The eyes have it

Eye tracking workshop #1

Attention, Computational Modelling and Eye movement (ACME) research group

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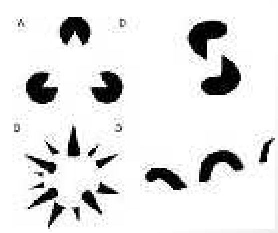
Underlying mechanisms

- Attention, etc?
- Saccades
- Pursuit
- Decisions
- Salience
- Language/reading

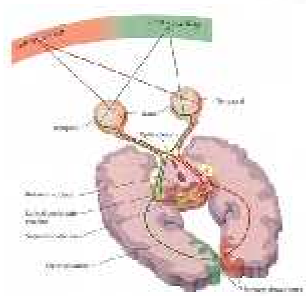
Myths and facts

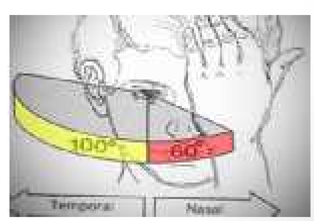
- Do we see with our eyes, and the brain simply interprets the image on the retina?
  - False
- The brain actively creates a representation that is not a simple reconstruction of the retina
  - We fail to see objects that are there, and see objects that aren't there



Vision

- Photosensitive cells in the eye
- Rods
  - Low levels of light intensity (esp. night)
  - Even distribution across retina
- Cones
  - Broad spectrum of wavelengths we interpret as colour (day)
  - Highest concentration at fovea
- Pathway through Lateral Geneculate Neucleus (LGN)
- Eventually to visual cortex
- Not completely contralateral
  - Both eyes go to both hemispheres
- Contralateral between visual field and initial hemisphere



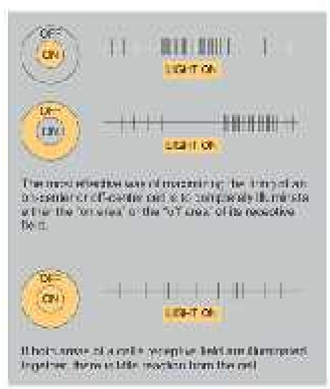


Compression

- Input transformation
  - Summarizes and analyzes during the process
  - Only a fraction of the light reaches the retina
  - retina also loses information
    - Most loss happens outside of fovea
  - Many cones can synapse to single peripheral bipolar cell
    - And only 1 million ganglion cells transmit through optic nerve
  - Summary is still amazingly accurate
    - Mostly edges and change information kept

Receptive fields

- Neurons are receptive to specific patterns and locations of light
- This pattern is called the 'receptive field' of that neuron
  - Discovered by chance – crack in projector slide caused a particular V1 neuron to fire constantly (Hubel and Weisel)
- Variety in receptive field in collections of neurons allow visual cortex to discover spatial patterns



Eg, neuron firing patterns of 'centre-surround' neuron in Lateral Geneculate Neucleus (LGN)

The visual coordinate system

- Spatiotopic coordinates
  - This is the world we *think* we see
  - Stable, unless objects are moving in the world
- But, As we move our eyes, the image on the retina changes
  - And neurons in the visual cortex are a 2D map of the retina
- Retinotopic coordinates
  - This is the world as it falls on the retina of the eye
  - If objects in the world fall on different neurons, how does the visual system know they are the same object?

Retinotopic coordinates

Spatiotopic coordinates

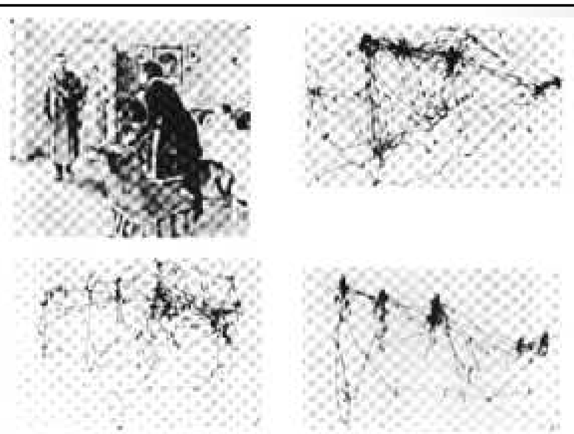
This is the problem of *construction*

Categories of eye movements

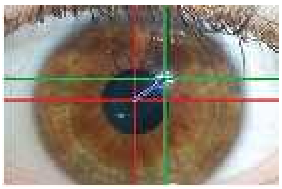
- Three very broad categories of topics
  - Review Kowler, 2011, Vision research
- Maintained fixations
  - Microsaccades (some recent evidence that these are on a continuum with saccades)
- Smooth pursuit
  - Not under voluntary control
  - Requires external stimulus
- Saccades
  - …

Gaze control

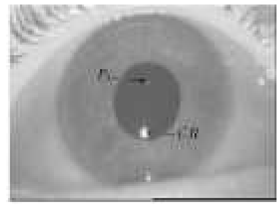
- Is there anything simpler than asking someone to look at something?
  - Natural – yes. Simple? Maybe not
- Our perception of the scene is stable, but the eyes make constant ballistic movements
- Saccades
  - 2 – 3 per second



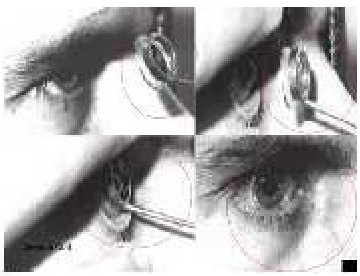
- Yarbus 1967,
- Scanpaths with instructions for
  - Search
  - Estimate economic status
  - Estimate age of family members



Pupil-CR



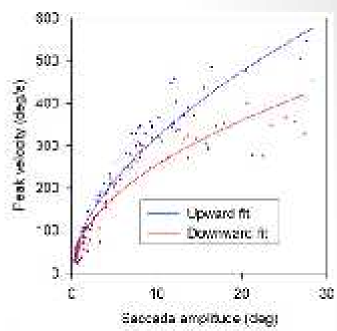
Purkinje



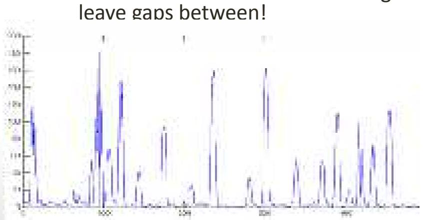
Coil

Fix detect Methods

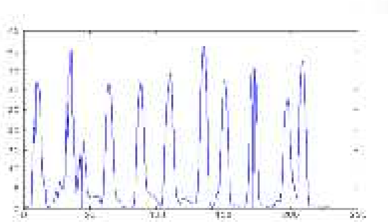
- Fixation detection based on I-VT (velocity threshold) algorithm
  - Salvucci and Goldberg [2000]
- Combined with Polynomial smoothing of coordinates to reduce noise
- **Typically 100 degrees per second threshold**
- Can also include minimum 50 ms duration
- What about blinks?
  - Initial partial occlusion can resemble a saccade
  - At most 30ms of lost signal in mid fixation (outside of screen coordinates, pupil == 0)
- Other algorithms can combine both velocity and acceleration (Eyelink)
- Saccade and fixation detection algorithms may leave gaps between!



Typical published velocities for saccadic amplitudes



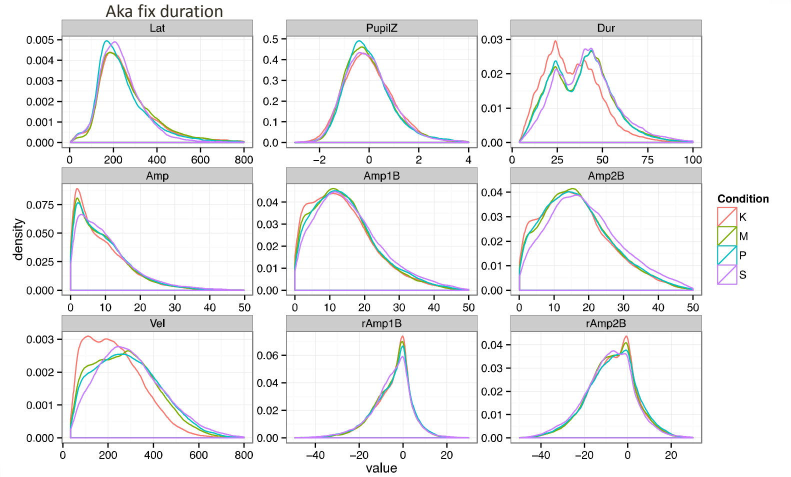
Velocity pattern example 1



Velocity pattern 2

Saccadic properties

Aka fix duration



Eye tracking output

samples

- X,y gaze position
  - Usually in screen pixel coordinates
- Time stamp in ms
- Pupil size
- Error codes

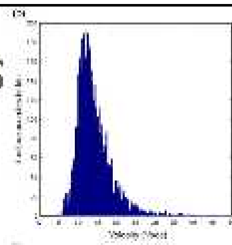
Note: eye tracking time stamps do not use the same clock as your experiment… (why, and how to solve that shortly)

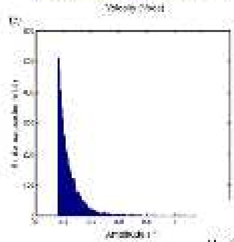
events

- Saccade (start, end)
  - Time (ms)
  - X1,y1,x2,y2
  - Peak velocity
  - Duration
  - latency
- Fixation (start, end)
  - Time(ms)
  - X,y
  - Pupil area
  - Duration
- Blinks
  - Time (ms)
  - Duration
  - These may be conflated with saccades
  - (saccade start, blink start, blink end, saccade end)
- User messages
  - Time (ms)
  - String

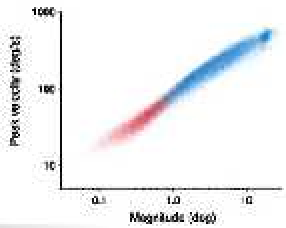
Microsaccades

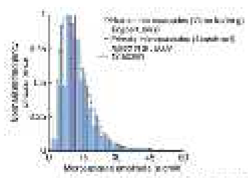
- Fixational saccades
- Typically 12 – 15 arcminutes
- Can exceed .5 degree
- microsaccades are on continuum with full saccades.
  - Mapped in the deep rostral of SC : (Hafed, Goffart, and Krauzlis (2009))
  - Role is to ensure accurate fixation?

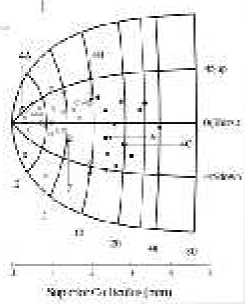




	Fixation	Free-viewing
N	[illegible]	[illegible]
Rate (N/sec)	0.6 ± 0.1	2.3 ± 0.1
Magnitude (deg)	0.56 ± 0.07	5.3 ± 0.3
Duration (ms)	13 ± 1	38 ± 1
Peak velocity (deg/s)	48 ± 4	217 ± 8

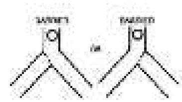




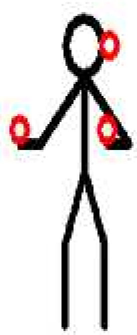


Smooth pursuit

- Smooth tracking is possible only with external stimulus
- We can combine saccades with smooth pursuit as we track multiple objects
- New research on 'predictive' tracking

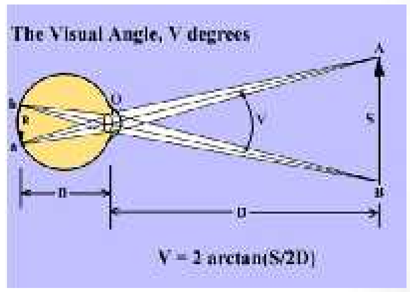


Top down control of tracking can take advantage of scene knowledge



Theoretical considerations

- Saccadic suppression
  - Visual system suppresses input during saccade
- Microsaccades influence EEG signal
- Eye movements and attention share similar networks
  - But not identical (no pre motor theory Smith, 2012)
- Control for setup by using degrees visual angle, not pixels



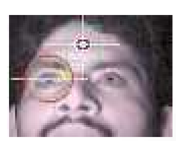
- The equipment

Eye tracking courtesy

- Many researchers will be using the same equipment
- Return monitor, camera and headrest to previous position if you need to change it
- Return eye tracker settings to default when done
- Same with monitor refresh rates and resolution
- Don't install background programs that could disrupt timing
  - Virus scanners, firewall
- Don't update software without asking everyone else
  - New versions of windows or experiment code may not be backwards compatible
  - Turn off automatic updates
  - I never connect experiment computer to internet for this reason
- Clean chin rest frequently
  - Or get gauze that can be replaced on a regular basis

Technical challenges

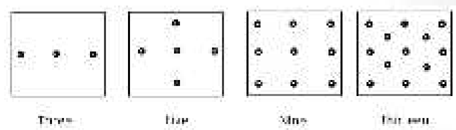
- Still not a trivial task
- Occlusion by upper lid
- Threshold problems
  - Are sclera and pupil greyscale values universal? Across individuals? Eye colour? Race? Medical conditions? Makeup?
- One to one mapping of gaze location and pupil image?
  - Only if you control for head position
  - Head tracking, chin rest
- Lighting
  - Dark pupil algorithms, but these require additional infrared source
- Accuracy limitations of camera?
  - Spatial accuracy improved by corneal reflection (.1 deg with artificial eye?)
  - Temporal accuracy improved with camera/cable technology (1000 hz +)
- Computational limitations?
  - Image processing
  - Triangulation
  - Saccade detection (Eye link only)
  - Various solutions

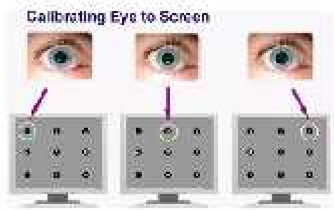


Still only compensates for small (20cm) head movements

Calibration

- Individual differences
  - Pupil size and shape
  - Pupil and iris shade (grey scale thrshold)
- Setup differences
  - These should be minimized!
  - Luminance (pupil size)
    - Control ambient lighting across participants
  - Camera/headrest/monitor placement
    - Use tape on desk to remember location
- **Validation** follows calibration and compares first vs second run.
  - Are the results consistent? Error in visual degrees
- **Drift correction** is a third single poin comparison at fixation for the start c each trial
  - Only Eyelink forces drift correction





The pupil changes are very subtle, but still detectable via computer. Pupil vs corneal reflexion is much easier to spot

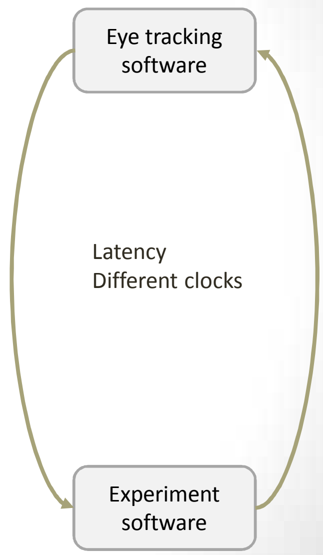
Specifications

	SMI tower	Eyelink 1000
Temporal resolution	1250 hz	1000 hz
Spatial resolution*	< .1 degree	< .1 degree
Set up	1 computer (two possible)	2 computers
Expt software	SMI expt creator, Matlab, Presentation, Python, C++, E-Prime, ….	Eyelink Expt builder, Matlab, Presentation, Python, C++, E-Prime, ….
Offline data	Gaze, saccades, blinks, messages, AOI	Gaze, saccades, blinks, messages, AOI
Online data	Gaze, AOI	Gaze, saccades, blinks, messages, AOI
Online latency	1ms ?	2-4 ms for samples, longer for events (4ms plus 10 samples for smoothing?)

*with a mechanical eye. Real accuracy depends on calibration

Dual computers/processes

- Eye tracking software is proprietary, so it is run as a separate program (SMI) or computer (SMI,Eyelink)
  - Dedicated computer has more resources free for online saccade detection
  - Single computer has lower latency between processes
- In both cases, this means that your experiment has to be run separately
  - What your subject sees, hears and interacts with uses its own program (ie matlab)
- Communication is bi directional
  - Request current eye information to use in your experiment
  - Send messages about expt events to insert in the eye tracking time stream
  - **These two methods are the ONLY way you can compare times of eye movements and expt events**



Example of display expt

- Trial starts
  - Send message to eye tracker of new trial, trial number
- Draw Fixation
  - Send message to eye tracker that fixation was drawn
  - Request gaze position from eye tracker and give error to subject if fixation not maintained
- Draw target
  - Send message to eye tracker
- Button press reaction time
  - Send message to eye tracker, include Button Reaction time (local button press time – local target display time)
- Or saccadic reaction time
  - Request gaze/saccade information
  - Calculate SRT (local time gaze information arrives – local time target presented)

- Send plenty of event messages to the eye tracker to let it know what is happening in your experiment
- The eyetracker saves a massive file of all gaze, event and messages that you can look through later in case you want to analyze something you didn't anticipate
- Warning though, don't send or receive messages every ms, since message buffer can overflow.
- In general, anytime the display changes, or the subject does something, let the eye tracker know

Other options

- SMI RED?
  - I think we still have a few of these
  - Ranging from 60 – 250 hz
  - Extremely portable!
  - Not suitable for SRT, saccade detection
  - Might be ok for pupilometry, ensuring fixation
- Android eye tracking apps?
  - Let me know!

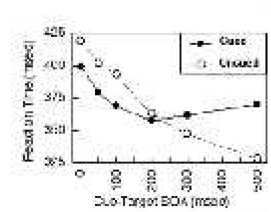
- Experiments

Experiment types, designs

- Simple display
  - marketing
- Simple, real time events
  - Responses and/or screen displays
  - Cuing
  - Search
- Control
  - Ensure fixation in otherwise typical behavioural experiment
- Eye movement feedback
  - Saccade detection, AOI
- User feedback
  - We typically aren't aware of eye behaviour
  - What if we show them where they look?
- Gaze contingent
  - Fast!
- Smooth pusuit
- Microsaccades
- Reading

Inhibition of return (IOR)

- Measured following the removal of attention from a spatial location
- Initial performance gain at cued location
- Switches to **performance cost**



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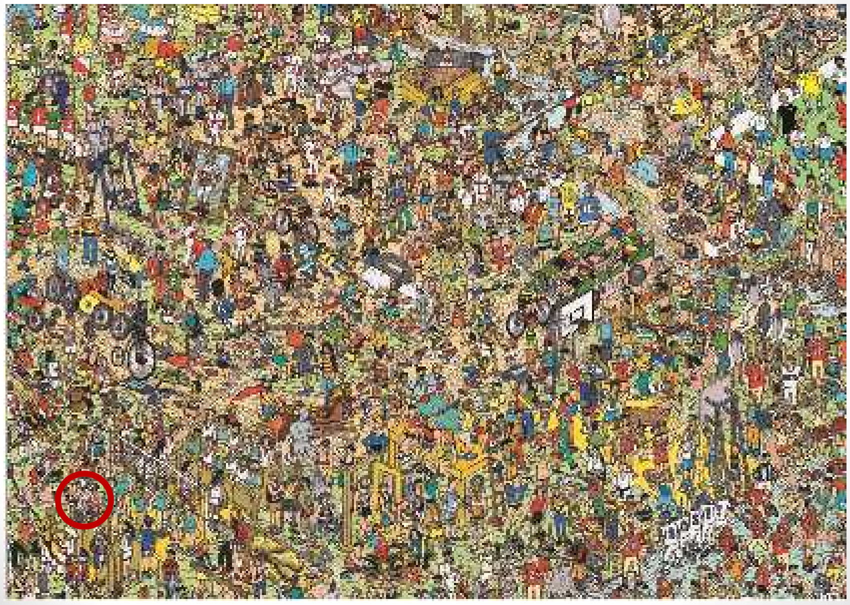
From Posner and Cohen, 1984

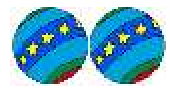
Search



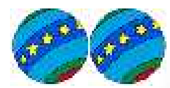
Change blindness

Gaze contingent (eg. Blanking Effect)

A) No Blank



B) Blank

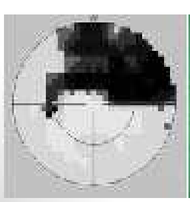


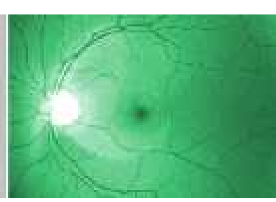
Deubel, Schneider, and Bridgeman (1996)

Gaze contingent (foveal)

Reading: parafoveal enhanced

Viewing: parafoveal blurred

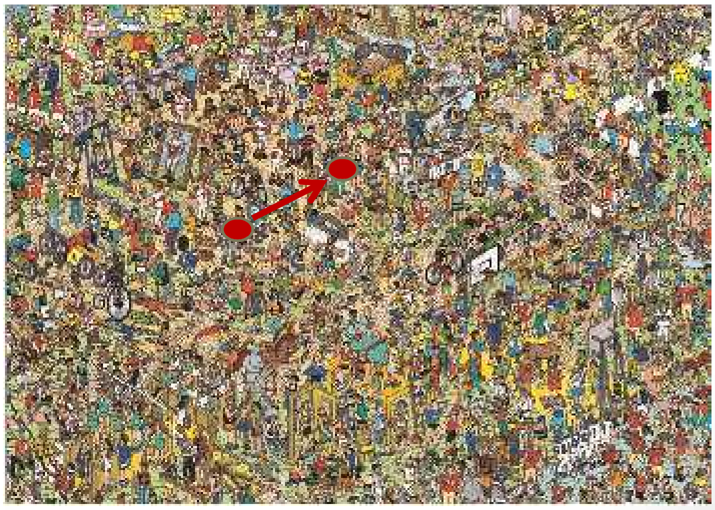




Simulate scotoma;
parafoveal or
foveal removed

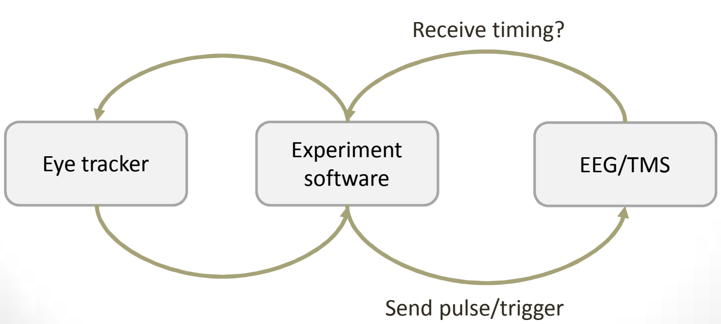
Social

Show user where someone else is searching? (real or confederate)



Nuroimaging

- EEG/TMS cannot connect directly to eye tracker
- Experiment software must be the link between eye tracker and EEG/TMS
- Matlab, presentaion and E-Prime can send signals through triggerbox
  - Others might be possible

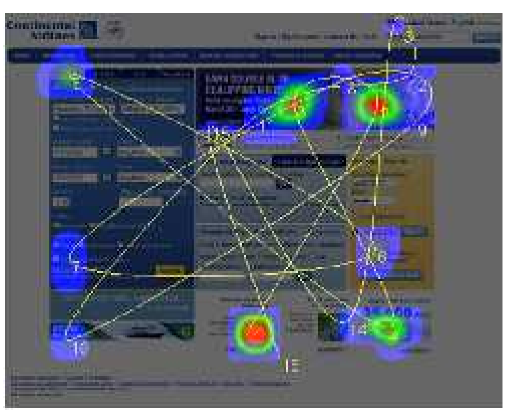


Analyses types

- visual/descriptive (marketing)
  - Heat maps
  - Video overlay
  - AOI
- Exclusion
  - Simply monitor gaze in an otherwise behavioural expt,
  - exclude trials with certain saccadic behaviour
- Area of interest
  - Number of fixations
- Simple RT
  - saccadic
- Pupilometry
- Scanpath
- Microsaccades
- Timcourse/path

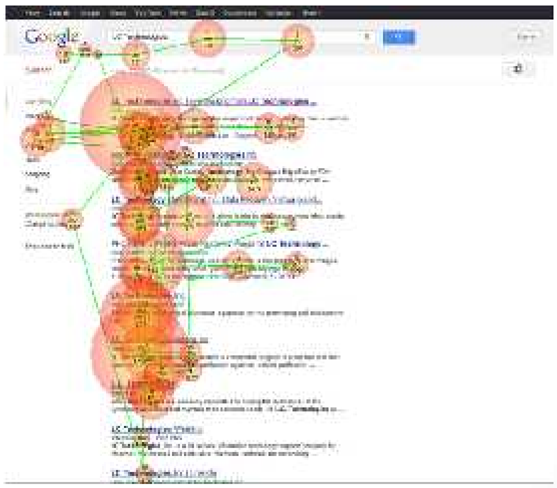
Heat maps

Usually spatial, occasionally spatio-temporal. Descriptive only, but can be enhanced with AOI for statistical analyses

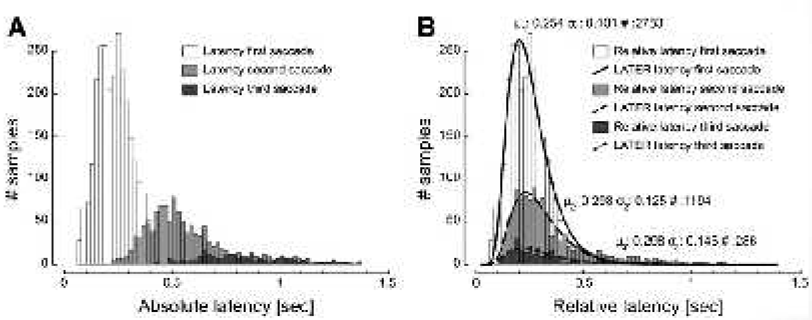


Scan paths

Spatio temporal, but harder to read with long paths



Saccadic reaction times

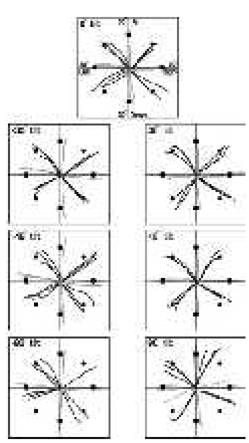


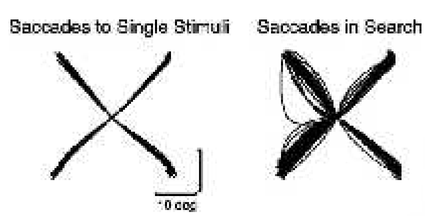
Puliometry

- Physiology
  - Individual differences
  - Luminance
  - Gaze direction
  - locus coeruleus-norepinephrine (LC-NE) system
- Cognitive
  - Workload
  - Arousal
  - Attention
  - Long term memory (encoding and retrieval)
  - …
- Difficulties
  - You must completely control for physiology to interpret cognitive differences in conditions
    - Z-score
    - Controlled lighting
    - Restrict fixation
  - Getting a cognitive effect is somewhat easy. Interpretation is often impossible

Saccade trajectories

- Trajectories influenced by attention, for example





- New paper:
- *"The pupil is faster than the corneal reflection (CR): Are video based pupil-CR eye trackers suitable for studying detailed dynamics of eye movements?"*
  - Hooge, 2016
  - Pupil-CR techniques only valid in high temporal resolution if the two have similar temporal dynamics
  - They show that Pupil and CR have significant lag
  - CR reaches peak velocity faster