Saccadic curvature and microsaccade analysis

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Saccadic Trajectory

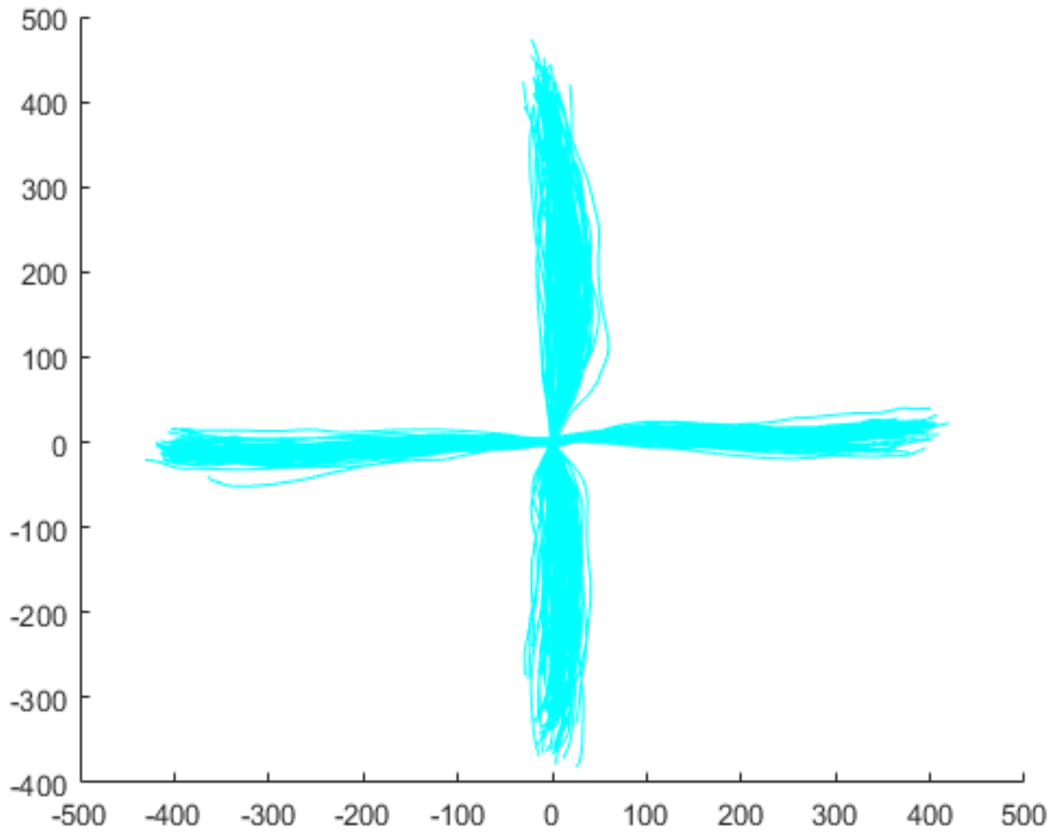
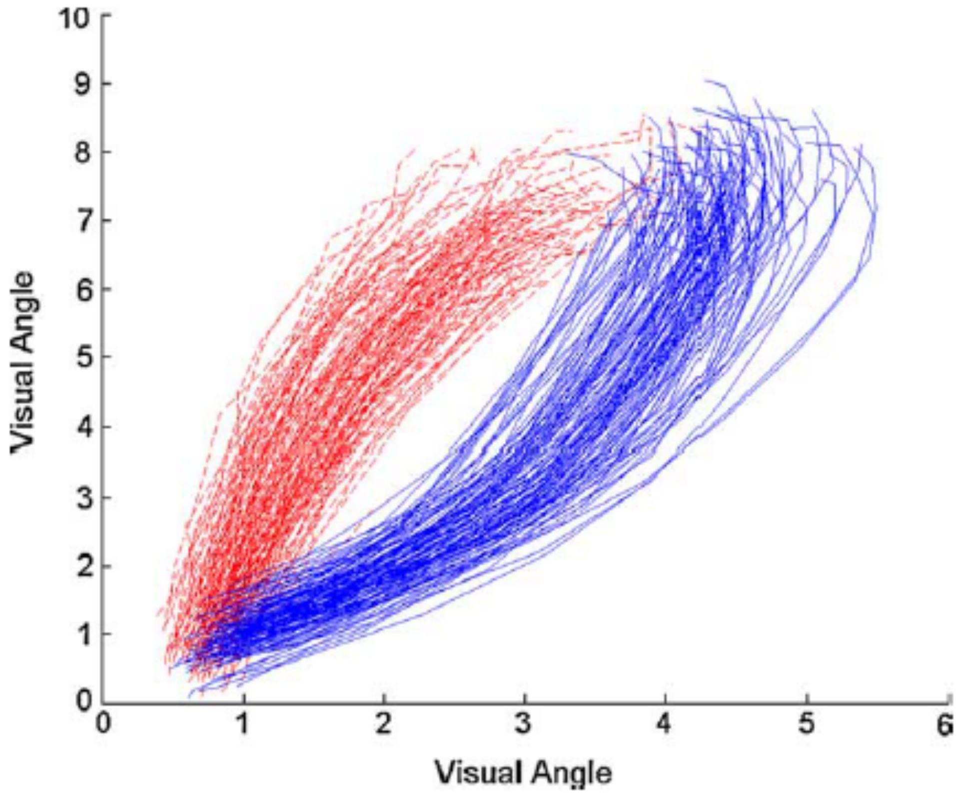


Image source: Master’s thesis

Saccadic Trajectory

- Curvature in human saccadic trajectory – are saccades ‘ballistic’ or not?
- Saccadic ‘signature’ yet variability
- Curvature vs. Deviation
- Difference across species
- Manipulated by attention, presence of distractors, memory, IOR -
  - Deviation towards
  - Deviation away



Across subject variability for the same task

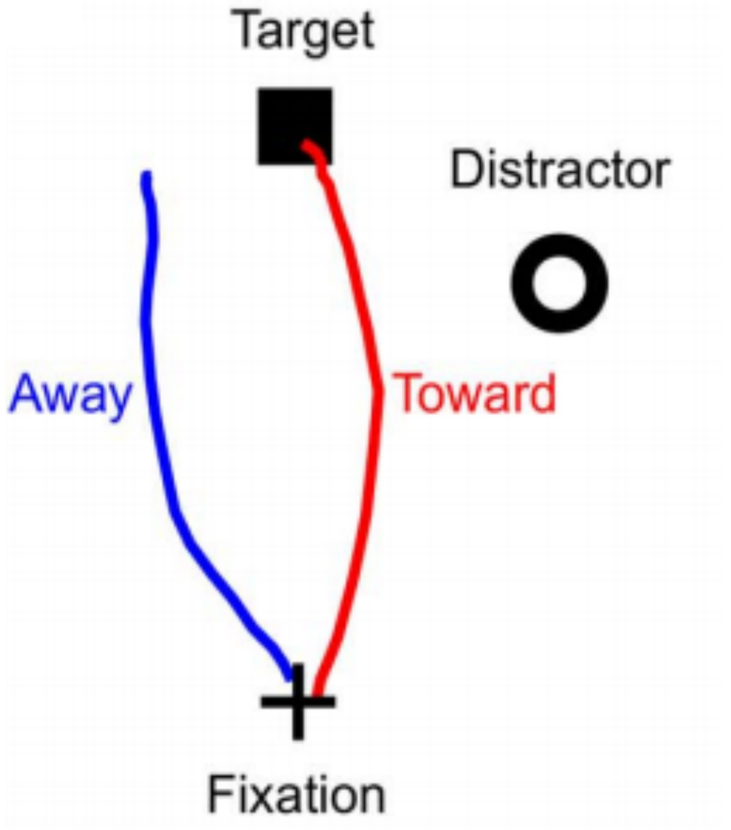
Image source: Stigchel et al., 2006

Deviation towards or away ?

- Population coding theory (Tipper et al., 1997)
  salience of distractor --> inhibition

- **Top-down preparation**
- Role of attention, memory

Lateral interaction (in the SC) theory –
Wang & Theeuwes, 2014



Sample saccade trajectories

Image source: Wang & Theeuwes, 2014

Mean signed curvature OR Maximum curvature:
(Doyle & Walker, 2001) *proposed by Smit and Van Gisbergen (1990)

Step 1:
Eye movement data indicating the horizontal and vertical location of the eye every 4 ms throughout the saccade was plotted to recreate saccade trajectory.

Step 2:
The most direct route from the start to the end of the saccade was then calculated and the actual saccade trajectory assessed relative to this route.

Step 3:
The distance between the actual saccade and the corresponding point on the direct route was measured at the point at which the saccade deviated most from the direct route (peak deviation).

Step 4:
Normalization - Peak deviation was divided by saccade amplitude to obtain a ratio value of curvature per unit amplitude.

Step 5:
The absolute direction of curvature (i.e., left or right) was calculated using saccade direction (clockwise or anticlockwise) and target location. Positive values were used to signify rightward curvature and negative values to indicate leftward curvature.

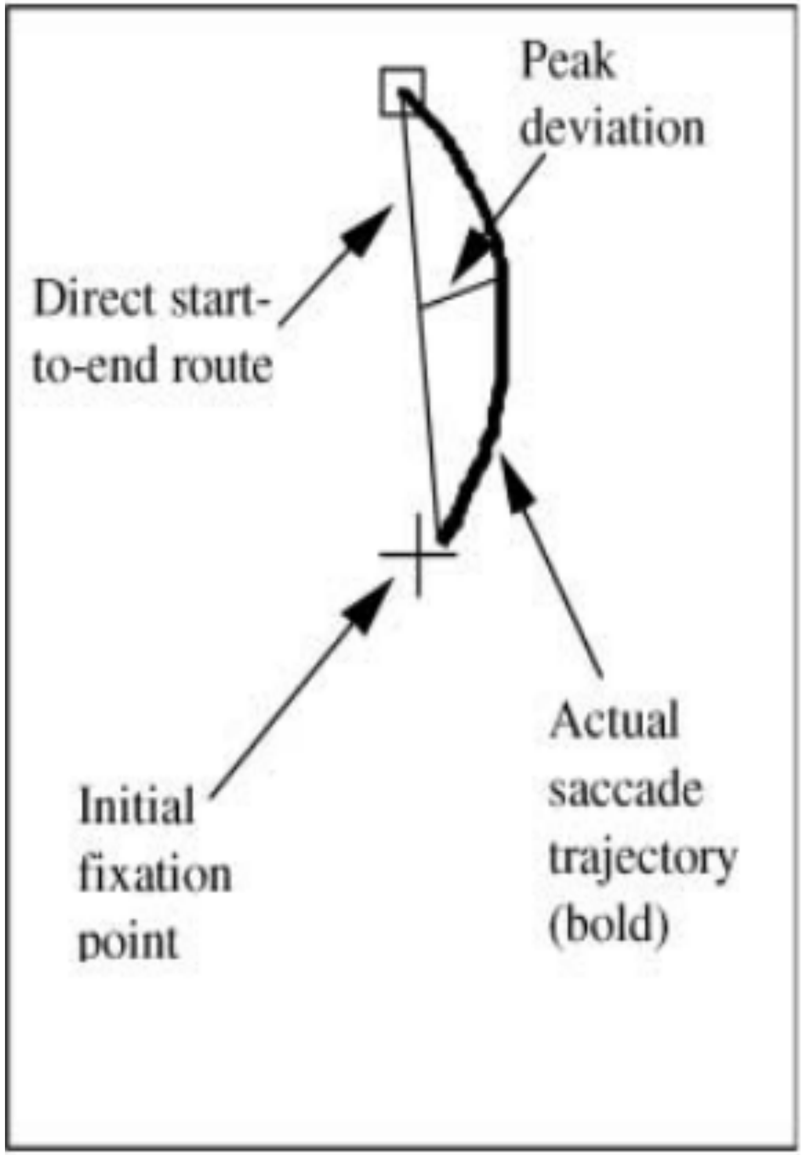


Image source: Doyle & Walker, 2001

Maximum area:
(Walker, McSorley & Haggard, 2006)

Step 1:
Rectangles drawn along the straight line from saccade start to saccade end and located between saccade samples are used to approximate the area of the curve.

Step 2:
Normalization – area under the curve was divided by saccade amplitude to obtain a ratio value of curvature per unit amplitude.

Step 3:
The absolute direction of curvature (i.e., left or right) was calculated using saccade direction. Trajectories deviating toward the distractor have been assigned positive curvature values, and those deviating away from the distractor have been assigned negative curvature values.

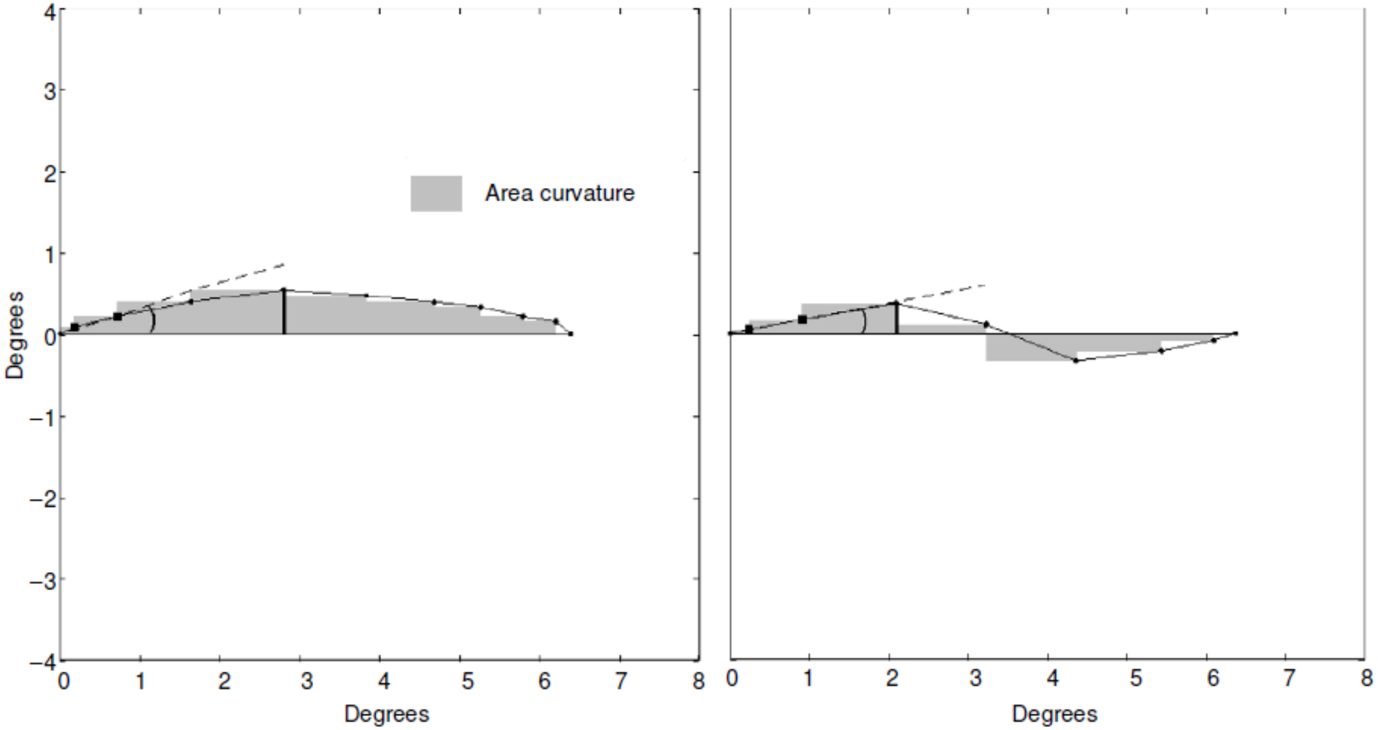


Image source: Ludwig & Gilchrist, 2002

Curve fitting approach:
(Ludwig & Gilchrist, 2002)

Step 1:
Every saccade was translated so that the axis through its starting and landing positions coincided with the abscissa (X- axis).

Step 2:
Four polynomials were fitted to each saccade:

- (1) a simple linear function,
- (2) a quadratic polynomial,
- (3) a cubic polynomial, and
- (4) a quartic polynomial

For each polynomial, the R^2 goodness of fit was calculated for each saccade, and the distribution of these R^2 values was plotted.

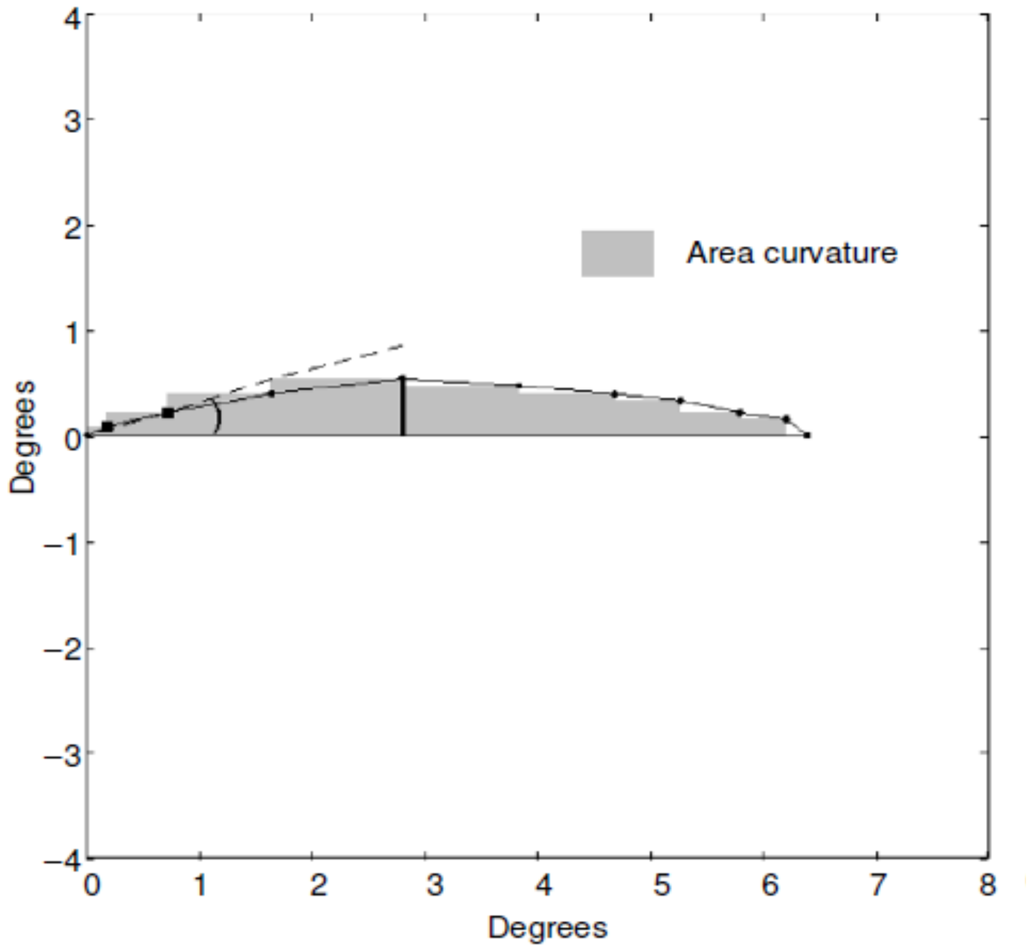


Image source: Ludwig & Gilchrist, 2002

Some other measures:
(Tudge et al., 2017)

Overall direction (OD):
Angle between a straight line from saccade start to saccade end and a straight line from saccade start to target position.

Saccade deviation (SD):
Mean of all angles formed by lines drawn from saccade start to each sample point in the saccade, as compared to a straight line from saccade start to the target position.

Overall initial direction (OID):
Like saccade deviation, but using only the first sample point occurring 10 ms after saccade start.

Initial direction (ID):
Like overall initial direction, but with angle calculated relative to a straight line from saccade start to saccade end, instead of to the target position.

Initial average curvature (IAC):
Like maximum curvature, but an average of the perpendicular distances to samples occurring within 10 ms of saccade start.

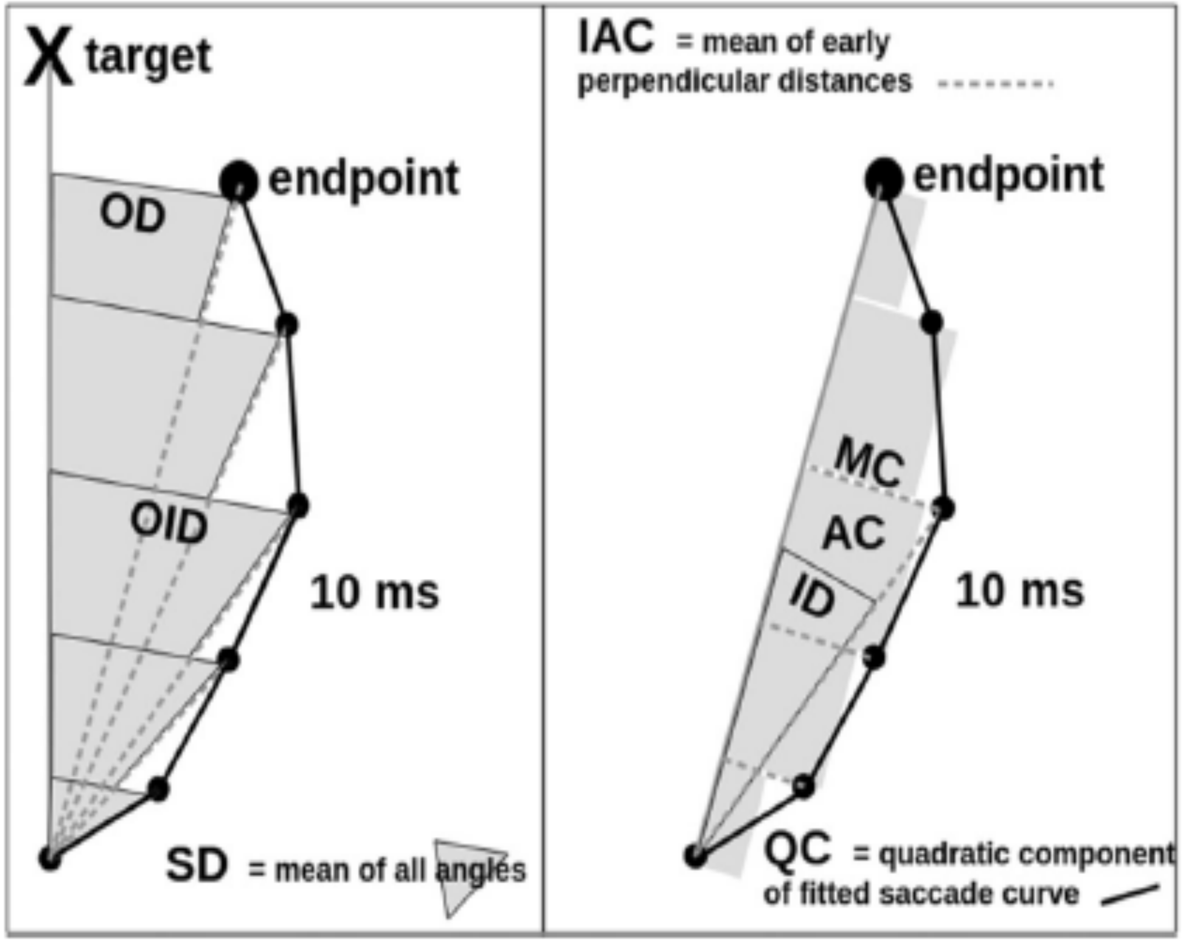


Image source: Tudge et al., 2017

Which method to choose ?

- Paradigm/objective of the study
- All points on the trajectory vs. a specific sample
- Reference line to endpoint vs. reference line to target
- Scientific literature, similar studies

Microsaccades

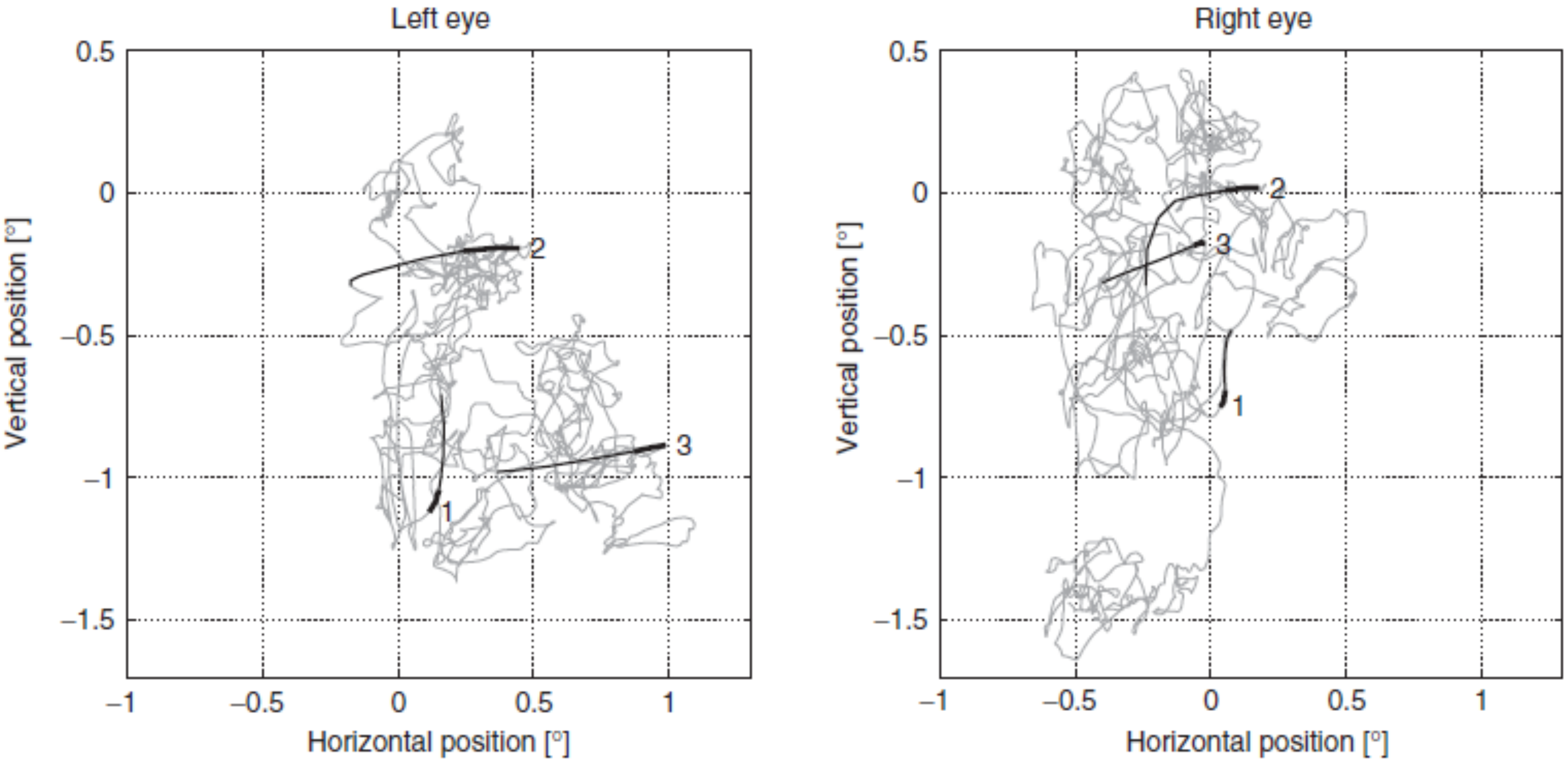
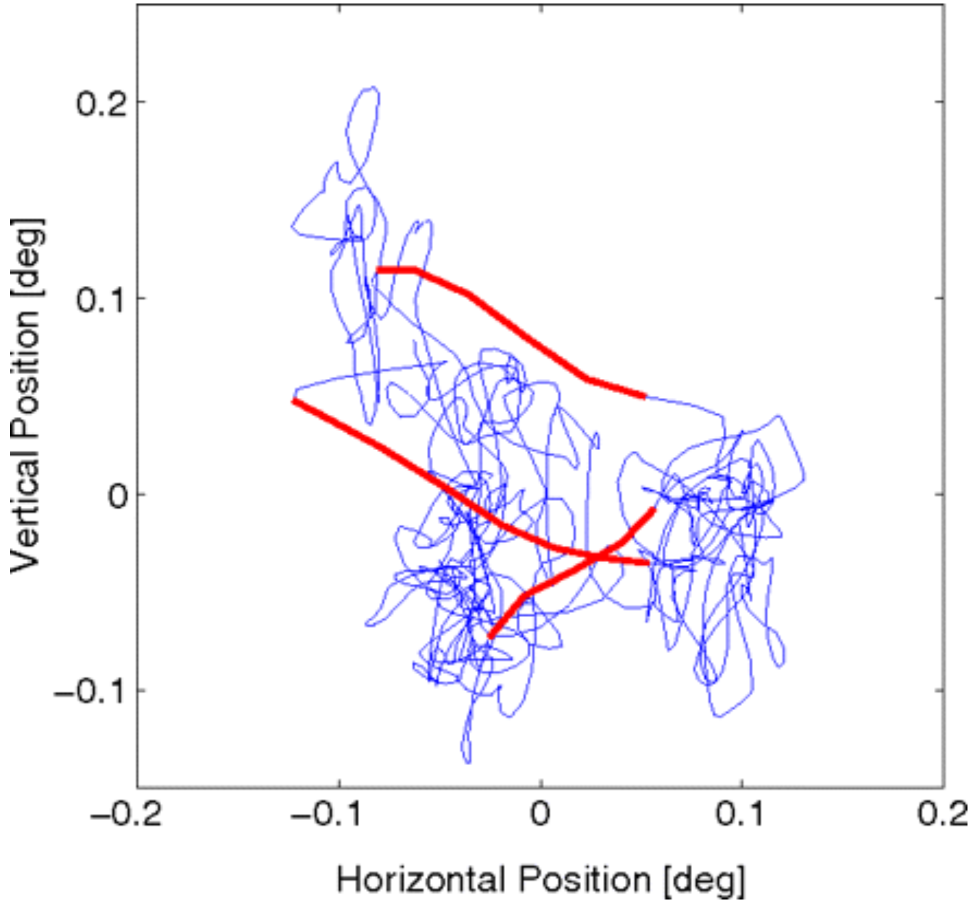


Image source: Engbert 2006

Microsaccades

- Smaller saccades, but during fixation(?)
- Do they serve any purpose?
- Cognitive modulation – attention, spatial cueing



Spatial representation of microsaccades (red)

Image source: Engbert et al., 2011

Velocity threshold algorithm (2D):

(Engbert & Kliegl, 2003); another version by Engbert & Mergenthaler, 2006.

Step 1:
The time series of eye positions is transformed to velocities,

$$V_{(n)} = \frac{x_{(n+2)} + x_{(n+1)} - x_{(n-1)} - x_{(n-2)}}{6\,\Delta t}$$

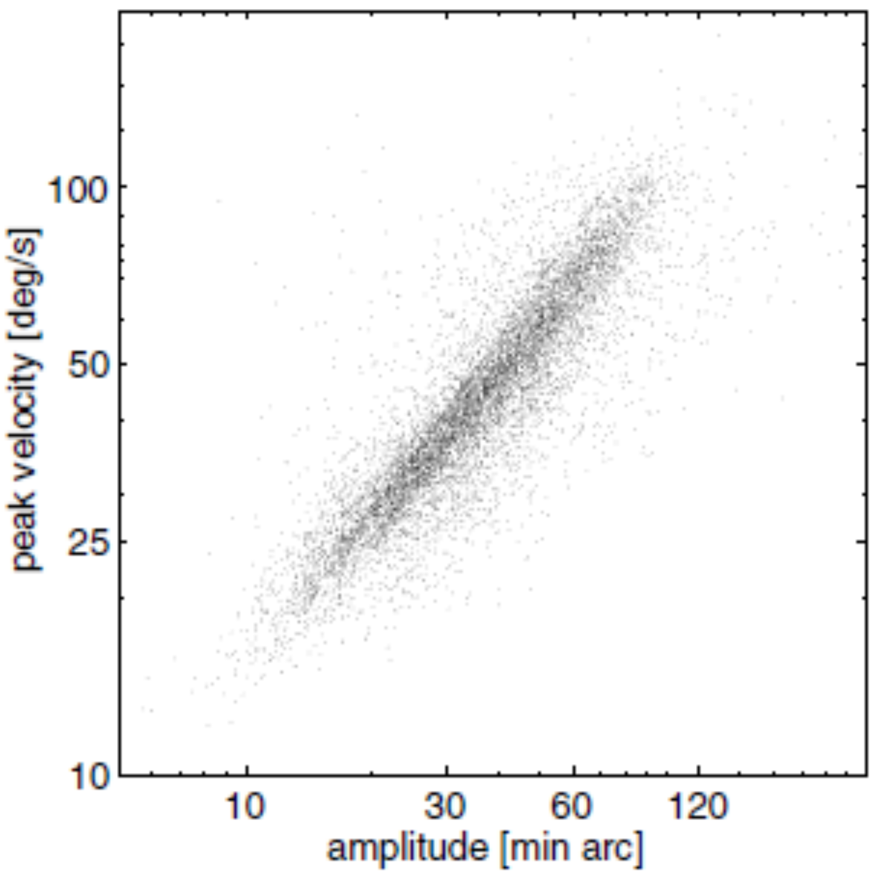
which represents a moving average of velocities over 5 data samples; Δt is the sampling interval.

Step 2:
Compute velocity thresholds for horizontal and vertical components (based on a multiple of S.D of velocity distribution).

Step 3:
Define distinction between monocular and binocular microsaccades

Step 4 (optional):
Verify algorithm validity by plotting 'main sequence'.

Toolbox available at - http://read.psych.uni-potsdam.de/index.php?option=com_content&view=article&id=140:engbert-et-al-2015-microsaccade-toolbox-for-r&catid=26:publications&Itemid=34



Main sequence

Image source: Engbert & Kliegl, 2003

Unsupervised clustering:
(Otero-Milan et al., 2014)

Step 1:
The time series of eye positions is transformed to velocities,

$$V_i = \frac{F_s}{6}(x_{(i+2)} + x_{(i+1)} - x_{(i-1)} - x_{(i-2)})$$

where x_i is the eye position (horizontal or vertical) at time i, v_i is the instantaneous eye velocity (horizontal or vertical) at time i, and F_S is the sampling rate.

Step 2:
Calculate velocity magnitude from horizontal & vertical components.

Step 3:
Use k-means to arrive at two potential clusters – microsaccades and noise. Features considered are peak velocity, initial acceleration, final acceleration.

MATLAB implementation at - http://smc.neuralcorrelate.com/sw/microsaccade-detection/

Some other methods:

Microsaccade detection using pupil and corneal reflection signals:
(Niehorster & Nyström, 2018)

Bayesian microsaccade detection:
(Mihali et al., 2017)

MATLAB implementation at - https://github.com/basvanopheusden/BMD

Order-statistic Time-window Analysis:
(Ohtani et al., 2016)