Designing eye tracking experiments to measure human behavior

Eindhoven, The Netherlands
August, 2010

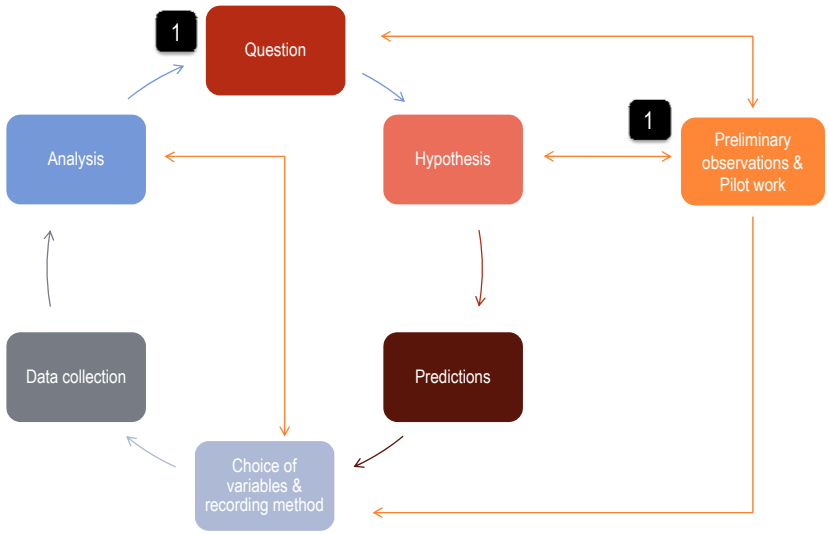
Ricardo Matos
Tobii Technology

tobii
www.tobii.com

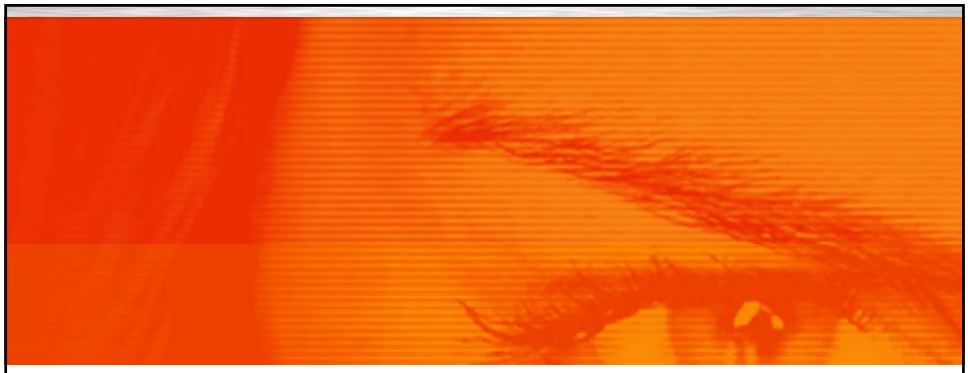
Steps involved in measuring behaviour

1. Formulate and initial question and make preliminary observations
2. Formulate hypothesis and make predictions
3. Choose behavioural measures and research design
4. Define each measure
5. Select the appropriate recording method
6. Practice the recording method
7. Collect data
8. Analyse data

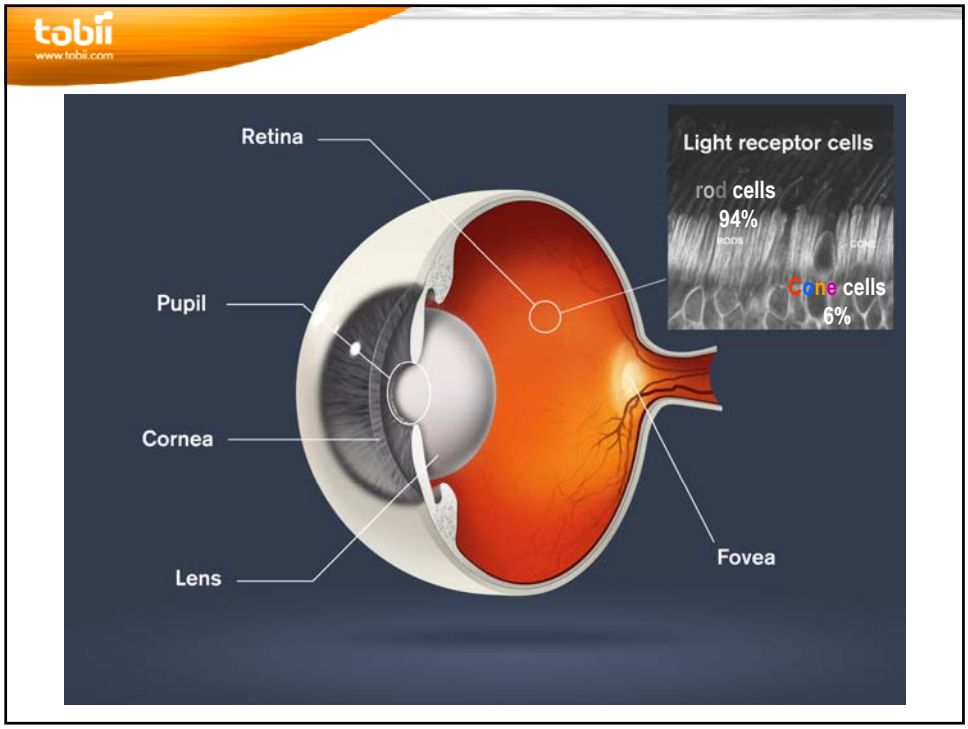
Cyclical nature of the research process



But first…

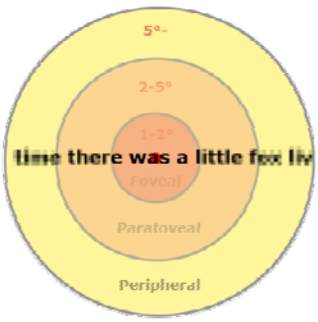


WHAT ARE WE MEASURING WITH EYE TRACKING?

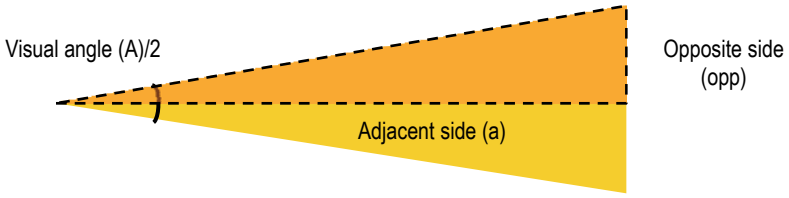


What do we see?

- The human visual field = 220º
- The 1-2º area of foveal vision is about the size of a thumbnail on an arm lengths distance

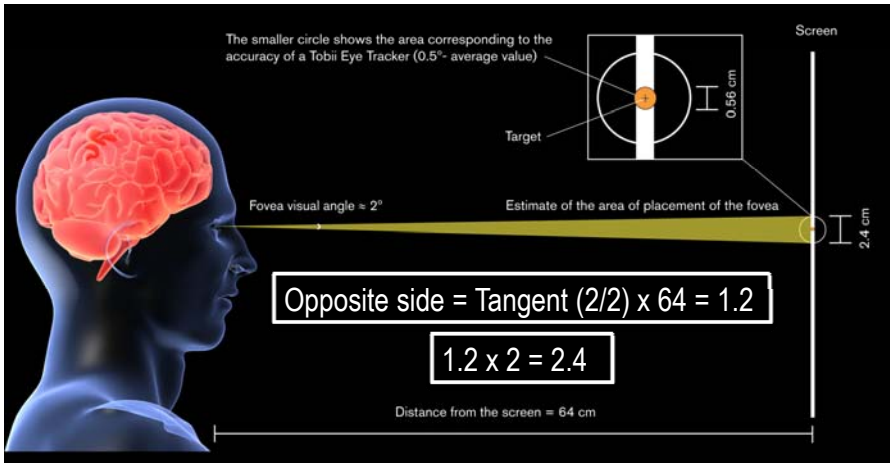


Visual angle trigonometry



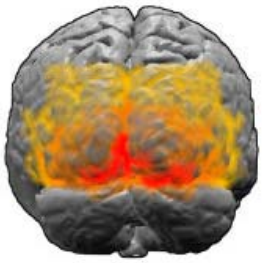
Opposite side = Tangent (A/2) x Adjacent side

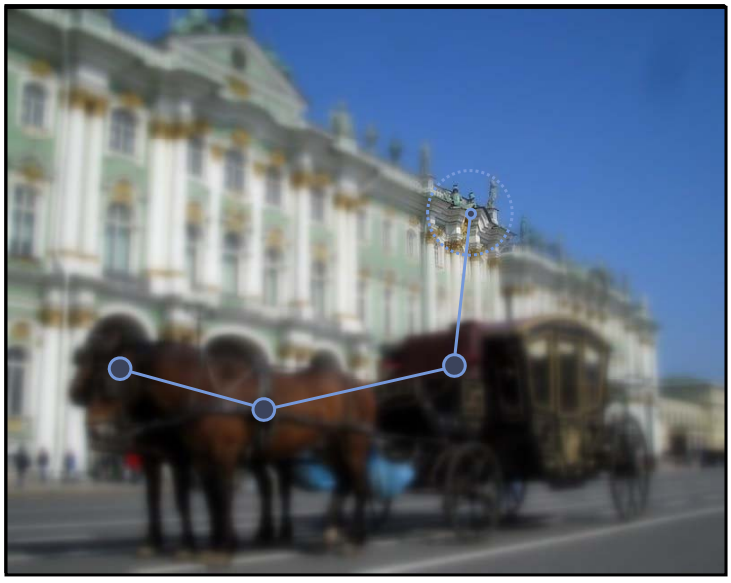
Visual angle calculation



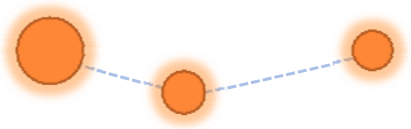
What do we see?

- The fovea is less than 1% of the retina but takes up over 50% of the visual cortex in the brain.
- Peripheral vision is mainly good at picking up movements and contrasts



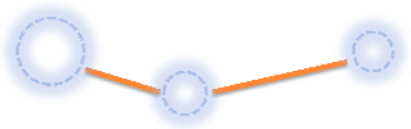


Fixations



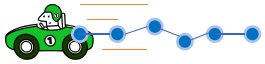
- The fixation lengths varies from about 100 to 600 milliseconds, during this stop the brain starts to process the visual information received from the eyes.
- All the information from the scene is (mainly) acquired during fixations.
- Typical fixation frequency is < 3 Hz
- The length of a fixation is usually an indication of information processing or cognitive activities.
- Common words get shorter fixations than less common words

Saccades



- Saccades are extremely fast jumps from one fixation to the other and the average length of a saccade is about 20-40 ms, can be up to 600o/s
- When reading English the mean saccade size is 7-9 letter spaces
- Saccadic suppression: vision is largely suppressed during the movement
- The end point of saccade cannot be changed during the movement
- Regressive saccades and the saccade pattern can reveal confusion and problems understanding

Smooth Pursuit



- Slow eye movements that stabilize the image of a slowly moving target on or near the fovea
- Typical speed is < 30°/s, the eye movements are initiated within 90-150 ms
- Above 30°/s smooth pursuit requires catch up saccades
- It is asymmetrical, we perform better when we follow objects moving horizontally, than vertically
- Associated to spatial attention, e.g. other objects beside the target are poorly processed

Eye-mind hypothesis

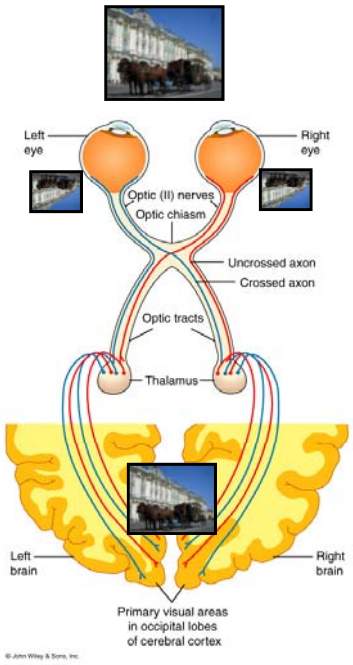
Link between eye movements and cognitive processes

tobii
www.tobii.com

Visual neurological pathway

The nerve impulses pathway from the retina to the visual cortex, located in the occipital lobe of the brain

e.g. Thalamus is related to consciessness and awareness

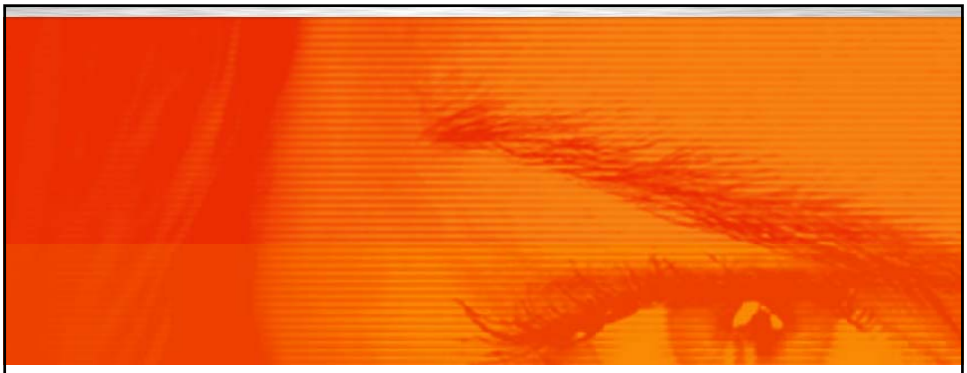


tobii
www.tobii.com

Back to designing an eye tracking experiment…

Steps involved in measuring behaviour

1. Formulate and initial question and make preliminary observations
2. Formulate hypothesis and make predictions
3. Choose behavioural measures and research design
4. Define each measure
5. Select the appropriate recording method
6. Practice the recording method
7. Collect data
8. Analyse data



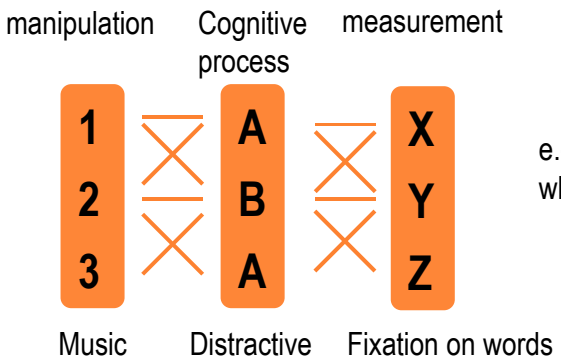
FORMULATING THE INITIAL RESEARCH QUESTIONS

Experimental design process

Translates the **hypothesis** into an empirical experiment where the **independent variable** appears as a **stimulus**, and the **dependent variables** are measured as an **object's reaction** to that stimulus.

Cognitive processes are complex

It is challenging to establish a specific association between eye movements and cognition



e.g. Music is distractive when reading

Cognitive processes are complex

Some associations are better understood than others, e.g.:

- Fixations are typically correlated with attention
- During reading regressive saccades are associated with comprehension difficulties
- Blink rate with psychoticism

Qualitative observations and analysis

Provides raw material for formulating questions; familiarity with subjects and test context

Gaze Replay

The Eiffel Tower is an iron tower built in 1889 in Paris, France. It was named after its designer, Gustave Eiffel, and is the tallest building in Paris. It was originally supposed to be built in Barcelona, Spain. The entire building weighs about 10,000 tons.

Get acquainted to your system…

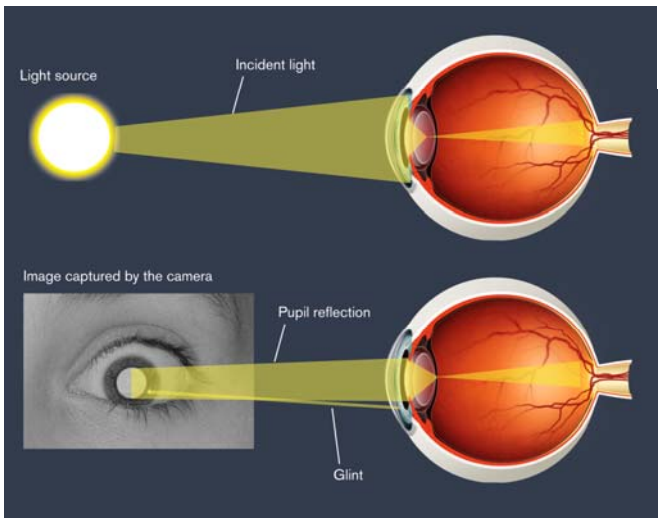
- Know what to expect from your eye tracker
- Familiarize with its specifications and usage

REMOTE EYE TRACKERS

tobii
www.tobii.com

How does remote eye tracking works

Pupil Centered Corneal Reflection



Remote Eye Trackers main technical features

tobii
www.tobii.com

Remote eye tracking equipment

Interactive Minds
Eyefollower

Tobii X60/120

SMI
iView Red

Tobii
T60/T120

LC Technologies
Eyegaze

ALS D6 Remote
Tracking Optics

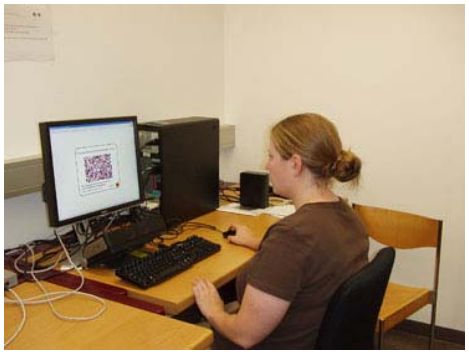
Tobii T60XL

SR- Research
Eye Link

tobii
www.tobii.com

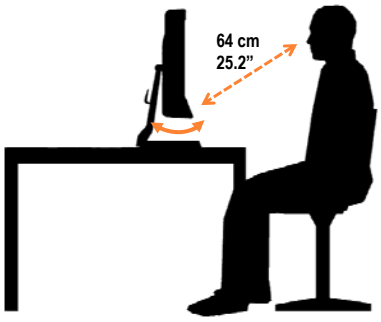
Eye trackers types

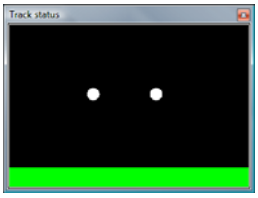
Tobii T60 / T120
Tobii T60 XL



Tobii x120

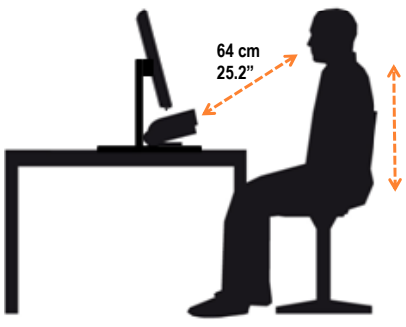
Tobii T Series Eye Tracker usage

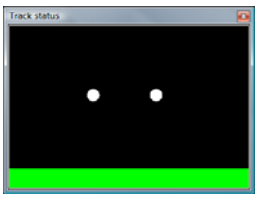




Tracking distance	50-80 cm
Head Movement Box	44 x 22 cm at 60 Hz 30 x 22 cm at 120 Hz

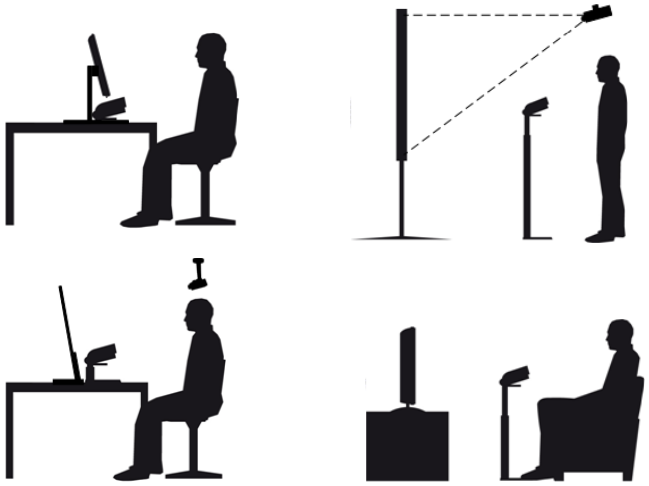
Tobii X Series Eye Tracker usage





Tracking distance	50-80 cm
Head Movement Box	44 x 22 cm at 60 Hz 30 x 22 cm at 120 Hz

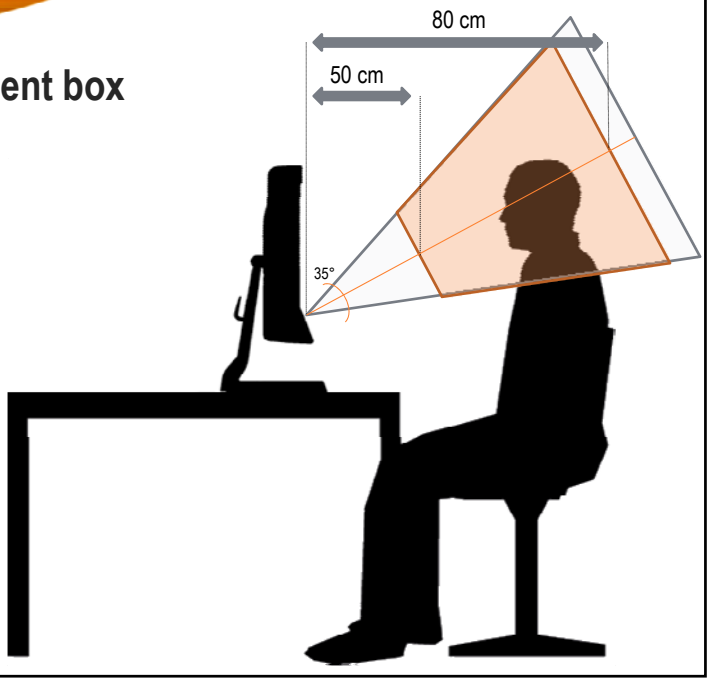
X60 / X120 is more flexible



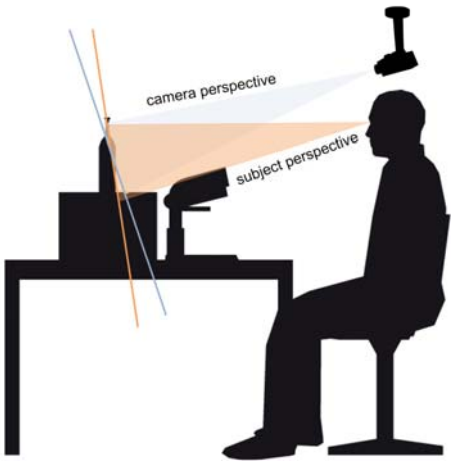
Head movement box

Head movement range

Camera field of view

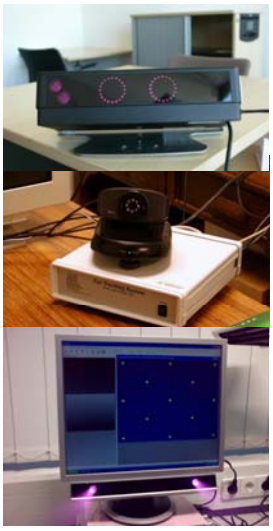


Paralax errors using a scene camera



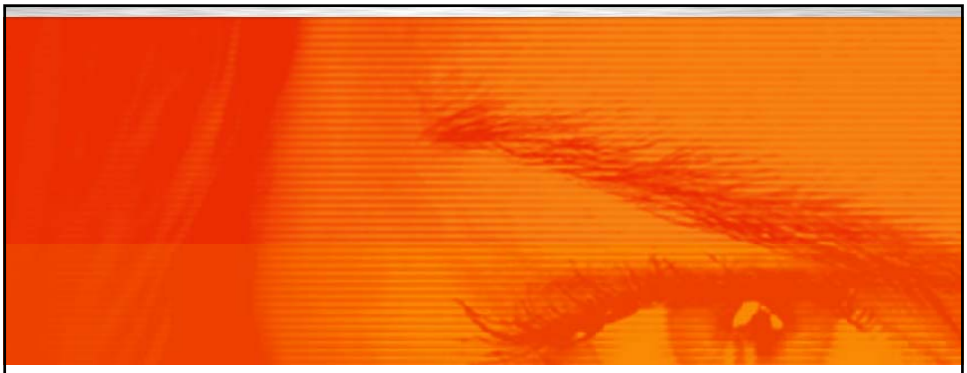
Remote Eye Trackers main technical features

- DP-BP Pupil corneal reflection techniques
- Dual or single sensor/eye camera
- Monocular or Binocular tracking
- Embeded processor or dedicated gaze data processor
- Feature detection or combined with 3D Eye Model
- Accuracy 0.5 - 2°



Difficult eye tracking circumstances

- Very high surrounding NIR-light levels (bright daylight or focused halogen spotlights)
- Some bi-focal and progressive glasses
- Very damaged or very dirty glasses
- Very ”droopy” eye-lids or extremely small pupils
- Very dark environments
- Always calibrate with background intensity similar to that of the stimuli
- Tobii Eye Trackers work with about 95% of the population but expect to have some problems with about 5-10% of your respondents.



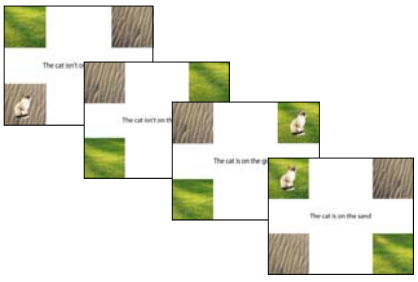
RESEARCH DESIGN AND CHOOSING THE BEHAVIORAL MEASURES

Design issues

- Controls, order effects and interactions
- Experimenter bias
- Task bias
- Independence of measures
- Coping with individual differences

Order effects: repeated exposure to stimuli

- Novelty
- Sensitisation
- Fatigue
- Performance
- Treatment interactions



Factorial design, randomization using Latin Square

Experimenter & subject bias

Expectations about the outcome of the experiment affect behaviour of: the subject, data recording and analysis

Double Blind experiment

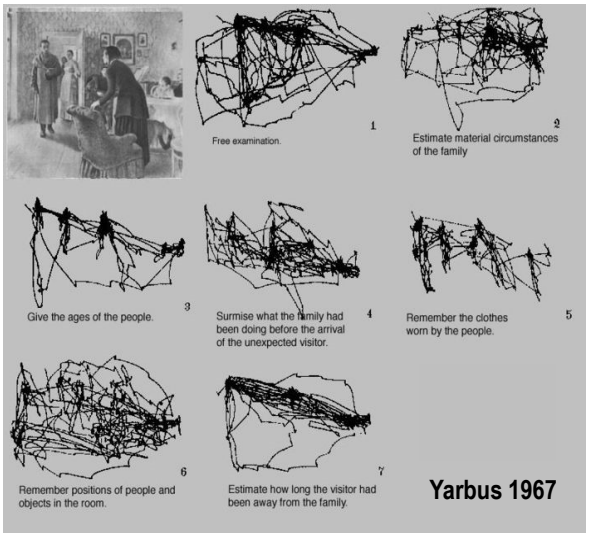
Neither the subject nor the test supervisor should know the treatment

High risk

✓

Task bias

- Free Observation
- 6 Tasks
- 3 min. recording of the same subject



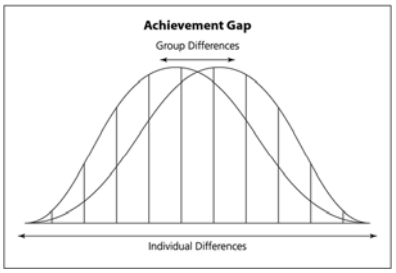
Task bias

- Should be neutral regarding the treatment and control
- Should be engaging
- Plausible story or transparent: stop the participant from trying to guess

Copying with individual differences

Increases the amount of variability within a group and reduces the power of a test

- **Repeated outcome measurements**
- **Baseline measurements**
- **Repeated Baseline and outcome measurement**
- **Increase the sample size**



Independence of measures

Statistical tests assume that the data is from a random sample and that each data point is independent

- **"Pooling fallacy":** treat repeated measurements of the same subject as if they were independent...

Treatment Measured

A → 6x
B → 6x
C → 6x

Individuals → 3

?

n = 18

n = 3

Independence of measures

Statistical tests assume that the data is from a random sample and that each data point is independent

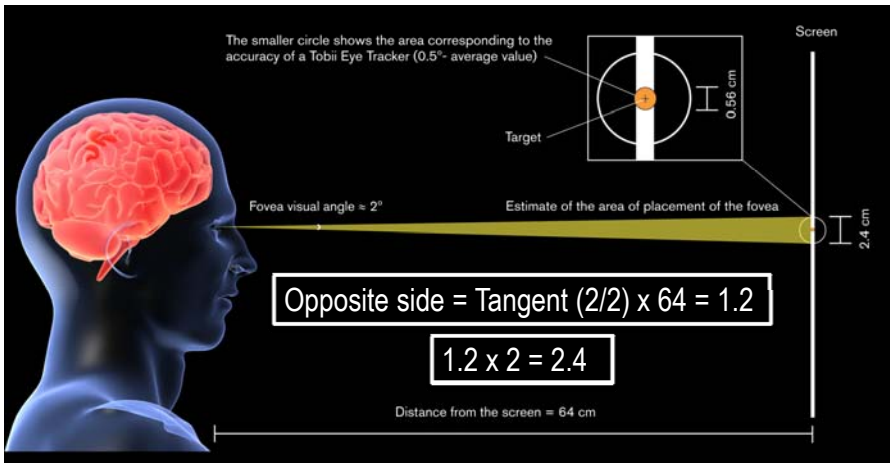
- **Group effects:** within group variation < between group… e.g. children belonging to the same school
- **Measures have non-trivial associations:**… e.g. fixations can be measured in duration, number of occurrences and mean duration. Only two of these measurements are independent.

Verify the conspicuosness of the setup

Different setups have a different impact on the subject's attention.

less conspicuos is less distractive

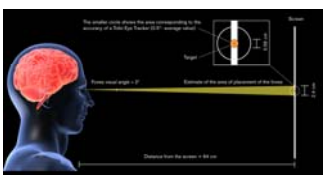
Human perception and eye physiology



Stimulus size and visual perception

Text size

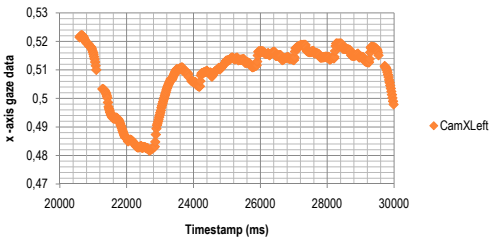
Text size

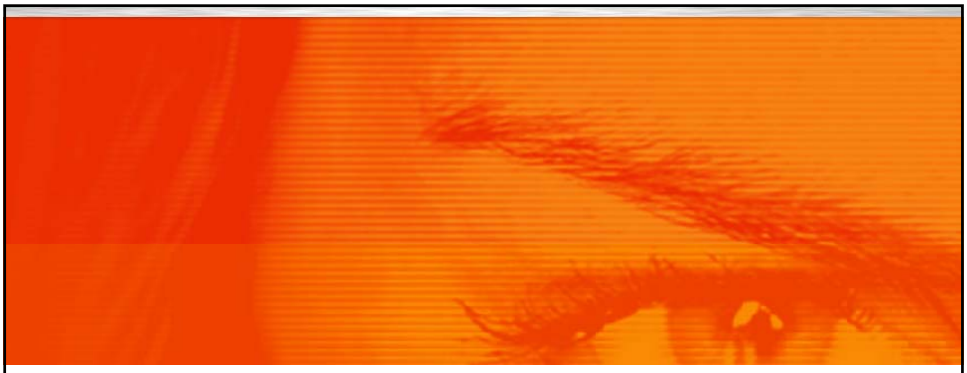


tobii
www.tobii.com

Before the test!

- Double check the setup and record some pre-trials
- Troubleshoot potential adverse light conditions
- Observe how pre-trials participants react to the setup
- Inspect the data: timing, accuracy, data loss





COLLECTING DATA

Eye tracker sampling rate

Which sampling rate I should use?

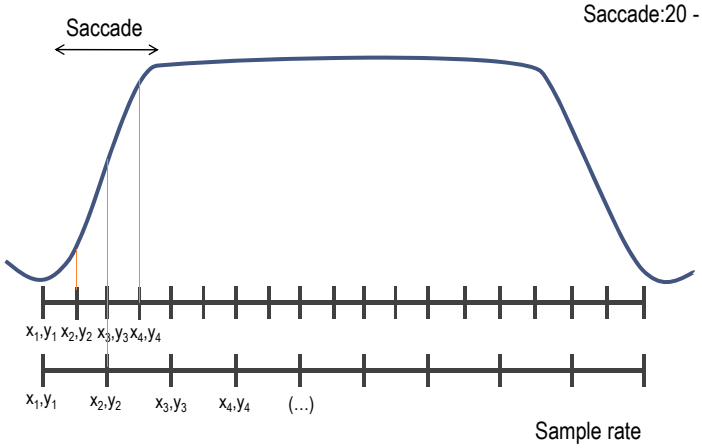
- What you need to detect or measure
- How precise you need to be

How much information should we collect ?

Eye tracker sample rate

Fixation:100 - 600 ms

Saccade:20 - 40 ms

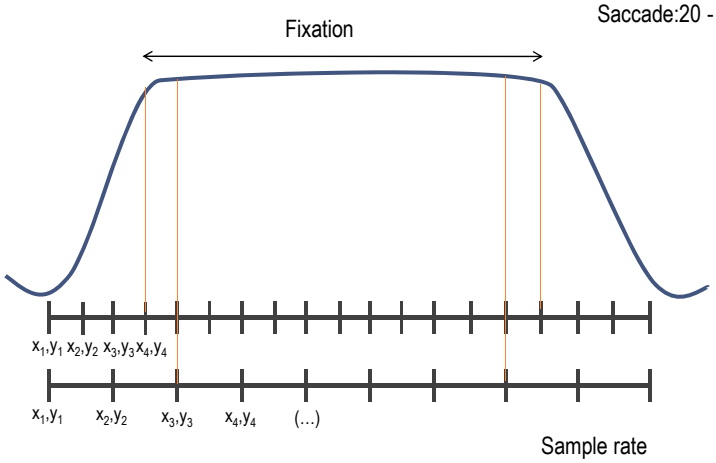


How much information should we collect ?

Eye tracker sample rate

Fixation:100 - 600 ms

Saccade:20 - 40 ms



Mean fixation duration error estimation study

(Andersson in progress)

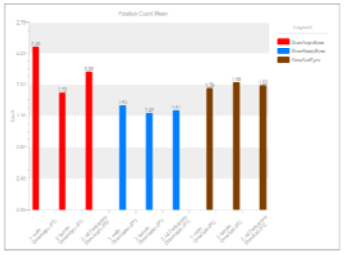
- Sampling error decreases with an increase in the number of fixations measured – even small effect differences can be detected a low sampling rates
- Inverse quadratic relashionship between number of fixations and needed sampling frequency

e.g. at 60 Hz you need 4 times as many fixations as with 120 Hz to produce an equivalent error

$(120/60)^2 = 4$

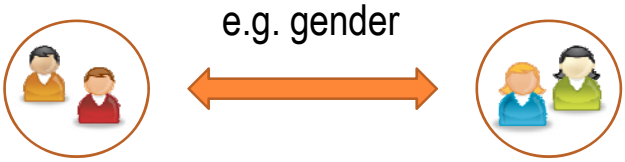
Quantitative analysis

- Participant groups (cross tabulation)
- Areas of Interest and AOI groups
- Fixation Filters



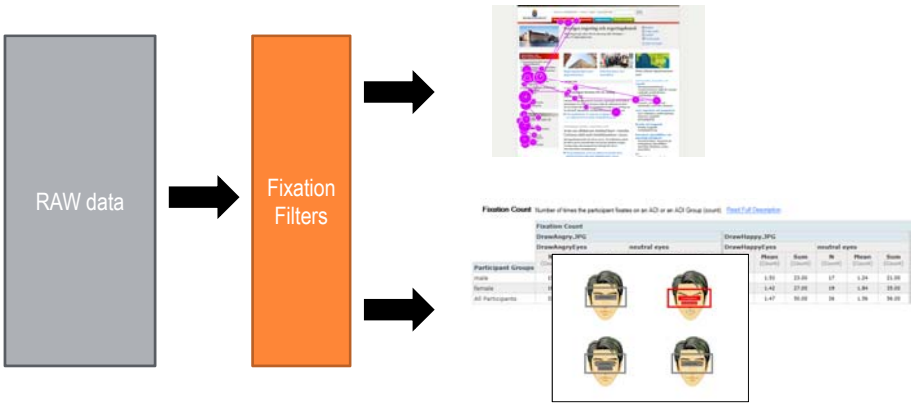
Participant independent variables

- Classifying participants according to relevant variables in your study
- Ad hoc or Post hoc ?



Data filters

Eye tracking data eye positions ”x” times per second (e.g. 120HZ = 120 samples per second)



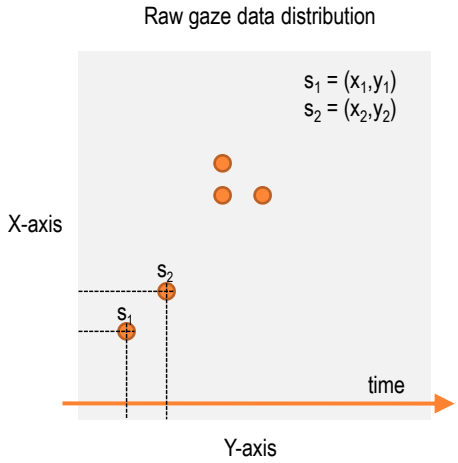
Fixation filters

- Reduces the amount of data for analysis
- Removes invalid data points and missing data
- Identifies fixations and saccades

Raw data

Tobii Fixation Filter

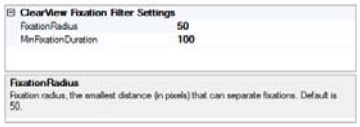
E.g. ClearView fixation filter (velocity algorithm)

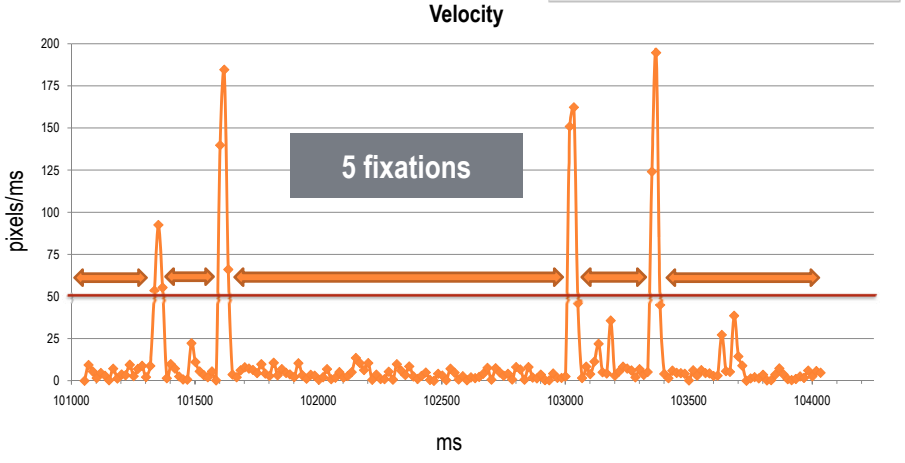


Calculating velocity (pixels/ms)

- $|s_2\text{-}s_1| = \Delta s_1/16.6\text{ms} = v_1$
- Repeat until $|s_n\text{-}s_{n-1}| = v_n$

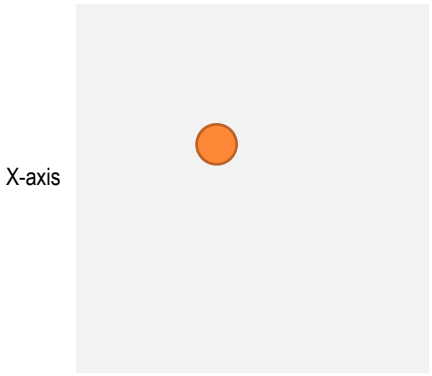
E.g. ClearView fixation filter





E.g. ClearView fixation filter (velocity algorithm)

Raw gaze data distribution



Calculating the position (pixels)

$$\text{Mean } (x) = \frac{x_1 + x_2 + \ldots + x_n}{n}$$

$$\text{Mean } (y) = \frac{y_1 + y_2 + \ldots + y_n}{n}$$

n = number of samples allocated to the fixation

Velocity threshold and the eye tracker sample rate

Velocity is calculated by $|s_2 - s_1| = \Delta s$ pixel/sample interval

50 pixels @ 50 HZ = 50/20 = 2.50 pixels/ms
50 pixels @ 60 HZ = 50/16.67 = 2.99 pixels/ms
50 pixels @ 120 HZ = 50/8.3 = 6.02 pixels/ms

x/16.67 = 6 pixels/ms → 100 pixels @ 60 HZ

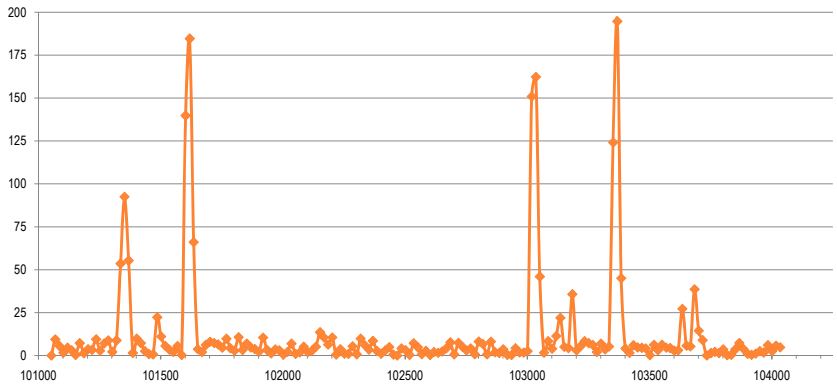
How to choose the right settings?

- Choose the settings according to litterature, or previous research
- Choose the settings based on your research question
- Plot a velocity diagaram of your gaze coordinates and check:
  - The lowest velocity saccades you want to keep
  - The highest velocity noise within fixation

It should always be higher than the fixation noise

How to choose the right settings?

Lower threshold = 20 - 130 °/s (include small saccades)
Upper threshold = 750 – 1000 °/s (excludes large saccades only)



AOI analysis discussion points…

- When to draw AOIs?
- How big should it be?
- Overlapping AOIs?

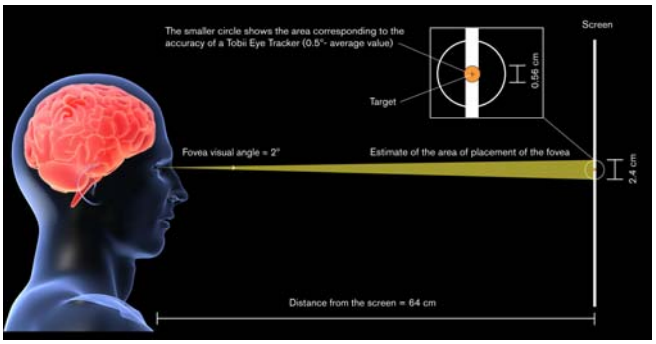
When to draw an AOI?

AOIs are part of your hypothesis

- After the recording: you change your hypothesis, high risk of biase
- Based on ”automatic” clusters: only as a cluster descriptor

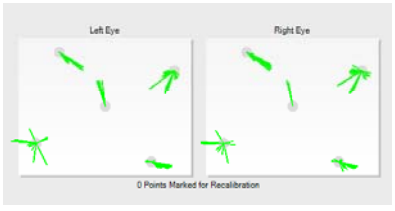
Size of an AOI

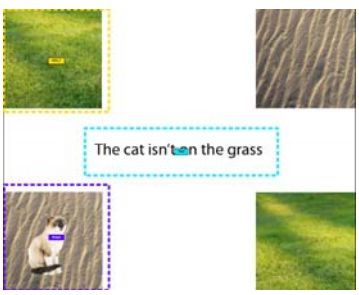
- Eye tracker accuracy (0.5-1°)
- Is limited by our fovea size (1-2°)



Size of an AOI

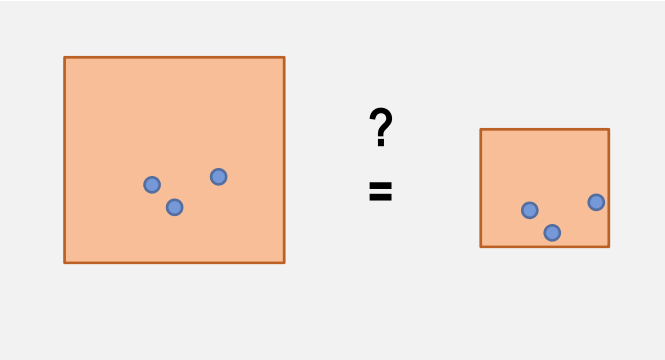
- Poor precision: false visits and transitions
- Poor accuracy: visits assigned to neighboring AOIs





Draw large AOIs if you expect poor precision

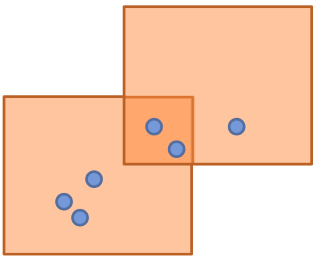
Normalizing your AOI metric?



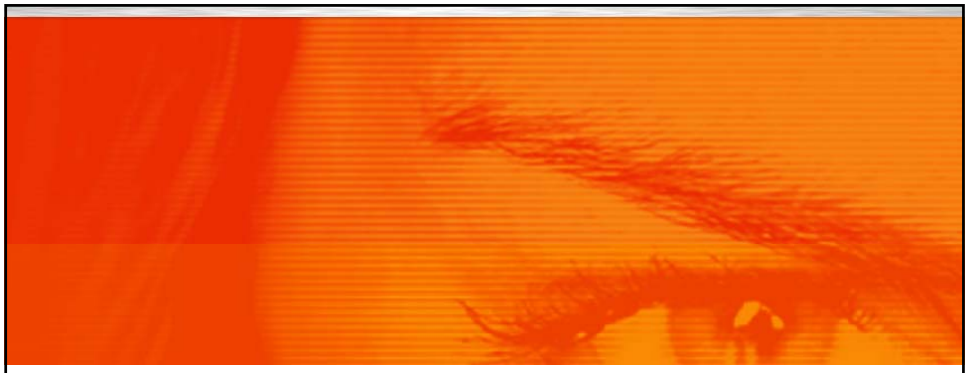
Divide metric by area when comparing two AOIs

AOIs should not overlap

- Should we count twice the fixations shared by the AOIs
- When to define transitions?



Tobii studio will count the fixations twice



EYE TRACKING METRICS

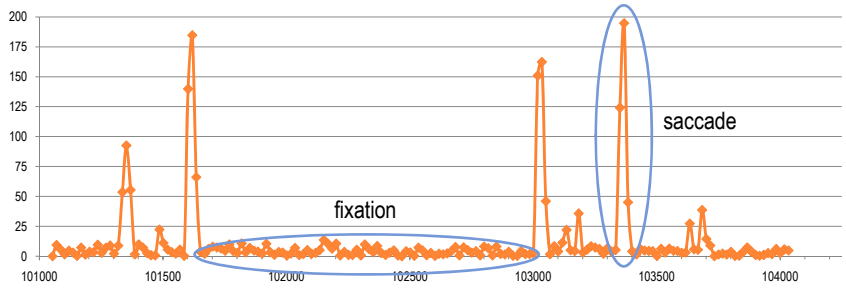
tobii
www.tobii.com

Eye tracking metrics

Are extracted based on Areas of interest (AOIs)

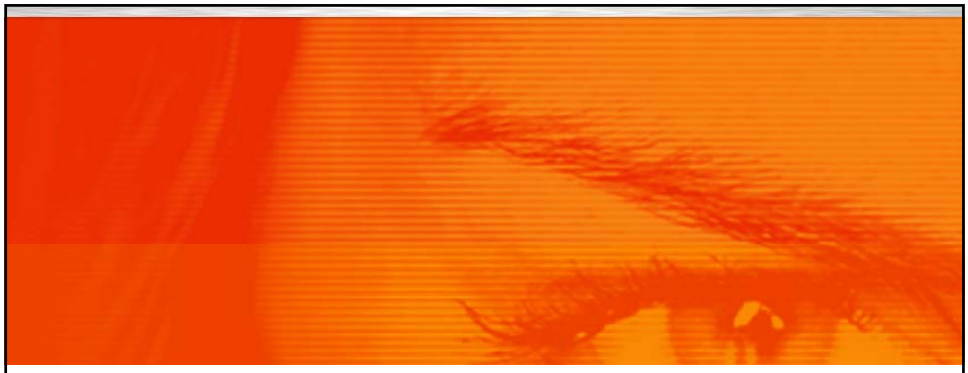
Metrics

- Eye movement states: e.g. fixations, saccades
- Participant actions (events): clicks, key presses
- Media events: media start and stop times
- Intervals between events: e.g. Time to first fixation



Examples of Eye Tracking Metrics

- First fixation duration
- Most fixations
- Time to first fixation, fixations before
- Gaze time
- Fixation order
- Movement between fixations (saccades)
- Visit duration
- Visit count
- Time from first fixation to mouse click

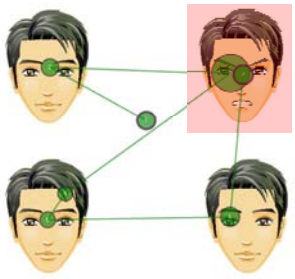


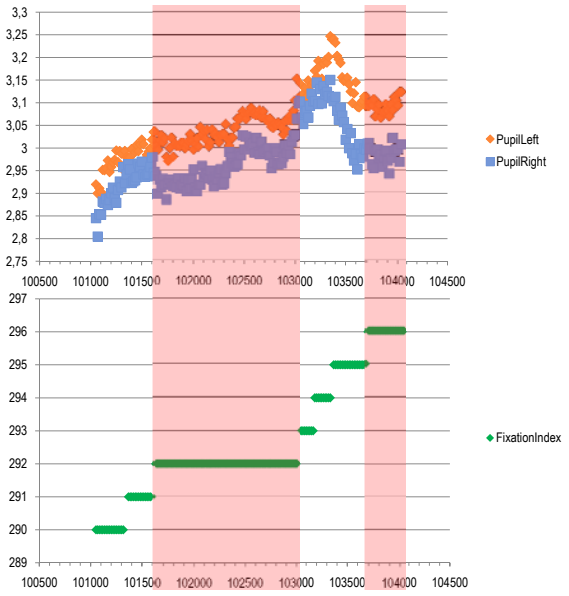
RAW DATA ANALYSIS

tobii
www.tobii.com

Raw data analysis

e.g. Pupill dilation





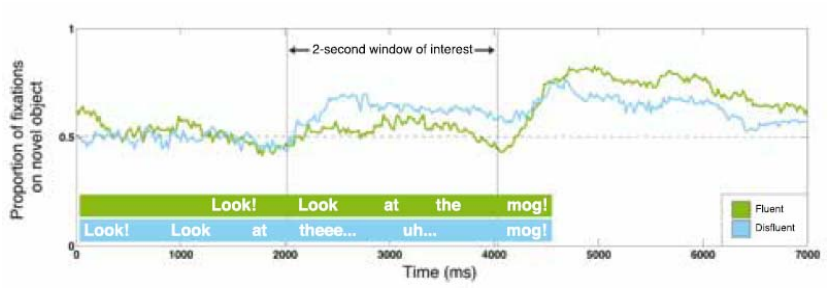
tobii
www.tobii.com

Word learning

Function of speech disfluency

Rochester Baby Lab, UK

Each display contained one familiar object (e.g., a shoe) and one novel object (e.g., a mog).

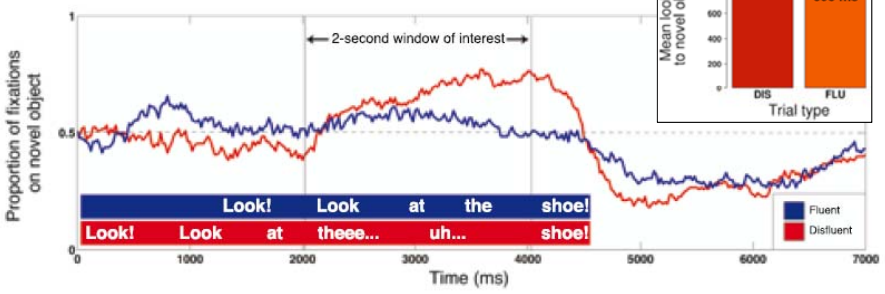


tobii
www.tobii.com

Word learning

Function of speech disfluency

Each display contained one familiar object (e.g., a shoe) and one novel object (e.g., a mog).



Raw data analysis

- Validity information

Left eye validity code	Right eye validity code	Eyes found	System left and right eye identification
0	0	Both	Correctly identified
4	0	Right	Correctly identified
0	4	Left	Correctly identified
3	1	Right	Estimated as probable
1	3	Left	Estimated as probable
2	2	One eye	Uncertain
4	4	None	Uncertain