Guidance of eye movements

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Overt attention
Covert attention
Neuronal basis of attention
Neglect
Action causes perception
Factors of eye movement control
Stimulus dependent contributions
High-level factors
Spatial factors
Saliency maps
Fixation duration
What is it good for?

Overt attention

Overt attention:
What is attention?

Everyone knows what attention is. It is the taking possession of the mind, in clear and vivid form, of one out of what seem several simultaneous possible objects or trains of thought. Focalization, concentration of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others, and is a condition which has a real opposite in the confused, dazed, scatterbrain state….

–William James (1890)

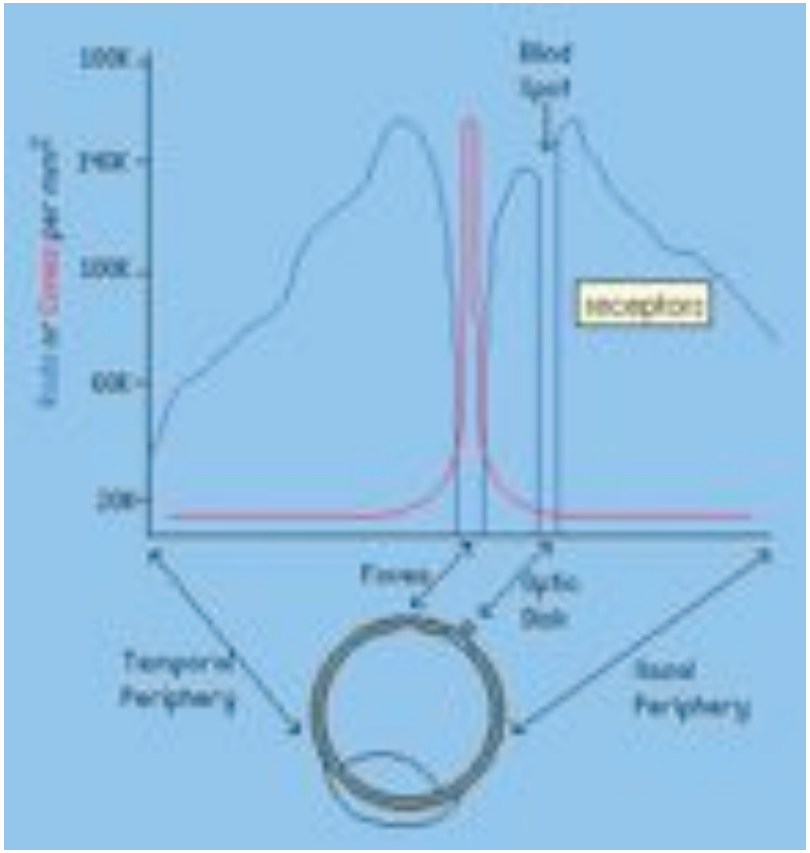
Attention is difficult to define.

Overt attention:
Overt attention

- Remember week 1, retina, dependence of spatial resolution on eccentricity
- Movements of the eyes allow selective acquisition of visual signals.
- Other sensory organs equally allow selective capturing of environmental signals.

Big point: Overt attention is measurable.

Overt attention:
Spatial acuity



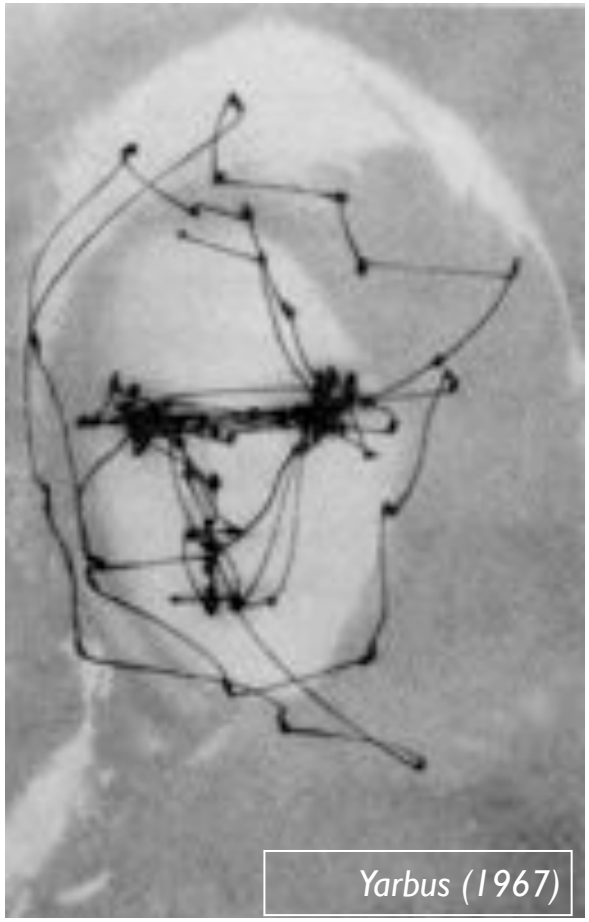
Due to the dramatic drop in cone density
the spatial acuity drops rapidly with increasing eccentricity.

Modern techniques for eye tracking

Schumann et al. (2008) J Vision, Einhäuser et al. (2008a,b) Ann NY Acad Sci

Eye movements are an observable expression of attention, nicknamed overt attention. Overt and covert attention have been shown to activate largely overlapping cortical structures. Therefore we take eye movements as a measure of attention

Since the time of Buswell and Yarbus eye tracking has come a long way. From subjective observation, intrusive aluminum rods or suction caps, we can now monitor eye movements with high precision in the lab as well as normal environments.



We can track eye movements under truly natural conditions.

Eye movements as a window to cognition

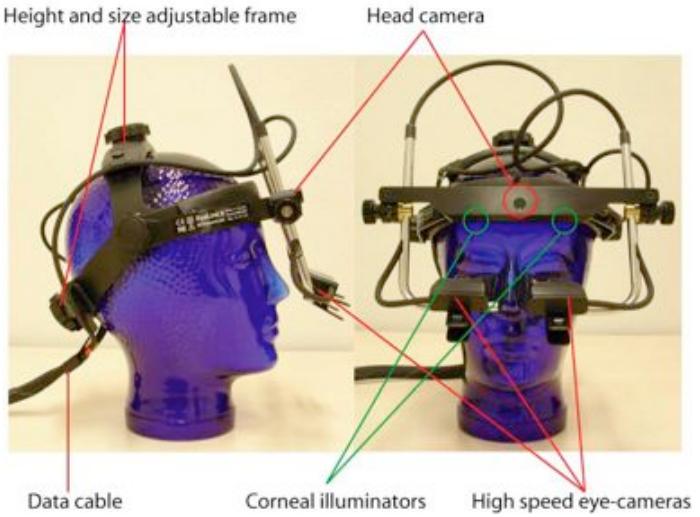
't Hart et al. (2009) Vis Cog

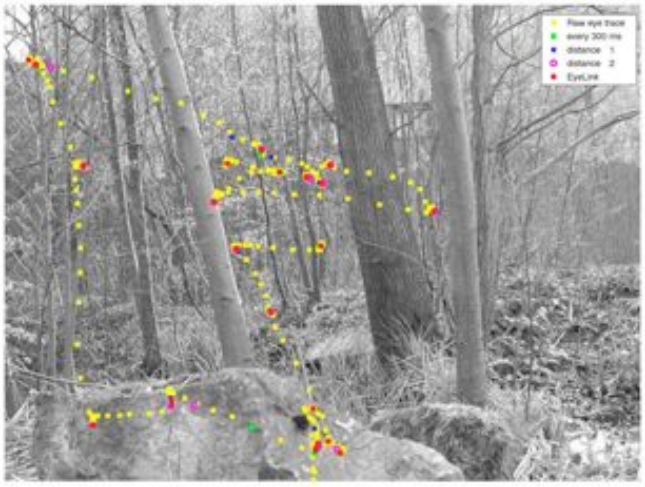
Eye movements are an observable expression of attention, nicknamed overt attention. Overt and covert attention have been shown to activate largely overlapping cortical structures. Therefore we take eye movements as a measure of attention. Since the time of Buswell and Yarbus eye tracking has come a long way. Present technology allows Mobile eye tracking in head and retinal coordinates (cooperation with Erich Schneider LMU München).

What is the relation of eye movements and cognition?

Overt attention:

Human eye-tracking



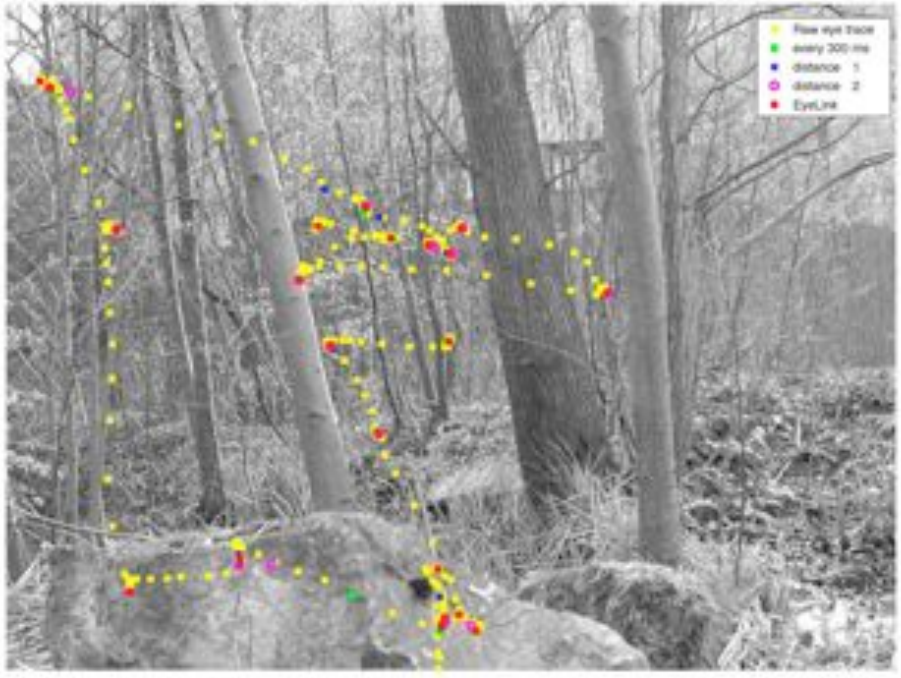


To differentiate types of eye movements high sampling rates are necessary.

Overt attention:
Eye movements

Motivation to investigate eye movements:

- the occulomotor system is reasonably well understood
- understanding the human visual system might help for machine vision
- this is all true, but here the emphasis is on eye movements as a window to cognition



Advantages:

- everybody is making eye movements all the time
- each one expresses a decision to make a saccade to a selected location
- 200 per minute --> fast statistics
- high precision measurements
- non-invasive
- intrinsic part of many aspects of cognition

Covert attention

Covert attention:
Helmholtz

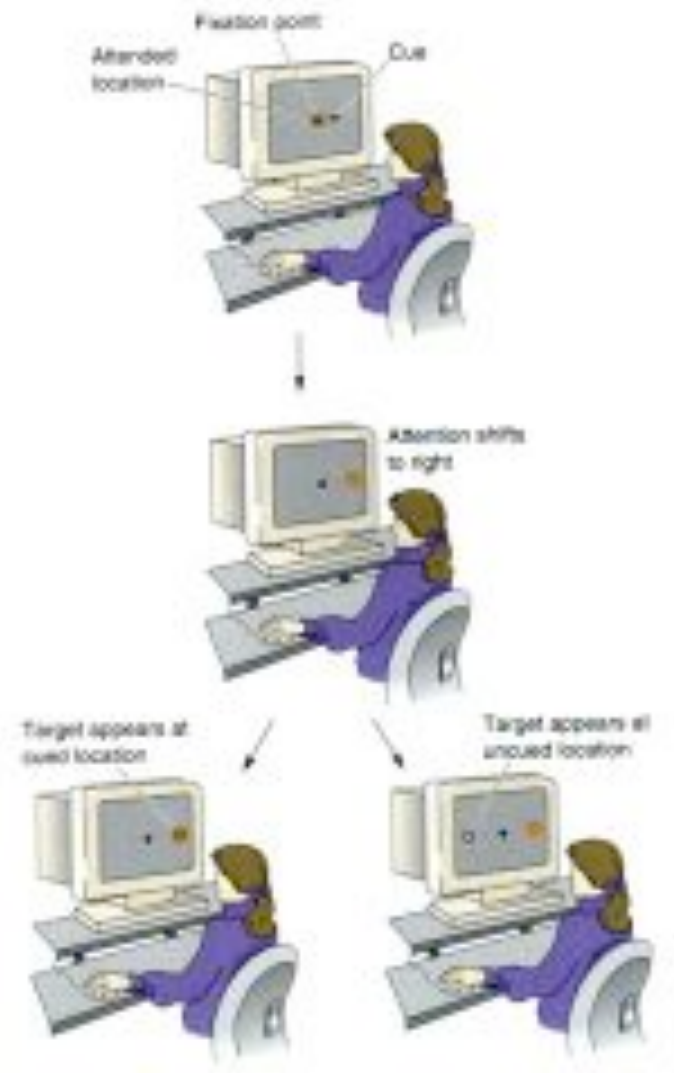
Hermann von Helmholtz (1894)

Helmholtz observed that we can **enhance perception**, if we focus our attention on a location in the visual field

However, enhancing perception in one part of the visual field takes place at the expense of other areas.

Processing may be enhanced in spatially localized regions without eye movements.

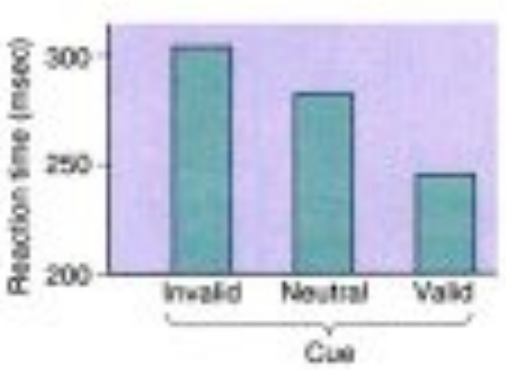
Covert attention:
A typical experimental setup



Performance is described by a spotlight of attention:

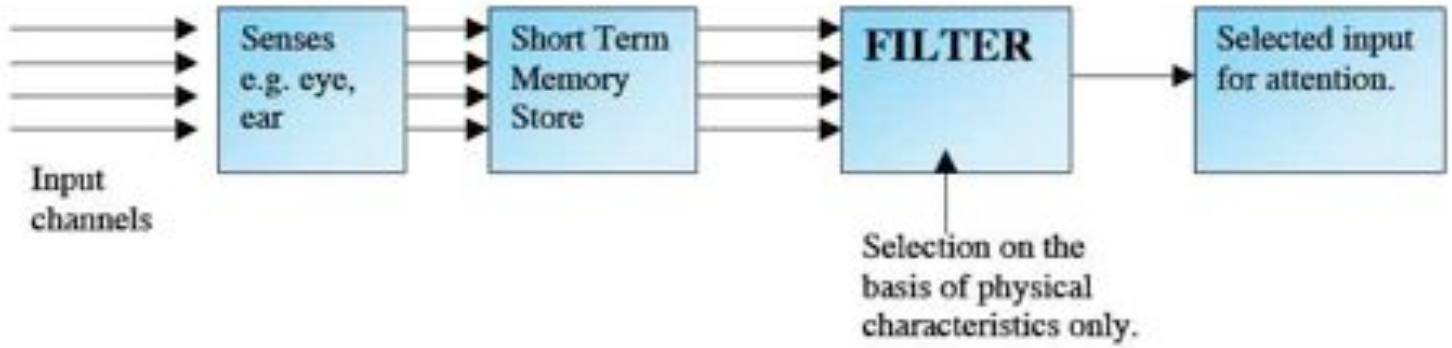
A central cue indicates the location of the upcoming target. Compared to the uncued situation (neutral), when the target appears after a short delay at the cued location (valid) the reaction time is reduced. When the target appears at the uncued location (invalid) the reaction time is prolonged.

These properties gave rise to the hypothetical sequence of "disengage - move - engage".



This task design is used in a really large number of studies.

Covert attention:
Early selection



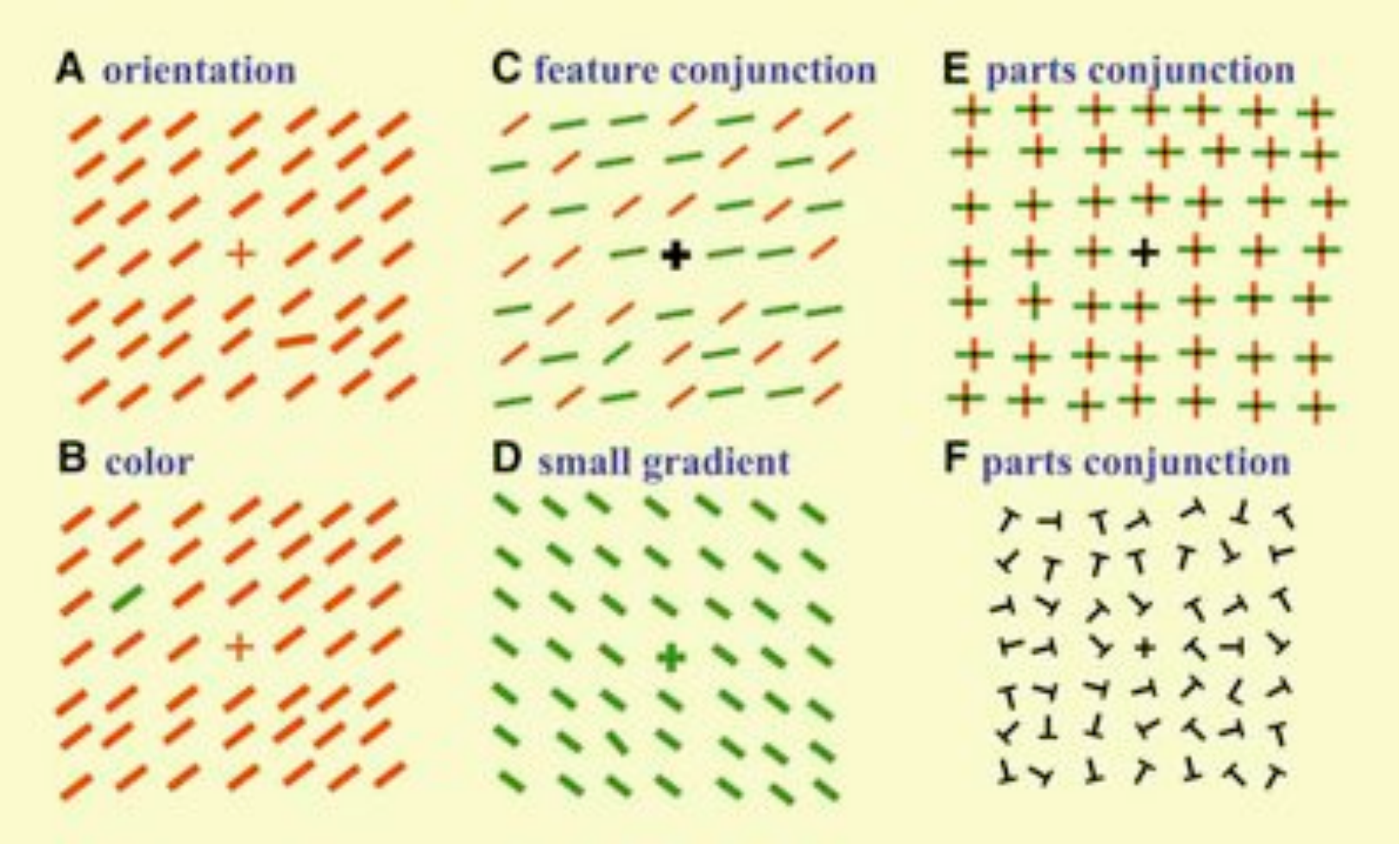
Broadbend's filter theory

- Similar to overt attention
- 2-stage processing (first parallel, then sequential)
- Selection is based on physical properties of the stimulus (e.g., pitch, loudness, etc...)
- Only one input channel can be processed at a time.
- Semantic interpretation only after selection.
- conscious control
- it takes time to shift attention
- Covert attention is modeled quite similar to overt attention.

The early filter theory models basic observations of attention.

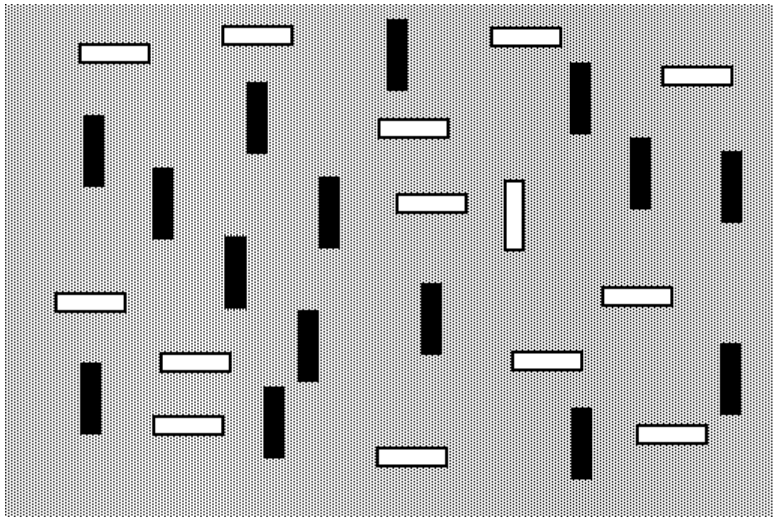
Covert attention:
Popout and conjunctions

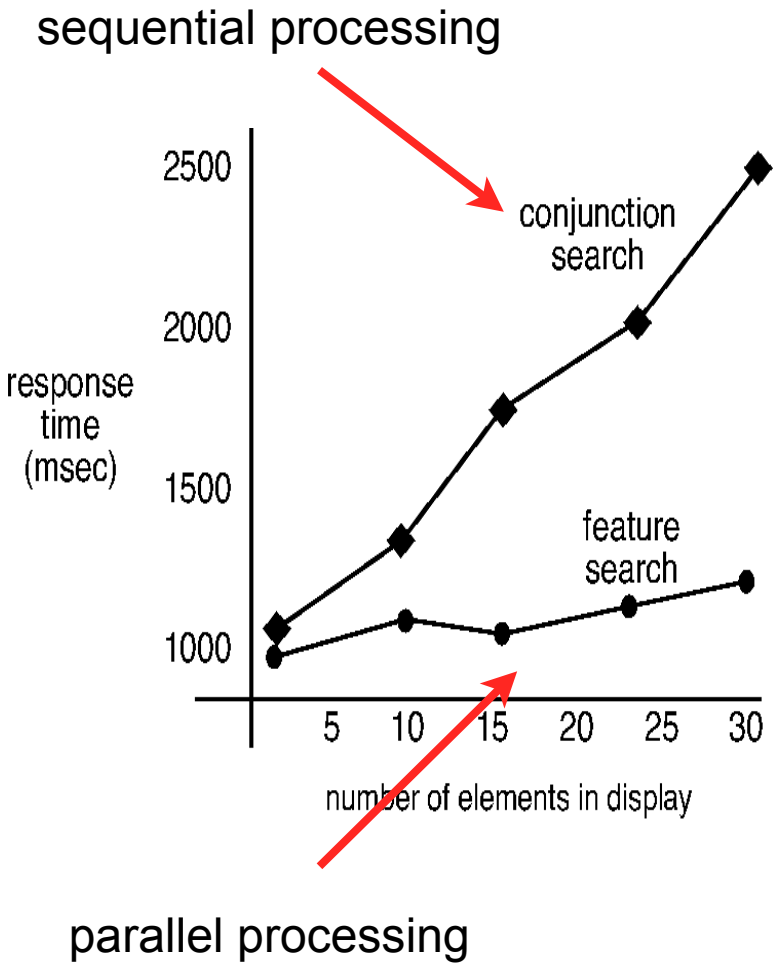
Ahissar & Hochstein (2002) Neuron



What pops out can capture the channel for further processing. Features that do not and are therefore only detected at the sequential stage.

Covert attention:
Popout II





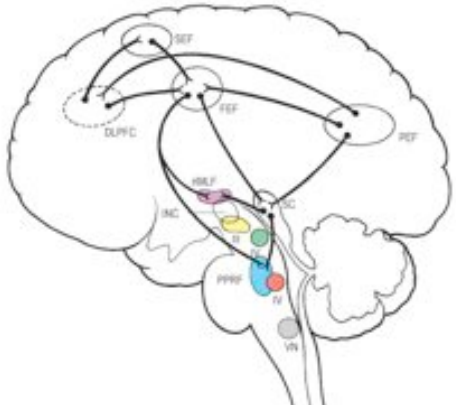
Pop out can be quantified by measuring the time needed per element. Near zero for parallel feature search and a finite slope (50ms/element) for conjunction search.

A clean case of sequential processing.
The more cows you have to check the longer it needs.

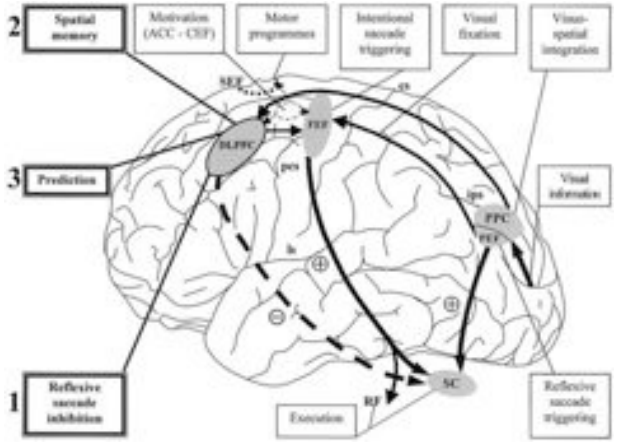
Neuronal basis of attention

Neglect:
Involved brain structures

Superior Colliculus (midbrain) is involved in reflexive selective visual attention, eye movements and movement of selective attention. It is directly involved in ocular motor output and receives direct visual input from the retina.



Thalamus (diencephalon) with different subnuclei modulates arousal. Pulvinar (also a part of the thalamus) might gate or filter selective attention and mediates engagement of attention.

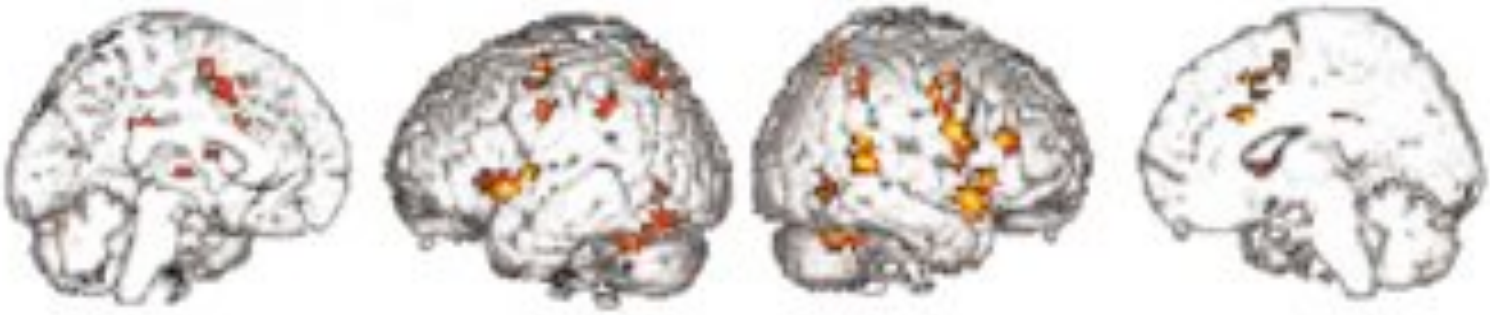


Frontal Eye Field(FEF) is an important area for the voluntary control of eye movements and voluntary selective visual attention.

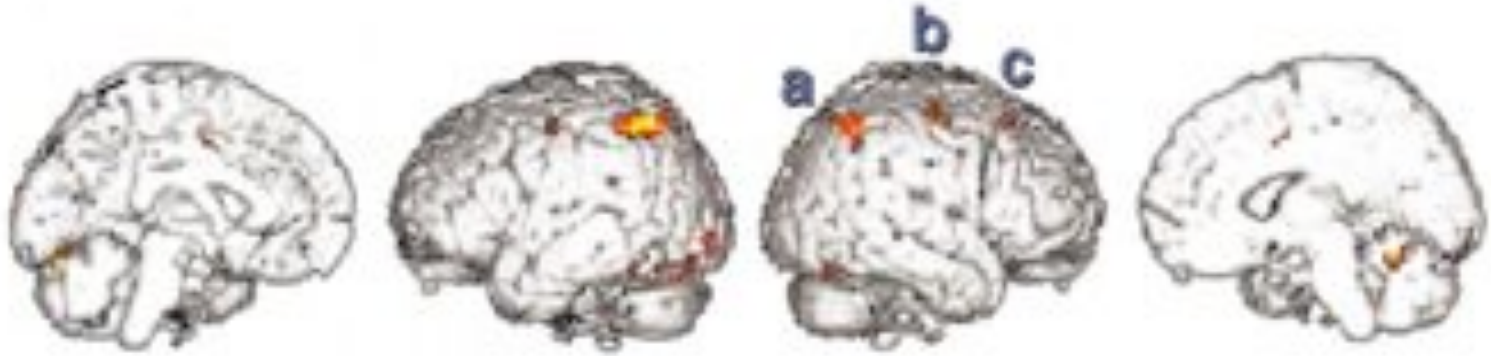
Neglect high lightens the role of posterior parietal cortex in attention.

Covert attention:
Attentional systems

(a) Common areas for *saccades* and *covert attention*



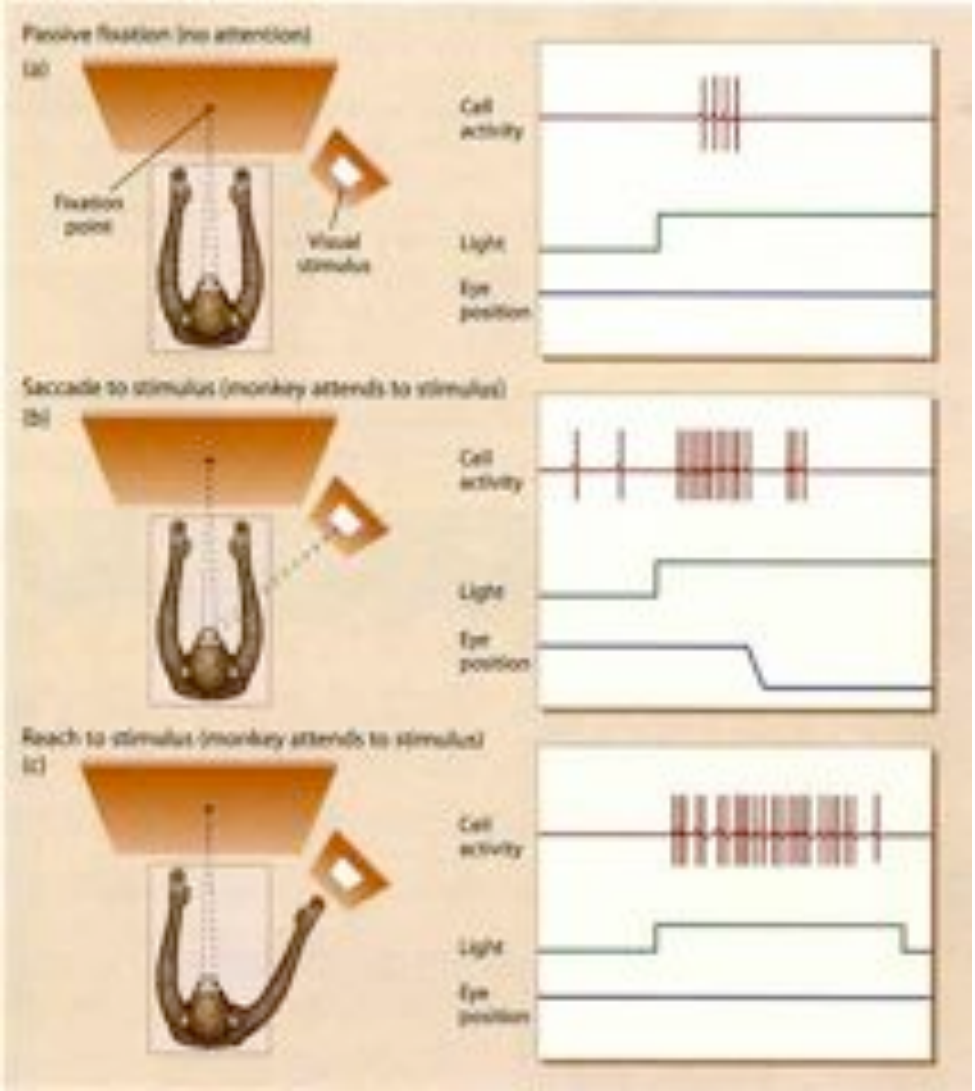
(b) Areas preferentially activated by covert *attention*



Cortical systems for overt and covert attention largely overlap.

Physiology:

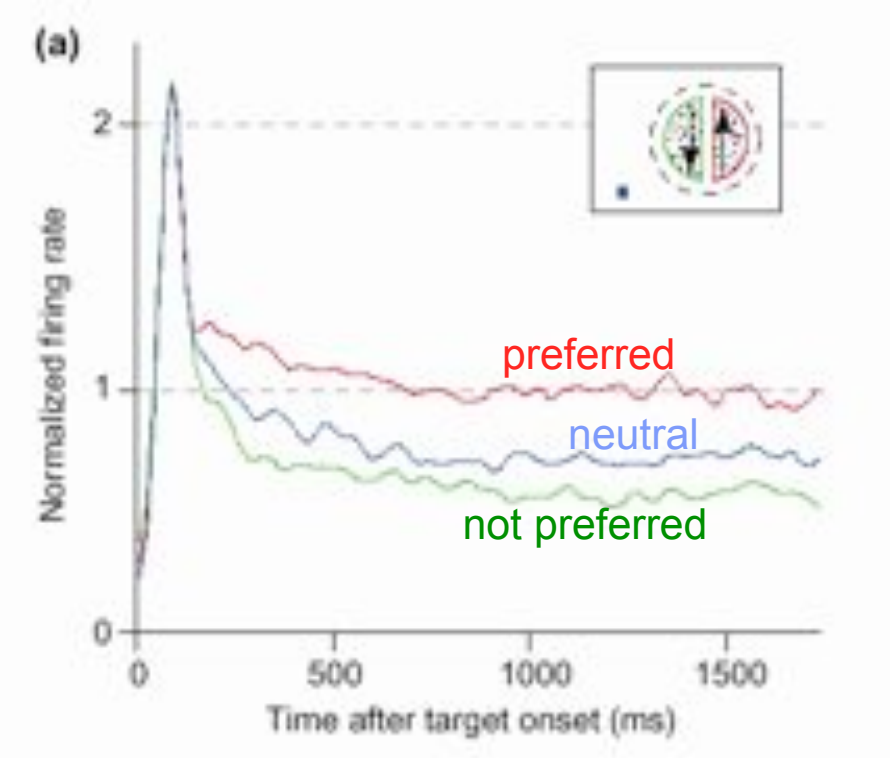
Basic observations



Attention modulates mean firing rates of cortical neurons.

Physiology:
MT & MST

Treue (2001) Trends Neurosci



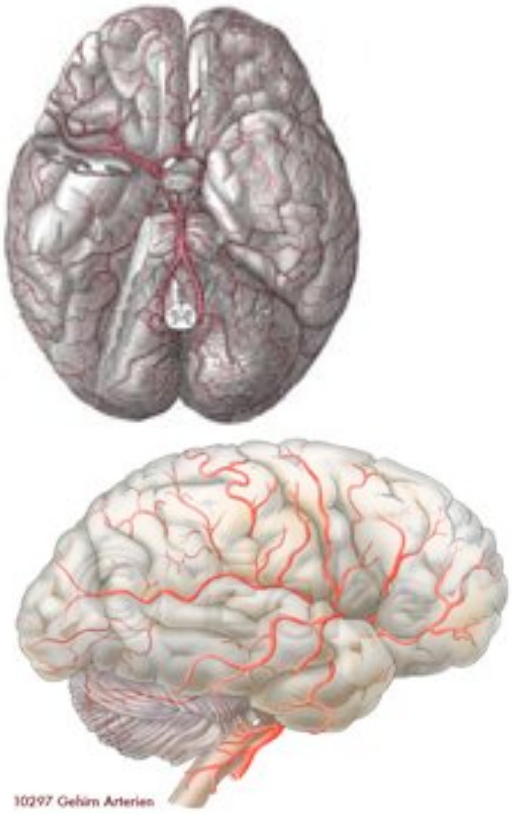
Neurons from the middle-temporal area (MT) and the medial superior temporal area (MST). The y-axis is the level of response relative to the sustained activity in the condition where attention was directed towards the preferred direction stimulus inside the receptive field. Two half-circle shaped random dot patterns were presented inside the receptive field, one moving in the preferred direction and the other in the anti-preferred direction of the neuron. The animal was instructed before every trial to direct its attention towards one or the other pattern (red and green curve), or to a square on top of the fixation cross (blue curve).

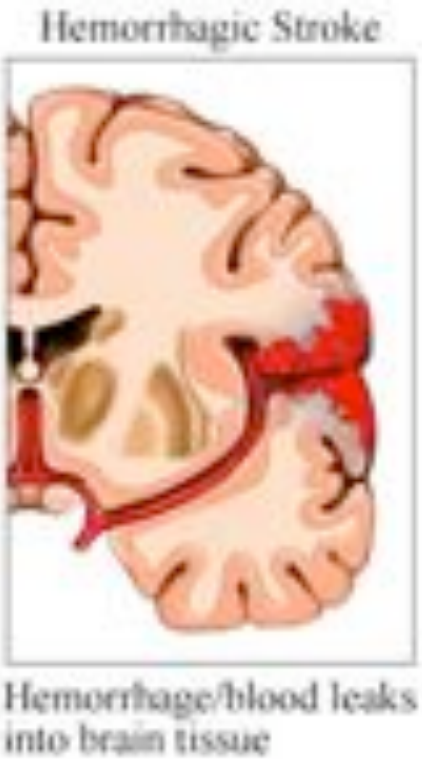
Attention modulates the tonic part of the neuronal response in higher visual areas.
The effect size is (grand average) in the order of 25%.

Neglect

Neglect:

Two kinds of strokes



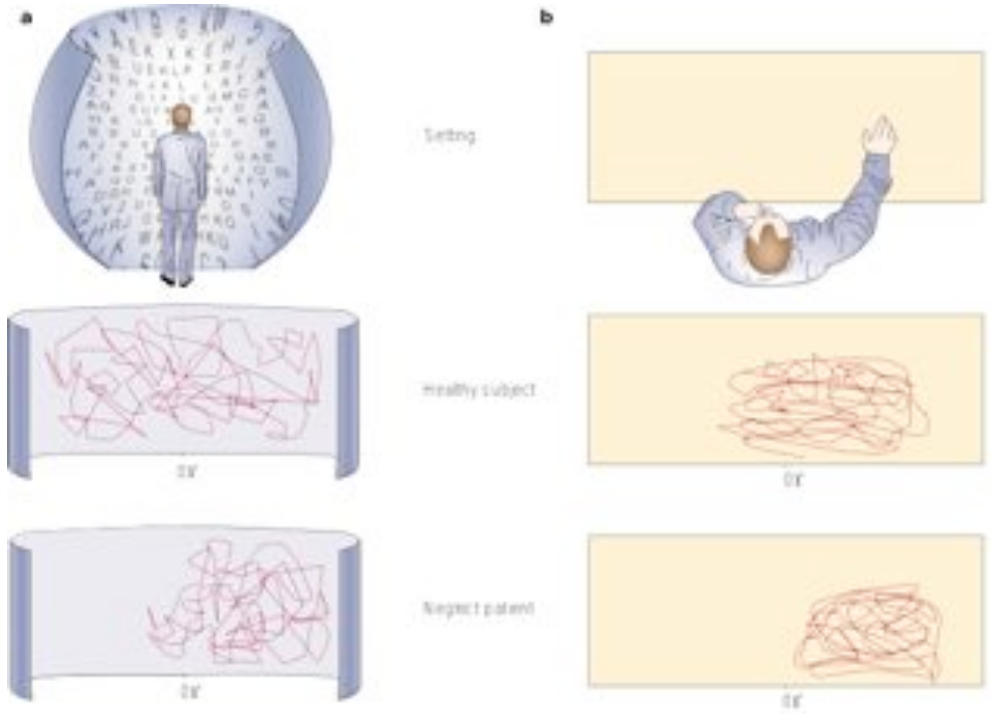


Many areas are involved in attentional processes. Still, lesions of the posterior parietal cortex have the most profound effects on behaviour.

Stroke is a common cause of neglect.

Neglect:
Exploration of space

Karnath (2001) Nature Neuroscience



visual searching tactile searching

Unilateral neglect involves a loss of orienting behaviours and exploratory search on the side contralateral to the lesion.

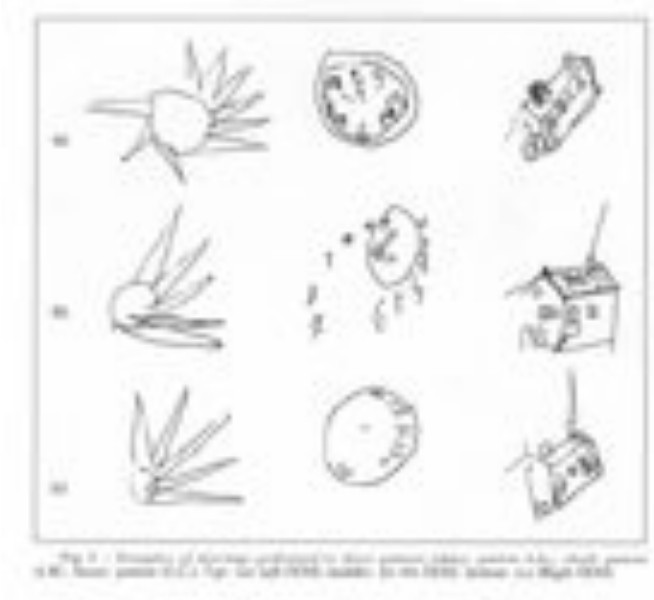
Patients are not aware of their deficit. The real life impairments are much more severe than a unilateral blindness

Bilateral Neglect (simultanagnosia): See one object at a time, usually in central fovea, almost like "tunnel vision".

Balint's syndrome: Trias of inability to move the hand to an object by using vision (optic ataxia); inability to voluntarily control the gaze (ocular apraxia); inability to recognize more than one object shown at the same time (simultanagnosia).

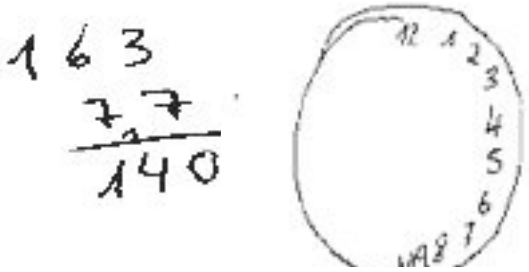
Neglect is a multimodal phenomenon.

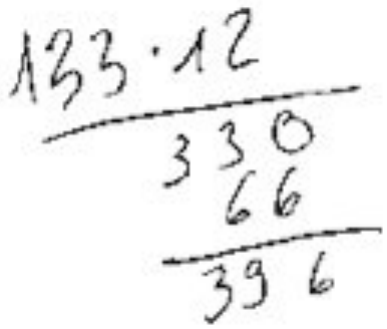
Neglect:
Symptomes



Clinical behaviour: Spontaneous deviation of the head and the eyes toward the ipsilesional side when addressed from the front of the left and ignoring contralesional located object or people

down**town**
green**house**
basket**ball**
desk**top**





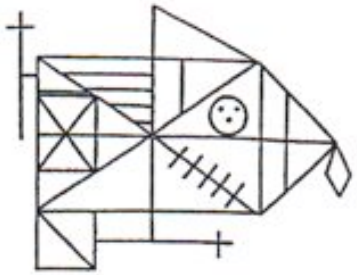
Neglect:
Recall

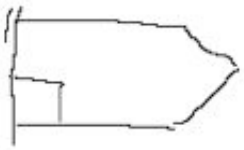
'Imagine you're in a familiar piazza in Milano that you know well on one side. What would you see?'; Now imagine you're on the other side of the piazza. What would you see?' Neglect occurs during memory recall.

Neglect is not a purely sensory disturbance, but involves memory as well.

Neglect:

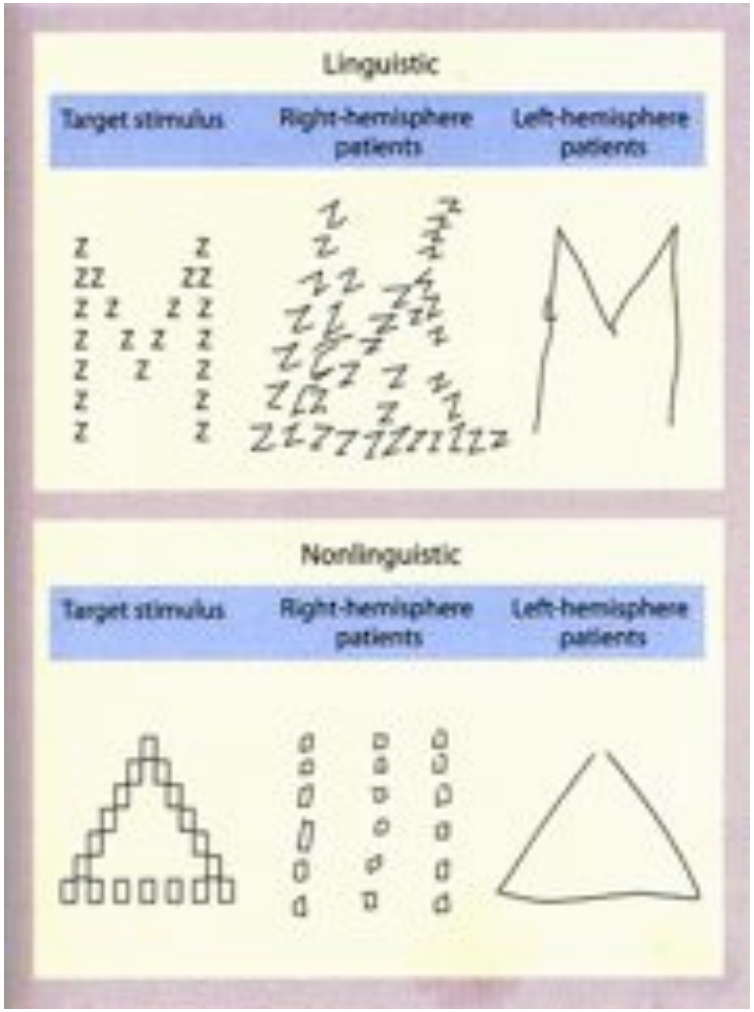
An effect of scale





Left hemisphere injury

Right hemisphere injury



Neglect after right and left sided lesions differ in scale:
Right side for global processing; left side for detailed processing.

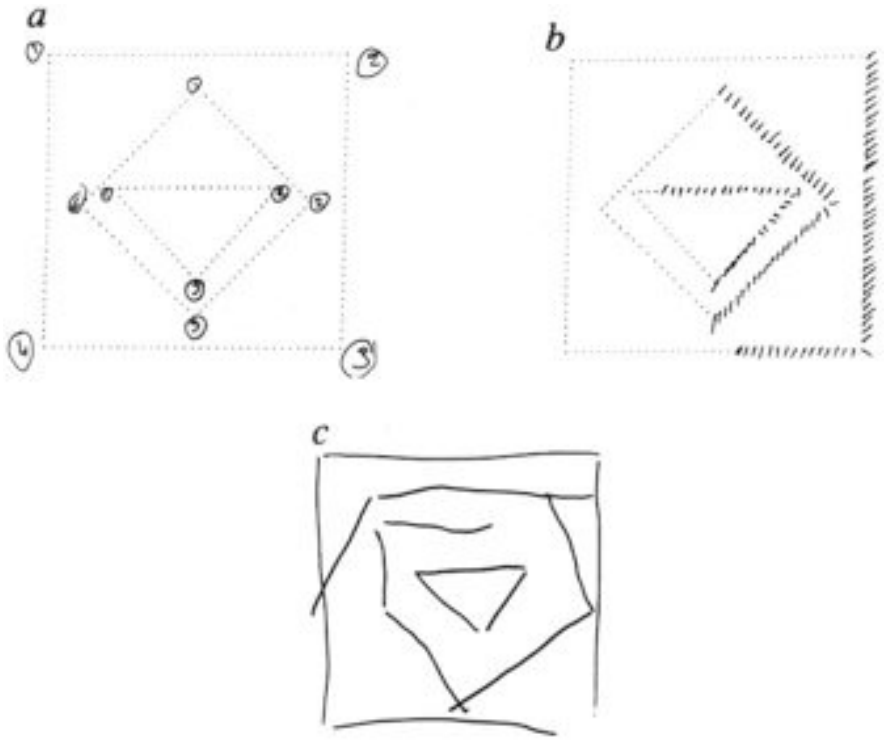
Neglect:
Local/global

Marshall & Halligan (1995) Nature

(a) Patient J.R.'s marking of the corners of a complex pattern. Note that the full extend of the figure is marked.

(b) Her attempts to cancel all the local components. Note that all left sided elements are neglected.

(c) Her copy of the stimulus display from memory. Note that the overall shape is reproduced.



After right sided lesion seeing the forest but only half of the trees.

Neglect:
Implicit processing

Describe the differences between upper and lower house.

→ patient: „no difference“

In which house would you like to live?

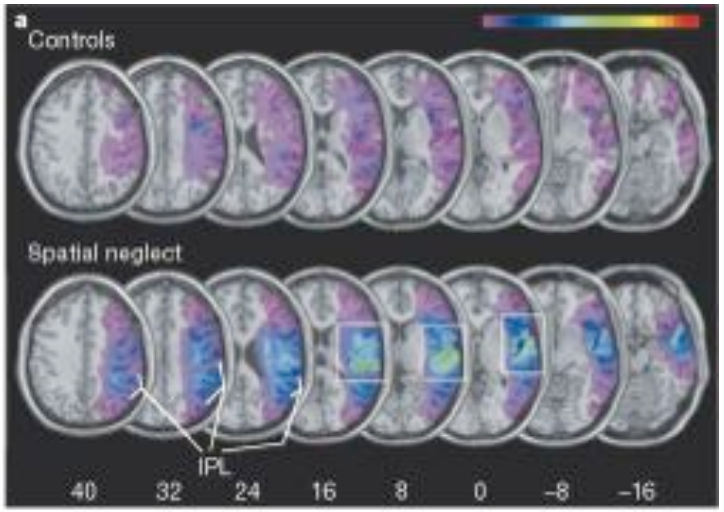
→patient: „the lower one“

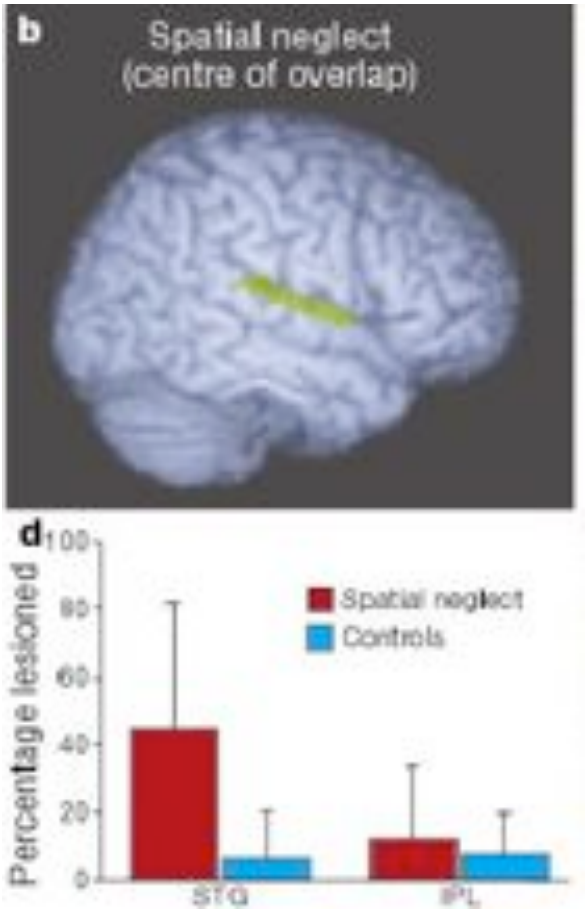
Even so striking differences of the two pictures are ignored, implicit processing is taking place.

Parts of neglected stimuli are implicitly processed.

Neglect:
Which brain areas?

Karnath (2001) Nature





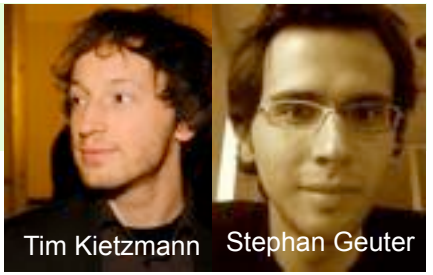
Are (right) posterior parietal lobe, angular and supramarginal gyri lesions really responsible for the symptoms in neglect? Most studies on neglect consider patients with additional primary defects of visual field (e.g. hemianopia was presented in 50-87% of the patients). Here is a study trying to separate the causes of visual field defects and neglect. It is focused on patients with 'pure' spatial neglect with no visual-field defects. Lesion analysis of patients without visual field defects and without (controls) and with spatial neglect. The number of overlapping lesions is illustrated by colour. The centre of overlap was defined as those voxels that showed lesions in more than 15 patients (green area).

A systematic relation to neglect is found in STG and not IPL.

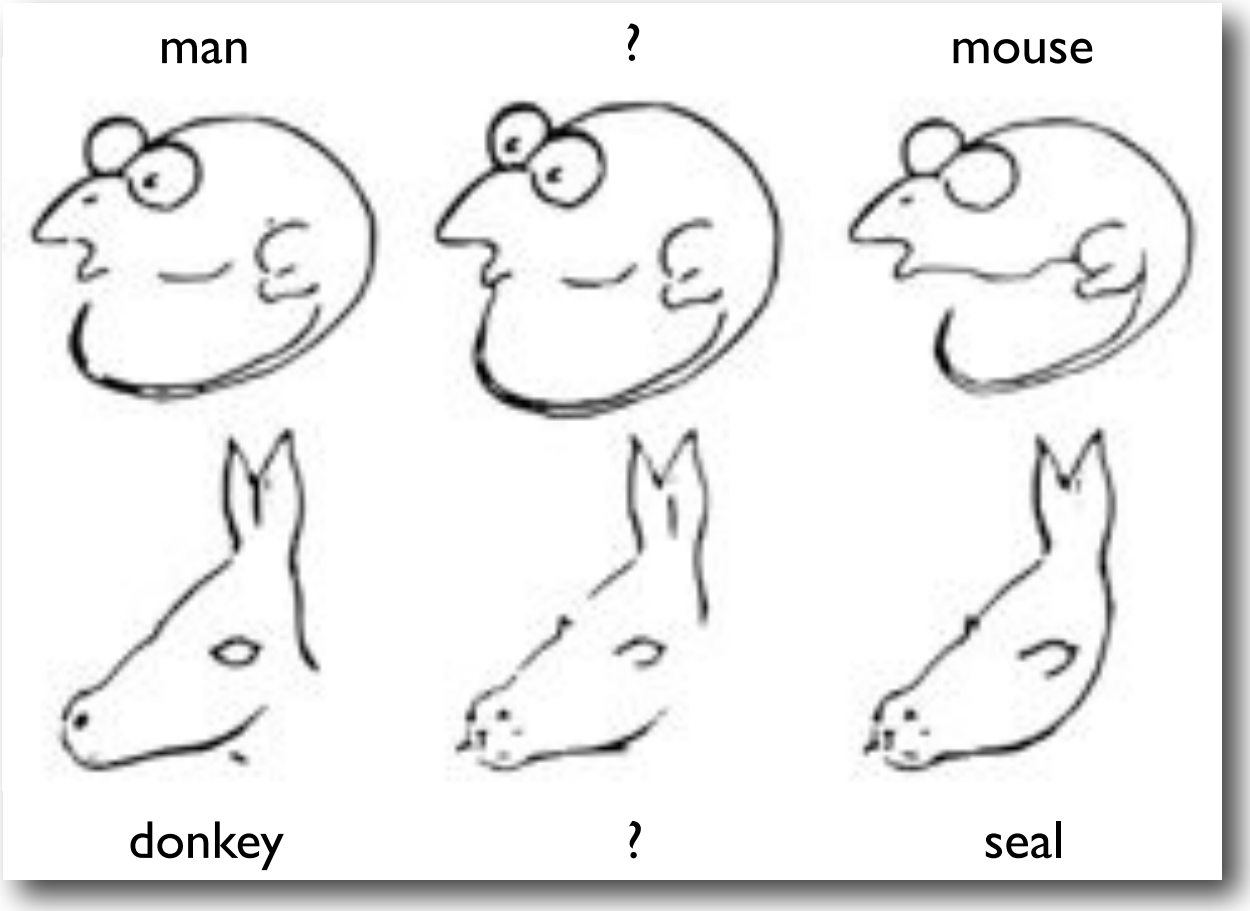
Neglect

Action <- causes -> perception?

What is the relation of eye movements and perception?



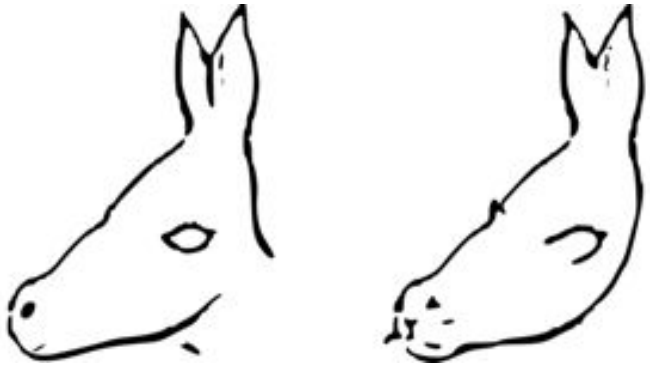
Kietzmann et al. (2010) PLoS One

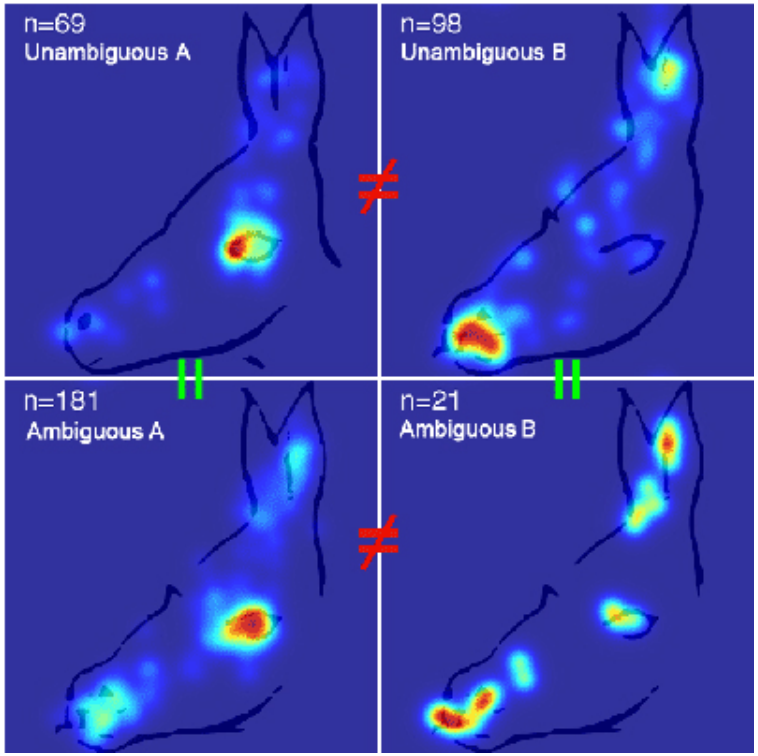


We use ambiguous figures to investigate eye movements with constant physical stimulation but varying perception.

Do we first look in a donkey specific pattern and then perceive the figure, or do we perceive a donkey and then look at characteristic spots?

The relation of action and perception



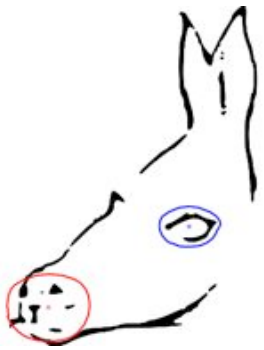


We observe strong systematic differences in fixation patterns of disambiguated stimuli, that are physically similar.

With physically identical stimuli the fixation pattern is correlated with the percept. The strength of effect in this example is at 64% percentile of 12 stimulus sets.

Importantly, the highest correlation is well before (800 ms reaction time corrected) the button press.

Furthermore, the percept can be systematically influenced by biasing the fixation pattern.

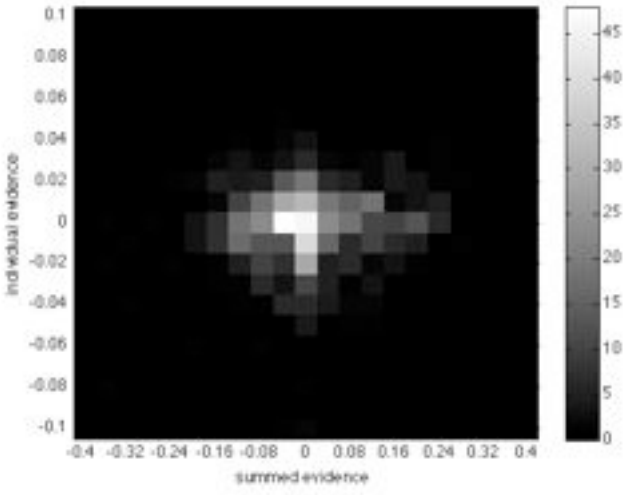


	Dist $A < B$	Dist $B < A$	Sum
Percept A	23	69	92
Percept B	4	88	92
Sum	27	157	184

Action precedes perception. A bias on action biases perception.

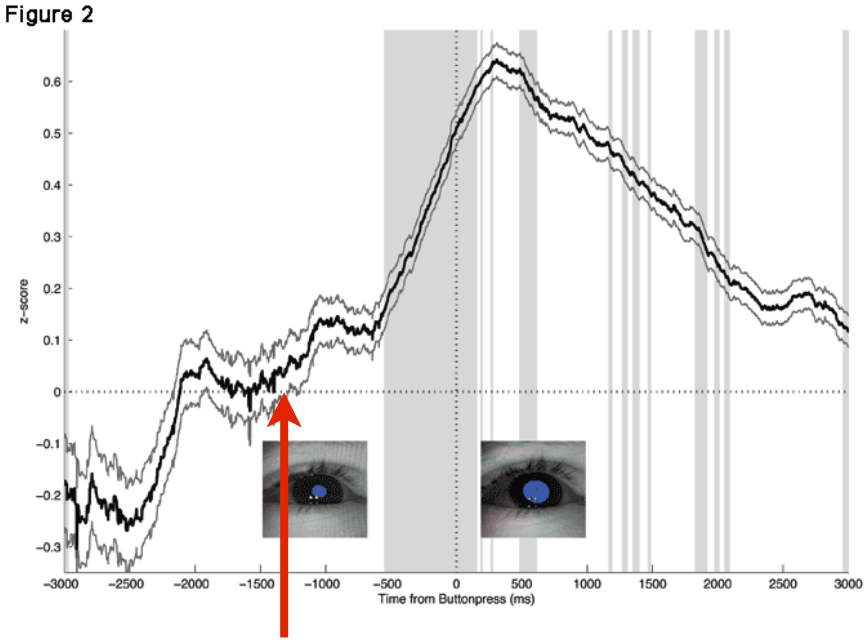
A causal influence of eye movement patterns

Does increasing evidence for one percept increasingly bias further selection of fixation points?



We do not find evidence for a correlation of cumulative and instantaneous pattern bias, and thus no evidence for an influence of a preconscious hypothesis.

Is the subjective report reliable? We measure pupil dilation as an indication of a perceptual decision.



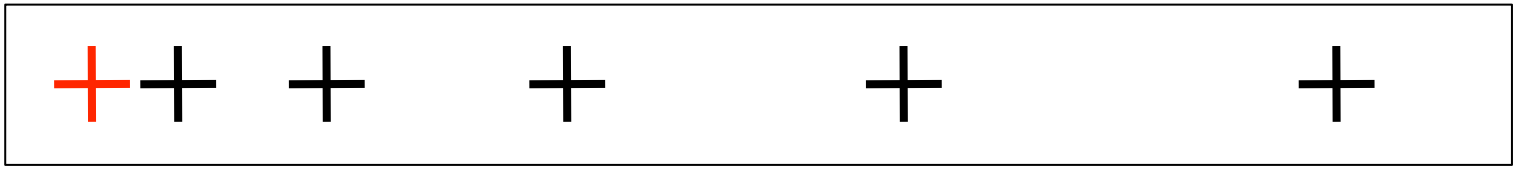
Maximal difference in fixation pattern occurs well before pupil dilation.

These results are compatible with a stimulus driven guidance of eye movements.

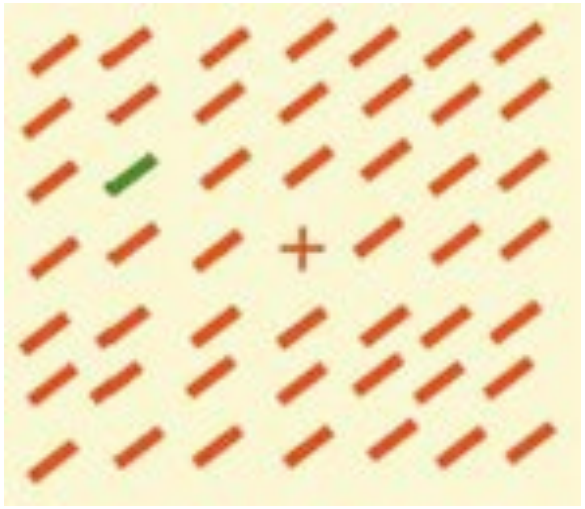
Factors of eye movement control

Factors in the selection of fixation points

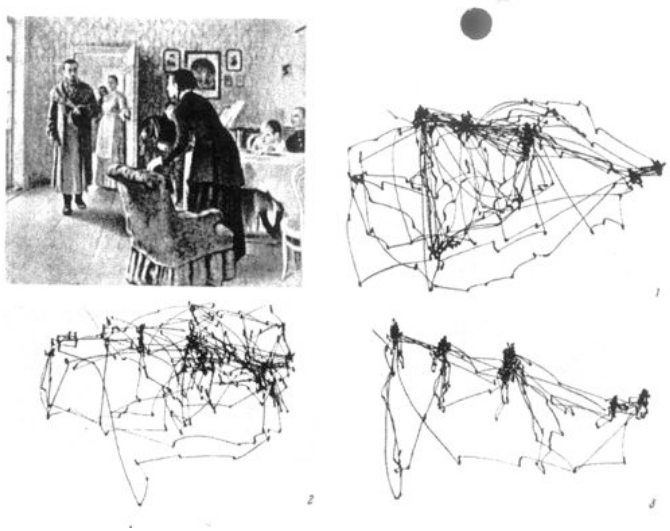
Proximity (spatial bias)



Low level features (bottom-up)



Task context (top-down)



What is the relative influence of these factors?

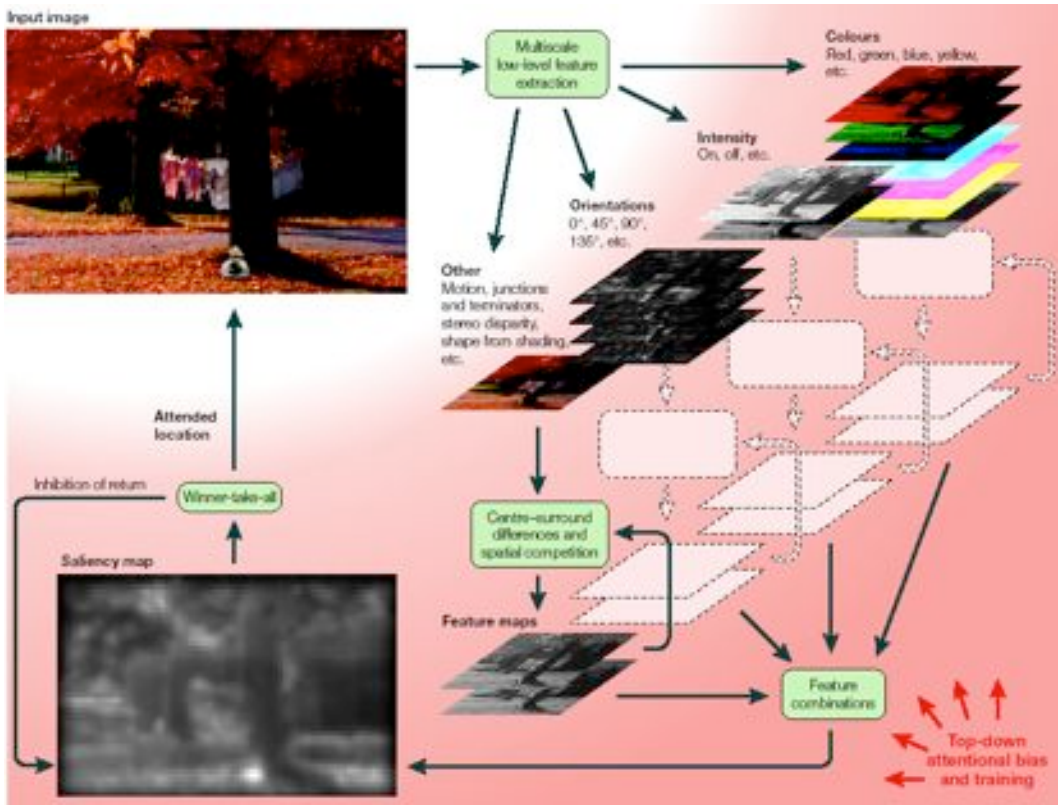
Where is the animal?

Salient signals and camouflage have its purpose in nature.

Stimulus dependent contributions

Salience maps:
Principles

Itti & Koch (2001) Nature Rev Neurosci



There are many different physical qualities that can make an object more salient than other objects in the display, such as its colour, orientation, size, shape, movement or unique onset. The salience map allows the most distinct object to be identified, independently of the particular features that it possesses, by receiving input from different feature maps that represent specific qualities of the scene and then summing these values.

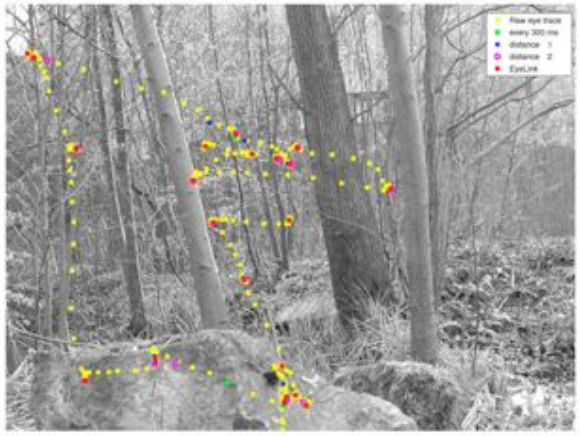
Figure 1 | **Flow diagram of a typical model for the control of bottom-up attention**. This diagram is based on Koch and Ullman's19 hypothesis that a centralized two-dimensional saliency map can provide an efficient control strategy for the deployment of attention on the basis of bottom-up cues. The input image is decomposed through several pre-attentive feature detection mechanisms (sensitive to colour, intensity and so on), which operate in parallel over the entire visual scene. Neurons in the feature maps then encode for spatial contrast in each of those feature channels. In addition, neurons in each feature map spatially compete for salience, through long-range connections that extend far beyond the spatial range of the classical receptive field of each neuron (here shown for one channel; the others are similar). After competition, the feature maps are combined into a unique saliency map, which topographically encodes for saliency irrespective of the feature channel in which stimuli appeared salient. The saliency map is sequentially scanned by attention through the interplay between a winner-take-all network (which detects the point of highest saliency at any given time) and inhibition of return (which suppresses the last attended location from the saliency map, so that attention can focus onto the next most salient location). Top-down attentional bias and training can modulate most stages of this bottom-up model (red shading and arrows)

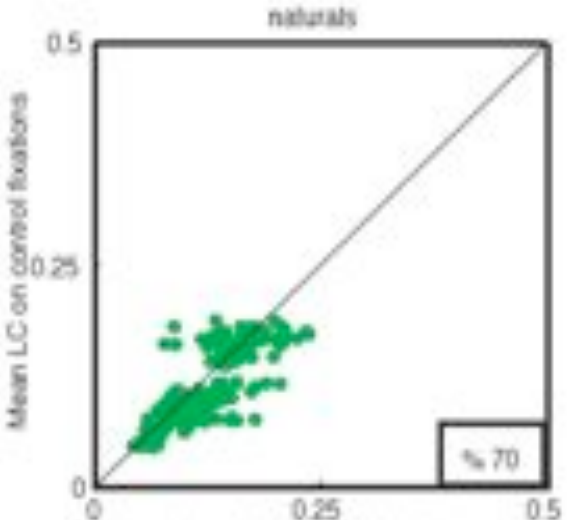
The relative distinctiveness of the object is represented in a featureless manner.

Salience maps:
Image properties at fixation points

Einhäuser & König (2003) Eur J Neurosc
Acik et al. (2009) Vision Res

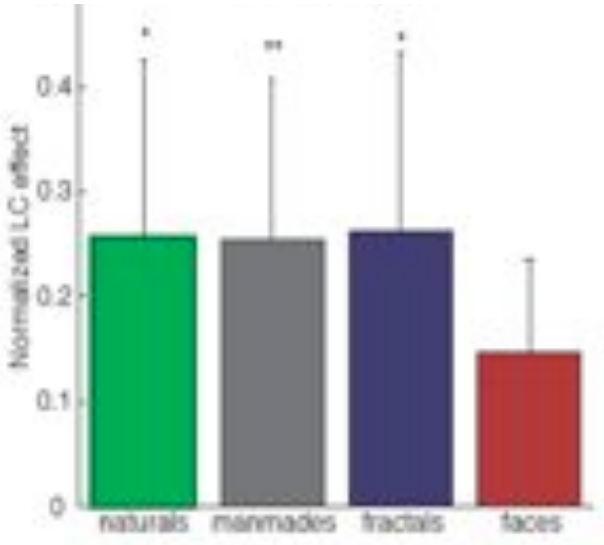
Measurement of eye movements: fast are shown in yellow, fixation points in red.





Luminance contrast at fixation points.

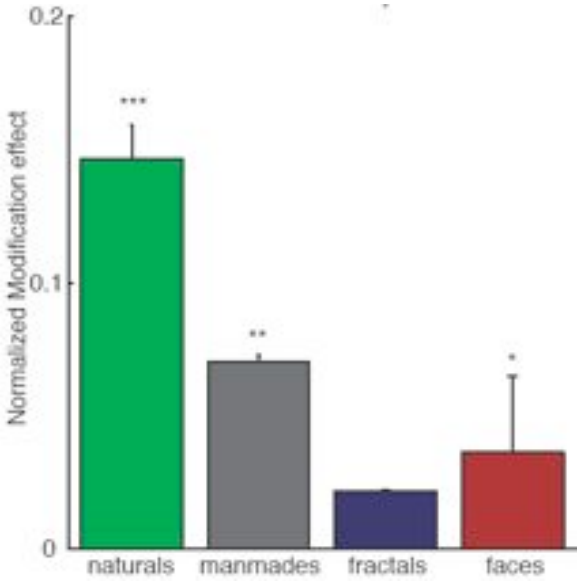
Comparison of luminance contrast at fixation points in natural visual stimuli and control locations. Each point depicts the average luminance contrast within one image. If luminance contrast is uncorrelated with the selection of fixation points we would expect all data on or near the main diagonal. The data are in line with previous results of Reinagel & Zador (1999)

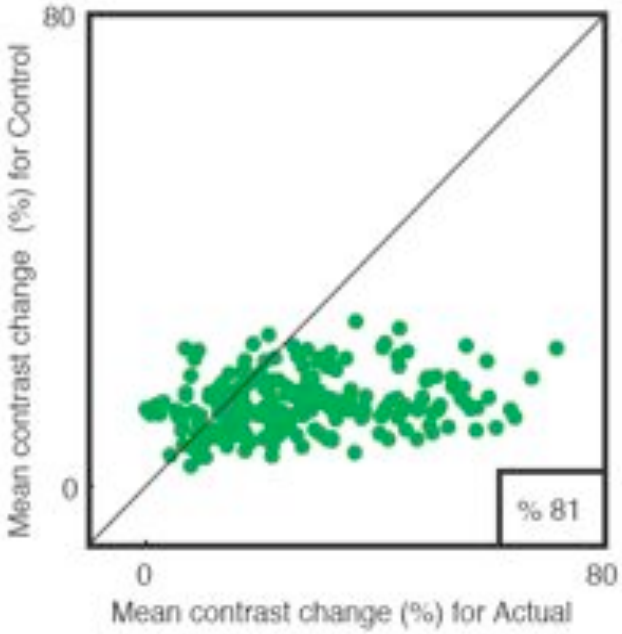


We find a systematic increase of luminance contrast at fixation points.

Salience maps:
A causal effect?

Einhäuser & König (2003) Eur J Neurosci
Acik et al. (2009) Vis Res

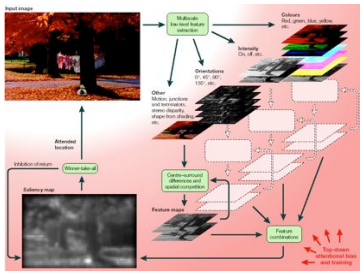




The effect of modifications of luminance contrast depends strongly on image category. For moderate changes no effect may be observed at all. Reductions of contrast may increase saliency.

Are we investigating the relevant features?

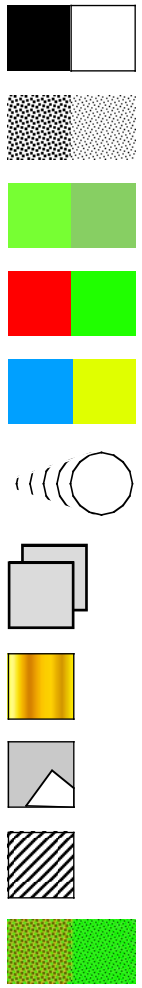
Salience maps:
Many more features



Onat et al. (submitted) Acik et al. (2014), Jansen et al. (2009) Journal of Vision, Einhäuser et al. (2009) Annals of the New York Academy of Sciences, Einhäuser et al. (2009b) Annals of the New York Academy of Sciences, Quigley et al. (2008) Journal of Eye Movement Research, Frey et al. (2008) Journal of Vision , Schumann et al. (2008), Journal of Vision, Harding et al. (2007) WAPCV 07, Einhäuser et al. (2007) Network: Computation in Neural Systems, Onat et al. (2007) Journal of Vision, Frey et al. (2007) Perception & Psychophysics, Moeller et al. (2007) NeuroReport, Saal et al. (2006) IEEE AICS, Einhäuser et al. (2006) Journal of Vision, Einhäuser et al. (2006) Vision Research

- luminance contrast
- texture contrast
- saturation
- r/g contrast
- b/y contrast
- motion
- depth
- phase symmetry
- intr. dimensionality
- sobel-filter
- 2nd order color contrast

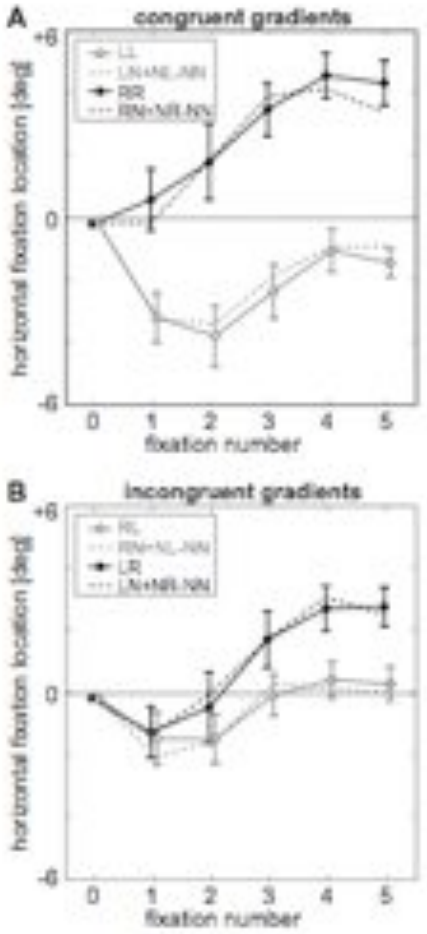
Studies on integration of information



By studying many different image properties we can better understand eye movements.

Salience maps:
Interaction of features

Engmann et al. (2009) Percept Psychophys



The combined effect of luminance and color is well predicted by an additive model.

Definition of dynamic features

Acik et al. (2014) J Vision

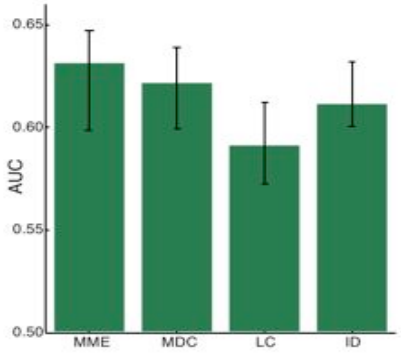
We compare the predictive value of dynamic and static features on dynamic (videos) and static (still frames taken out of these videos) stimuli.

Interaction of features

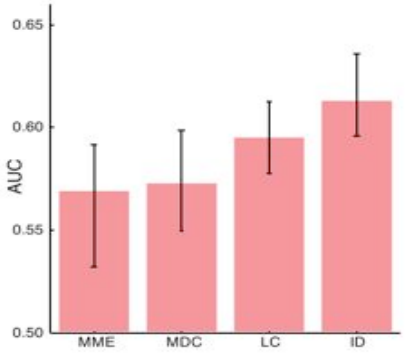
Acik et al. (2014)

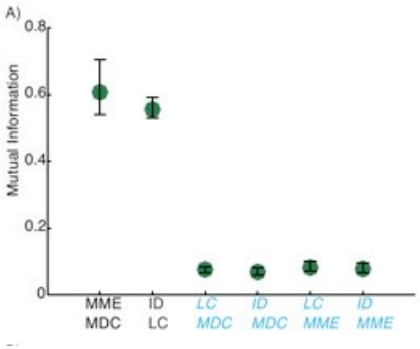
Evaluation of different approaches for extracting visual information suitable for learning eSMCs

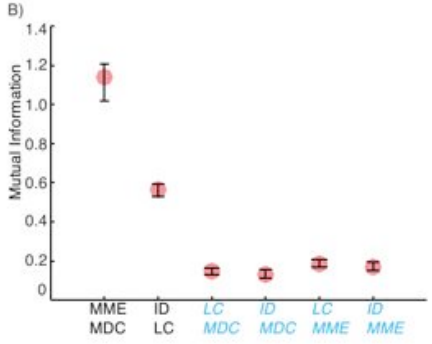
Viewing videos



Viewing static







Dynamic saliency maps predictions

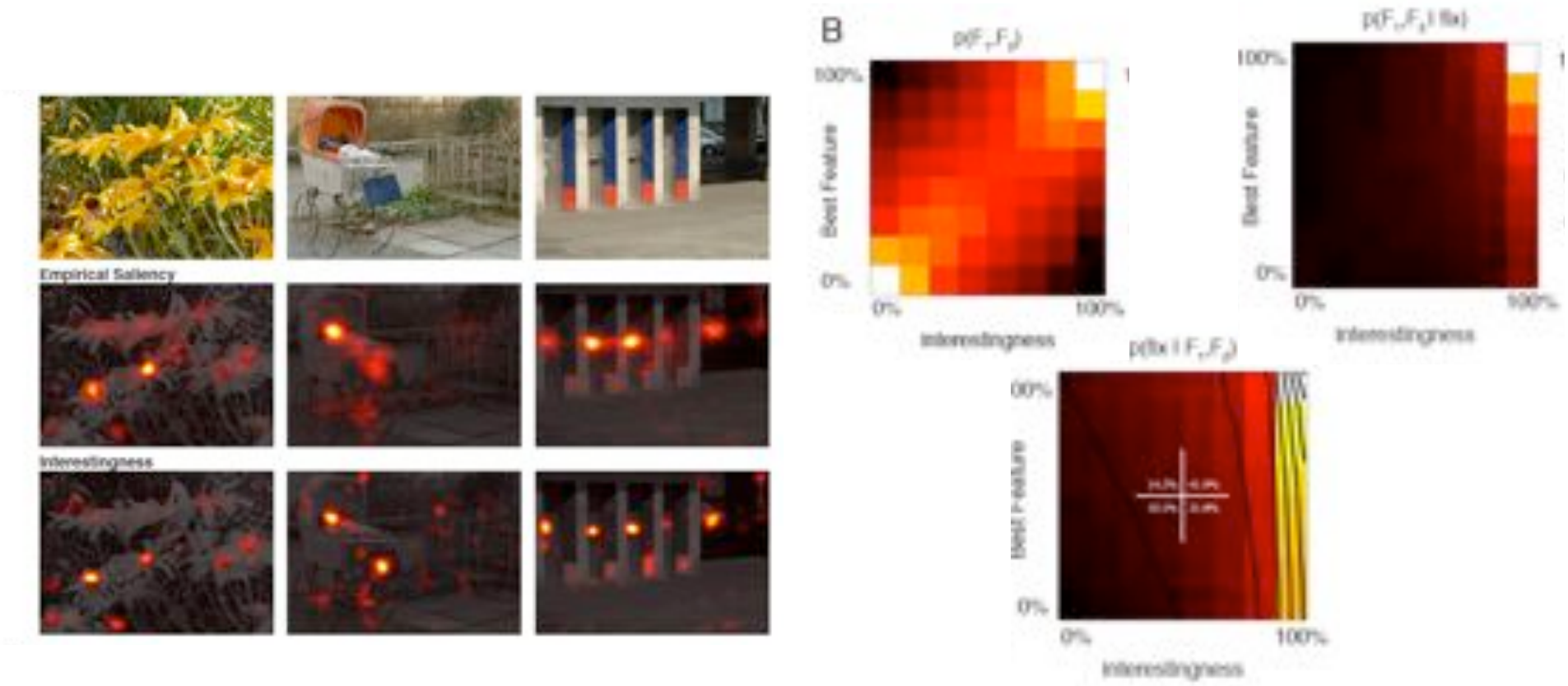
Motion cues are effective (~50%) in static images.

Motion and static features predict behavior independently.

This is a very strange contrast. Our current hypothesis is that the missing prediction power is supplemented by high-level processing. This predicts a lag in fixations of motion-salient regions in static images.

Motino features have about 50% predictive value in static stimuli as well, although they are not correlated with low level static features.

A comparison with the high-level feature "interestingness".

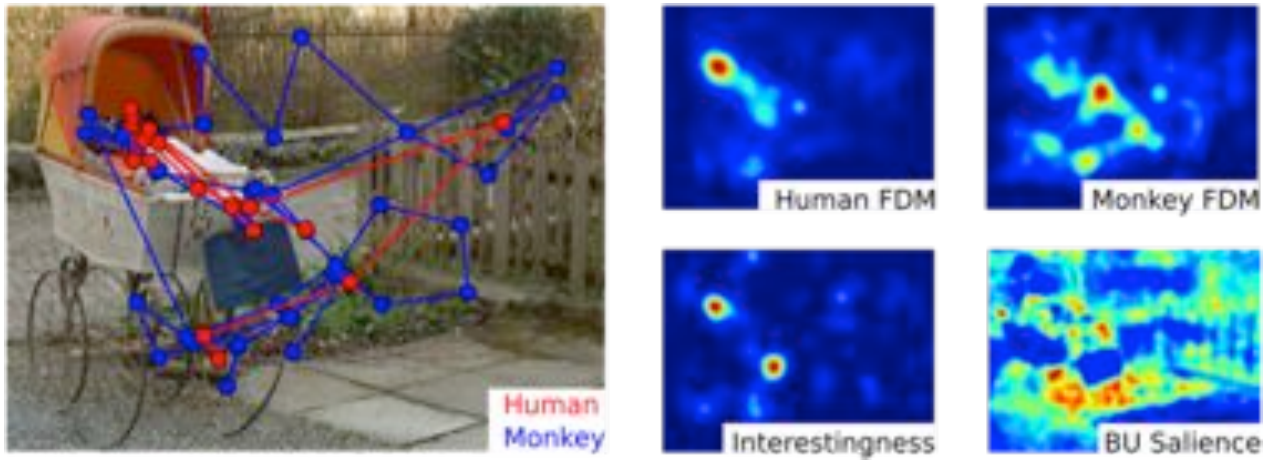


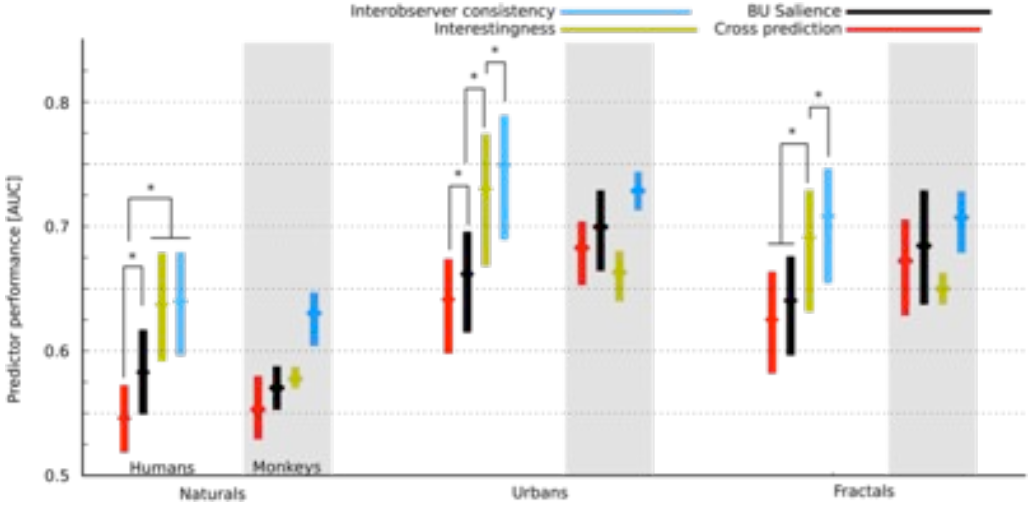
Interestigness (clicks' maps) are highly predictive of fixation locations and highly correlated with best features.

Low-level image features are maximally effective at those locations that had already high interestingness ratings.

... continued later when we discuss fixation duration.

A comparison with the high-level feature "interestingness".





Interestigness (clicks' maps) are highly predictive of fixation locations and highly correlated with best features.

Low-level image features are maximally effective at those locations that had already high interestingness ratings.

... continued later when we discuss fixation duration.

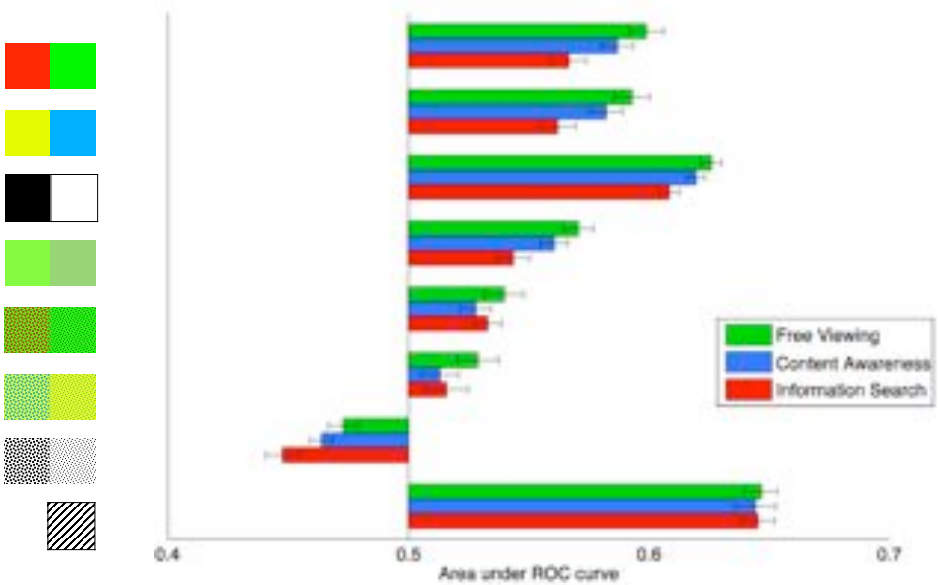
High-level factors

Geometrical and high-level factors:
What is the role of the task?

Betz et al. (2010) J Vis

Viewing visual stimuli in the context of three different tasks shows that the correlation of features with fixation points varies in strength, however, the pattern remains constant. The effect of task context in this experiment can not be modelled by a modulation of low level feature maps.

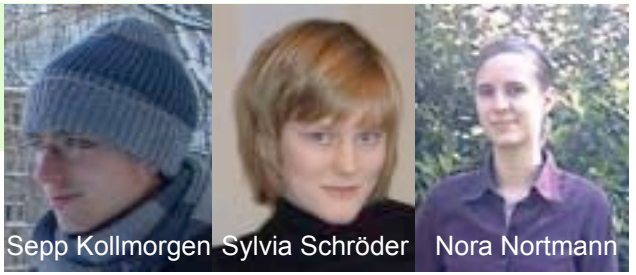
Strength of correlation of different features in three different tasks.



See also Lipps & Pelz 2004 „While subjects' eye-movement patterns were clearly task dependent, the patterns are much less dramatic than those shown in Yarbus' now classic illustrations."

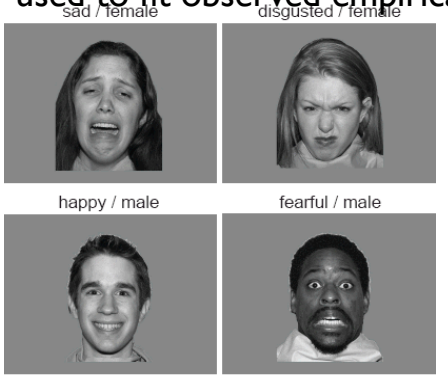
We find evidence for strong top-down. As a consequence, the prediction of fixations in different tasks may be based on the same fingerprint of features.

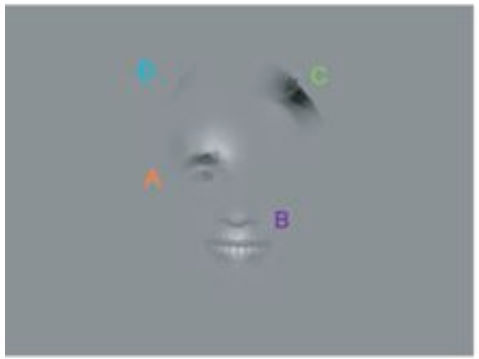
Dissecting different contributions

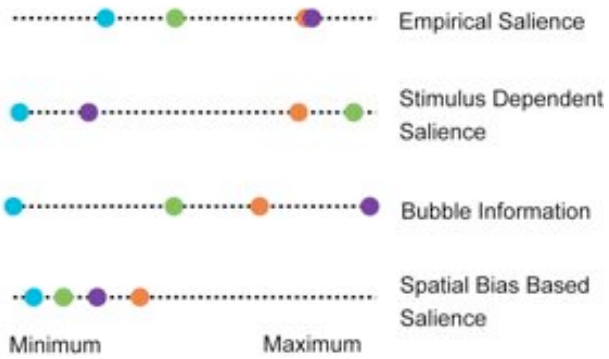


Kollmorgen et al. (2010) PLoS Comp Biol

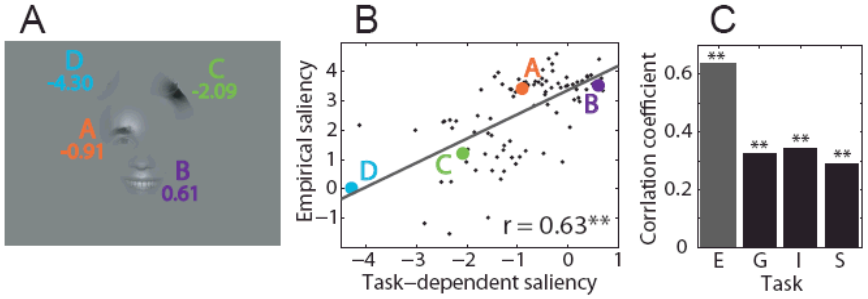
Two sets of images are investigated in the context of two different tasks (each). Contributions of stimulus dependent saliency (local feature contrasts), task related saliency (performance gain contingent on fixation of the bubble) and spatial bias (probability to fixate a bubble for purely geometrical reasons) are used to fit observed empirical saliency.







Here an example for task related saliency is shown. Information gained by fixation of a bubble is converted to task dependent saliency that in turn is fitted to the observed empirical saliency. The histogram shows the correlation coefficient in 4 different tasks.

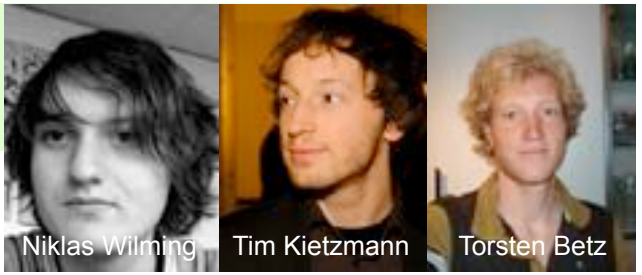


		Stimulus-dependent saliency	Task-dependent saliency	Spatial bias
Gender	Correlation coefficient *r*	**0.235 ***	**0.326 ****	**0.362 ****
	Semi-partial correlation coefficient *s r*	0.213 *	0.304 **	0.329 **
	Multivariate regression	R = 0.518**, R^2 = 0.269**, adjusted R^2 = 0.244		

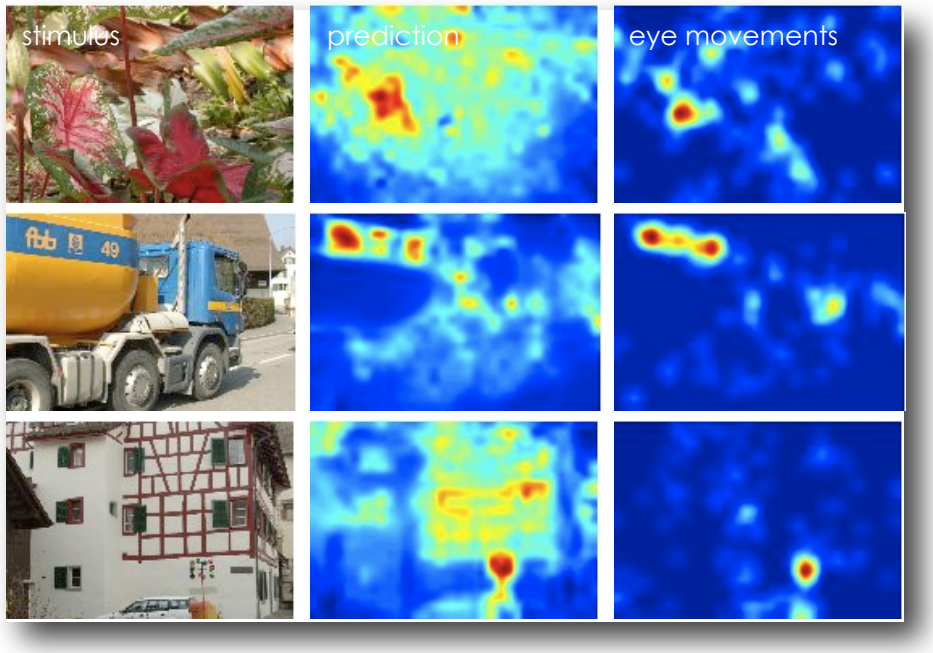
High level information, spatial properties as well as low level features contribute significantly to guidance of eye movements.
Partialization leads only to a moderate reduction of correlation.

Saliency maps

Modelling of overt attention: How good can we get?



Wilming et al. (2011) PLoS one



high salience

low salience

The quality of the model is characterized by the area under the ROC curve (AUC) to classify points being fixated or not. 0.50 is random guessing, 1.00 is perfect.

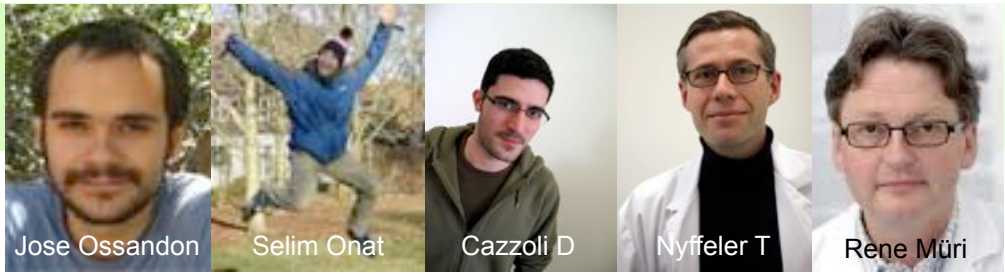
Natural	0,75
Fractal	0,79
Urban	0,75
Web pages	0,87

In the last category the model is as good as a classical experimental study with 7 subjects.

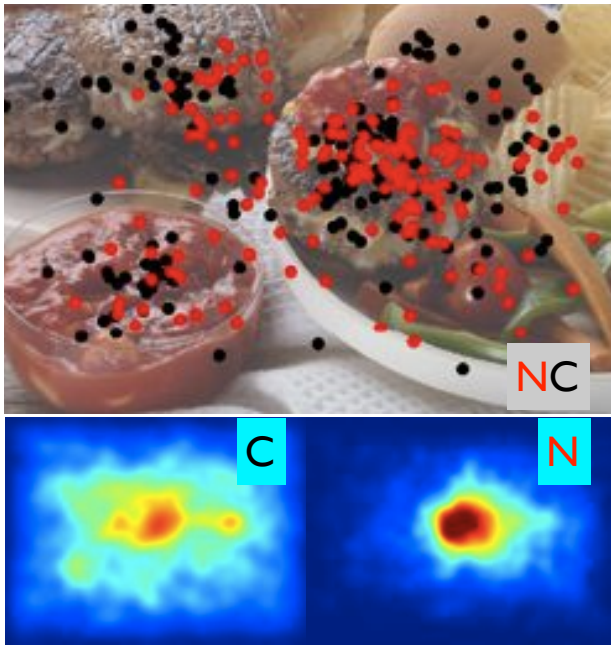
The model makes qualitatively and quantitatively good predictions, compatible with the initial hypothesis.

Is a low-level salience map real?

Osandon et al. (2012) Neuropsychologica

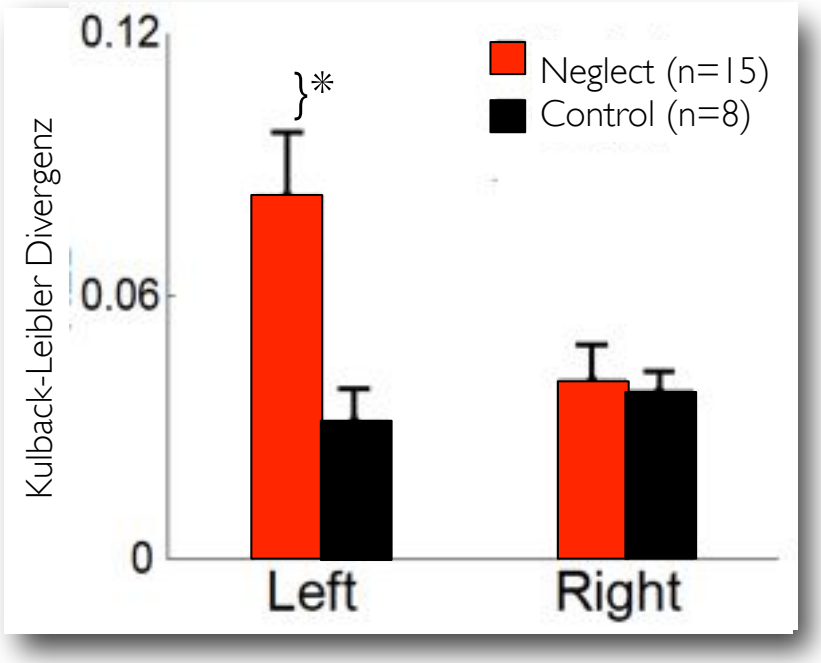


Spatial distribution of fixations



Compared to controls (C) neglect patients (N) show a reduction in contralesional exploration.

Relation of fixations to image features

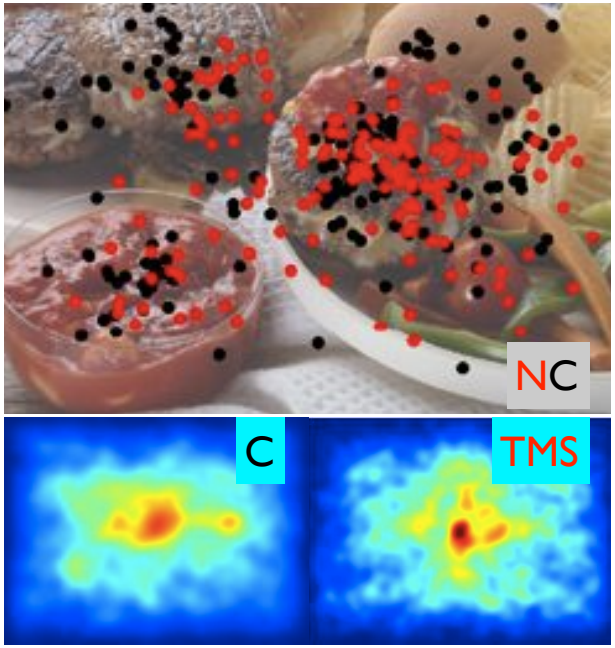


Neglect patients show a largely increased influence of low-level features on the neglected side.

Spatial hemineglect unmasks a stimulus dependent salience map.

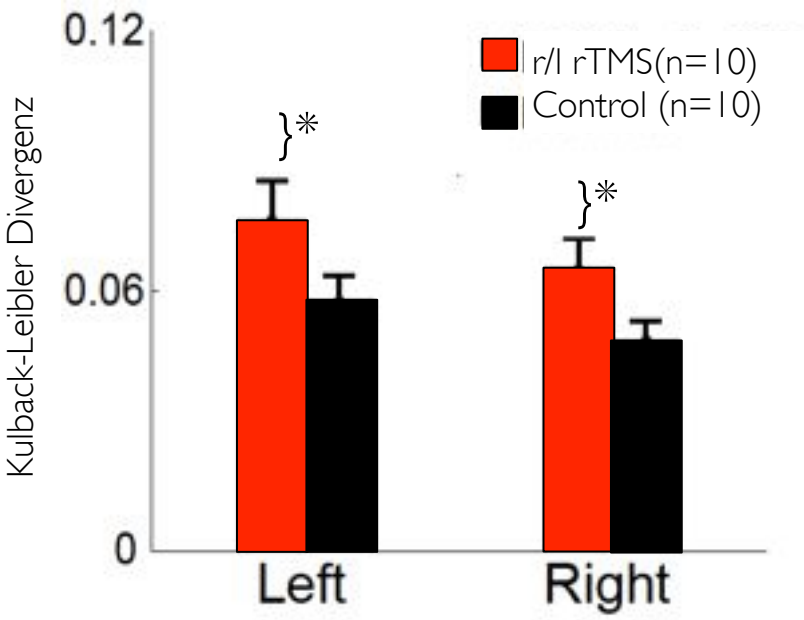
Is a low-level salience map real?

Spatial distribution of fixations



Neglect patients (N) show compared to controls (C) the defining reduction in contralesional exploration. Please note that the spatial extend of exploration on the ipsilesional side exploration is slightly reduced.

Relation of fixations to image features

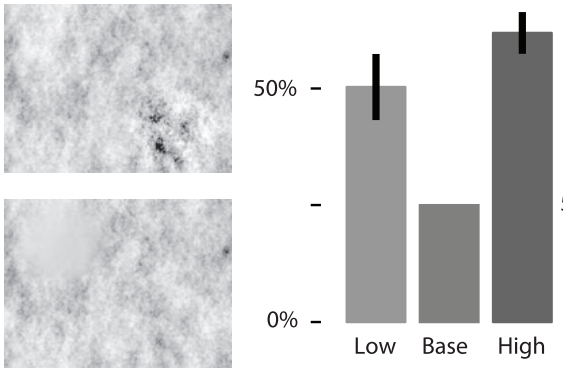


Neglect patients show a largely increased influence of low-level features on the neglected side. This holds in comparison to the ipsilesional side and to control subjects.

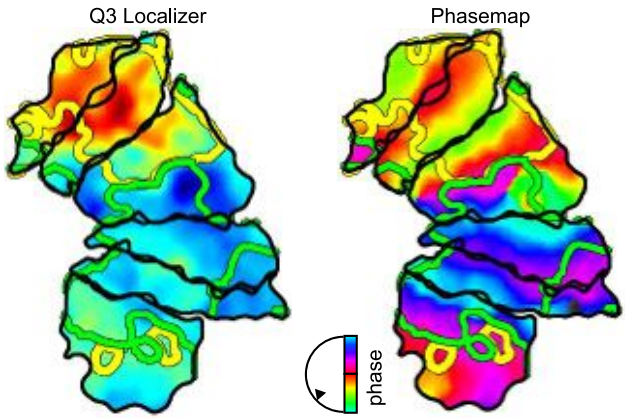
Bilateral parietal TMS unmasks a stimulus dependent salience map.

Is the saliency map encoded in early visual cortex?

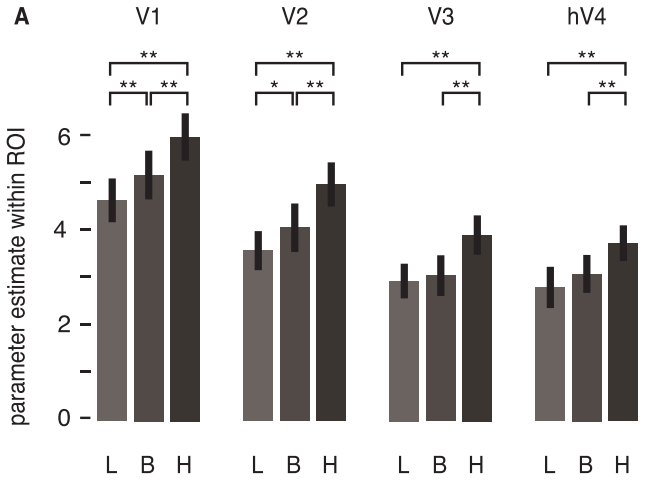
Betz et al. (2013) J Vision

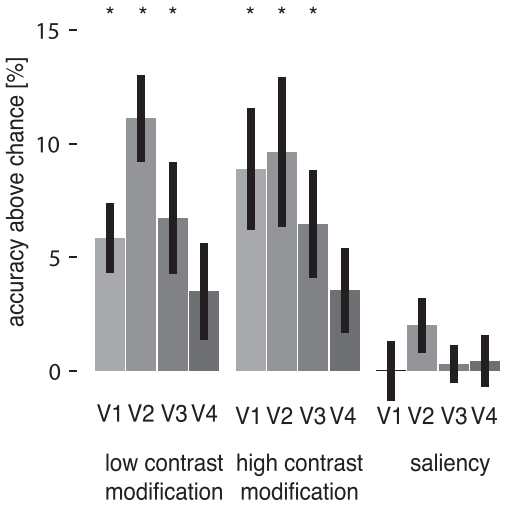


Visual stimuli (left) and initial fixations to modified quadrant (right). Both locally enhanced and reduced luminance contrast increase salience.



Topographic maps of early visual cortex.





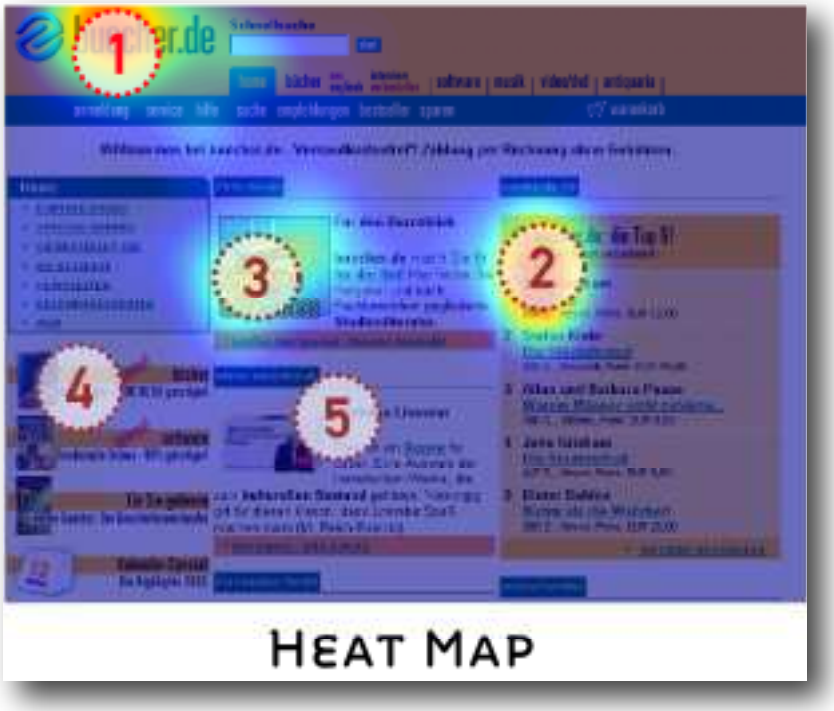
Bold activation for reduced contrast high saliency stimuli is lower not higher than unmodified stimuli (top). Along similar lines, multivariate decoding methods can decode contrast modifications but not saliency in early visual cortex (V1-V3, left).

No.

What is it good for?

Modelling of overt attention: Doing something useful

EYEQUANT
ATTENTION ANALYTICS



HEAT MAP

- young healthy students
- kindergarten (4-5y)
- pupils (12-14y)
- adults (30-55y)
- seniors (65y+)
- color blind
- > 700 subjects total

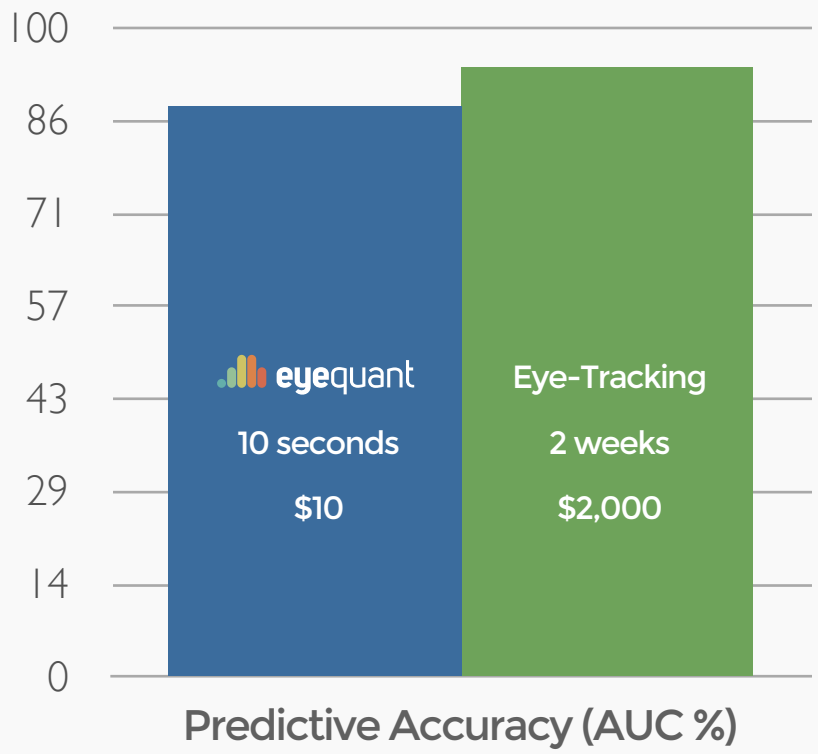
- web-based platform
- tools for detailed analysis
- spin-off in ’09
- break even ’10
- external investor ’11
- relocation: Berlin ’12

Optimization guided by the eyequant techniques leads to a substantial increase in conversion rate.

eyequant

How Accurate is it?

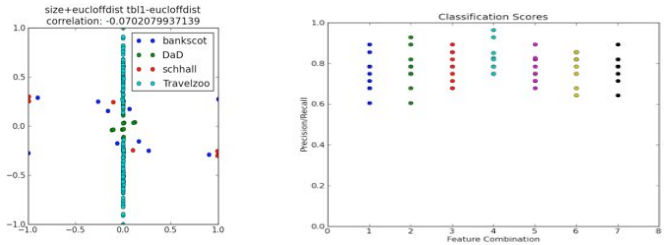
Evaluation: 90% as accurate as real eye-tracking!



Predicting conversion rates

EYEQUANT
ATTENTION ANALYTICS

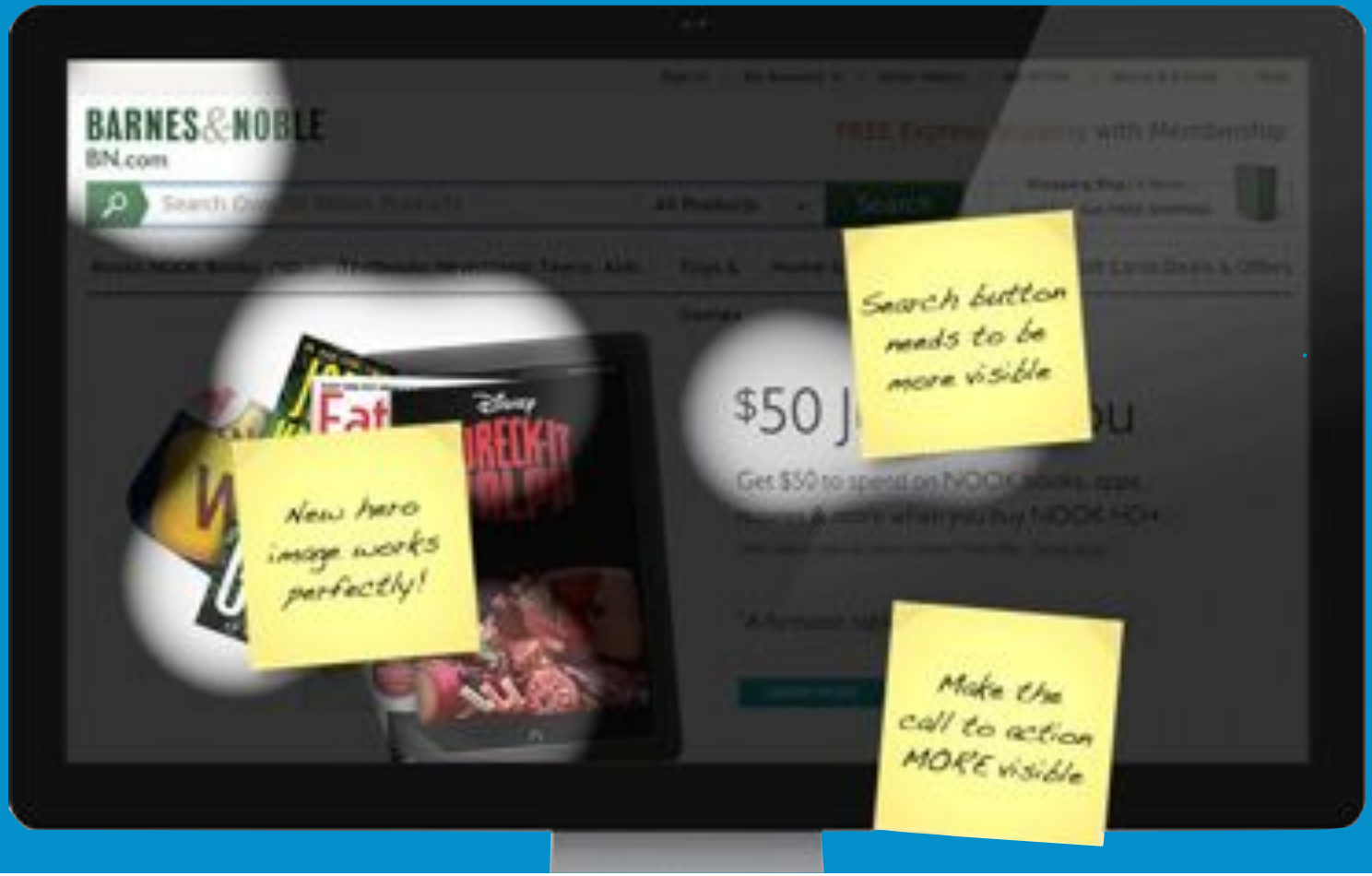
Based on the prediction of gaze movements we evaluate competing designs for landing pages (A/B test). On the test-set (nested cross-validation) the prediction achieves a precision of 80%.



Optimization guided by the eyequant techniques leads to a substantial increase in conversion rate.

eyequant

Service Overview



eyequant

What is EyeQuant?

an artificial intelligence that instantly predicts how users will look at your website

Eye-Tracking study with 50 users

EyeQuant instant analysis

eyequant

How does it work?

Conduct hundreds of Eye-Tracking Studies

We investigate how users look at designs in the first few seconds of their visit and track millions of fixations.

Statistical Modeling and Machine Learning

We analyze the data to find correlations between fixations and statistical image features. Using machine learning algorithms, we build models that use image characteristics to predict attention.

EyeQuant SaaS Technology

We provide instant access to the most accurate models directly from the EyeQuant web service.

eyequant

How Accurate is it?

Side-by-side comparisons

Eye-Tracking

38 Users

EyeQuant

Instant Prediction

eyequant

How Accurate is it?

Side-by-side comparisons

Eye-Tracking

38 Users

EyeQuant

Instant Prediction

How Accurate is it?

Side-by-side comparisons

Eye-Tracking

38 Users

EyeQuant

Instant Prediction

Why should I care?

Case Study: Groupon increases conversion rate by 52%

Original Page
users are distracted by images

EyeQuant Optimized Page
users immediately see offer and CTA

Who else uses EyeQuant?

...and hundreds more, from small online shops and freelancers to global brands

eyequant

What are people saying about it?

Kevin Gentil-Cantin, Conversion Specialist at Google

"I'm testing a lot of tools, and EyeQuant is one of the best and most useful I discovered during the last year, and your support is a big part of it."

eyequant

What are people saying about it?

Stephen Pavlovich, Managing Director at Conversion Factory

"EyeQuant has become one of our go-to tools that we use for every project."

Gabriel Beck, Head of Conversion Optimization at Explido

"With EyeQuant our landing page analyses become both faster and more specific."

Bobby Hewitt, CEO at Creative Thirst

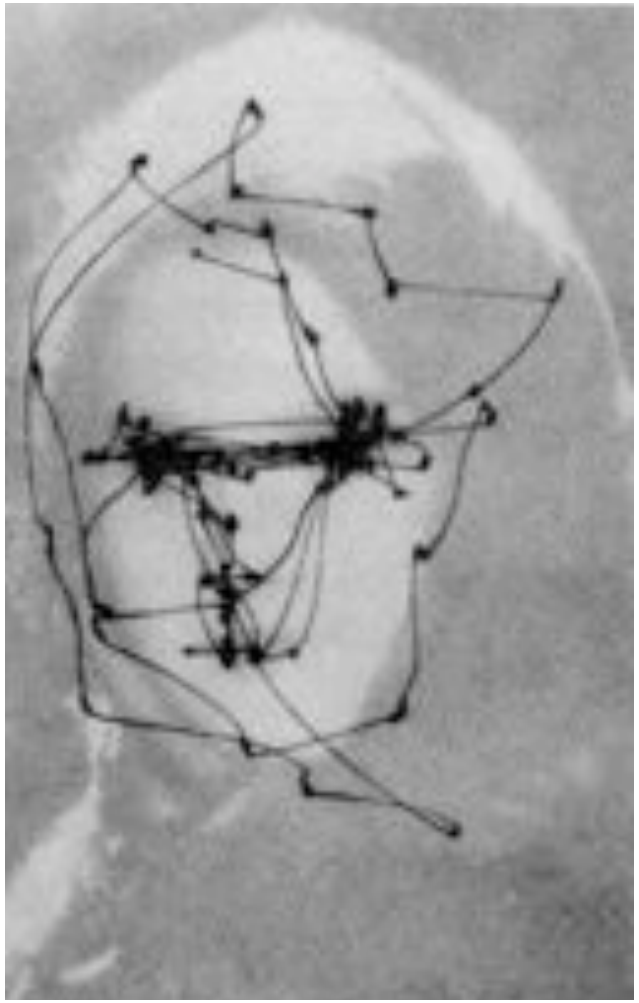
"There's no better tool than EyeQuant to gain immediate, actionable insight that you can apply to any test."

Jörg Dennis Krüger, Co-Founder at Conversion Boosting

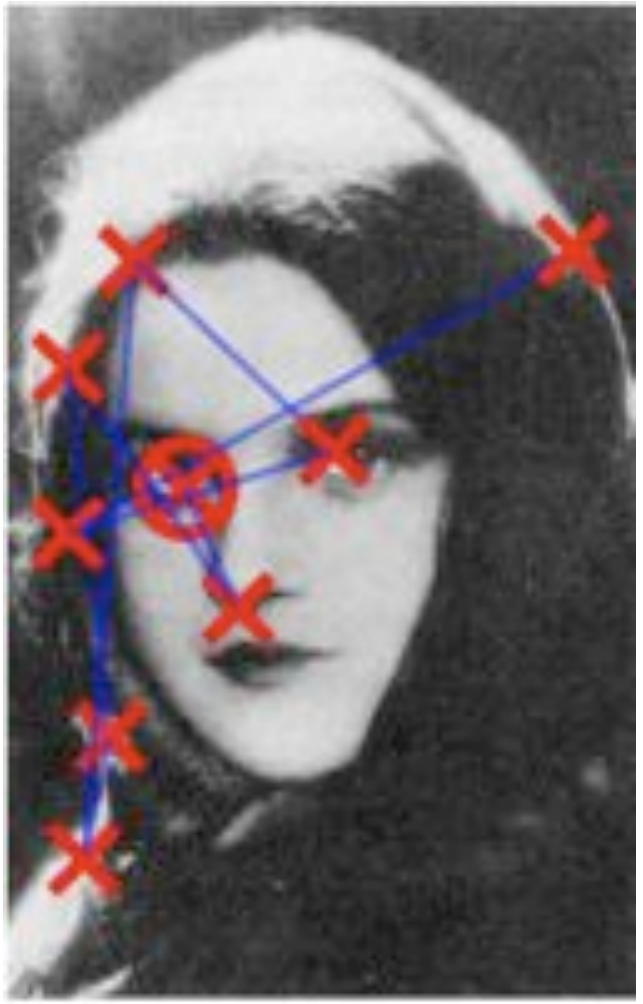
"EyeQuant helps us to quickly identify significant optimization potentials, resulting in even better conversion rates and more value for our customers."

Nitty gritty details:
Predicting gaze movements

Yarbus



EyeQuant



Summary & thanks ...

- Eye movements are a window into cognition.
- Stimulus properties, task context and spatial properties contribute independently to the control of eye-movements.
- Dynamic features make an important contribution even on static images.
- Saliency maps predict eye movements at high performance levels. This is useful for a commercial application. Cortical lesions and TMS unmask a stimulus dependent salience map.
- Horizontal asymmetry is a robust property not directly related to known brain asymmetries.
- IOR is facilitation, saccadic momentum and (relative) acceleration of return and therefore contributes to optimal foraging.
- It is possible to train new sensorimotor contingencies with subsequent consequences on perception.

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