

The logo for Hochschule Neu-Ulm, consisting of the letters 'HNU' in a stylized, bold, white font.

Hochschule Neu-Ulm
University of Applied Sciences

The background is a photograph of a university campus, overlaid with a semi-transparent purple filter. On the left is a long, modern building with a series of windows. On the right is a tall, cylindrical tower with a checkered pattern. In the foreground, there are trees and a paved walkway with a few people walking.

**INTRODUCTION TO
EYE TRACKING FOR MATH
PART I (SET-UP, ...)
PART II (ANALYSIS, ...)**



Hochschule Neu-Ulm
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COMPUTER INTERACTION
AND WEB DEVELOPMENT

CONTENT OVERVIEW

**INTRODUCTION TO
EYETRACKING FOR MATH
→ PART I**

- 1. USER STUDY DESIGN**
- 2. EYE TRACKING**
- 3. EYE TRACKING FOR MATH**

USER STUDY?

Definition



A **user study** is any kind of research that involves users, e.g.,

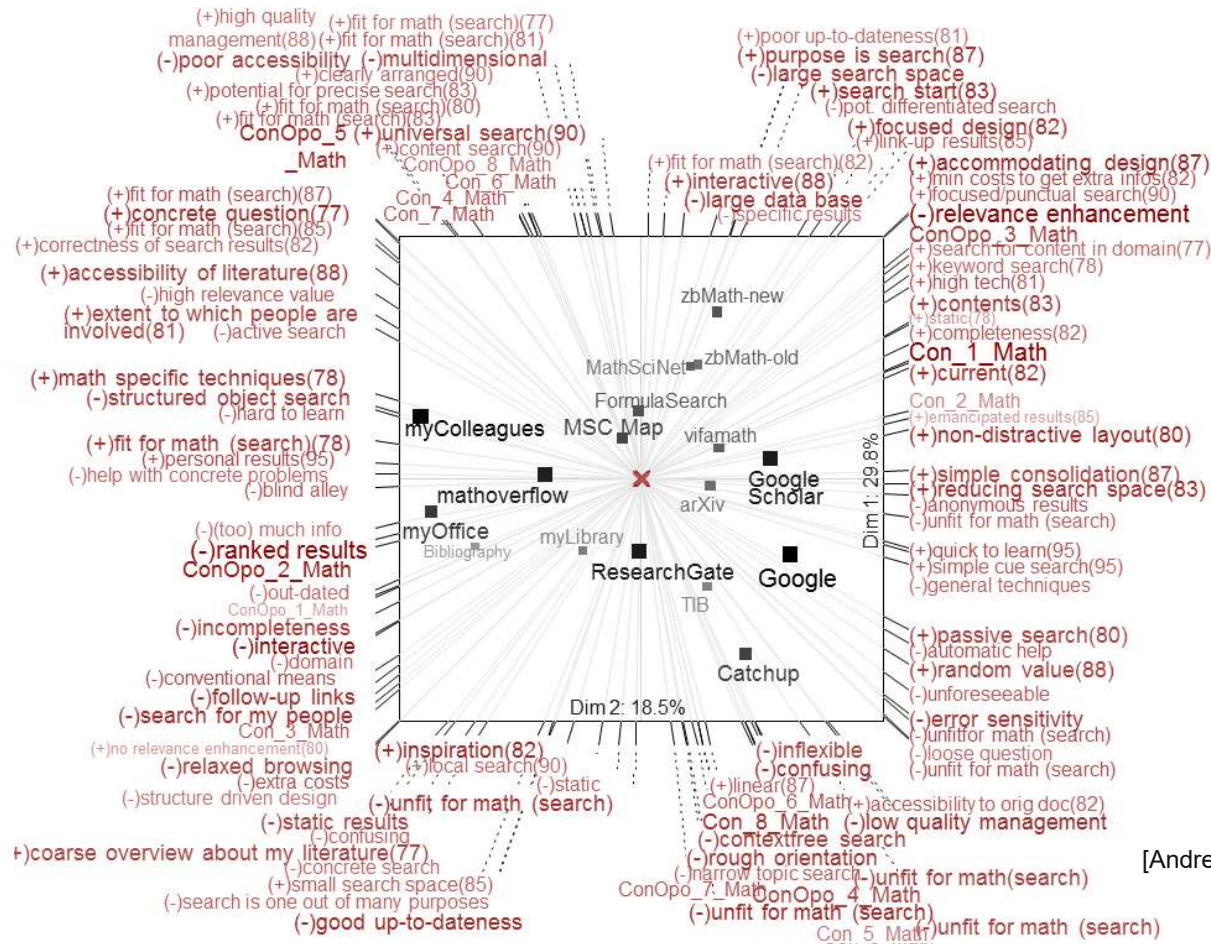
- Understanding the value of a product to users (usability testing)
- Understanding a target group by their behaviour and opinions (user research)
- *But not:* checking whether a software still has bugs (unit testing)

TARGET GROUP: MATHEMATICIANS

Are mathematicians special?



Use of mathematical Search Interfaces (mSI) by mathematicians?



[Andrea Kohlhasse: „Mathematical Search Interfaces and the Information Gap“, 2014]

TARGET GROUP: MATHEMATICIANS

Are mathematicians special?



Use of mathematical Search Interfaces (mSI) by mathematicians?

P 1 *“Mathematicians do not assess mSIs based on familiarity.”*

P 2 *“Mathematicians trust human and community resources.”*

P 3 *“Finding is the primary mathematical search task.”*

P 4 *“Mathematicians appreciate social interaction as a mathematical tool. In particular, it is a mathematical practice to collaborate and exchange feedback.”*

P 5 *“Mathematicians aim at adopting a search tool as a medium.”*

P 6 *“Mathematicians appreciate function over form.”*

P 7 *“Mathematicians care more for the outcome than the input.”*

P 8 *“Mathematicians want to be empowered in the search process.”*

P 9 *“Mathematicians base their information search process on transparency of the search result.”*

P 10 *“Mathematicians expect to find meaningful information in the search result.”*

[Andrea Kohlhase: „Mathematical Search Interfaces and the Information Gap“, 2014]

USER STUDIES ARE RESEARCH

→ They follow a general research process

1. Find interesting question(s)
2. Pick the right method(s)
3. Set-up and conduct a study
4. Analyze the collected data
5. (Discuss your findings)



PICK THE RIGHT METHODS

Find your methodology!



- Only if you know, **what you want to find out**,

you can decide **which methods** you need to apply to answer your research questions!

- This reasoning is your **methodology** (and needs to be documented in your final report)

→ We cover specific methods:

- Eye Tracking
- Emotion Tracking
- Think Aloud Protocol
- Surveys

VALIDITY OF METHODS

Guideline for clean insights: Triangulation

Triangulation by using the **see-say-do-triangle**:

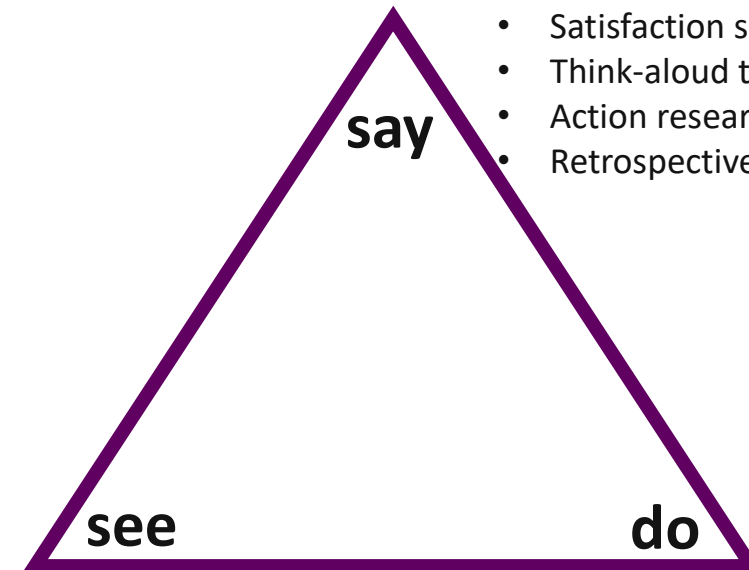
- Validate what users **see**
- Listen to what users **say**
- Measure/notice what users **do**

Getting Feedback:

- Interviews or questionnaires
- Satisfaction surveys (e.g., SUS)
- Think-aloud test
- Action research
- Retrospective cued recall

Observation:

- Eye Tracking
- Cognitive walkthrough
- User journey maps
- Use of personas



Performance Data:

- Time on task
- Mouse clicks
- Error rates
- Dwell time

WHY SEE-SAY-DO TRIANGLE?

Homer Simpson designs a car ...

„Edsel Corsair“

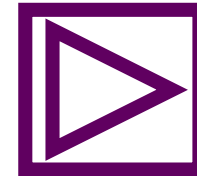


[https://en.wikipedia.org/wiki/Edsel_Ford resp. Edsel]

Ford later claimed to have performed more than adequate, if not superior, product development and market research work in the planning and design of the new vehicle. Particularly Ford assured its investors, and the Detroit automotive press, that the Edsel was not only a superior product (as compared to its Oldsmobile/Buick competition), but the details of its styling and specifications were the result of a sophisticated market analysis and research and development effort that would essentially guarantee its broad acceptance by the buying public when the car was introduced [<https://en.wikipedia.org/wiki/Edsel>]

The Homer

Owner	Powell Motors
Maker	Powell Motors - designed by Homer
Use	Concept, designed for the "average" American
First Appearance	Oh Brother, Where Art Thou?



3:34

[<https://www.youtube.com/watch?v=WPC-VEqBPHI>]

Why was it a failure?

THE HOMER

Why was it a failure?

- No triangulation used
- No representative sampling of users
- Users' beliefs about their wants and needs are typically too short-sighted

(Henry Ford:

„If you asked users before the invention of the automobile what they wanted, they would have answered a coach with 10 horses instead of 1“!)



HNH

EYE TRACKING?

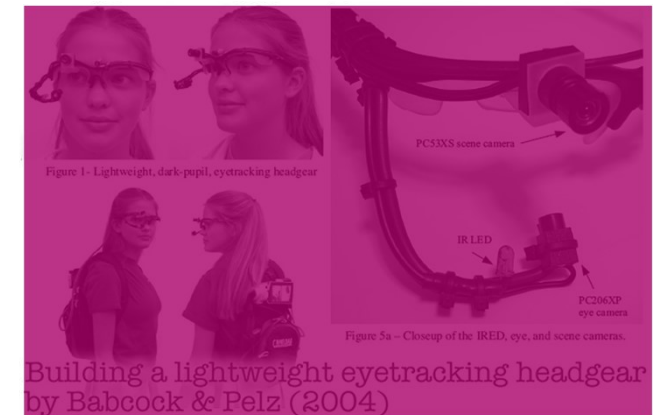
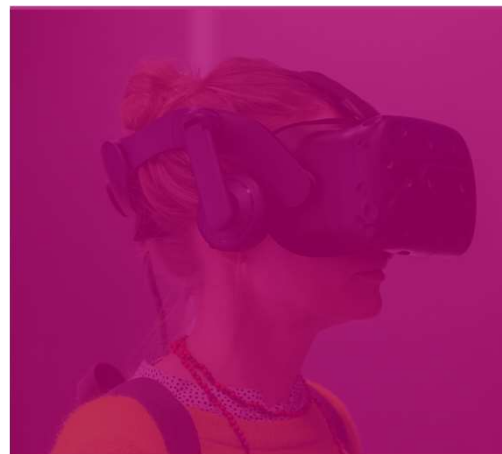
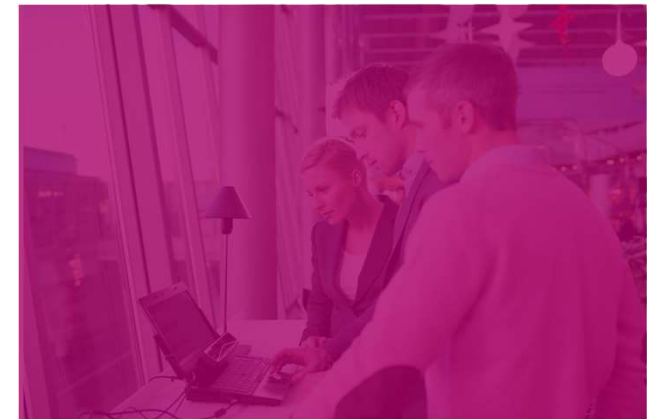
What is it and
what is it good for?

METHODS: EYE TRACKING

Eye-mind hypothesis

- An observation method to learn
 - Where a person is looking (at any given time)
 - In which order a person is looking at a given stimulus
 - How long a person is looking at one spot

- Eye trackers can be used
 - Stationary in a lab
 - Mobile laptop setting
 - Virtual Reality (even as input modality)
 - With glasses: „everywhere“

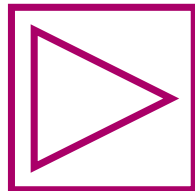


AN EYE TRACKING EXPERIMENT

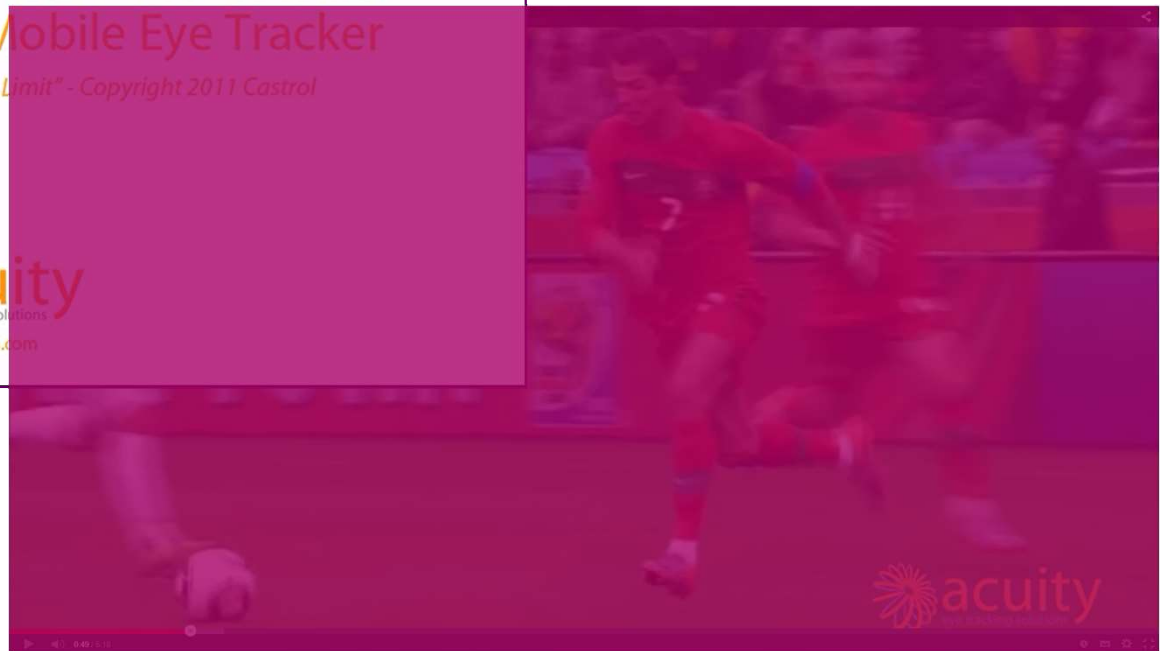
With „arrogant“ soccer player Cristiano Ronaldo

Eye Tracking Cristiano Ronaldo Using the Dikablis Mobile Eye Tracker

Taken from "Ronaldo - Tested to the Limit" - Copyright 2011 Castrol



0.14sec; 3.14min



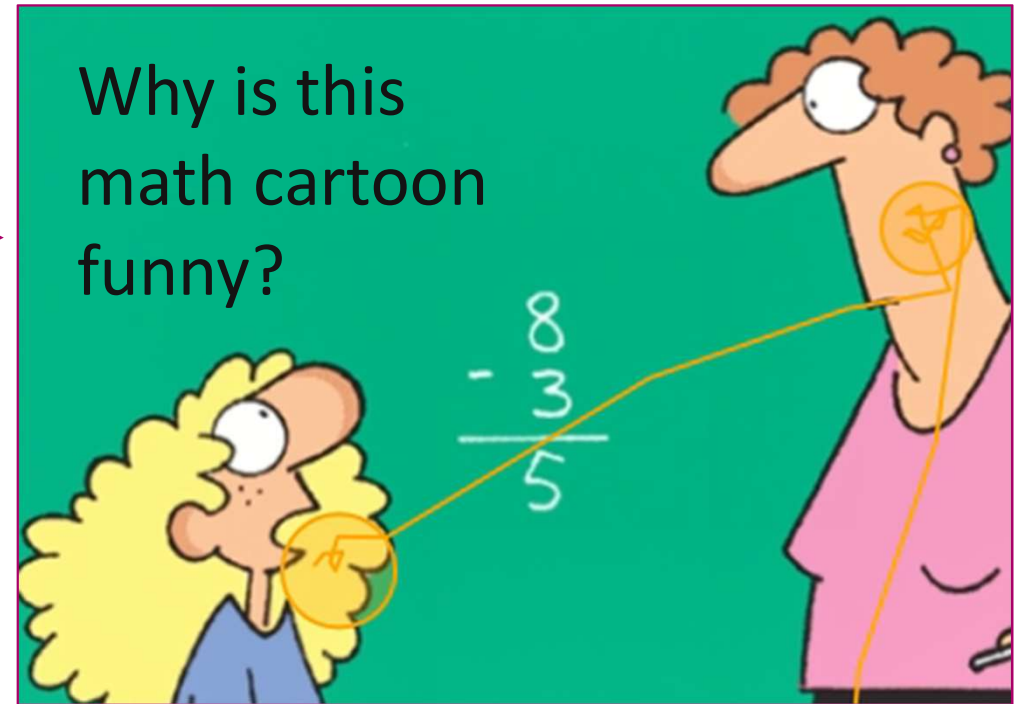
[https://www.youtube.com/watch?v=dZcCpBp4_rU]

WHAT CAN BE STUDIED?

With a mobile or stationary eye tracker device?

Screen-Based Study:

- Still images
- Videos
- Software applications
- Websites



<https://www.glasbergen.com/math-cartoons/cartoons/page/2> #18

The social context to interpret the math task makes it funny.



WHAT CAN BE STUDIED?

With a mobile or stationary eye tracker device?



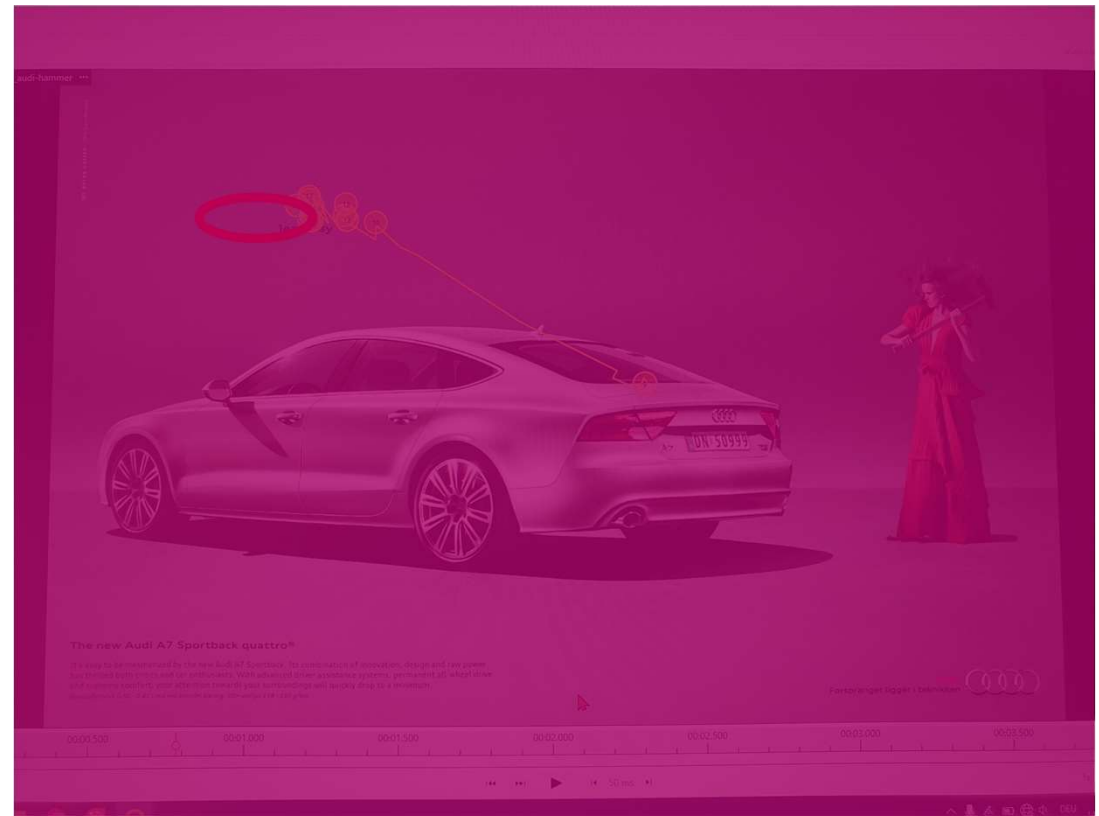
Screen-Based Study:

- Still images
- Videos
- Software applications
- Websites

EYE TRACKING EXAMPLE 1

Confirming hidden assumptions in street ads

- Car advertisement
 - Intended for use on ad boards along busy streets
- Hidden assumptions
 - Drivers have an emotional relationship with their cars
 - Women might be jealous
- Hidden assumptions in ad
 - Scanning: Car – aggressive woman?
 - Reading: „jealously“
 - Understanding the brand message:
This car strongly affects!



EMOTION TRACKING?

(Very short) Intro and Examples

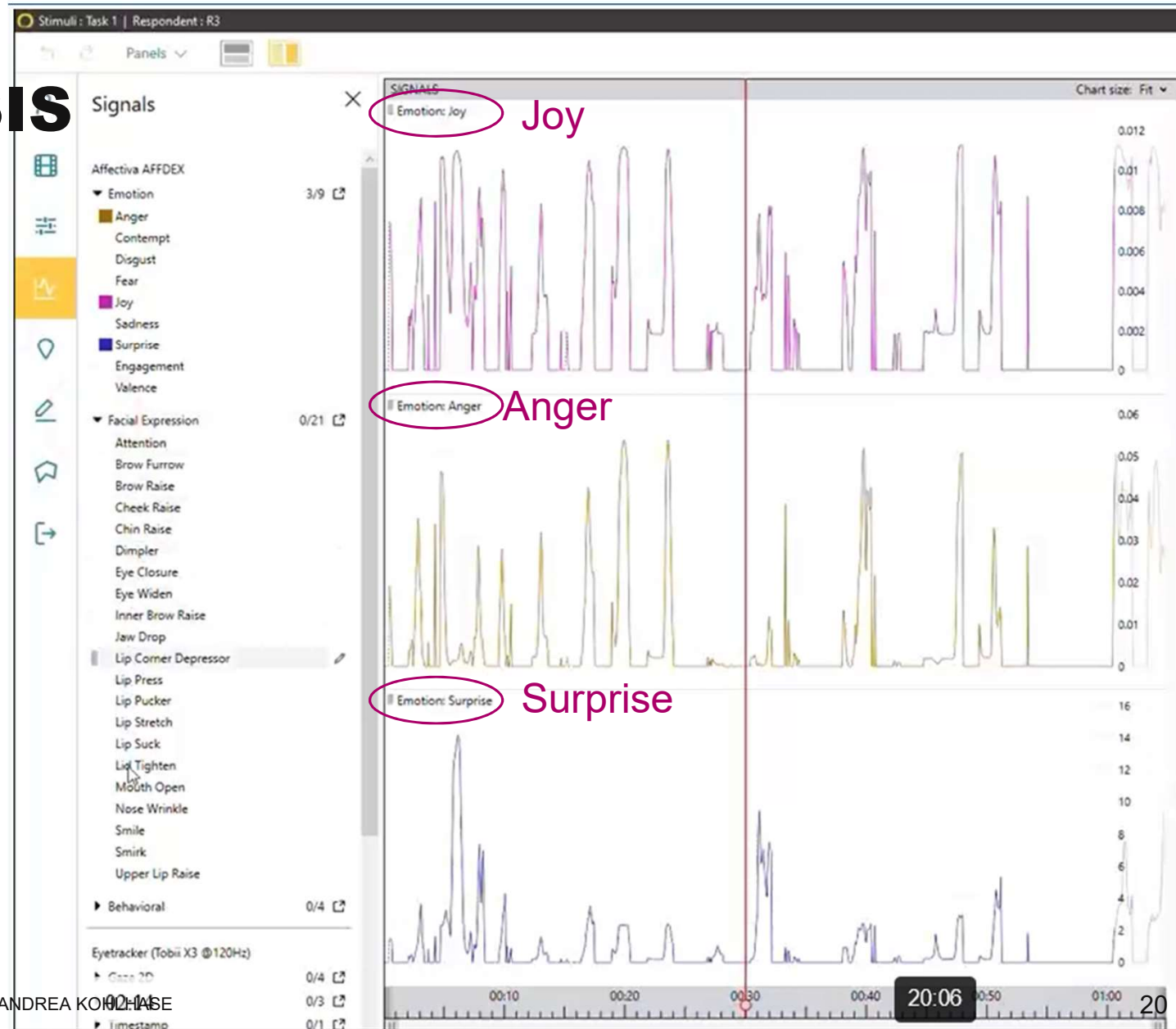
METHODS: EMOTION ANALYSIS

➤ Based on facial micro expressions recorded with a camera

➤ Emotions:

- Anger
- Contempt
- Disgust
- Fear
- Joy
- Sadness
- Surprise

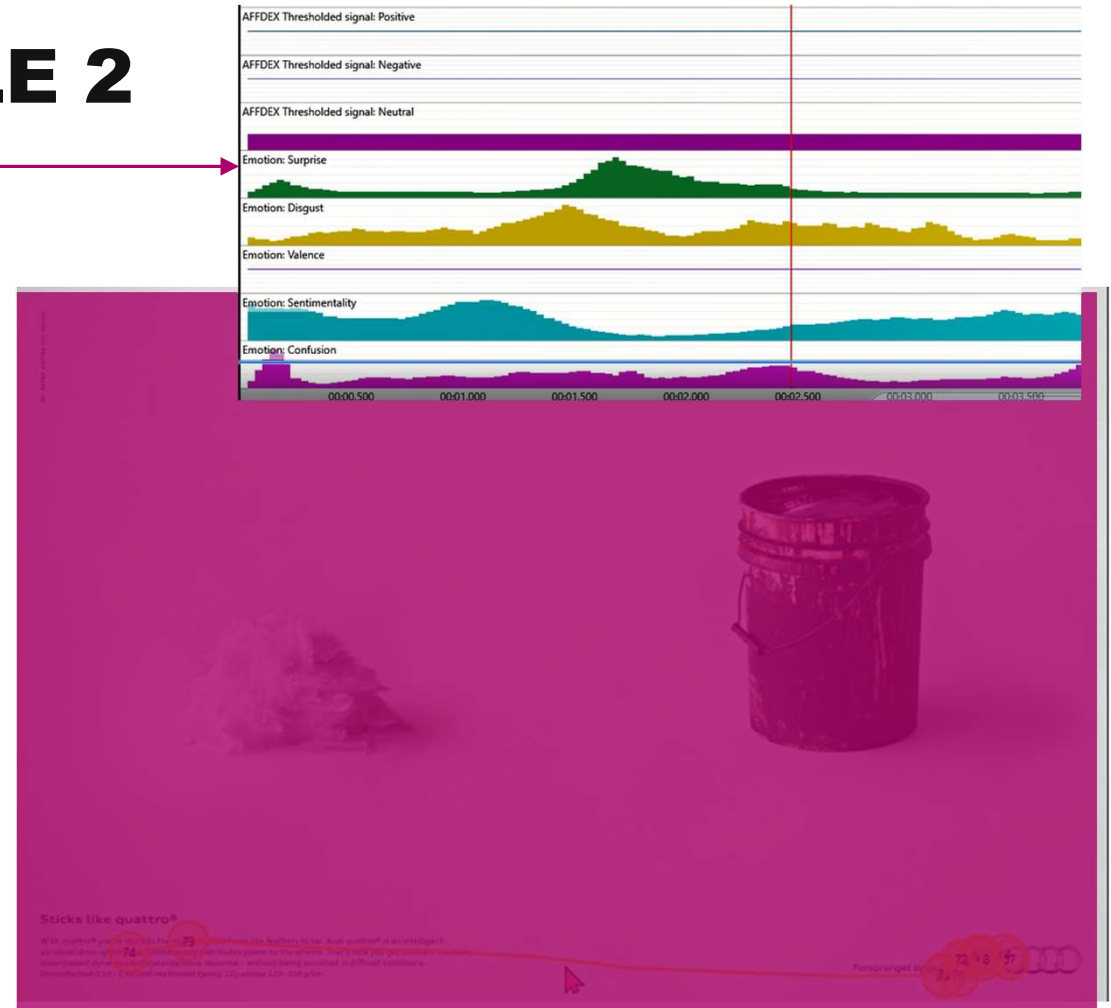
-
- Attention
 - Engagement
 - Valence (pos./neutral/neg.)



EYE TRACKING EXAMPLE 2

Together with emotion analysis

- Car advertisement
 - Intended for use on ad boards along busy streets
- Hidden assumption
 - The car *sticks* to the road
- Hidden assumptions in ad
 - Scanning: Tar - Feathers?
 - The association from tar/feathers to a car is clear
 - If not, reading the text in the lower left corner for clarification
 - Understanding the brand message:
This car is safe!



SURVEYS?

Some things you should be aware of ...

METHODS: SURVEY

Creating one is a form of art!

Facts about a person

Self-assessments about a person



Types of Questions

- Demographics, psychographics, content (knowledge, behaviour, evaluations, persuasions)

Form of Questions

- Open questions

- Closed questions

- Researcher needs to know all relevant answers beforehand

- Decide on kind of scale

- Single answer (radio button)

- Multiple answers (checkbox)

- Likert scale



- Semantic scale



- Decide on number of responses

- odd (always has a neutral element)

- even (always forces a tendency)

JEFF SAURO'S SOURCES OF SURVEY BIAS



[<https://measuringu.com/survey-biases/>]

- **Social desirability** *Don't you agree that recycling is an important initiative for companies to embrace?*
- **Yeah saying** *Do you want your coffee machine to have different profiles?*
- **Order effects** *What is your weight? Do you like chocolate?*
- **Prestige** *How much influence do you have on IT purchase decisions at your firm?*
- **Threat & hostility** *Are you married? (If divorced → negative thoughts)*
- **Sponsorship** (disclosing sponsors may impact responses)
- **Stereotype** (gender, race, technical ability, education → may reinforce stereotypes)
- **Mindset** (Carry-over effects) *Last time you used amazon, were you satisfied?
What is your overall impression on amazon?*
- **Motivated forgetting** (people forget events they don't like, they also invent events)

THINK ALOUD PROTOCOL?

Perfect for some
Eye Tracking scenarios

METHODS: THINK ALOUD PROTOCOL



A supportive method

- With a **thinking aloud protocol**, you observe participants while using a product and ask them to continuously think out loud — that is, verbalizing their thoughts as they move through the user interface.
- It sounds simple, but humans do not like to speak in a monologue, so often the stream of words stops inbetween
 - **Variant:** Let two participants use the product, so that they communicate about the product when one of them is using it.
- When to apply?
 - Usability testing
 - As support for whenever you cannot look inside the user, but are interested in her motivation/intent for acting

"Thinking aloud may be the single most valuable usability engineering method."

[Nielsen: „Usability Engineering“, 1993]

PLAN YOUR STUDY

Simple advice and
Eye Tracking metrics

PLAN YOUR STUDY

What do you need?



- Maybe, you have decided on your main study right now
 - by choosing your main method, e.g., eye tracking

- Now, think of your research questions again:
 - Can you really get all the answers by applying this method?

- For instance, with *eye tracking* you can get close observational data, but you don't know
 - what your participant is thinking and
 - why she acts like she does

So, maybe, you should add the *Think Aloud Protocol* to enhance your data collection. Moreover, you might want to use factors (like gender, age, education, ...) for your data analysis, so add a *pre-test* to gather demographics. Maybe, you want to know, how stressful the experience of product usage has been, so you add a *post-test*.

PLAN YOUR STUDY

How do you want to gather your data?

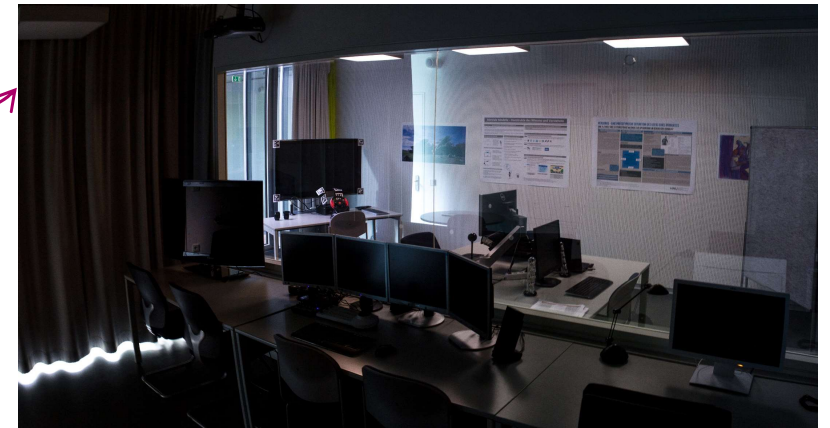
Which kind study is sensible for answering your research question?

➤ Field Study

- Natural setting → natural behavior
- Difficult for data gathering

➤ Lab Study

- Unnatural setting → possibly biased behavior
- Easy for data gathering

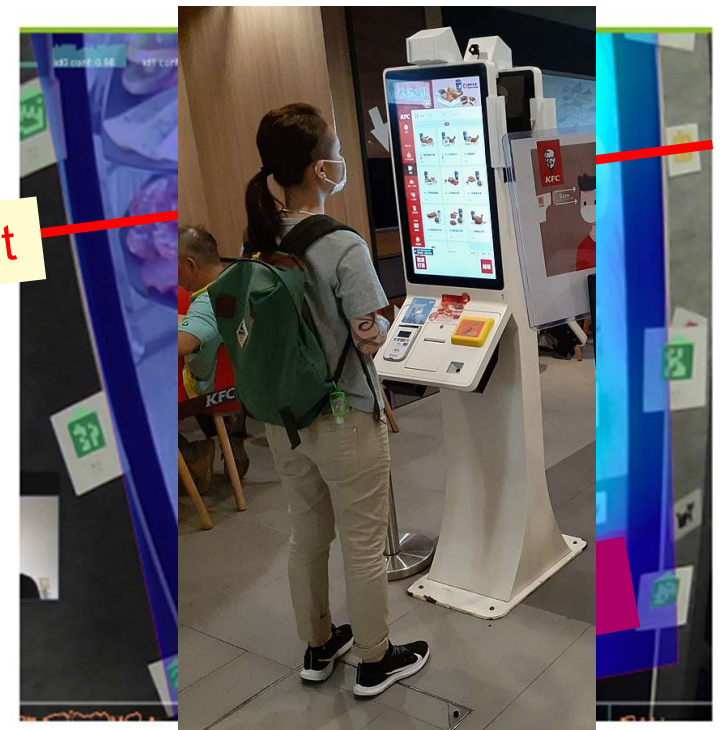


EYE TRACKING EXAMPLE 3

Detecting a design flaw

- We tested a (German) self-order terminal for a bakery
- Method: Eye Tracking experiment with think aloud test, pre-test (Interview), post-test (NASA-TLX)
- Setup: Participants stood in front of the terminal (start screen) and were told a scenario and
- Ad-hoc observation: many participants were confused how to continue
- Analysis via data visualization: Heat map
- Result: Participants didn't look at the bottom, where the concrete call-to-action was located

Average Eye Height



PLAN YOUR STUDY

Which metrics?



- Every method typically allows for **several metrics** to be tracked
- **Study your method** to gain the most from it and choose
- Think of **accompanying metrics** which data are easily elicited on the way.
- For instance, let us look at the **eye tracking method**
 - Many eye tracking software systems allow you to add a video stream of your participant.
 - Some of the **metrics** (see next slide)

PLAN YOUR STUDY: EYE TRACKING

Metrics provided by an eye tracker

- Where a person is looking (at any given time)
 - Point-of-Gaze (Location)
- In which order a person is looking at a given stimulus
 - Order of fixations
- How long or how often a person is looking at one spot
 - Fixation counts
 - Visit counts
 - Duration of fixation in an area-of-interest
- When and how often a person blinks → Blink rate
- How the eyes react with respect to stimulus conditions
 - Pupil dilation, saccadic intrusions



analyses are possible for any set among the participants

see [Poole&Ball: Eye Tracking in HCI and Usability Research: Current Status and Future Prospects]

SET-UP THE STUDY

Make the method ready

➤ For instance, for **eye tracking** you need to decide

- on **tasks** for the user
- how to **communicate** them to the user
- on which (concrete) visual **stimuli** to be used
- on the order of tasks (random, fixed)

➤ Make yourself familiar with the moderation process

Humans are task-driven, so many usability tests need tasks.

Imagine, you want to find out on amazon.com, whether the book „Jane Austen: Pride and Prejudice“ is available as a used copy.

How would you phrase the task?

Your mother's birthday is approaching. She likes Jane Austen, but the new books are still too expensive for your budget. Maybe, you find a used copy on amazon.com.

SET-UP THE STUDY

Make the method ready



➤ For instance, for **eye tracking** you need to decide

- on **tasks** for the user
- how to **communicate** them to the user
- on which (concrete) visual **stimuli** to be used
- on the order of tasks (random, fixed)

Imagine, you want to understand, how elderly people check whether they spend more than their available 100 laris on a shopping spree on amazon.com?

How would you motivate the task?

➤ Make yourself familiar with the moderation process

It's your birthday. You allowed yourself to spend 100 laris on gifts from you to you. But you really cannot go over that limit. So let's have a look at amazon.com now and have fun shopping ...

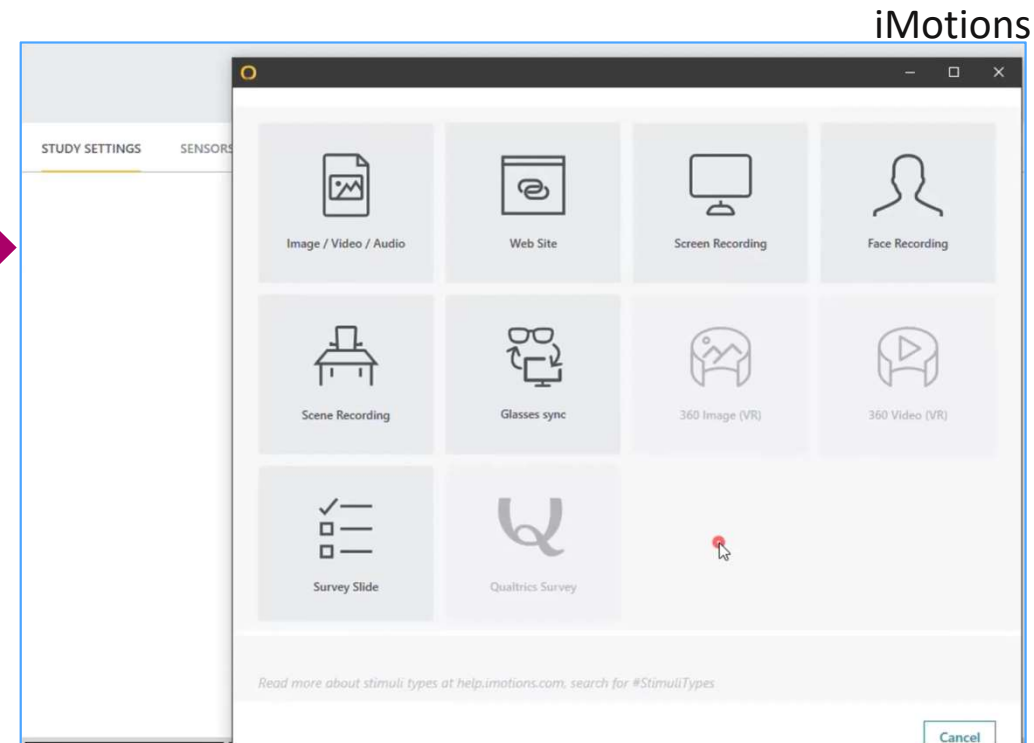
SET-UP THE STUDY

Make the method ready

➤ For instance, for **eye tracking** you need to decide

- on **tasks** for the user
- how to **communicate** them to the user
- on which (concrete) visual **stimuli** to be used
- on the **order** of tasks (random, fixed)

➤ Make yourself familiar with the moderation process



SET-UP THE STUDY

Organization



Whatever method(s) you have chosen, now you have to decide on all the **organizational elements**.

You have to determine:

- (exact) target group(s)
- Number of participants (theoretical and practical)
- Incentives for participants
- Date and time of study
 - Appointments for participants
- Availability of technology needed/reservations?
- Accessoires
 - Data privacy form
 - potential Forms printed out
 - pen (for signing, filling out, ...)
 - Time stopper
 - Situational items (lamps, chairs, ...)
 - Context items (candy, napkins, ...)

CONDUCT THE STUDY

Bad things do happen



- Every experiment can fail due to lots of reasons
- Do the best you can (and plan as meticulously as possible)
- Note down the participants names and encode them, e.g., for eye tracking
 - We keep a list of real and code name like [Andrea Kohlhase| P4]
 - The code name is associated to all the data, that is, the eye tracking data, the pre- and post-test data, ...
- Don't forget to write down (you forget after a while),
 - how many people you asked to participate,
 - How many participated
 - The dates and duration of running the study
 - The exact version and name of any technology you used in the study
- Make a safety copy of your collected data!

EYE TRACKING FOR MATH

Research Examples

EYE TRACKING EXAMPLE 4

Do we read math expressions like text or like an image?



Two-Dimensionality

breaking a single line

$$c_1(\delta(x))^{-\lambda_1} \exp\left(\int_{\delta(x)}^{\eta} \frac{z_1(s)}{s} ds\right) \leq a(x) \leq c_2(\delta(x))^{-\lambda_2} \exp\left(\int_{\delta(x)}^{\eta} \frac{z_2(s)}{s} ds\right)$$

3 lines that belong together

$$\begin{array}{l} b = 11 \\ a + b = 16 \\ a = ? \end{array}$$

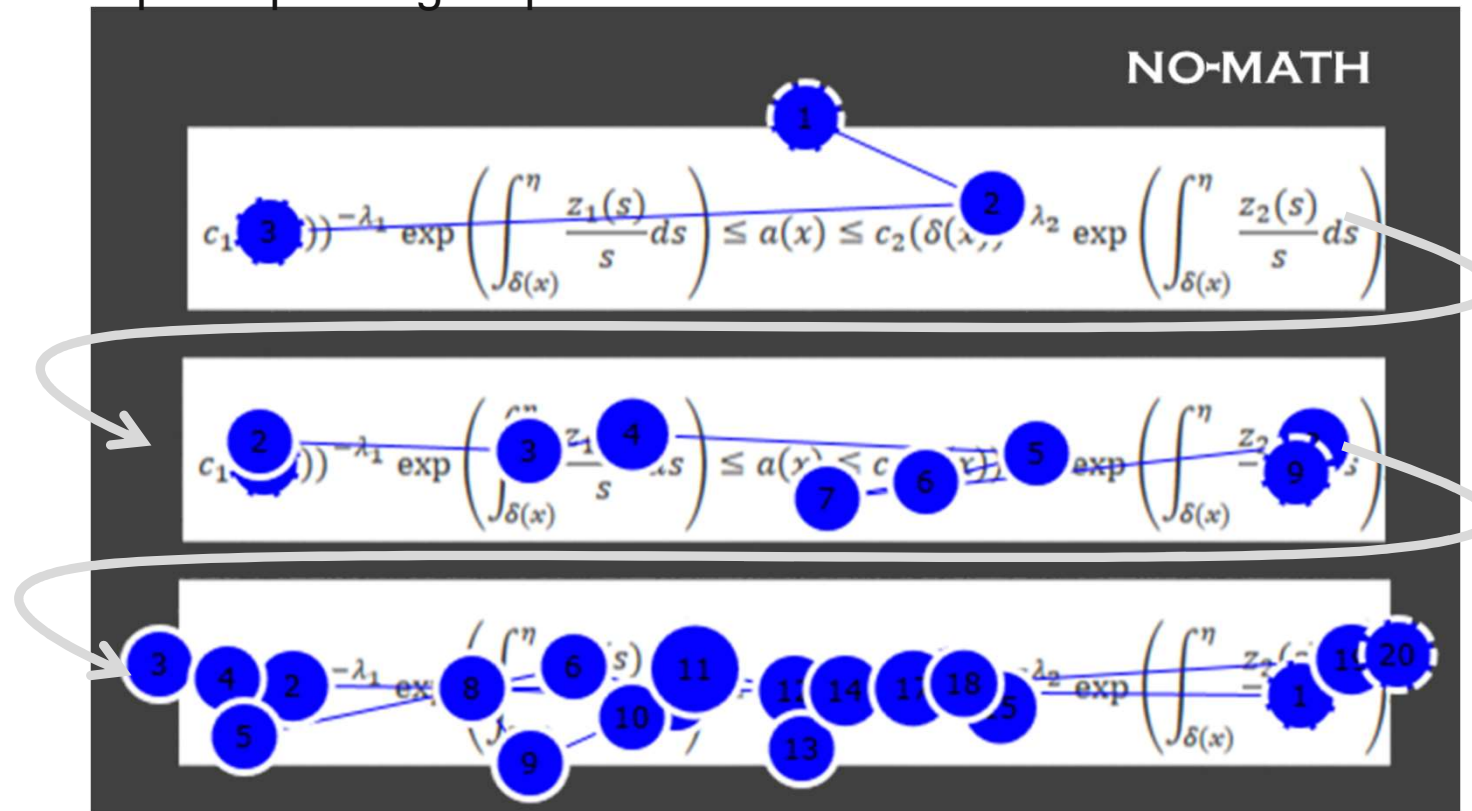
→ Text or Image?

TEXT OR IMAGE?

Let's find out

A participant's gazeplot

- math-oriented (MATH)
- non-math-oriented people (NO-MATH)



TEXT OR IMAGE?

Let's find out

- math-oriented (MATH)
- non-math-oriented people (NO-MATH)

Neither Text
nor Image

Visual
Structure

MATH

Panel 1 (Top): $c_1(\delta(x))^{-\lambda_1} \exp\left(\int_{\delta(x)}^{\eta} \frac{z_1(s)}{s} ds\right) \leq a(x) \leq c_2(\delta(x))^{-\lambda_2} \exp\left(\int_{\delta(x)}^{\eta} \frac{z_2(s)}{s} ds\right)$

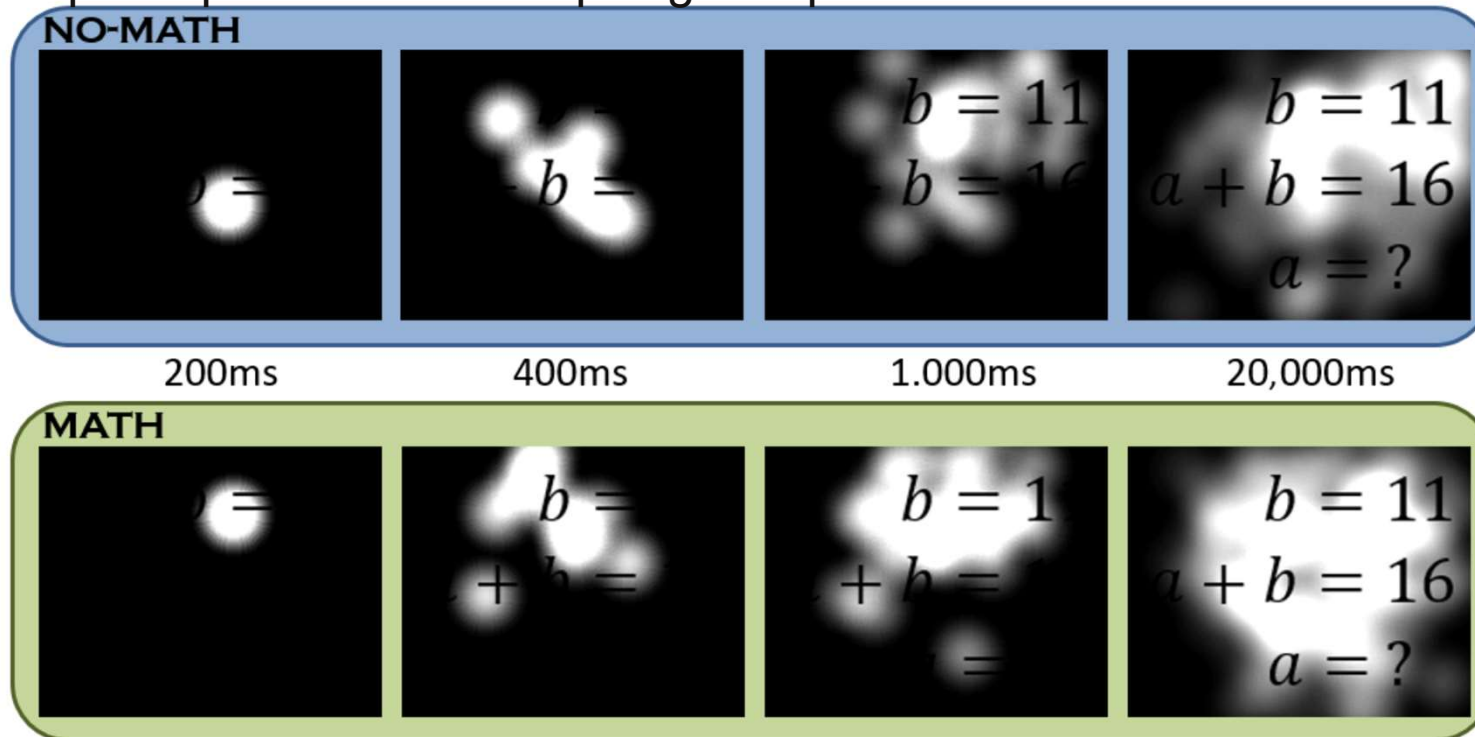
Panel 2 (Middle): $c_1(\delta(x))^{-\lambda_1} \exp\left(\int_{\delta(x)}^{\eta} \frac{z_1(s)}{s} ds\right) \leq a(x) \leq c_2(\delta(x))^{-\lambda_2} \exp\left(\int_{\delta(x)}^{\eta} \frac{z_2(s)}{s} ds\right)$

Panel 3 (Bottom): $c_1(\delta(x))^{-\lambda_1} \exp\left(\int_{\delta(x)}^{\eta} \frac{z_1(s)}{s} ds\right) \leq a(x) \leq c_2(\delta(x))^{-\lambda_2} \exp\left(\int_{\delta(x)}^{\eta} \frac{z_2(s)}{s} ds\right)$

TEXT OR IMAGE?

What, if we use a more simple math expression?

A participant's series of spotlightmaps



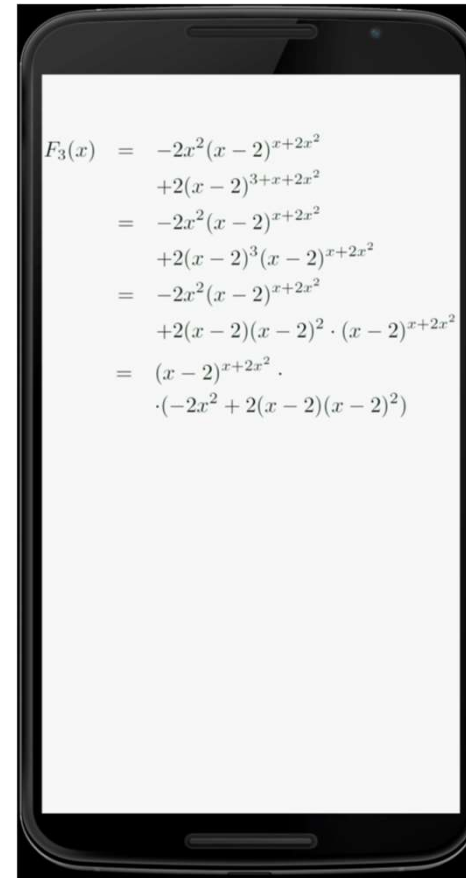
➡ Math Literacy!

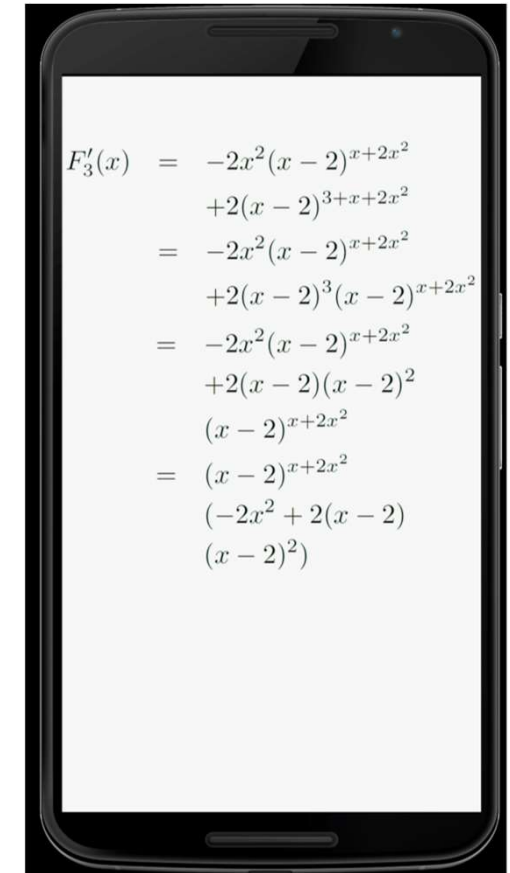
EYE TRACKING EXAMPLE 5 (FAILURE)

Decoding of math in different media



- Linebreaks in math expressions
- The question for the participants:
„Is this a correct equality system?“
- The study failed as the task involved too much cognitive load
→ Desperate participants


$$\begin{aligned}F_3(x) &= -2x^2(x-2)^{x+2x^2} \\ &+ 2(x-2)^{3+x+2x^2} \\ &= -2x^2(x-2)^{x+2x^2} \\ &+ 2(x-2)^3(x-2)^{x+2x^2} \\ &= -2x^2(x-2)^{x+2x^2} \\ &+ 2(x-2)(x-2)^2 \cdot (x-2)^{x+2x^2} \\ &= (x-2)^{x+2x^2} \cdot \\ &\quad \cdot (-2x^2 + 2(x-2)(x-2)^2)\end{aligned}$$


$$\begin{aligned}F'_3(x) &= -2x^2(x-2)^{x+2x^2} \\ &+ 2(x-2)^{3+x+2x^2} \\ &= -2x^2(x-2)^{x+2x^2} \\ &+ 2(x-2)^3(x-2)^{x+2x^2} \\ &= -2x^2(x-2)^{x+2x^2} \\ &+ 2(x-2)(x-2)^2 \\ &\quad (x-2)^{x+2x^2} \\ &= (x-2)^{x+2x^2} \\ &\quad (-2x^2 + 2(x-2) \\ &\quad (x-2)^2)\end{aligned}$$

SUMMARY

Intro to Eye Tracking for Math



- User Study Design
 - Mathematicians as a special target group
- Eye Tracking
 - What is it and examples for what it is used for?
 - Accompanying methods
 - Emotion Tracking
 - Think Aloud Protocol
 - Surveys
- Eye Tracking for Math

WANT TO BE A PARTICIPANT IN A REAL EYE TRACKING EXPERIMENT?



Please tell me and
we arrange a time slot today, tomorrow or Wednesday!

- The experiment will last up to max. 30mins.
- **A new learning experience** and this will stay in mind
- We (hopefully) can look at your data in class on Friday morning!

HNU

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