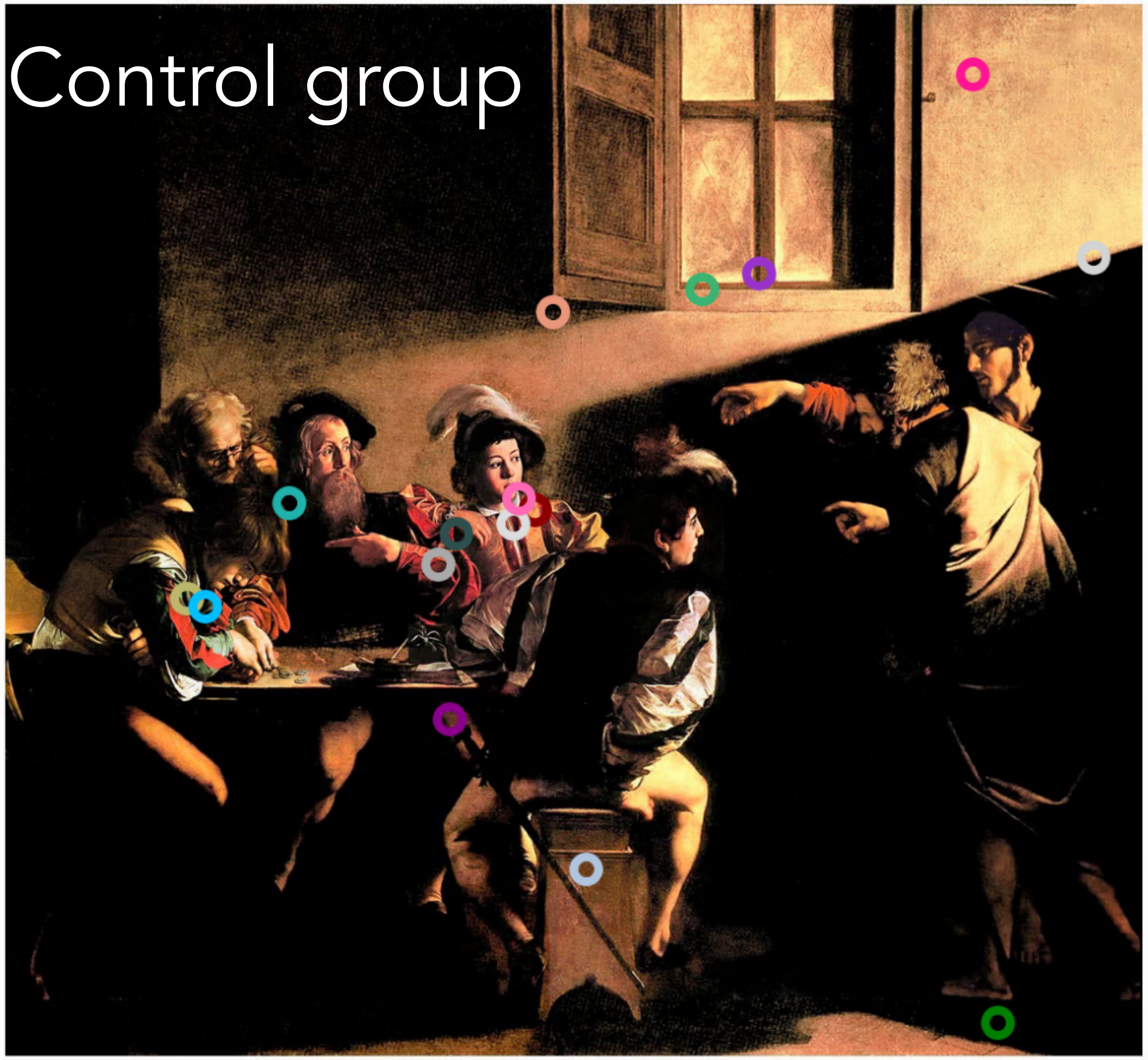
ATTENTION CUEING WITH AD DURING MULTIMEDIA LEARNING

- The aim of the experiment was to test effectiveness of AD as visual attention cues when learning complex visual material.
- **Hypotheses:**
  - AD effectively guides visual attention,
  - AD facilitate focal patterns of eye movement
  - AD fosters learning outcomes
- **Design:** between subjects design (AD vs. no AD)
- **Sample:** High school students (*N* = 60, male and female, 15-16 y.o.)
- **Procedure:**
  - learn 2 classical art paintings during 4.5 minutes presentation each
  - comprehension task: jigsaw puzzles
- **Equipment:** SMI RED (250 *Hz*) eye tracker

Krejtz et al. 2016

VISUAL ATTENTION GUIDANCE WITH AD CUES

120 seconds of stimuli presentation



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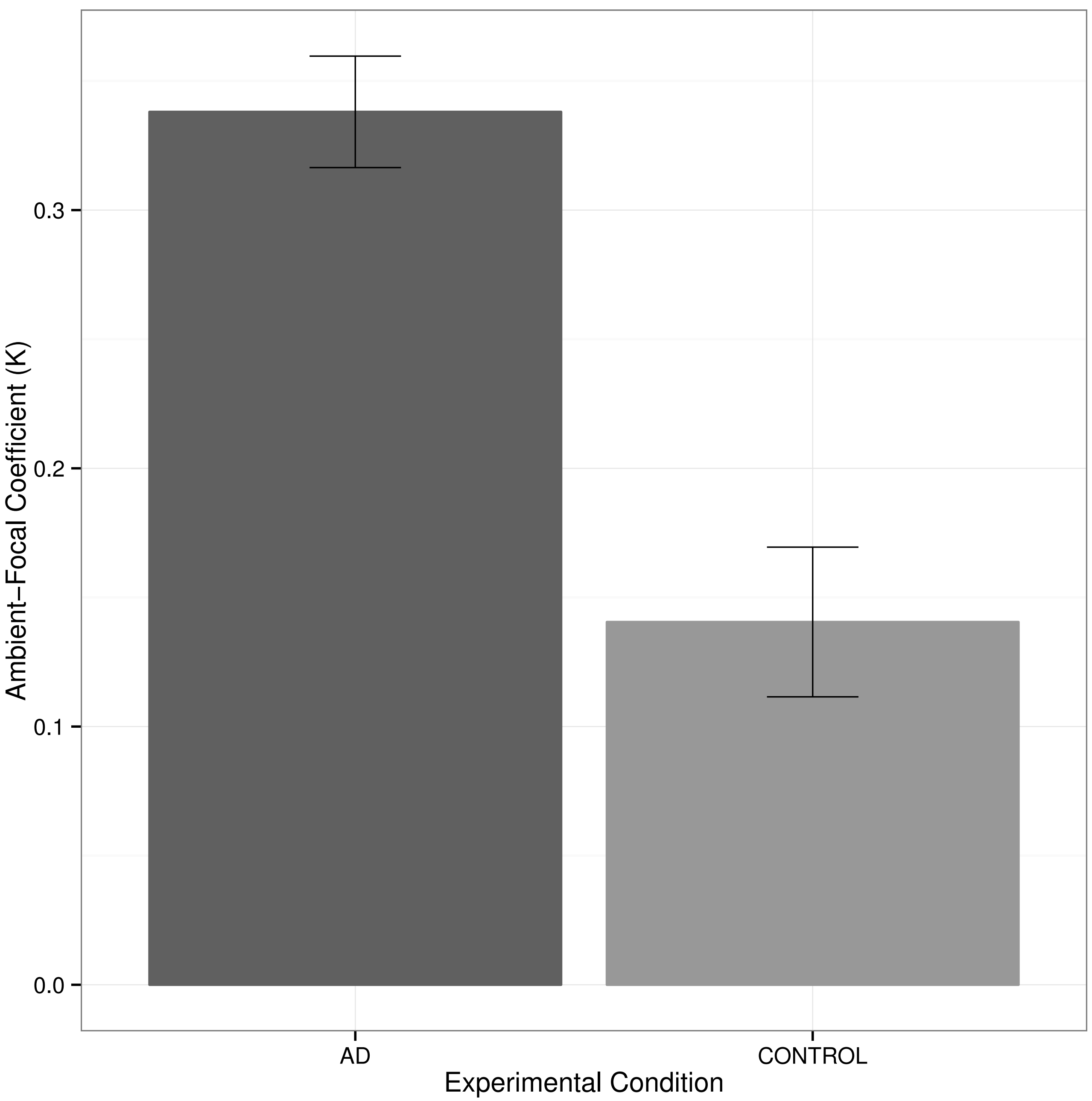
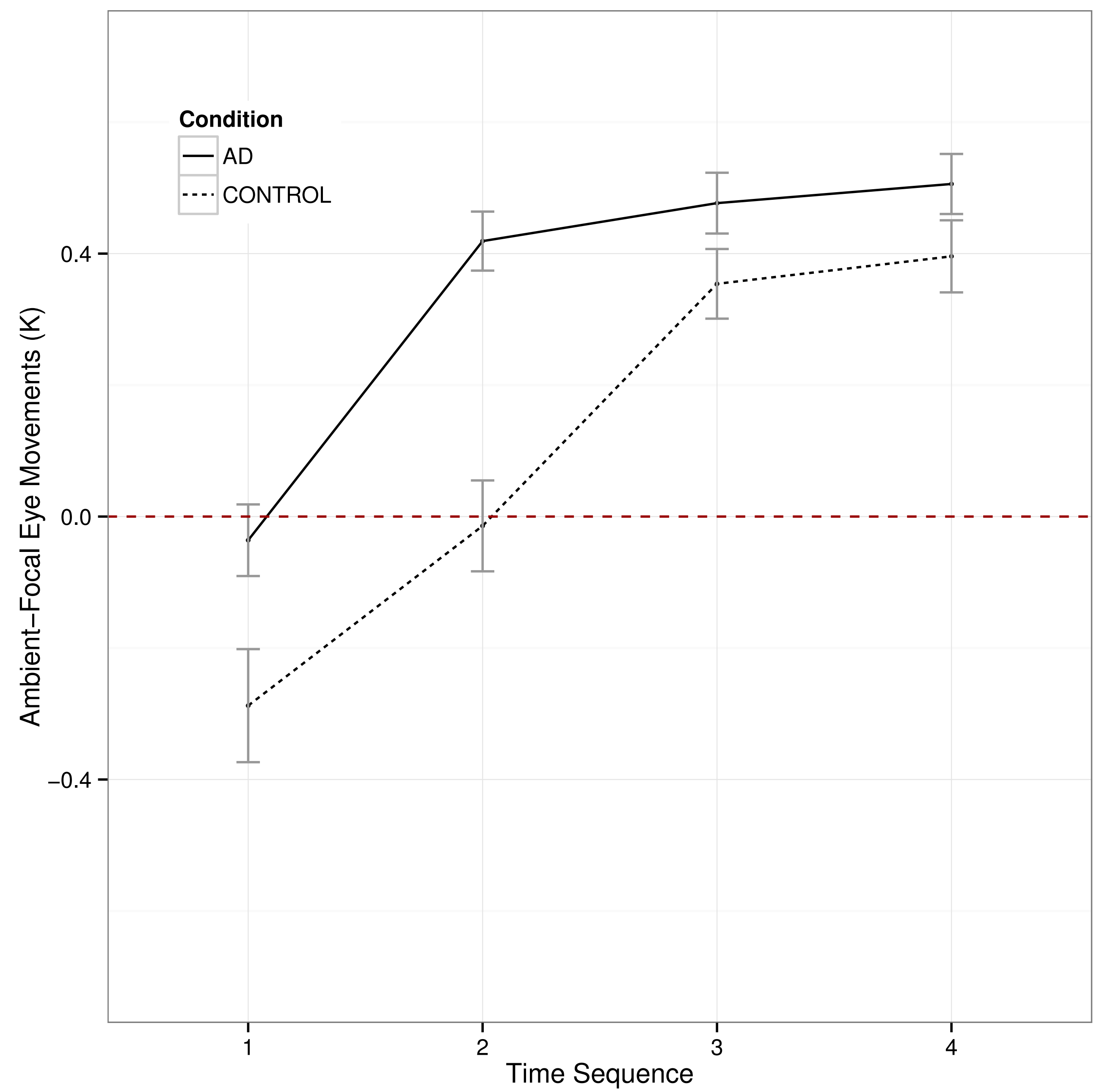
MORE FOCAL EYE MOVEMENTS PATTERNS WITH AD ATTENTION GUIDANCE





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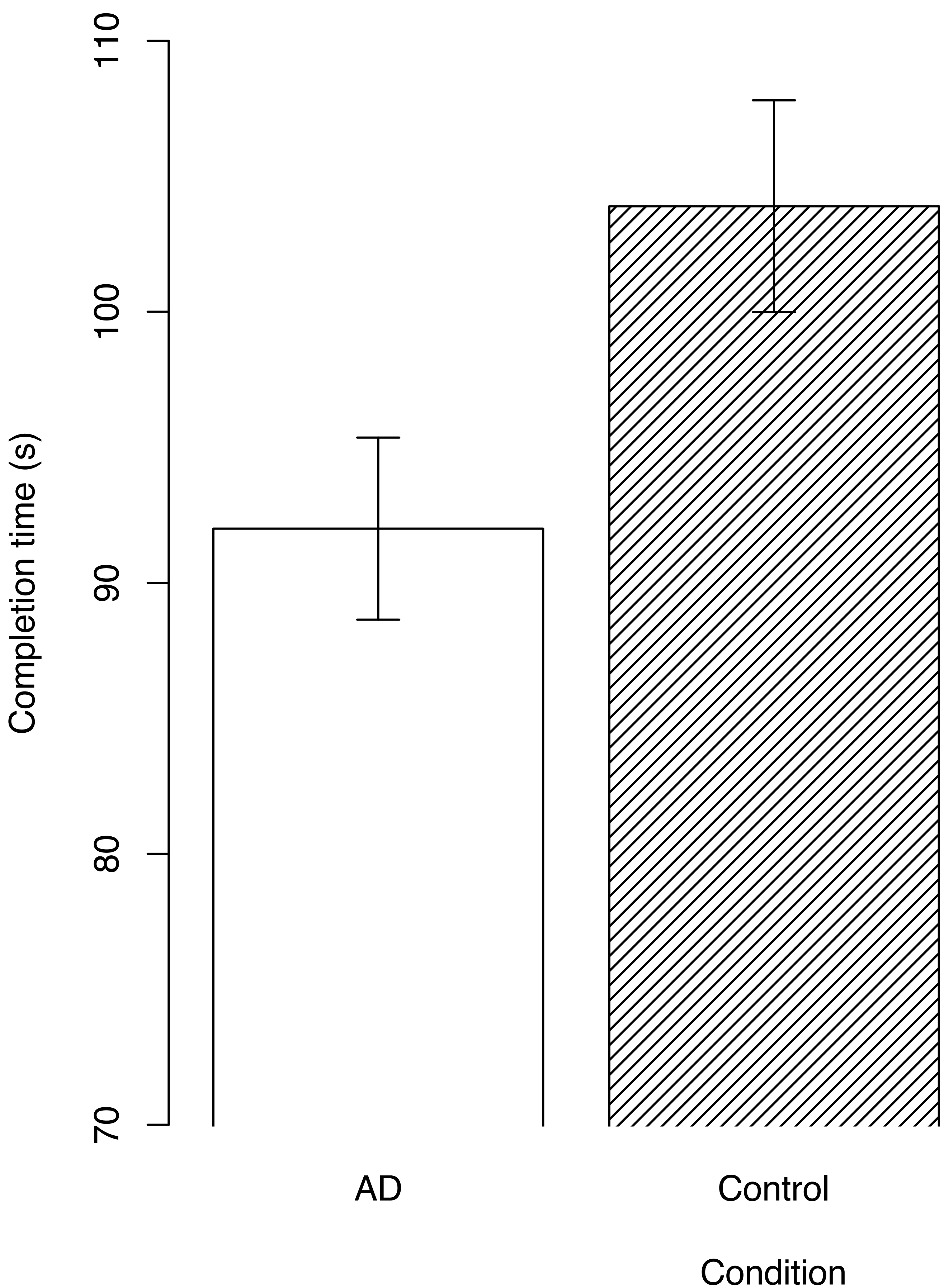


LEARNING EFFECTIVENESS

- No effects for jigsaw puzzle completion (ceiling effect)
- Faster jigsaw puzzle completion times after learning with Audio Description

Krejtz et al. 2016

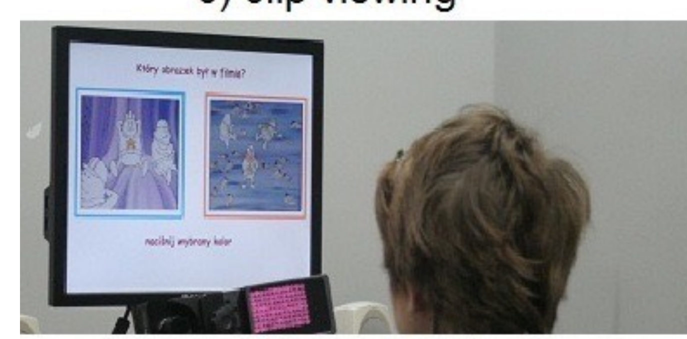
AD VISUAL ATTENTION CUEING WHEN LEARNING WITH EDUCATIONAL MOVIES

- **Hypotheses**
  - AD guides students’ visual attention towards important information when learning with movies
  - AD modifies students eye movement pattern facilitating more focal information processing
  - Children watching clips with AD will have higher comprehension scores than those watching clips without AD
- **Design:**
  - one factorial between-subjects design (with or without AD)
- **Sample:**
  - N = 44 kids, 7-9 y.o.
- **Procedure:**
  - 2 min. educational video clips watching
  - Recognition task
  - Structured interview
- **Equipment:**
  - SR Research Eye Link 1000 (500 *Hz*) eye tracker


a) dot placing


b) calibration - the shooting eyes


c) clip viewing

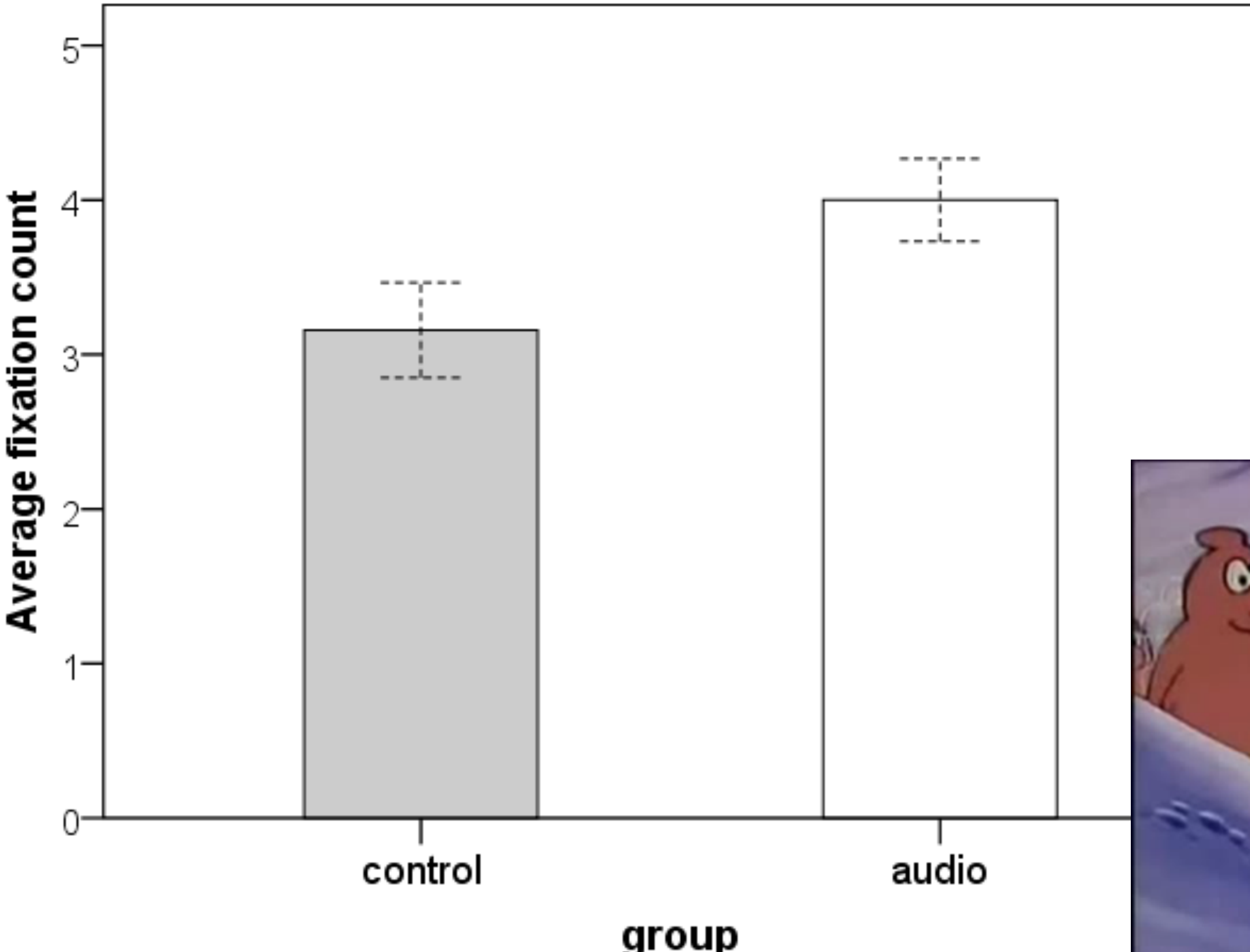

d) scene recognition test

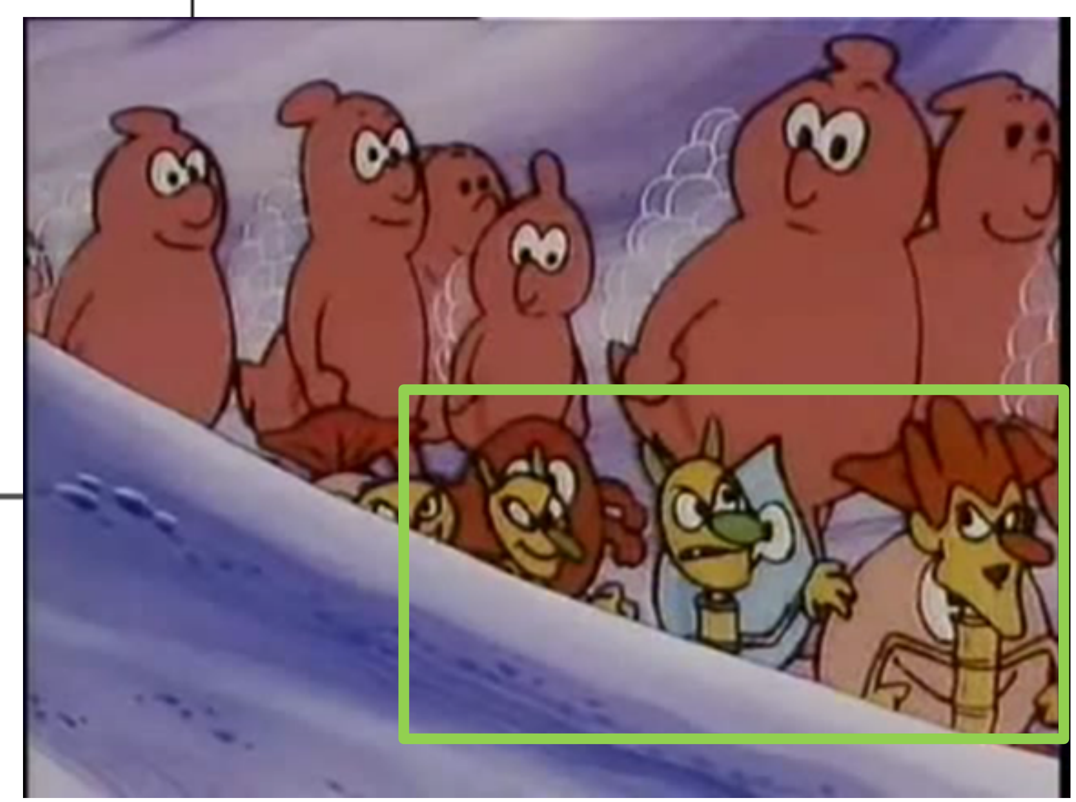
Krejtz I. et al. 2012, Krejtz K. et al. 2012

STIMULI EXAMPLE WITH AUDIO DESCRIPTION

Krejtz I. et al. 2012, Krejtz K. et al. 2012

MORE FIXATIONS ON IMPORTANT AREA OF INTERESTS

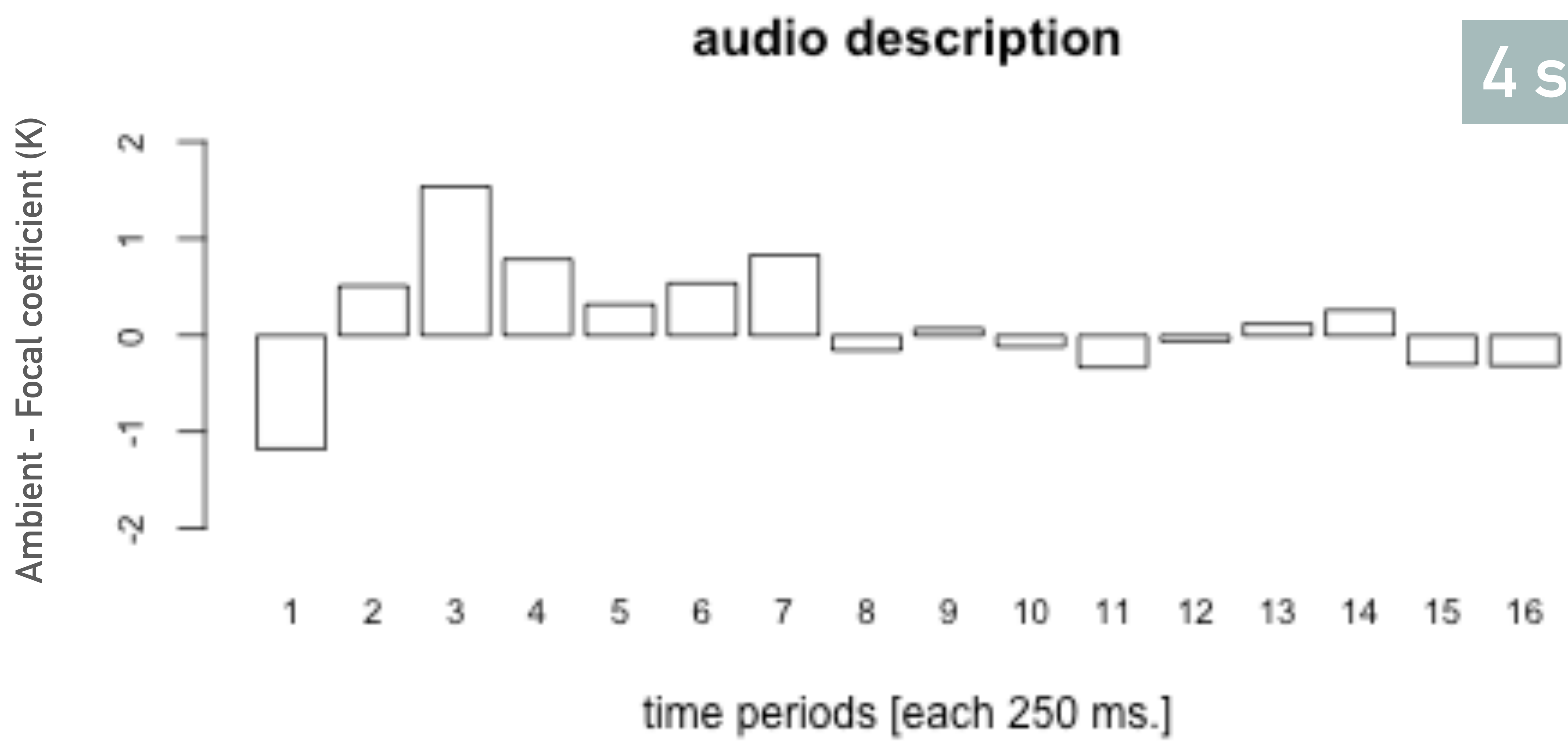


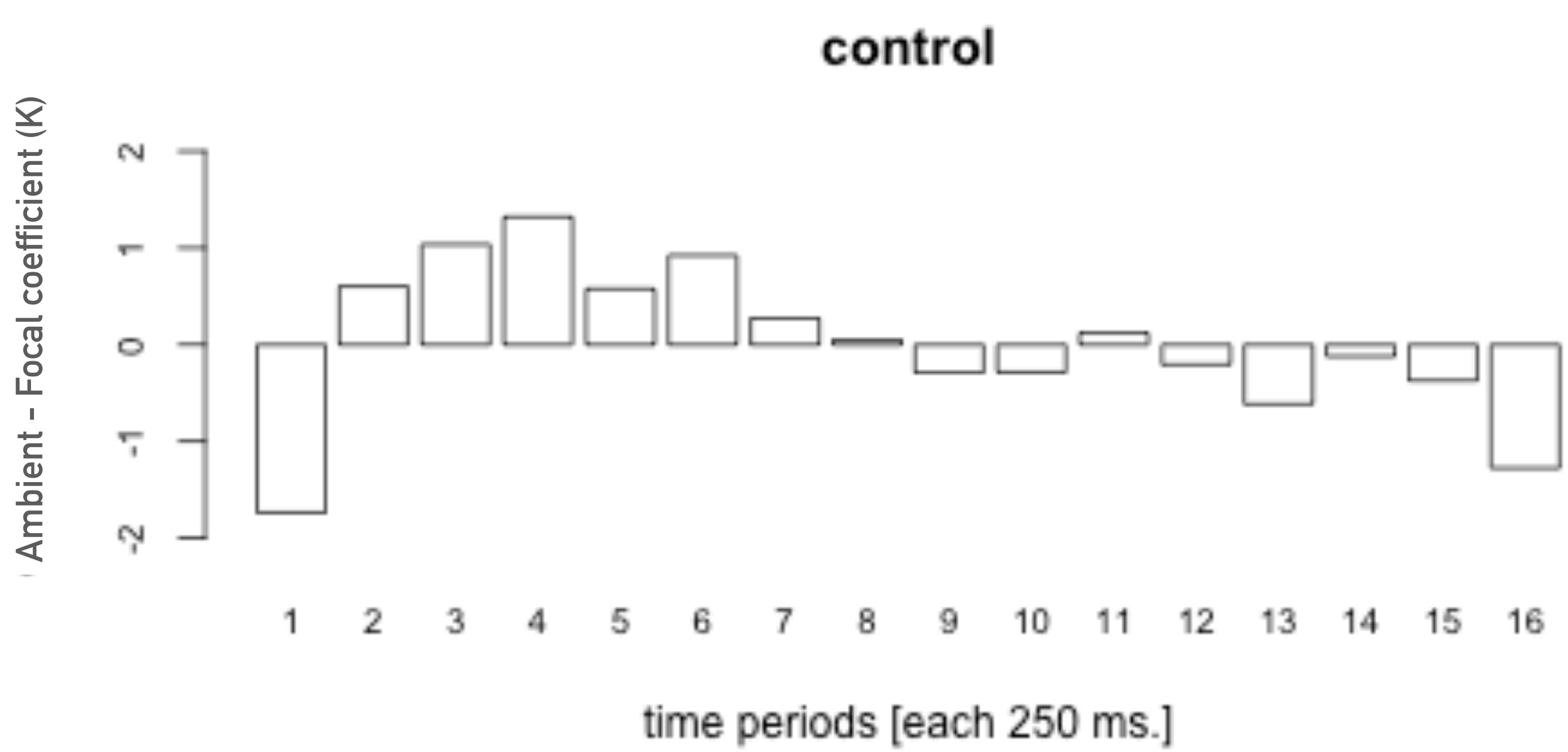


Krejtz I. et al. 2012, Krejtz K. et al. 2012

DYNAMICS OF VISUAL ATTENTION DURING SELECTED PERIOD OF THE CLIP

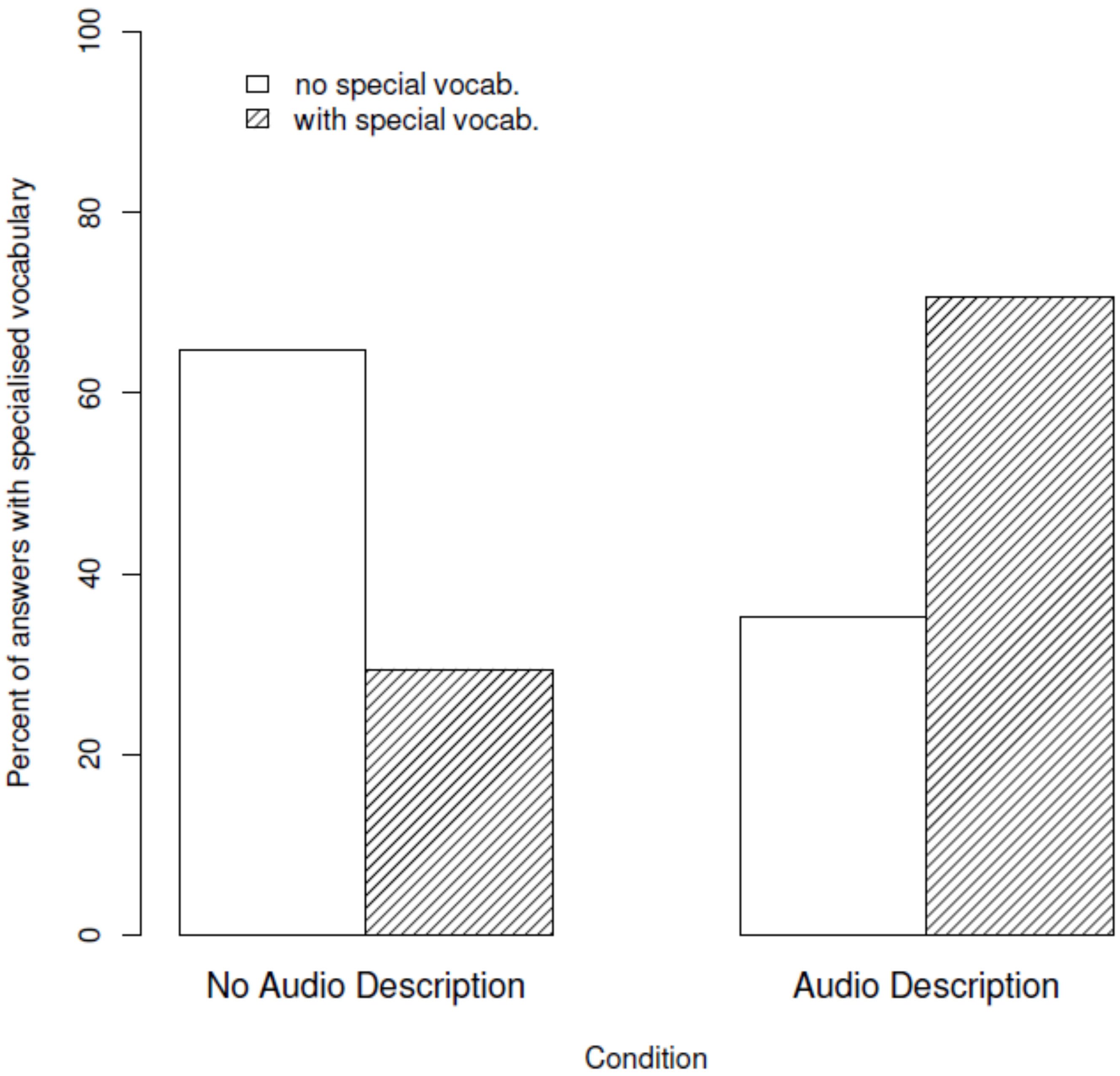
4 sec. viewing sample





Krejtz I. et al. 2012

LEARNING OUTCOMES



control group

```
R:  Alright, tell me if you remember who
    copied themselves?
G:  White cells and girls in ships copied
    themselves.
R:  Great, and what do antibodies do?
G:  Antibodies...which ones were antibodies?
R:  Well, what do you remember...do you
    remember which of them were the
    antibodies?
G:  No.
R:  OK, it doesn't matter.  And do you
    remember who attacked the organism?
G:  The organism was attacked by the...the
    sticks.
R:  Uhm.
G:  The brown sticks, I don't know what
    they're called.
R:  Ok, it's alright.  And what is mitosis?
G:  I have no clue.
R:  Good, that's all.  Have you remembered
    anything else in the meantime?
G:  No.
R:  Good, thanks.
```

ad group

```
R:  OK, tell me now, do you remember who
    copied themselves,... got replicated?
G:  White cells and these...ships.
R:  Alright.  And what did antibodies do?
G:  Antibodies did...they...scared away
    the...they crawled over the viruses and
    as if they started to melt, something
    like that.
R:  OK, now, and who attacked the organism?
G:  Viruses.
R:  Great, and what is mitosis?
G:  Dividing into twos.
R:  Fantastic, thank you very much.
```

Krejtz I. et al. 2012, Krejtz K. et al. 2012

ATTENTION GUIDANCE WITH VISUAL CUES

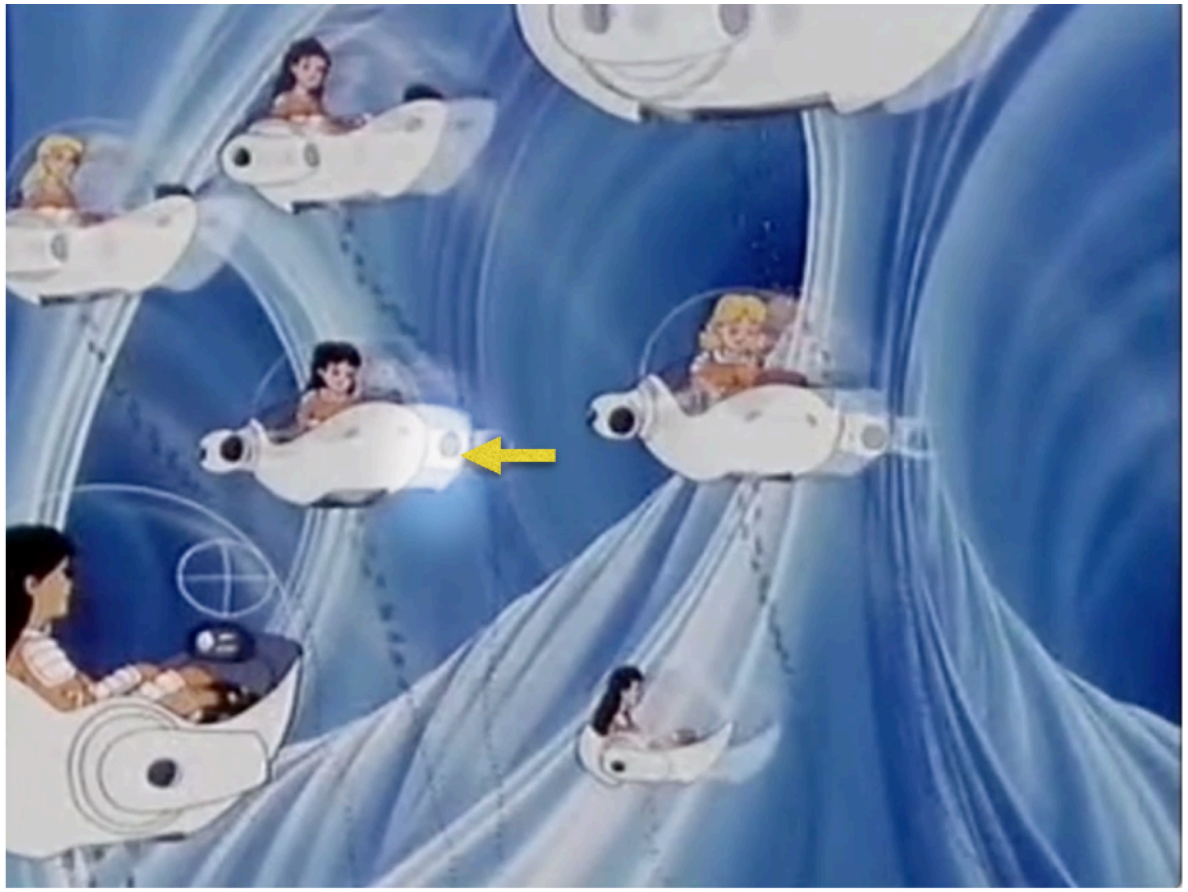
- Classic signals (e.g., colour change, sudden appearance, and changes in luminance contrast) are effective in static illustrations
- They may be too weak to capture attention in dynamic environments such as animations (de Koning et al. 2009, Lowe & Boucheix 2011) or movies
  - The solution may be to use a dynamic signals e.g., spreading-colour cues (Boucheix & Lowe 2010, Jamet 2014)
  - Another promising technique is **Subtle Gaze Direction (SGD)** defined as
    - subtle image modulation (luminance modulation or warm-cool modulation) to influence gaze direction (see Bailey, McNamara, Sudarsanam & Grimm 2009)
    - SGD modulation are often not consciously perceived by subjects

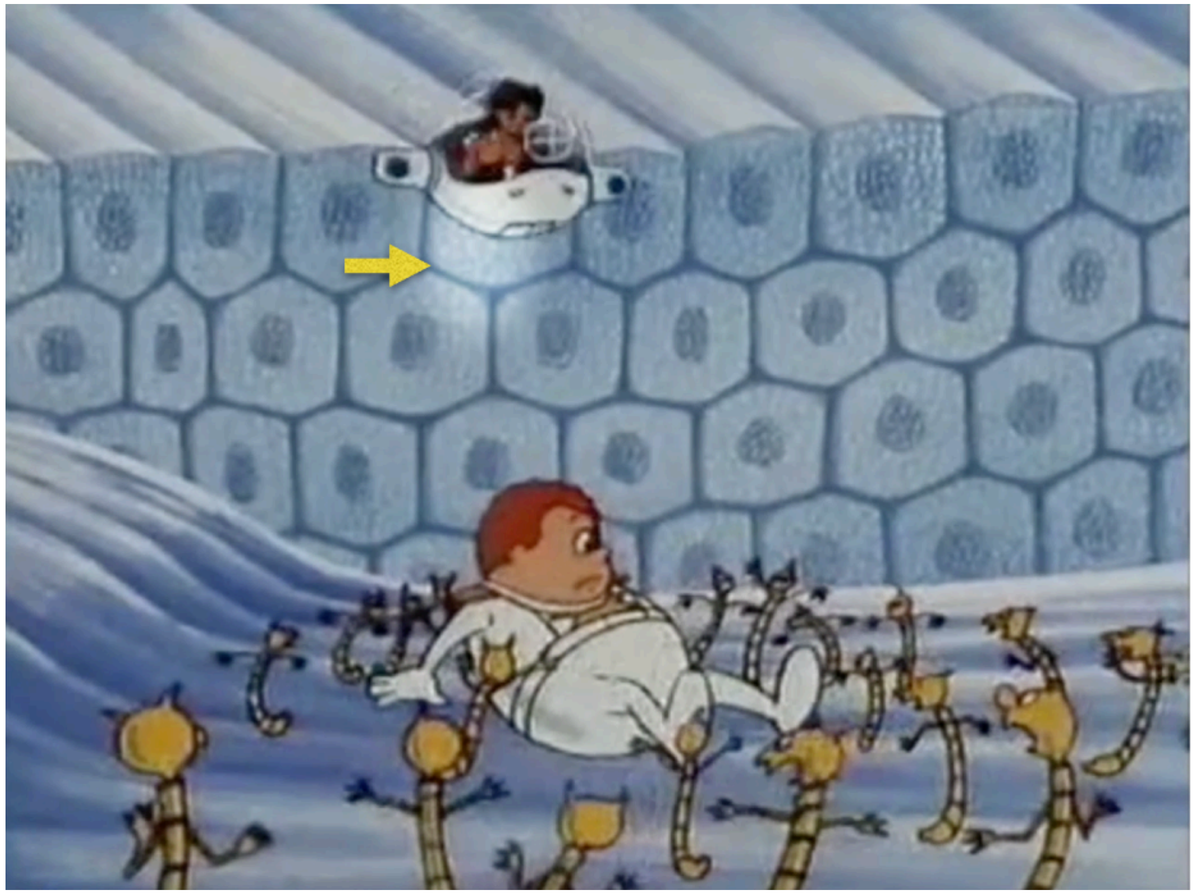
ATTENTION CUEING WITH AD AND SGD

- **Hypotheses:**
  - Audio Description (AD) as well as Subtle Gaze Directing (SGD) modifies children's eye movement characteristics facilitating longer focal processing
  - AD and AGD foster learning effectiveness
  - Expected additive effect on eye movements patterns changes and learning effects of both techniques
- **Design:**
  - 2 (AD) x 2 (SGD) between-subjects eye tracking experiment
- **Sample:**
  - N = 59, 6-10 y.o.
- **Procedure:**
  - 2 min. educational video clips watching
  - Recognition task
  - Structured interview
- **Equipment:**
  - GazePoint 3 (60Hz) eye tracker , 17'' laptop screen (1820 x 900 resolution)

Krejtz et al. in preparation

EXAMPLES OF SUBTLE GAZE DIRECTION CUES





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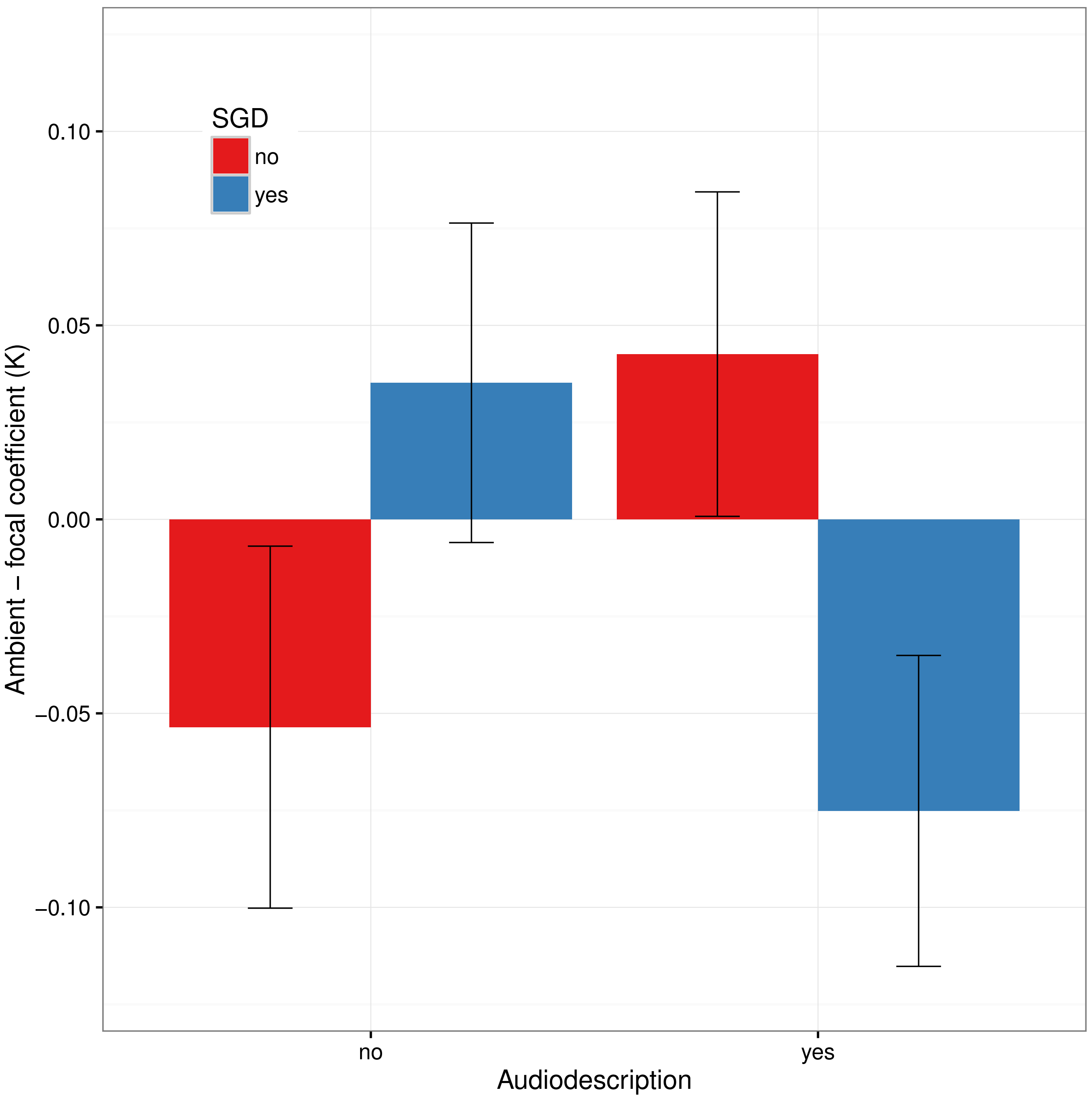
AMBIENT – FOCAL EYE MOVEMENTS MODERATED BY AD AND SGD



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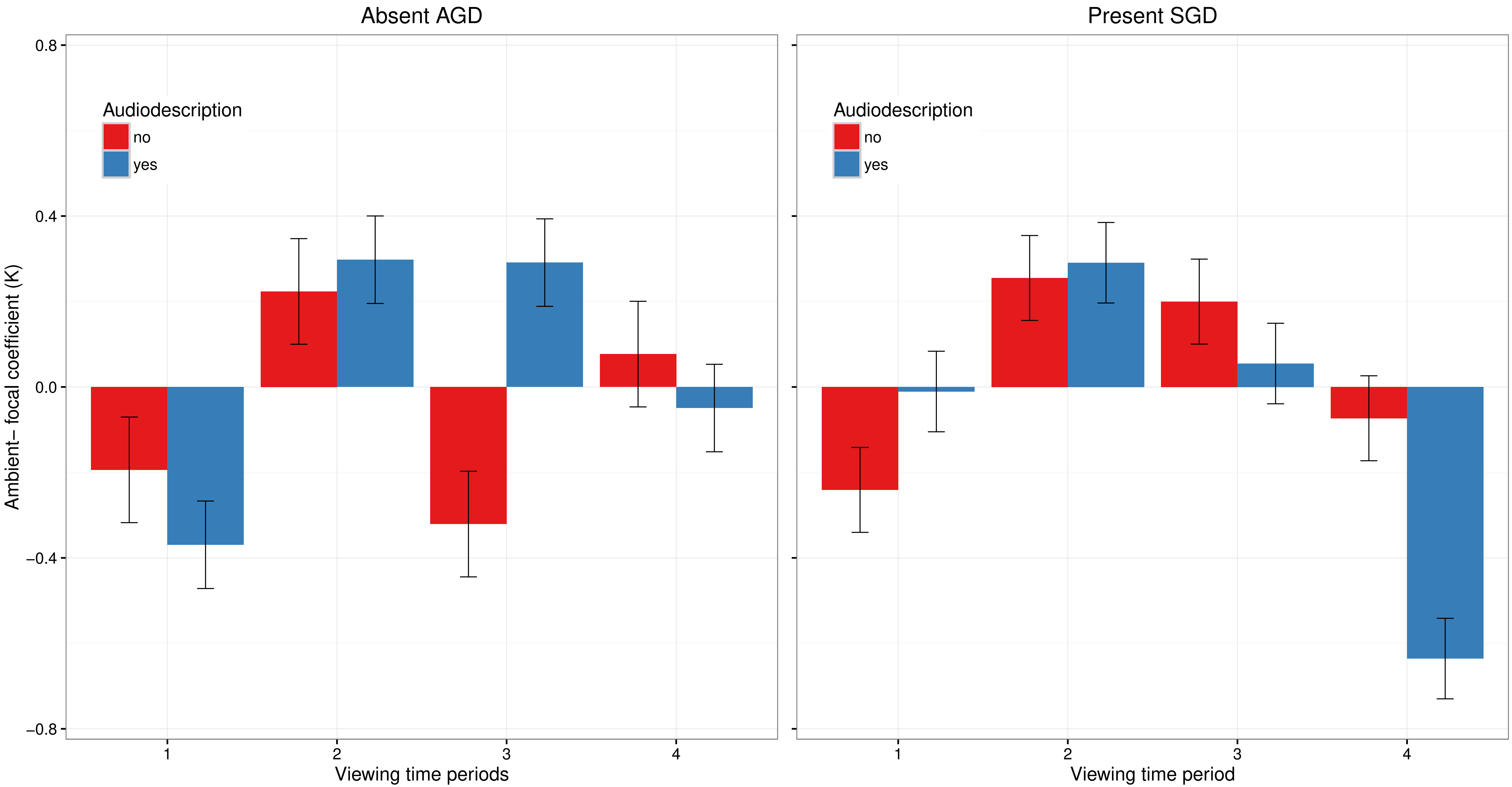
AMBIENT - FOCAL EYE MOVEMENTS DYNAMICS MODERATED BY AD AND SGD



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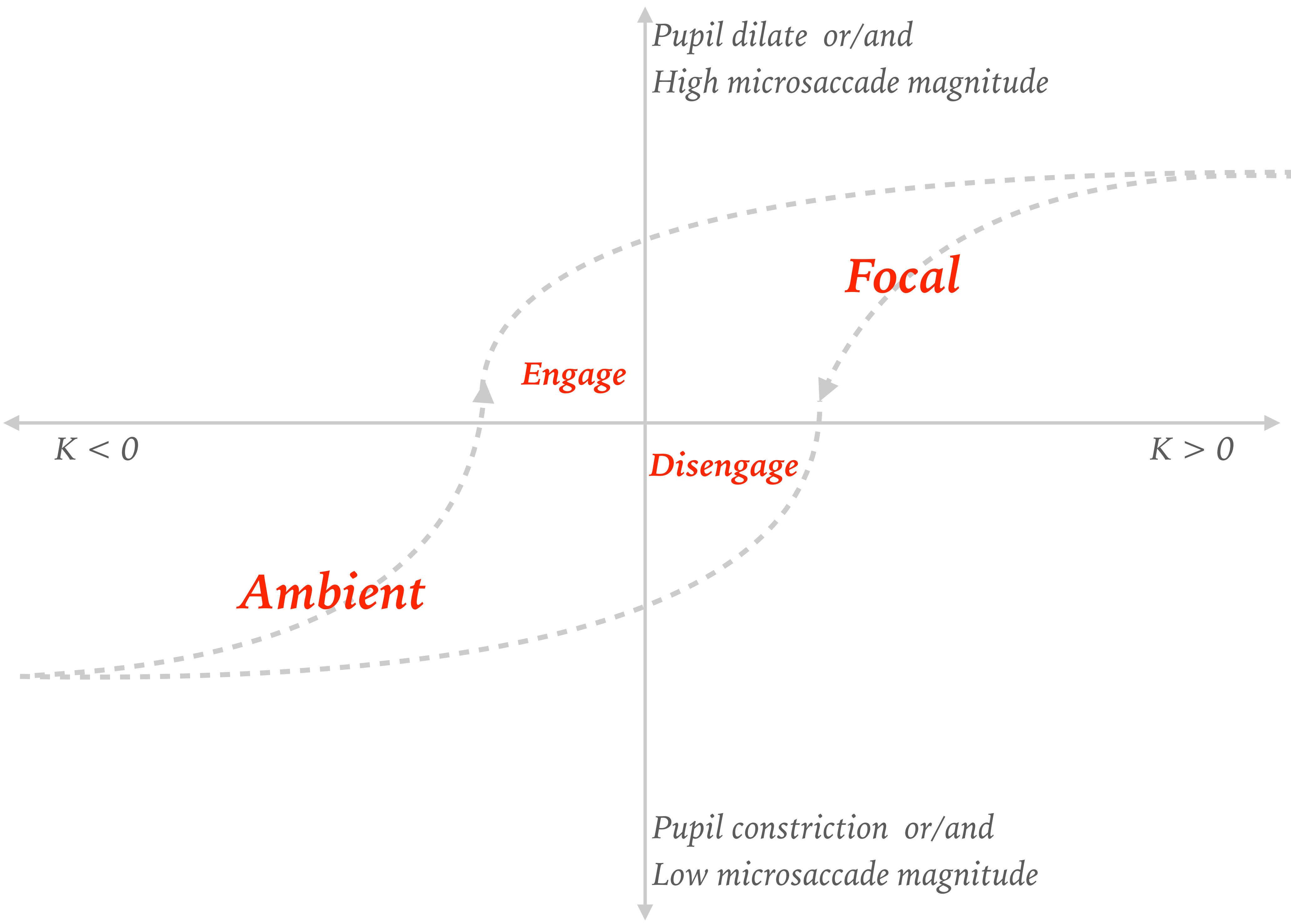
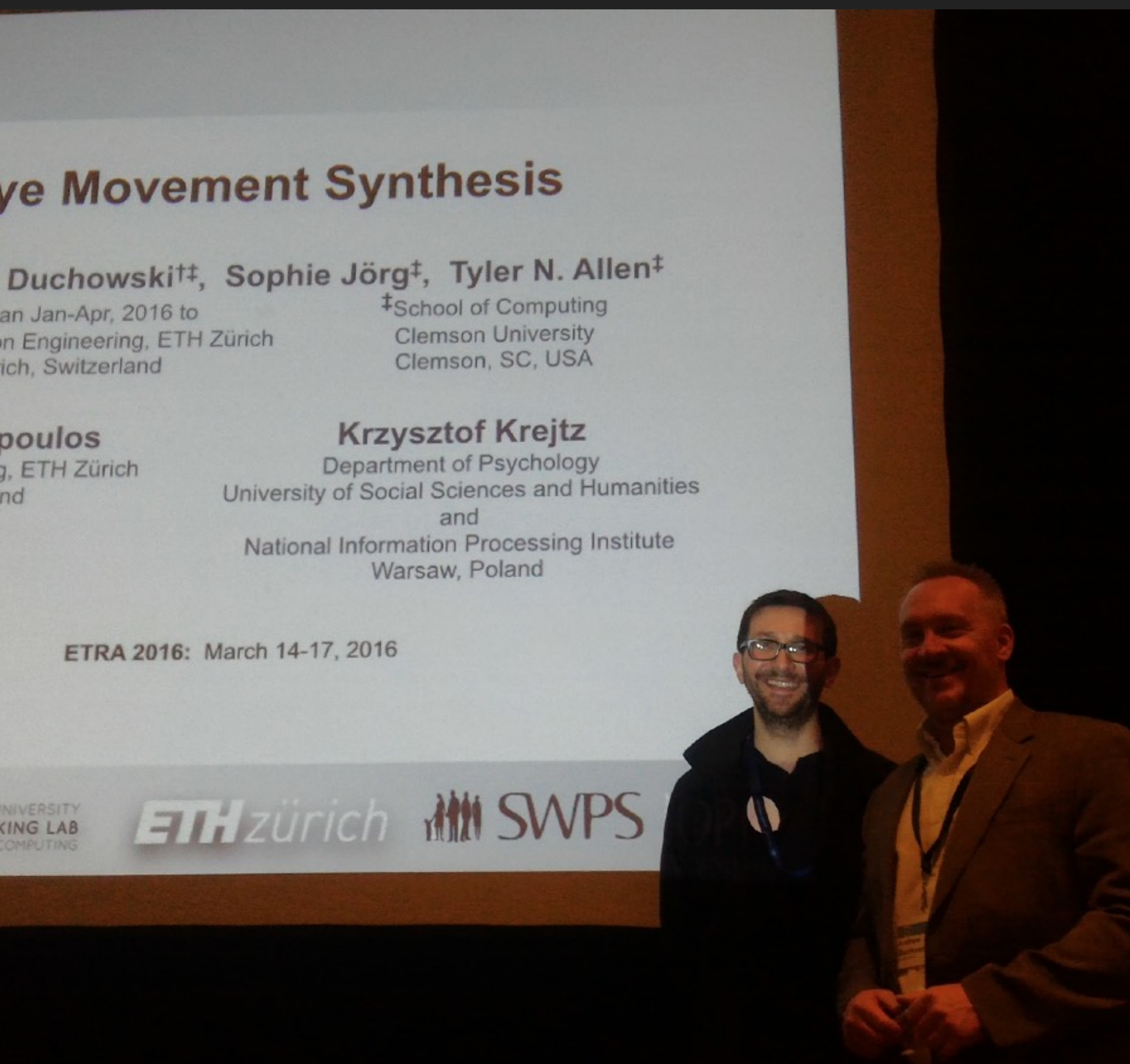
CAPTURING AND MANIPULATING AMBIENT – FOCAL DYNAMICS IN MULTIMEDIA LEARNING CONTEXT

- Continuous shifts between ambient and focal attentional modes may be captured by proposed ***K*** coefficient
  - a straightforward, easy to interpret eye movements based measure
- The dynamics of ambient-focal shifts may be moderated by top-down (e.g. emotional state or auditory cues) as well as bottom-up processes (e.g. visual clutter and stimulus saliency or subtle gaze cues)
- Manipulating the dynamics of ambient-focal dynamics benefit learning with multimedia materials
  - Cueing attention (with over or covert cues) prolongs focal stages during learning
  - Adding AD or SGD to multimodal material leads to better memory, deeper processing and faster retrieving from memory of learned material
- However covert and overt attentional guidance jeopardise focal processing and learning
  - Presumably may overload of working memory (need for further research)

OUTLOOK TOWARDS A DYNAMICAL MODEL OF ATTENTION





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