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EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

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EYE TRACKING ANALYSES PIPELINE FOR RESEARCH ON TEXT AND VISUALISATION

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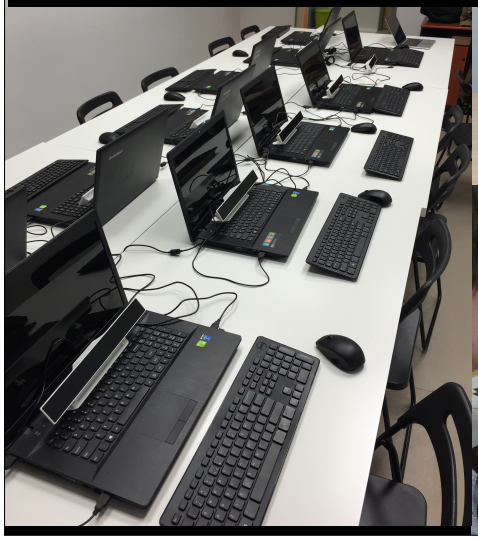
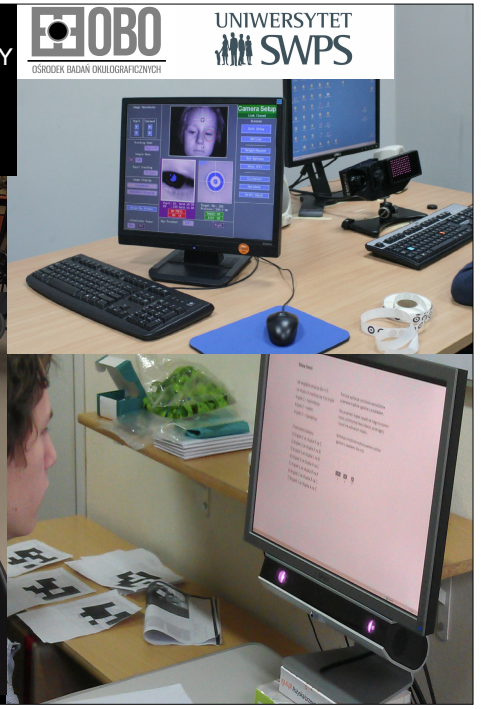
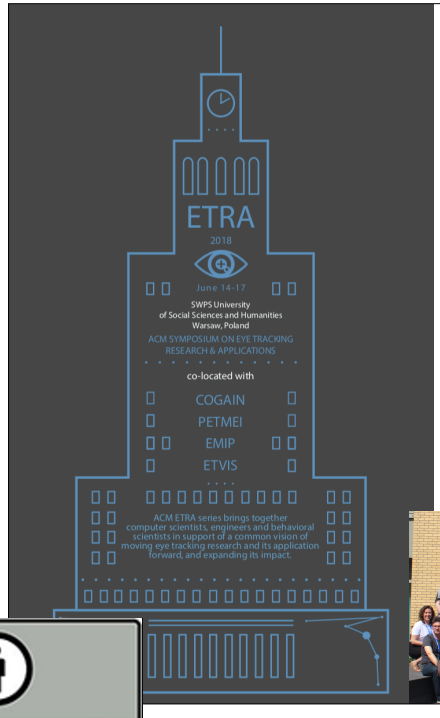
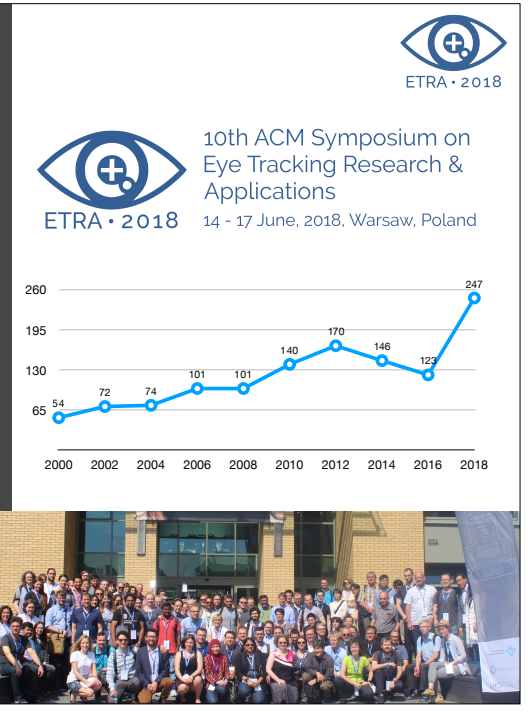
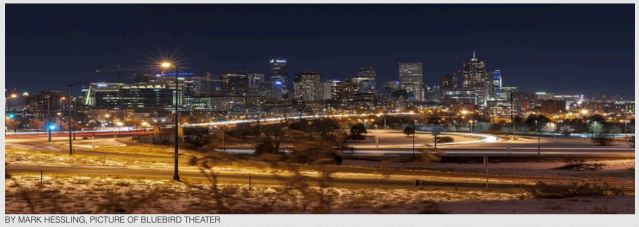










BY MARK HESSLING, PICTURE OF BLUEBIRD THEATER

ETRA

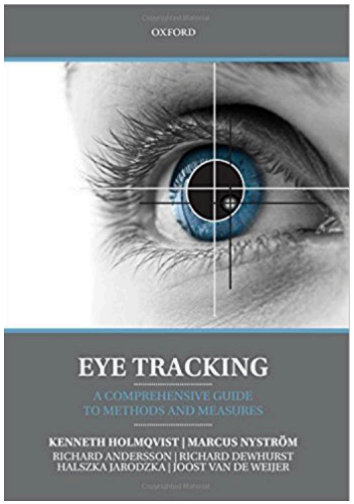
ETRA 2019

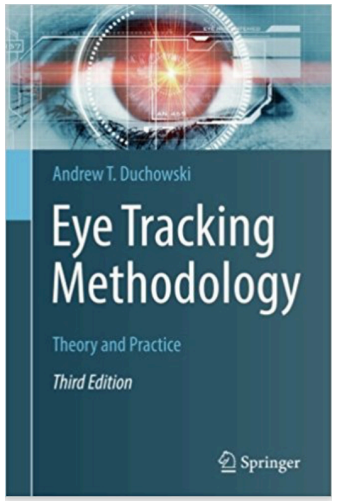
2019 ACM SYMPOSIUM ON EYE TRACKING RESEARCH & APPLICATIONS

DENVER, COLORADO

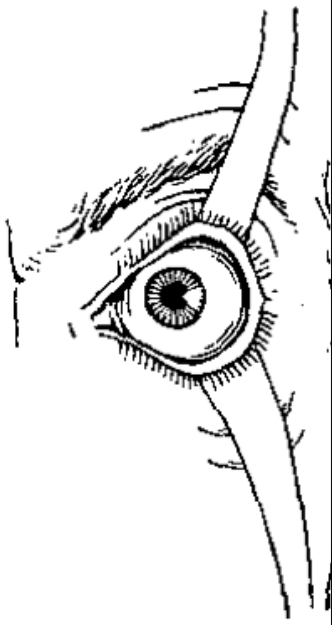
JUNE 25-28, 2019

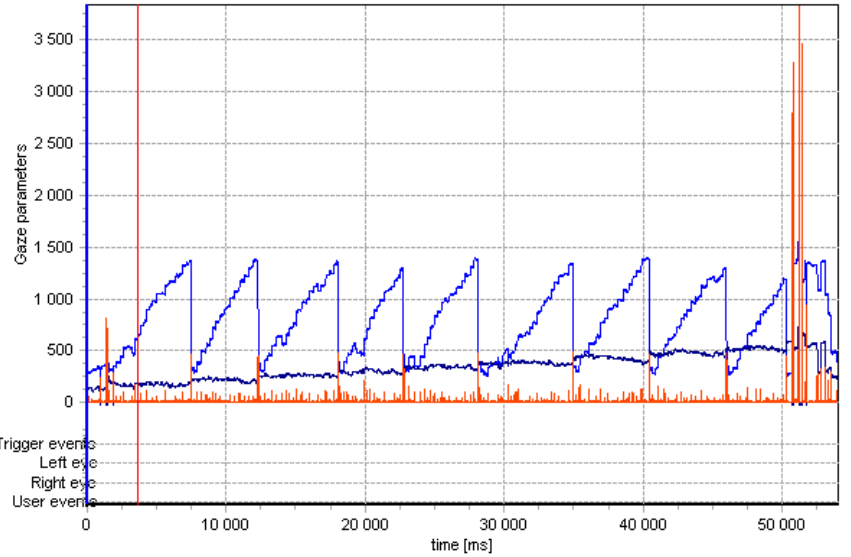
RECOMMENDED READING



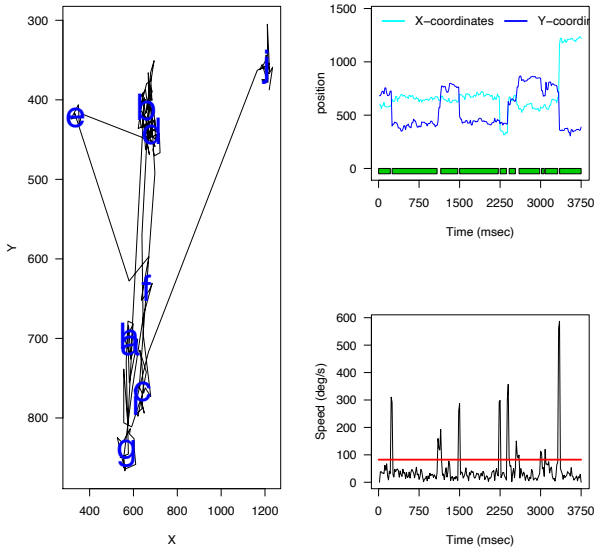


MAKING SENSE OF EYE MOVEMENTS DATA

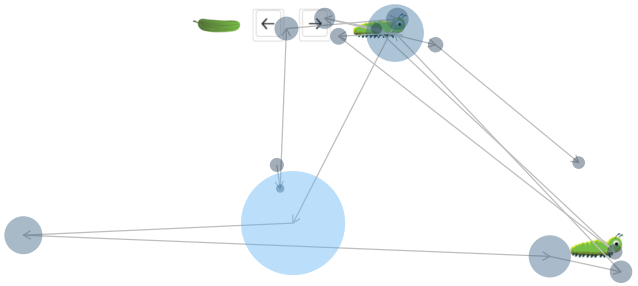




MAKING SENSE OF EYE TRACKING DATA - ANALYTICAL VISUALIZATIONS



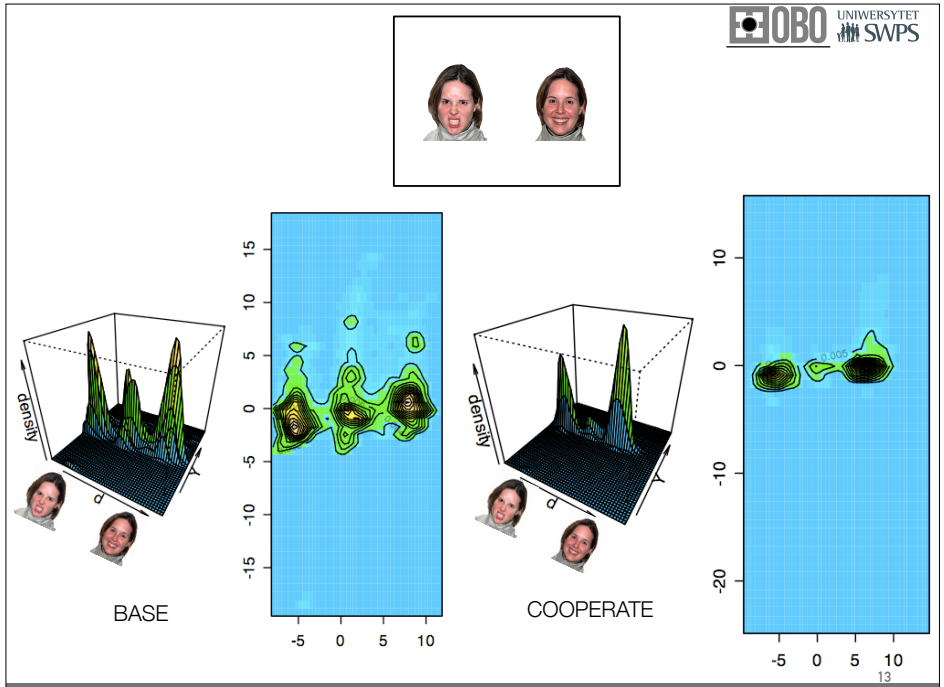
SCANPATHS



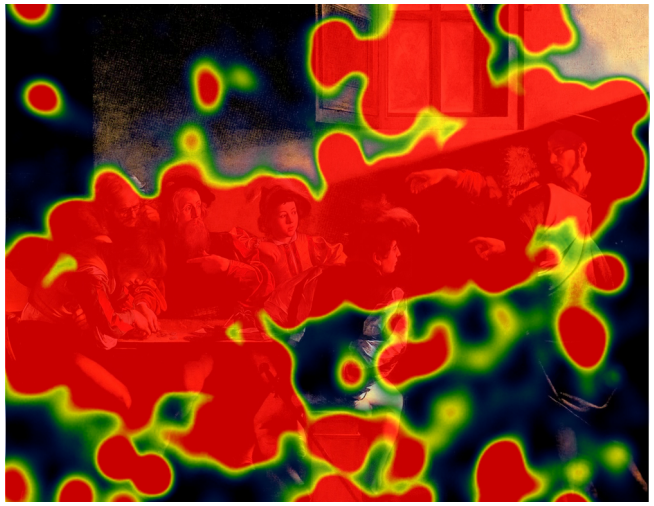
GROUPED SCANPATHS

al. (2016)

FIXATION MAPS



HEATMAPS



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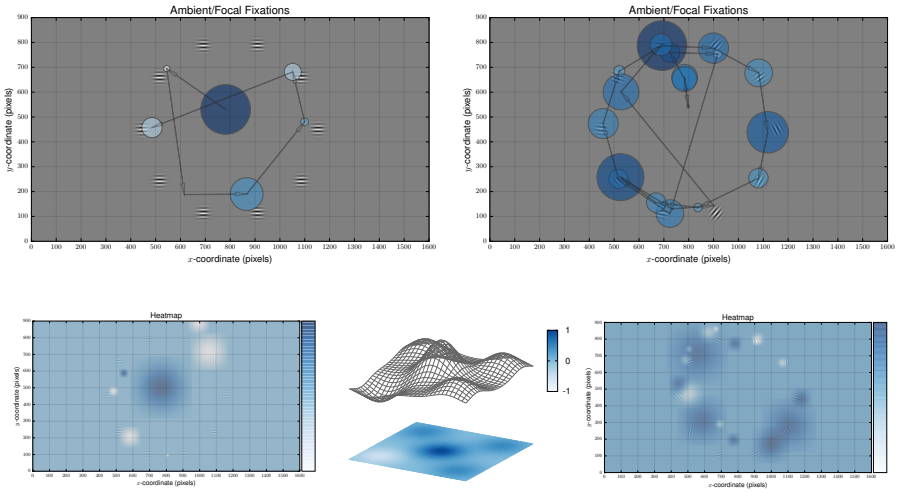
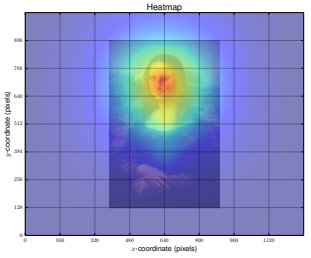
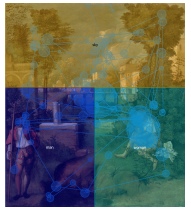
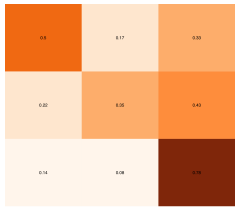


TWO APPROACHES TO EYE MOVEMENTS ANALYSES

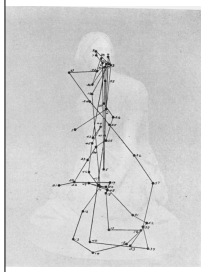
- Gaze-location approach
  - AOI/ROI analyses
  - fixations distribution
- Visual attention process approach
  - scanpaths analyses
  - transition matrices entropy
  - relation between fixations and saccades







> Eye tracking data contains ONLY information on what the person was looking at

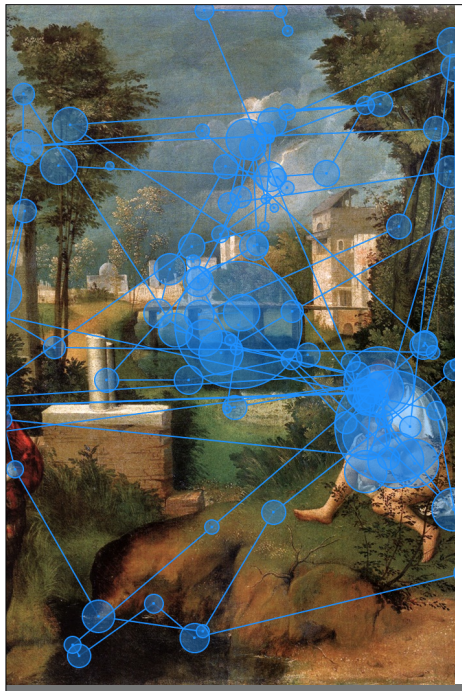


(Duchowski, always)

WHY TRACK THE EYES?

> 'Of course, visual attention is intimately related to where we are looking and to eye movements. Perhaps there is nothing much to explain here: we just attend to what we are looking at'.

(Styles, 1997)



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

BASIC EYE MOVEMENTS ::: FIXATIONS

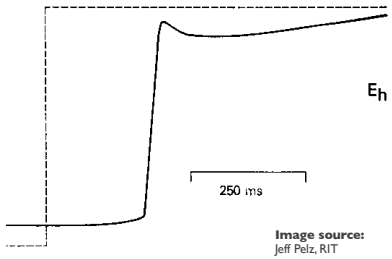
- Role: stabilize image in fovea
- Points in time and space between saccades
- Fixation duration varies depending on stimuli and top-down processes
- During fixations visual stimuli are process cognitively

- **micro-movements / fixational movements**
  - microssaccades (amplitude 0,1°, duration av. 12ms)
  - tremor (amplitude <0,1°, duration 0,05-0,1°/sec)

Martinez-Conde i in. (2004)

BASIC EYE MOVEMENTS ::: SACCADES

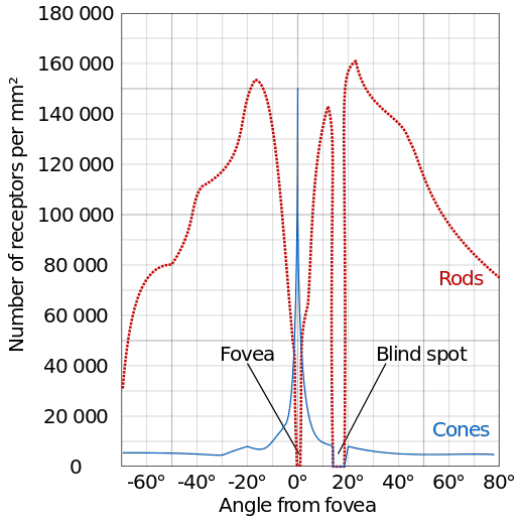
- Role: reposition the fovea
- Reflexive (bottom-up vision), attentional (top-down)
- Saccadic inhibition
- Basic parameters:
  - amplitude < 1° up to 45°
  - velocity > 500°/second

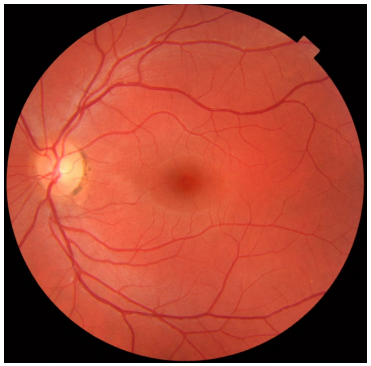


VISUAL INFORMATION PROCESSING DURING FIXATIONS

- 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*)

RODS AND CONES ON THE RETINA





PERCEPTUAL SPAN - ACUITY LIMITATION

- Central and peripherial vision
  - foveal/central means 2° of vision from the center of eye fixation
    - the region from which we presumably pick up information during a fixation
  - parafoveal: 2-5° on either side of fixation
  - Peripheral: > 5° on either side of fixation

READING FROM THE EYE MOVEMENTS PERSPECTIVE

sequence of fixations (approx. 150 to 300 ms) and saccades (approx. 30 ms)

- information uptake is largely restricted to fixations.

(Rayner,1998)

SOURCES OF PROBABILITY OF FIXATION ON WORD

- Frequency in the body of language
- Context
  - Consistent context shortens fixations
- Length of the word
  - Longer words = longer fixations
- Simple vs multiple meaning
- Familiarity with a word
- Age at what a word was learnt

(Brysbaert & Vitu, 1998; Rayner & Schotter 2012; Rayner & McConkie, 1976)

SKIPPING

- Whereas a majority of the words in a text are fixated during reading, many words are skipped
  - **content** words are fixated about 83 - 85% of the time,
  - **function** words are fixated about 35 - 38% of the time
- As length of the word increases, the probability of fixating increases
  - 2-3 letter words are only fixated around 25% of the time, words 8 letters or longer are almost always fixated

REGRESSIONS

- good readers are very accurate in sending their eyes to that part of text that caused them difficulty
- poor readers engage in more backtracking through the text
  - a few letters long - correction of too long saccade
  - short within-word regressions - processing problems
  - longer regressions - problems with understanding

FIXATION AND SACCADES TIME PARAMETERS

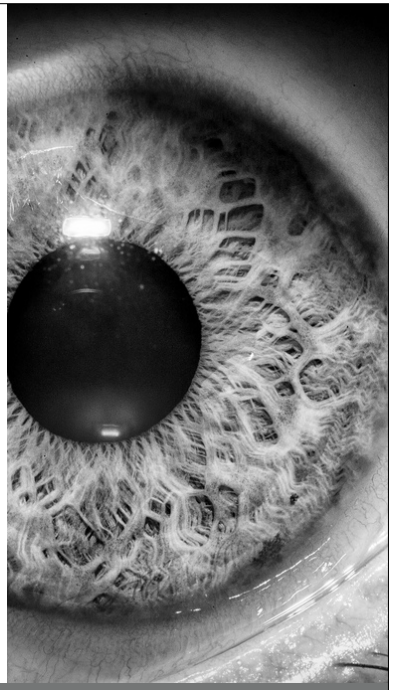
	fixation duration	saccade amplitude
Silent reading	225 ms	2° (8 letters)
Oral reading	275 ms	1.5° (6 letters)
Visual search	275 ms	3°
Scene perception	330 ms	4°
Music reading	375 ms	1°
Typing	400 ms	1° (4 letters)

(Rayner, 1998)

PERCEPTUAL SPAN IN READING

- Size of the perceptual span is relatively small and asymetrical
  - no more than 3-4 letters to the left of fixation (McConkie & Rayner, 1976; Rayner, Well, & Pollatsek, 1980)
  - to about 14-15 letter spaces to the right of fixation (McConkie & Rayner, 1975; Rayner, 1986)
- It varies across text difficulty - smaller for difficult text
- It's variability depends on reading skills and age
  - beginning readers have a smaller perceptual span (12) than more skilled readers (14-15) Rayner (1986)
  - older readers have a slightly smaller and more asymmetrical perceptual span than younger readers (Laubrock, Kliegl & Engbert,2005).

HYPERTEXT READING



HYPERTEXT - INTRODUCTION

Hipertext is quite new way of presenting information, that lets users easily browse between documents.
After the introduction it was enthusiastically accepted (i.e. because of its interactivity and flexibility e.g. (Jacobson, Spiro, & Urbana, 1993)).
Currently theres growing evidence for the shortcomings of this format, and that it can negatively influence processing of information:

- non-linear presentation of narrative text decreases comprehension (Zumbach i Mohraz, 2008)
  subjective sarisfaction from reading is lower for hypertext
- compared to traditional text (Heo i Hirle, 2001), because of the dissorientaion
- links negatively influence the searching efficiency, the less the links the better the information is searched (Khan, Locatis, 1998)
- efficiency of hypertext depends on prior knowledge of readers - hypertext influence information prcessing for readers with low lovel of knowledge of the subject (Lawless, 2007)

Krejtz et al. 2016

PROCEDURE

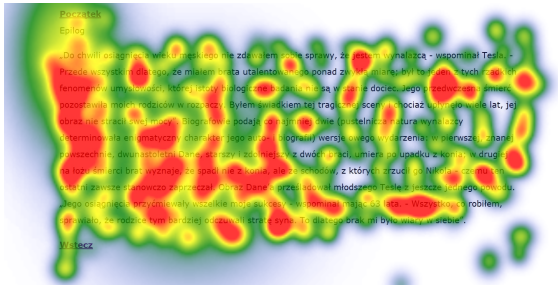
Forty participants took part in the study. They read the popular scienctific article either presented as a hypertext or text divided into the paragraphs. Eye movements were recorded using SMI RED 250 eye-tracker.

Krejtz et al. 2016

PLAIN TEXT – HEAT MAPS

First page

Last page

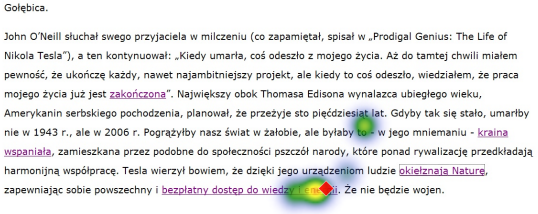


Krejtz et al. 2016

HYPERTEXT

First page

Last page

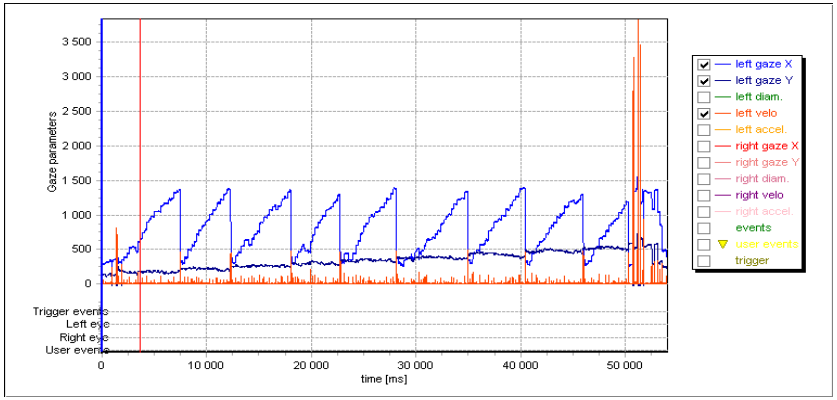


Gołębica.

John O'Neill słuchał swego przyjaciela w milczeniu (co zapamiętał, spisał w „Prodigal Genius: The Life of Nikola Tesla"), a ten kontynuował: „Kiedy umarła, coś odeszło z mojego życia. Aż do tamtej chwili miałem pewność, że ukończę każdy, nawet najambitniejszy projekt, ale kiedy to coś odeszło, wiedziałem, że praca mojego życia już jest zakończona". Największy obok Thomasa Edisona wynalazca ubiegłego wieku, Amerykanin serbskiego pochodzenia, planował, że przeżyje sto pięćdziesiąt lat. Gdyby tak się stało, umarłby nie w 1943 r., ale w 2006 r. Pogrążyłby nasz świat w żałobie, ale byłaby to – w jego mniemaniu - kraina wspaniała, zamieszkana przez podobne do społeczności pszczół narody, które ponad rywalizację przedkładają harmonijną współpracę. Tesla wierzył bowiem, że dzięki jego urządzeniom ludzie okiełznają Naturę, zapewniając sobie powszechny i bezpłatny dostęp do wiedzy i energii. Że nie będzie wojen.

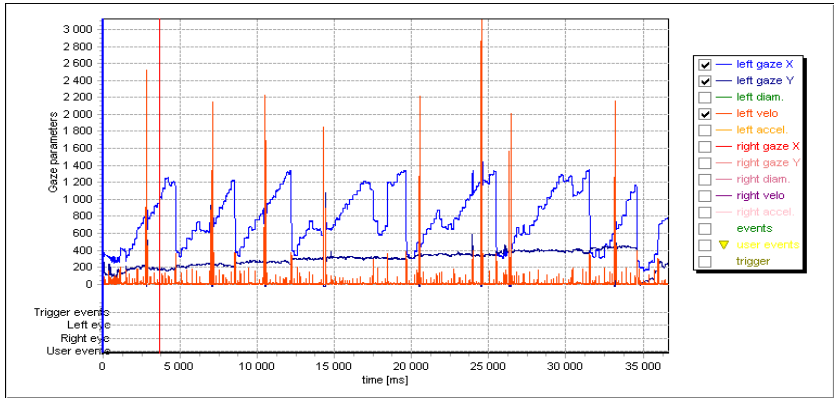
Krejtz et al. 2016

PLAIN TEXT – READING PATTERN



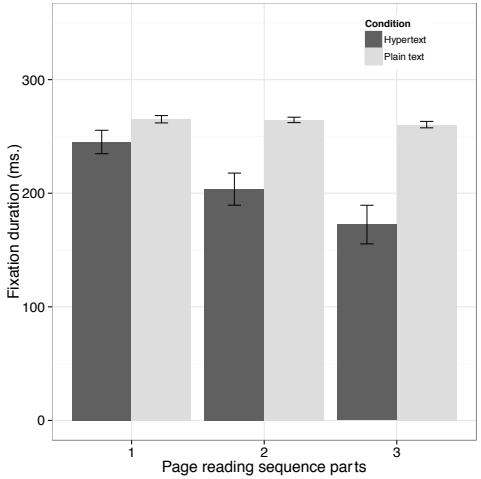
Krejtz et al. 2016

HYPERTEXT – READING PATTERN

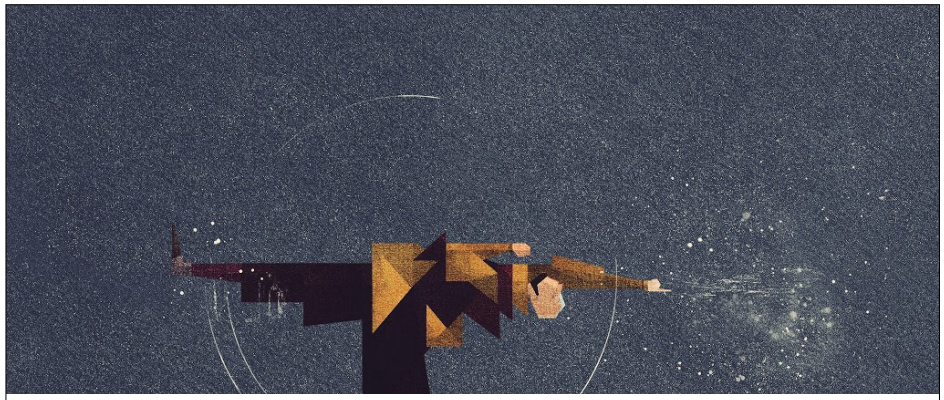


Krejtz et al. 2016

FIXATION DURATION OVER READING TIME



Krejtz et al. 2016



EYE TRACKING RESEARCH PROCESS

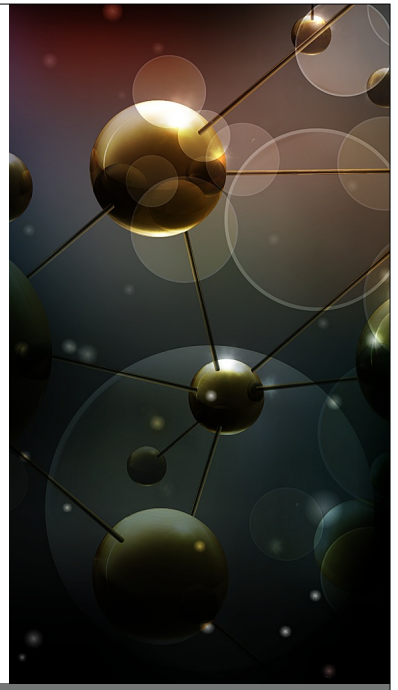
RESEARCH PROCESS

- Research questions
  - Observations
  - Theory
  - Hypotheses
- Research design
  - Variables
  - Operationalization
    - Measures
    - Procedure
- Data
  - Collection
  - Analyses
- Conclusions
  - Discussion
  - Possible implementations

STEPS IN EYE TRACKING DATA ANALYSIS

- Data pre-processing - looking for fixations and saccades
- Data preparation
  - quality check
    - individual trial visualizations
- **Dealing with missing and outlying data**
- New variables calculations
- Initial relationships and difference visualizations
- Descriptive statistics
- Statistical significance tests

RESEARCH DESIGNS

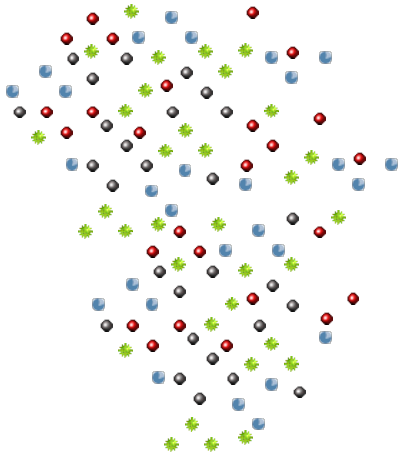


VARIABLES

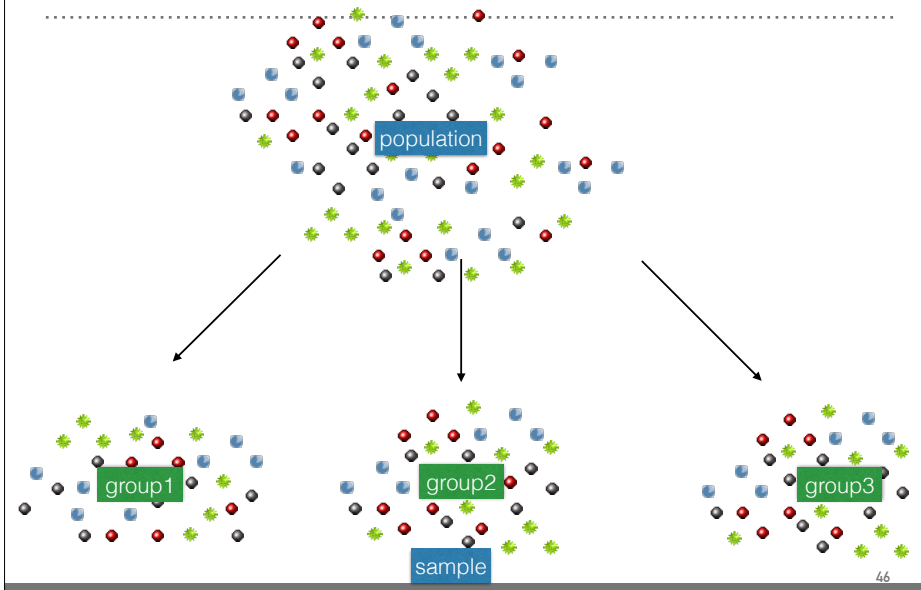
- Behavioral, biological, cognitive, emotional or attitudinal characteristics on which people differ
  - A characteristics that have more than one values
  - Examples: level of internet addiction, number of friends on FB, email response latency, time needed to acquire a material from internet,
- Why are we so interested in variables?
  - We want to explain their **source of variability** in order to explain and/or predict certain behaviors.

EXPLAINING THE VARIABILITY

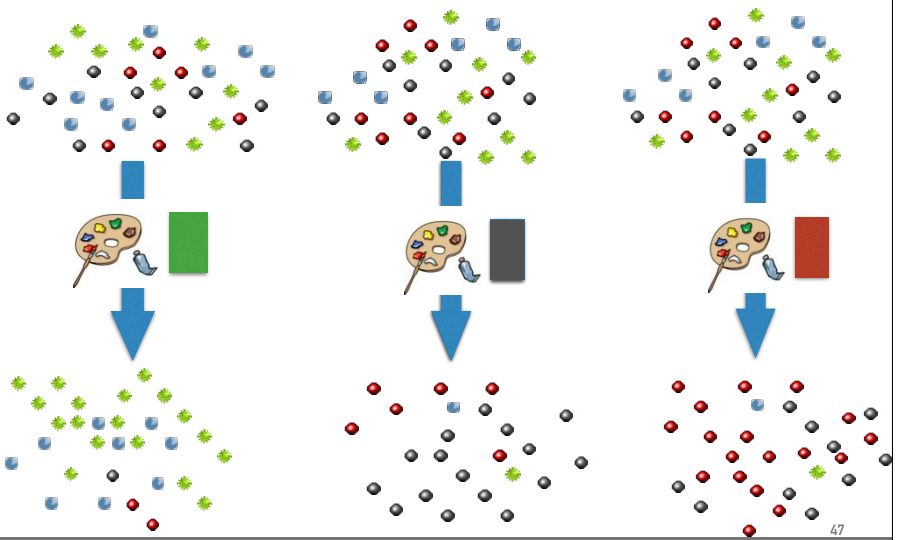
DEPENDENT VARIABLE (INITIAL VARIABILITY)



RANDOM ASSIGNMENT TO EXPERIMENTAL GROUPS



INDEPENDENT VARIABLE LEVELS MANIPULATION



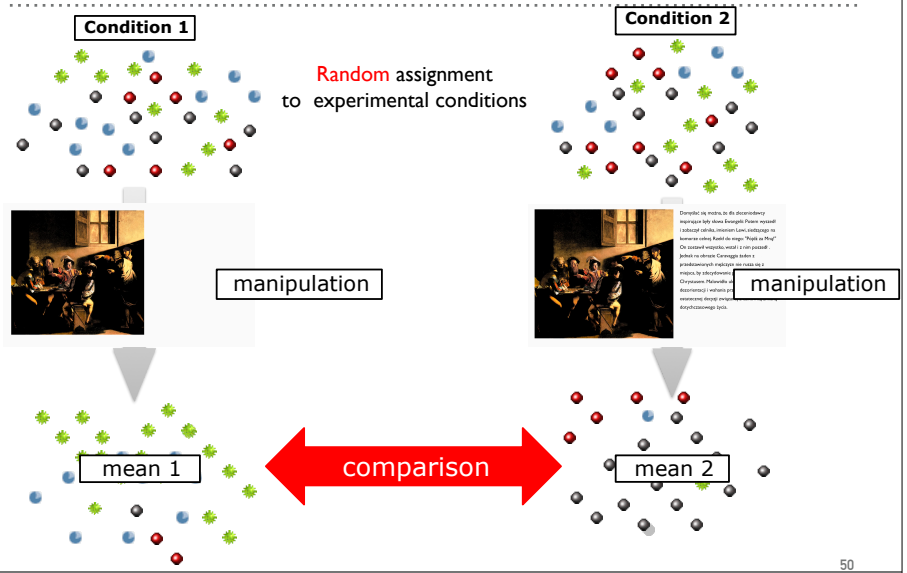
TYPES OF RESEARCH DESIGN

- **Correlational**
  - seeking for relations (covariance) between variables
- **Quasi-experimental**
  - seeking for differences between natural groups
- **Experimental**
  - seeking for causality
  - Follows single difference paradigm

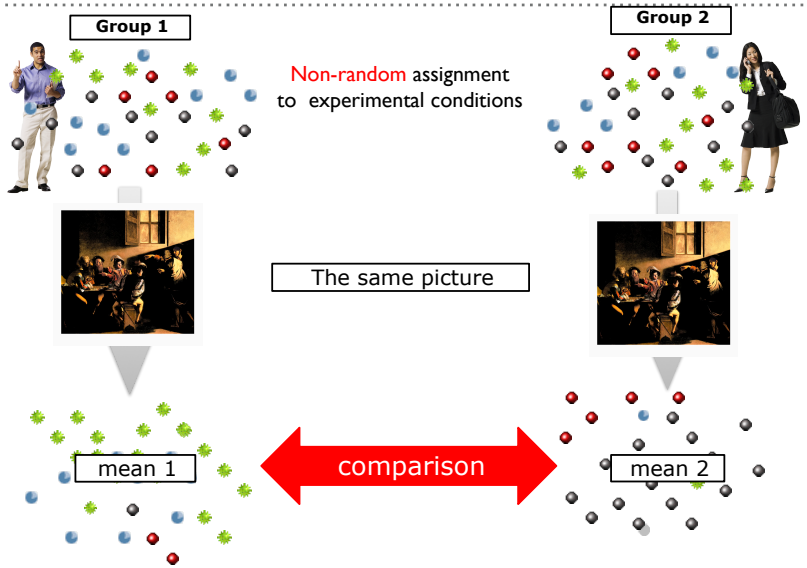
VARIABLES IN EXPERIMENTS

- An experiment is an attempt to determine the cause-and-effect relations.
  - Three types of variables:
    - **Dependent variable** - measured
    - **Independent variable** - can be directly manipulated
    - **Extraneous variables** - controlled during the experiment (they can influence the dependent variable)

BETWEEN-SUBJECTS EXPERIMENTAL DESIGN

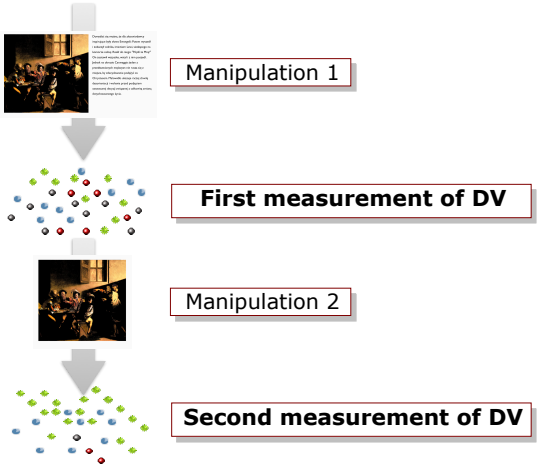


BETWEEN-SUBJECTS QUASI EXPERIMENTAL DESIGN



WITHIN-SUBJECTS EXPERIMENTAL DESIGN (REPEATED MEASURES)

Every participant takes part in each of the conditions.

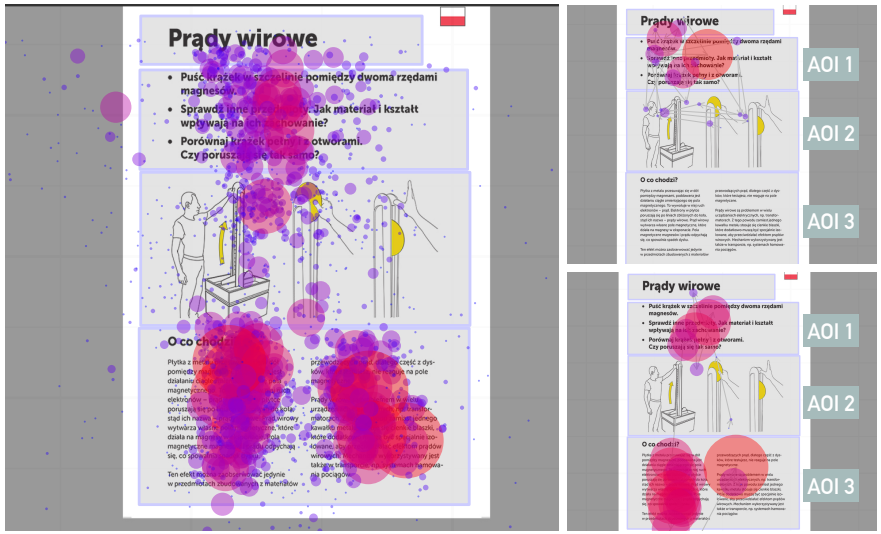


2X2 DESIGN

- The structure of factorial design is specified by:
  - How many IVs were manipulated
  - How many levels there were of each variable
- The simplest factorial design is 2x2
- 2x2 tells us:
  - There were two independent variables
  - Each with two levels

HOW CAN WE HANDLE WITH THE BIG NUMBER OF PARTICIPANTS?

- When including a new IV to the experiment we can decide whether
  - it would be a between-subjects IV
  - or within-subjects
    - A repeated measures (within-subjects) factorial design requires participants to participate in every condition; problems with order and carry over effects
- Solution: a mixed design
  - one or more between subjects IVs, and one or more within-subjects IVs



DATA STRUCTURE : LONG VS. WIDE FORMAT

- LONG: one row for each **value** that you have
  - many R statistical procedures, e.g. ANOVA use this format
  - mostly used with within-subject and mixed designs
- WIDE: one row for each **subject** that you have
  - used by many commercial statistical software e.g. IBM SPSS
  - mostly used with pure between-subject design

DATA STRUCTURE : WIDE FORMAT

subject	gender	AOI1-fixation_number	AOI2-fixation_number	AOI3-fixation_number
S1	M	23	3	2
S2	F	3	4	33

DATA STRUCTURE : LONG FORMAT

subject	gender	AOI	fixation_number
S1	M	1	23
S1	M	2	3
S1	M	3	2
S2	F	1	3
S2	F	2	4
S2	F	3	33

READING THE MASTER PAINTINGS

ARTWORK LEARNING AND AUDIO DESCRIPTION

- Experiment:
  - test viewing patterns with Audio Description (AD) and w/out

Audio source: Text-to-speech AD courtesy of Agnieszka Szarkowska.

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)

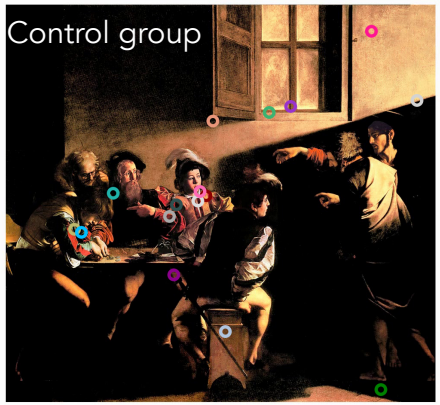
ATTENTION CUEING WITH AD DURING MULTIMEDIA LEARNING

- 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



Krejtz et al. 2016

ARTWORK AND AUDIO DESCRIPTION

- Establish grid for labels, e.g., A1, A2, ...
- Grid granularity will affect statistics
  - for both scanpath comparison and transition analysis

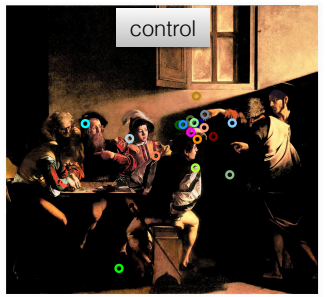


Image source: Krzysztof Krejtz, EG 2013 tutorial.

ARTWORK AND AUDIO DESCRIPTION

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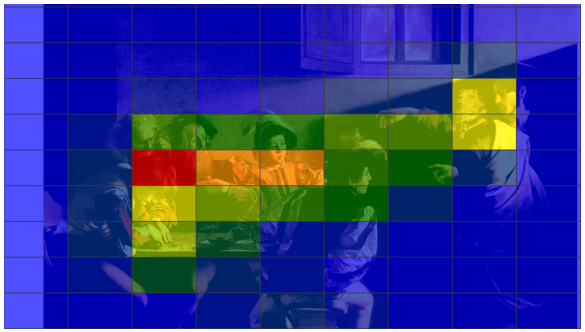

Image source: Krzysztof Krejtz, EG 2013 tutorial.

ARTWORK AND AUDIO DESCRIPTION

- Codify standardized Levenshtein distance, e.g.,
  - P01: H8-D9-E8-K2-M2-L2-O2-O2-K4-J4-F7-F8-...
  - P02: B7-A7-D10-J6-J4-L3-N2-O2-J6-L5-L5-N4-...

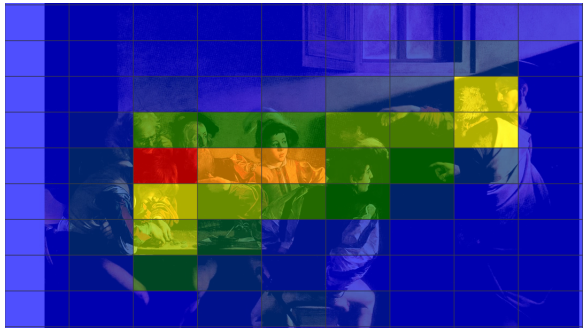

Image source: Krzysztof Krejtz, EG 2013 tutorial.

ARTWORK AND AUDIO DESCRIPTION

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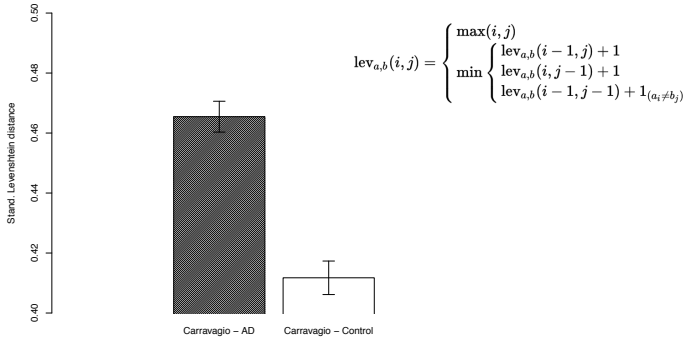
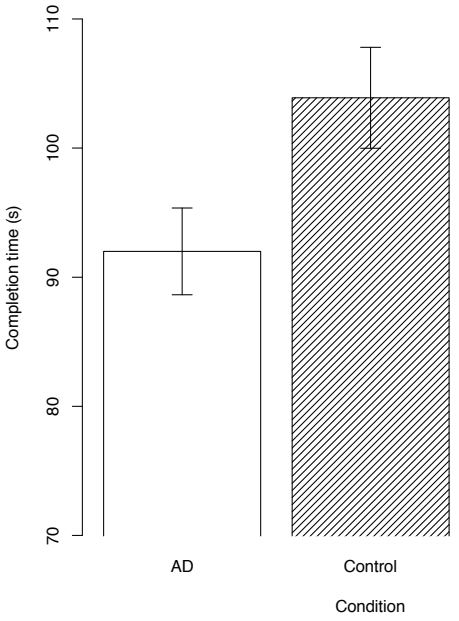


$$\mathrm{lev}_{a,b}(i,j) = \begin{cases} \max(i,j) \\ \min \begin{cases} \mathrm{lev}_{a,b}(i-1,j)+1 \\ \mathrm{lev}_{a,b}(i,j-1)+1 \\ \mathrm{lev}_{a,b}(i-1,j-1)+1_{(a_i \neq b_j)} \end{cases} \end{cases}$$

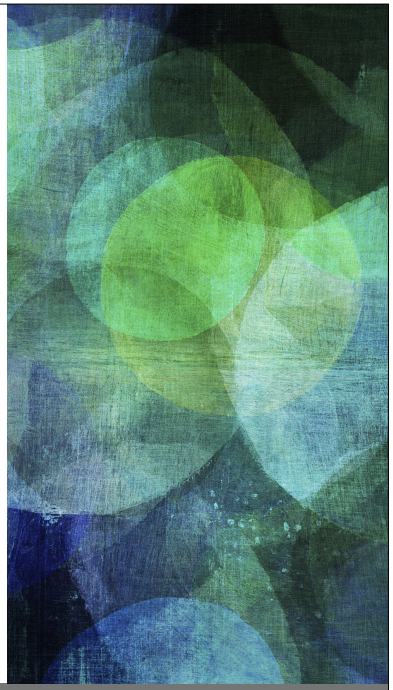


LEARNING EFFECTIVENESS

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

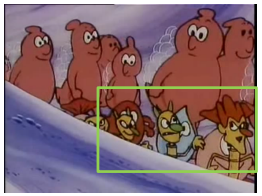
Krejtz et al. 2016

AREA OF INTEREST (AOI)

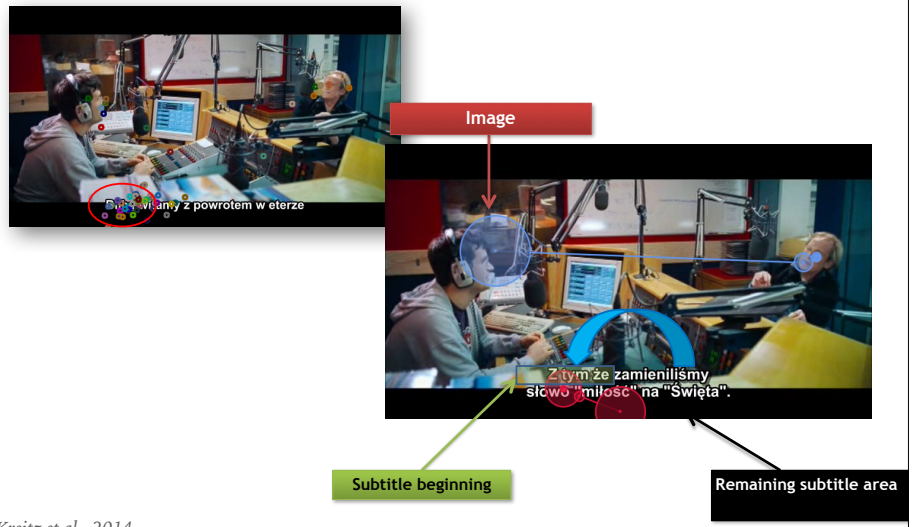


AREA OF INTEREST (AOI)

- Area/Region of visual field of particular interest concerning the hypotheses
  - Content/stimuli driven
  - Data driven
  - Gridded AOIs



EXEMPLARY DATA-DRIVEN AOIS

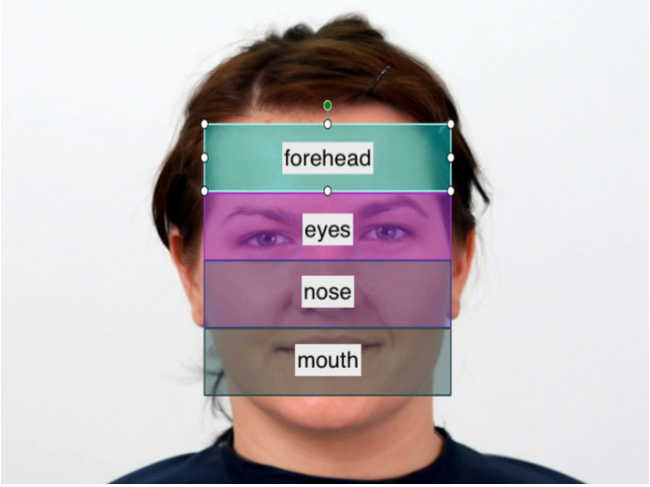


Krejtz et al., 2014

AOI - A FEW RULES OF THUMBS

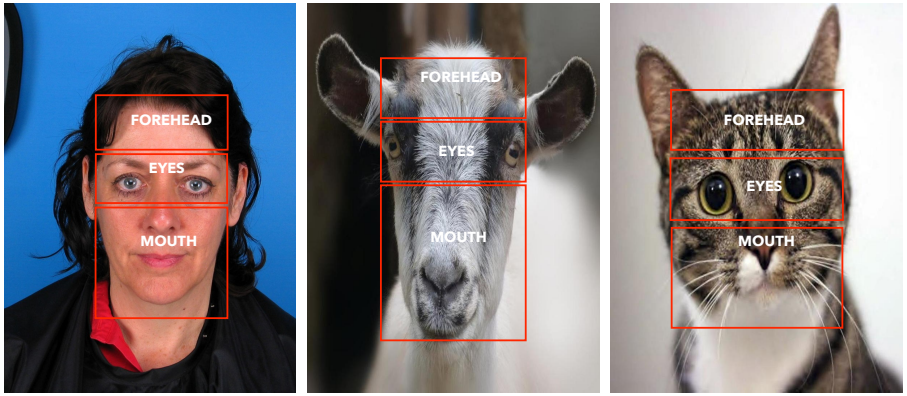
- AOIs definition strictly reflect hypotheses
- AOIs can not overlap
- Make them bigger than you want to
  - approx. 0.5deg on each side
- When analysing text the best is to make AOI around each word
- If possible keep the same size for all AOIs on one stimuli

EXEMPLARY AOIS ON FACE STIMULI

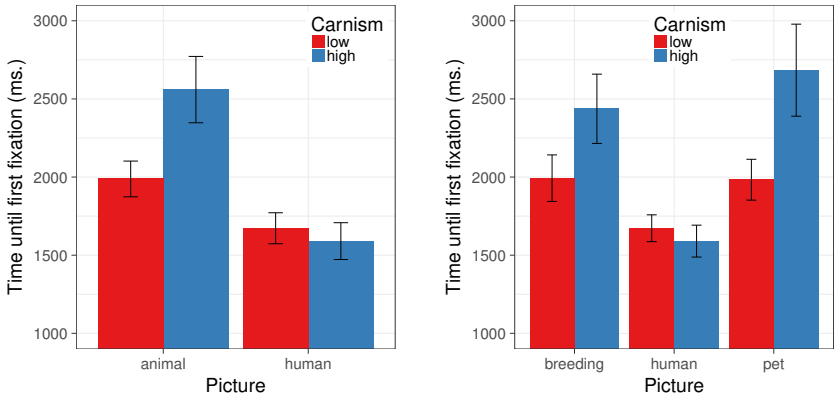


Krejtz at al. (2018)

AREAS OF INTEREST



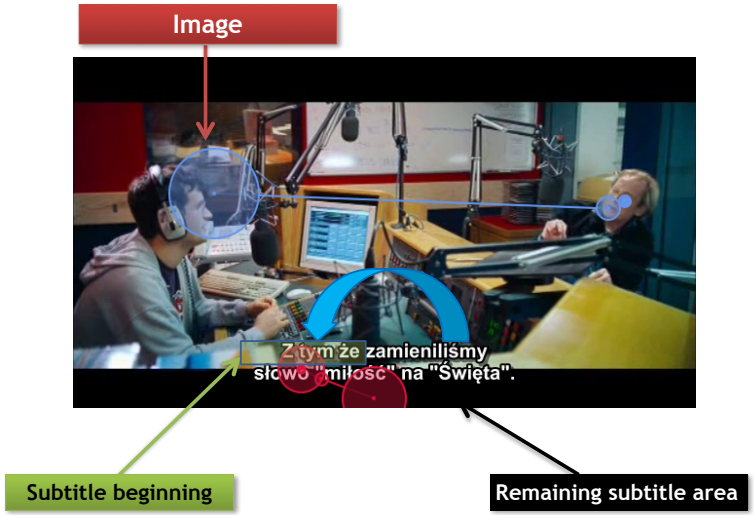
LOOKING INTO THE EYES



BASIC AOI STATISTICS METRICS

- Number of fixations
- Dwell time
- Average fixation duration
- Time to first fixation
- Number of regressions
- Subject hit count
- Transition matrix

TRANSITION MATRIX ANALYSIS



Krejtz et al., 2014

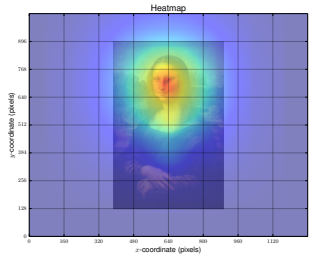
TRANSITION MATRIX WITH PROBABILITIES

FROM \ TO	BEGINNING	IMAGE	REST
BEGINNING	0.35	0.22	0.43
IMAGE	0.06	0.74	0.21
REST	0.11	0.28	0.62

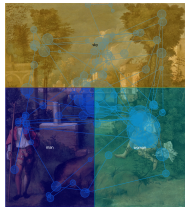
EYE MOVEMENTS DYNAMICS

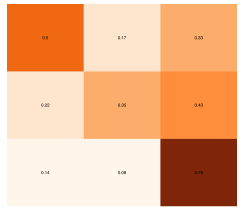
TWO APPROACHES TO EYE MOVEMENTS ANALYSES

- Gaze-location approach
  - AOI/ROI analyses
  - fixations distribution



- Visual attention process approach
  - scanpaths analyses
  - transition matrices entropy
  - relation between fixations and saccades





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”

TWO-STAGE MODELS OF VISUAL PROCESSING

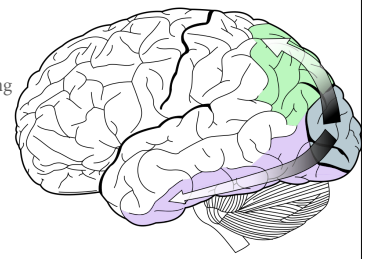
- The models often relates to
  - pre-attentive processing
    - spatially parallel
    - computation of simple visual features
    - non or nearly non attentional costs
  - attentive processing
    - spatially serial
    - computation of complex visual representations (involving combinations of features)
    - 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*)
- **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)
- **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



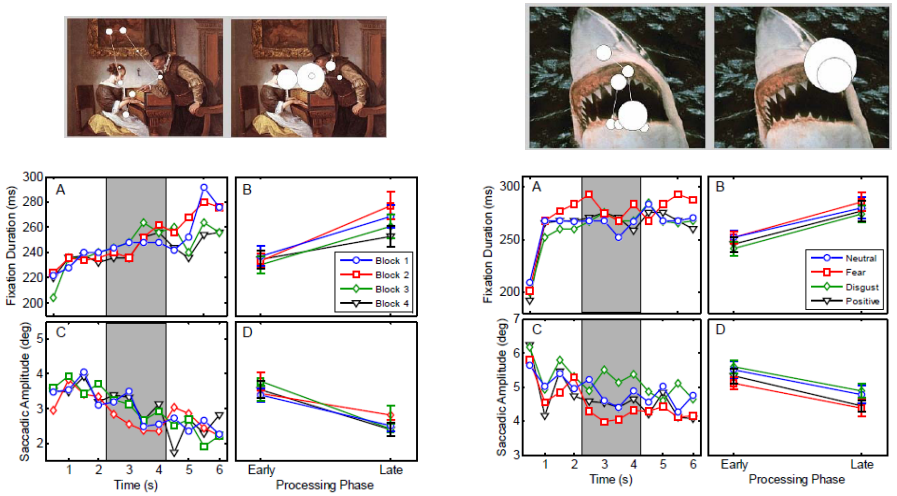
Visual identification

VENTRAL PATHWAY

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

AMBIENT - FOCAL EYE MOVEMENTS

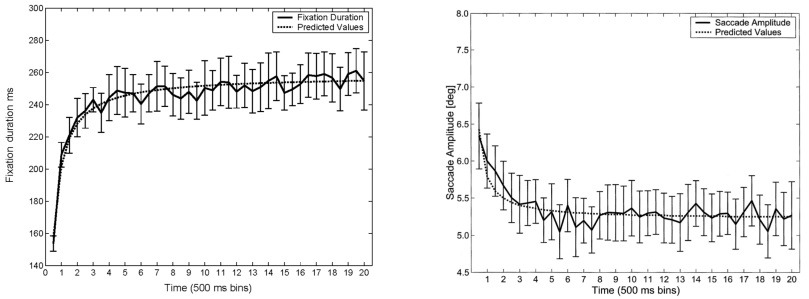
FIXATION DURATION AND SACCADE AMPLITUDE AT EARLY AND LATE STAGE OF INFORMATION PROCESSING



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

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INTERPLAY OF AMBIENT AND FOCAL INFORMATION PROCESSING

- Neither dorsal nor ventral systems fully controls attentional processes in isolation at any stage (see Vossel et al. 2015, Shomstein & Behrmann 2010)
- Since visual processing of complex stimuli is a continuous interplay between ambient and focal processing, it should be conceptualized on a single continuous scale (Krejtz at al. 2012, 2016)

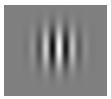
$$\mathcal{K}_i = \frac{d_i - \mu_d}{\sigma_d} - \frac{a_{i+1} - \mu_a}{\sigma_a} \quad \text{such that} \quad \mathcal{K} = \frac{1}{n}\sum_n \mathcal{K}_i$$

SEQUENTIAL (FOCAL) VS PARALLEL (AMBIENT) VISUAL SEARCH

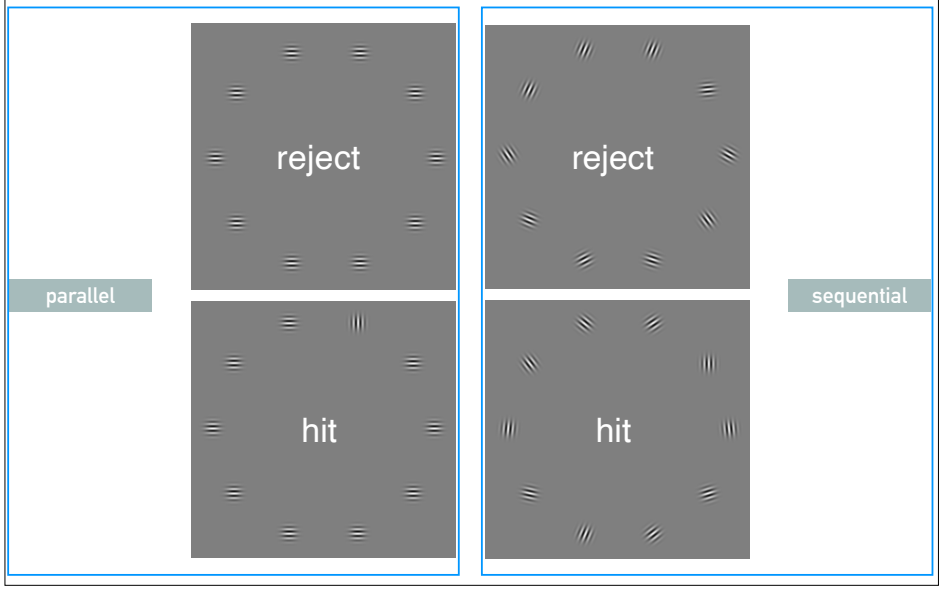
- **Assumption:** Ambient processing are related to parallel search and focal processing to sequential search (e.g., Nothdurft 1999)
- **Hypothesis**:
  - Sequential Visual Search Task (VST) will evoke focal eye movements while parallel VST will evoke ambient eye movements.
- **Design:**
  - within-subjects 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

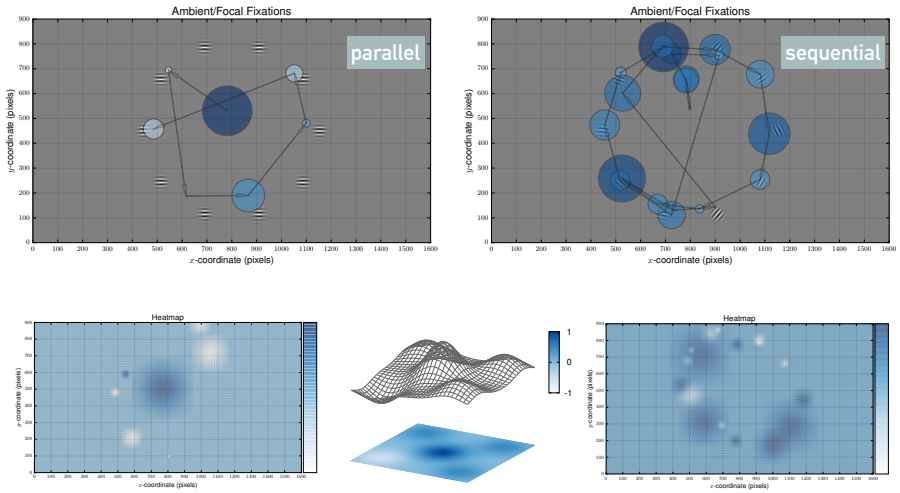


Find the target

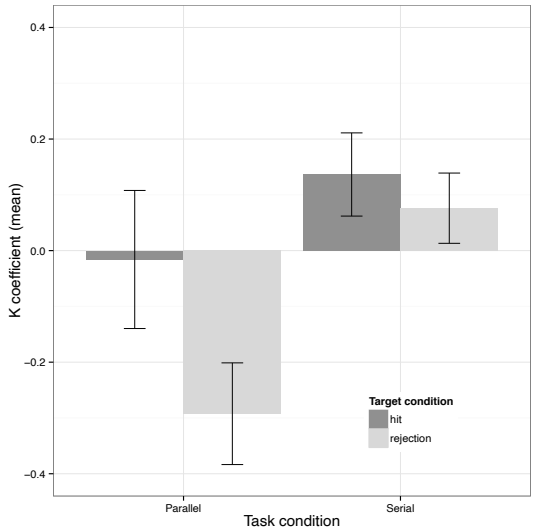


EXEMPLARY EYE MOVEMENTS VISUALISATIONS

Krejtz et al., 2016



FASTER RT AND MORE AMBIENT EYE MOVEMENT DURING PARALLEL VISUAL SEARCH



Krejtz et al., 2016

Interactive multimedia keep students focused

Impact of interactive educational tools on dynamics of attention and learning effectiveness

Krzysztof Krejtz (SWPS University, Warsaw, Poland)

Olga Borkowska (SWPS University, Warsaw, Poland)

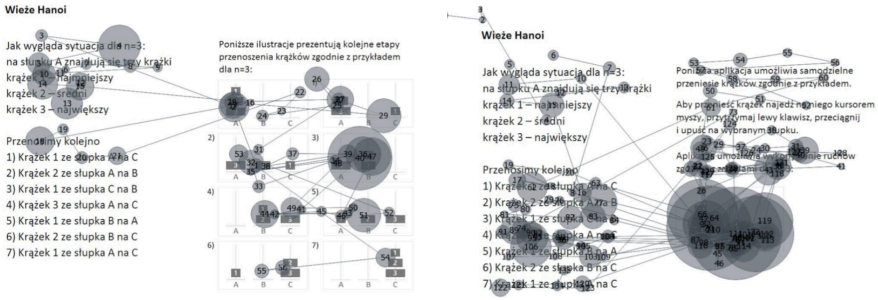
Andrew T. Duchowski (Clemson University, Clemson, SC, USA)

The challenge of multimedia learning researchers is to promote meaningful learning by **increasing active processing** while **reducing cognitive load**

Clark 1999, Sweller 1999, van Merrienboer 1997

Influence of interactive multimedia on visual attention allocation

- Using entropy-based comparison of gaze transition matrices Krejtz et al. (2016) showed that interactive simulation elicited more careful visual investigation of the learning material as well as reading of the problem.



Learning with multimedia instructions

- **Multimedia Effect**
  - People learn better from words and picture than words alone (Butcher 2014, Mayer 2002, Paivio 1986, Sadoski & Paivio 2001)
- **Affective & motivational component**
  - Visualizations enhance maintaining learner's attention by increasing attractiveness and motivation (Shah & Freedman 2003, Pintrich 2003)
- **Working memory capacity limitations**
  - Multimedia effect may be undermined when sufficient cognitive resources (Sweller 1999) are not present (Moreno & Mayer 2007, Kalyuga 2012)

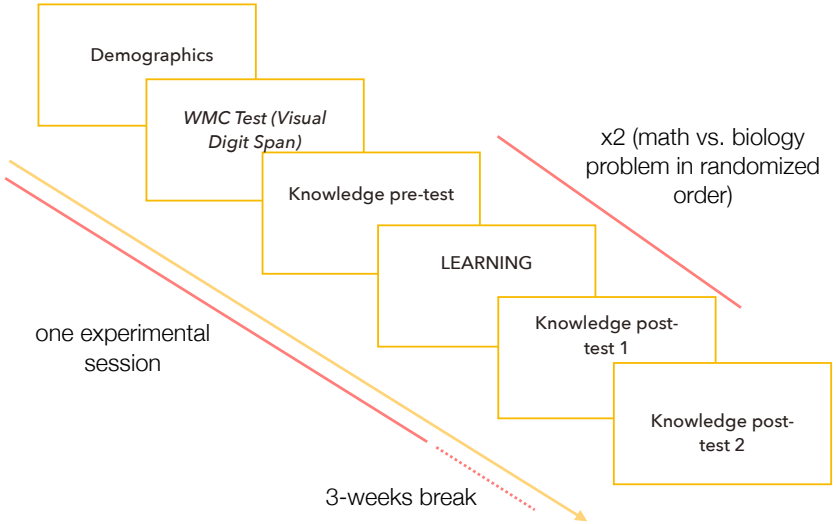
Hypotheses

- The use of the interactive learning instructions will affect
  1. Attention dynamics and allocation during learning
     - more focal attention
     - more attention on textual instructions
  2. Learning effectiveness
     - increase short- and long-term learning effects
- Interactive materials require higher working memory capacity (WMC)

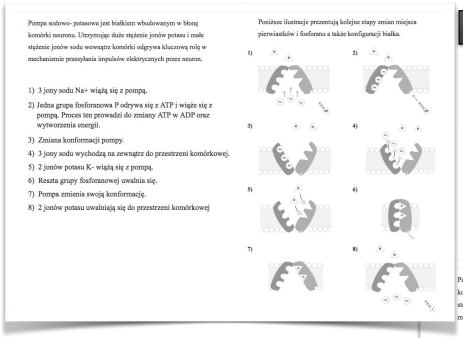
Method

- **Sample**
  - 20 psychology students (13f, aged: *M* = 25.50, *SD* = 8.46)
- **Equipment**
  - Eye tracker GazePoint 3 (60Hz)
  - Controlled by PsychoPy 2 experimental script
  - Python and R scripts for data processing & statistical analyses
- **Experimental design**
  - **2** (math vs. biology learning topics) **x 2** (static vs. interactive multimedia) **mixed design**

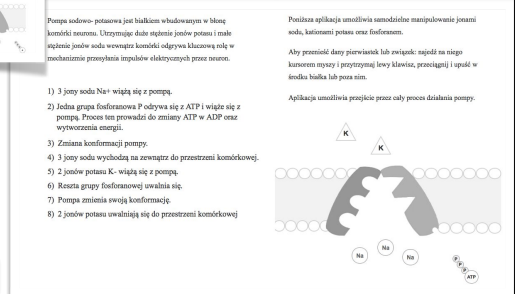
Method



Exemplary stimuli

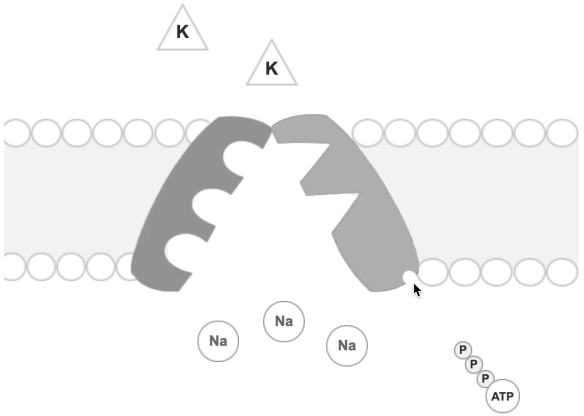


Static visualisation condition



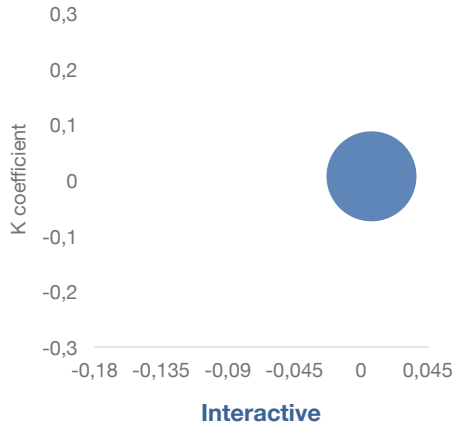
Interactive visualisation condition

Interactive stimulus example (biology: sodium-potasum pomp)

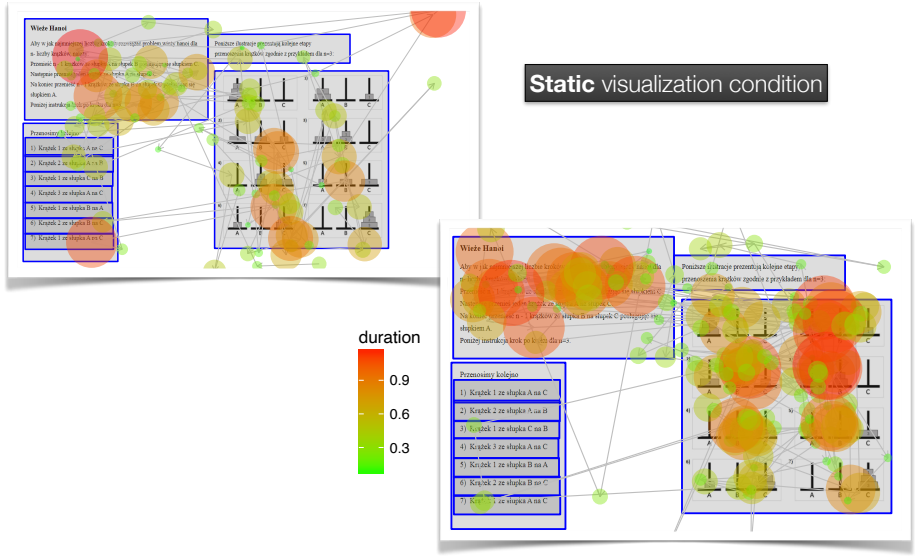


Results Focal attention during learning

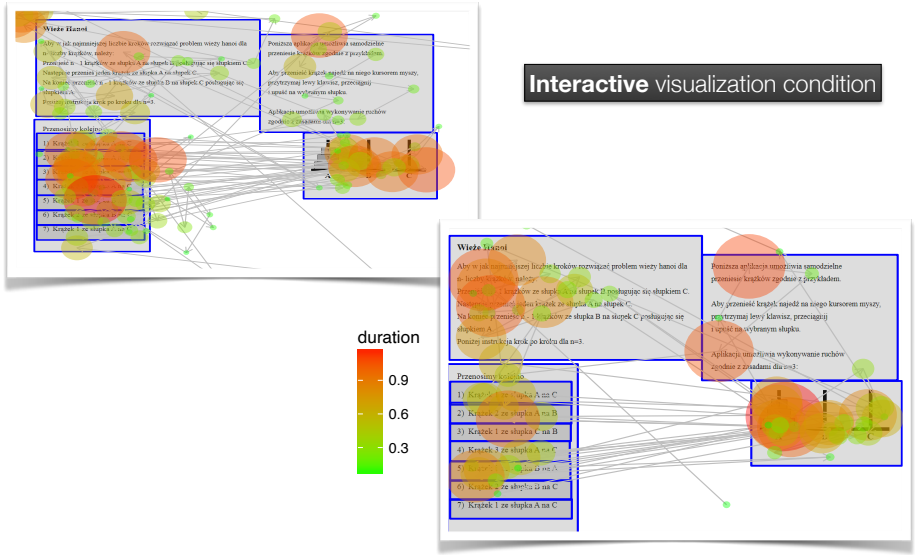
- Significantly more focal attention while learning with interactive visualization



Results distribution of attention - exemplary scan paths

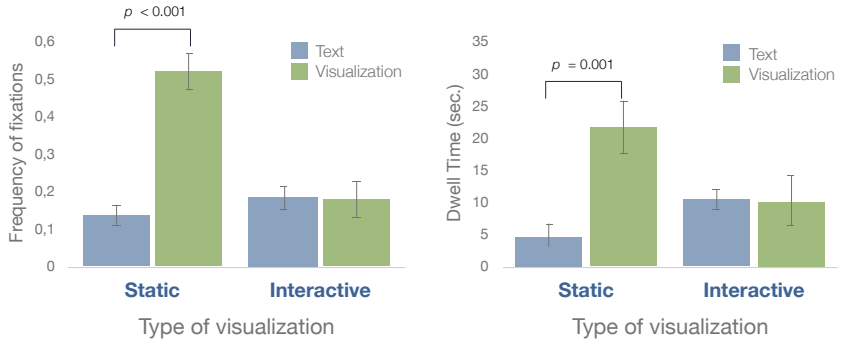


Results distribution of attention - exemplary scan paths



Results distribution of attention

- Equally distribute attention between text and visualization in interactive condition but only for Hanoi Tower problem



Results Effectiveness of learning

- Better short- and long-term effects of learning with interactive multimedia.
- The **higher WMC** the better **short-term** learning outcome in **interactive** condition