Segmenting and analyzing flight trajectories in moths

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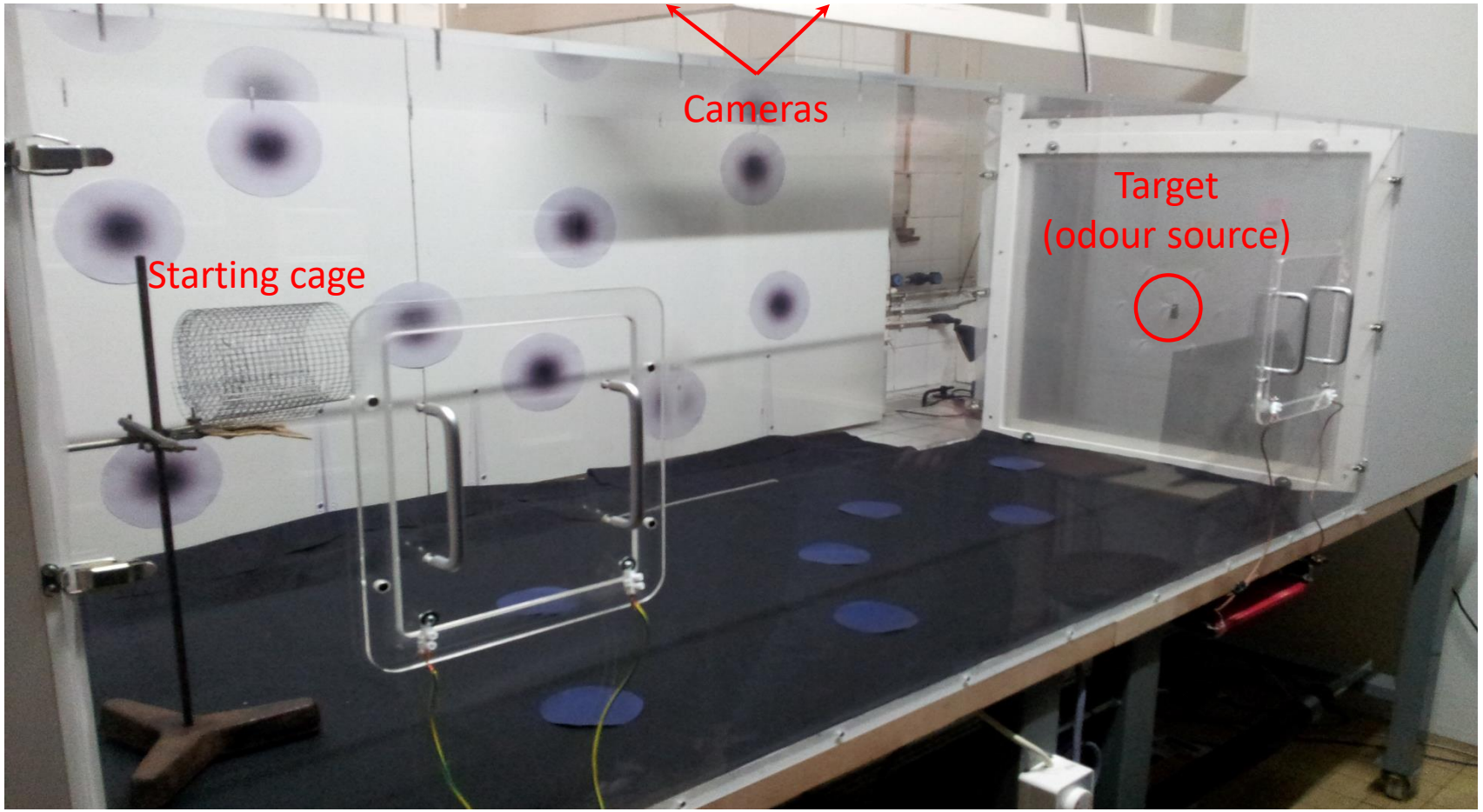
Purpose of the talk: discuss the methodology

The question

- We are interested in sex-pheromone tracking in male moths
- We use wind-tunnel and a pair of cameras to record 3D trajectories (x, y, z + t)

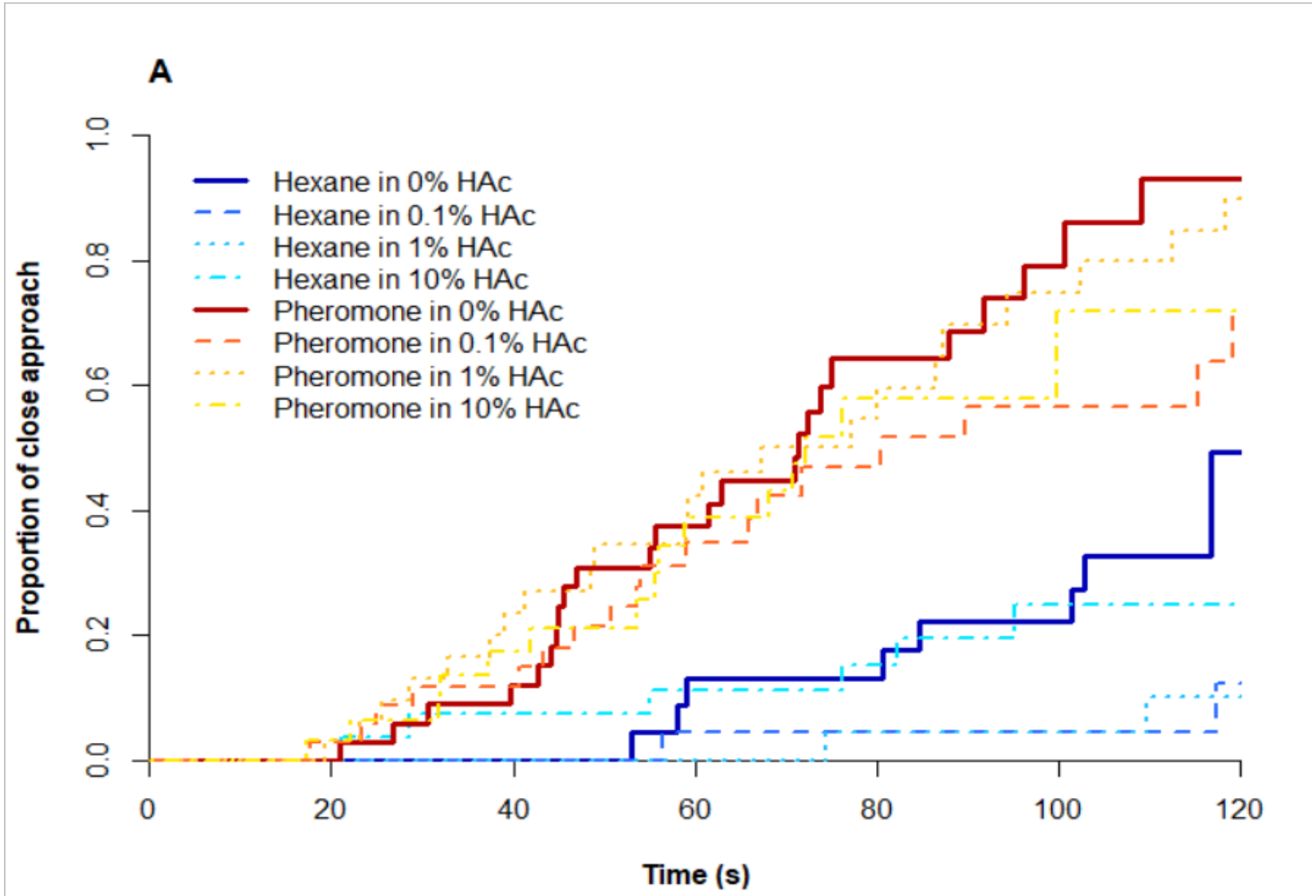


8 groups n = 21-34:

- With/without sex-pheromone
- 0%, 0.1%, 1% or 10% HAc

(odorant background)

Behavioural results

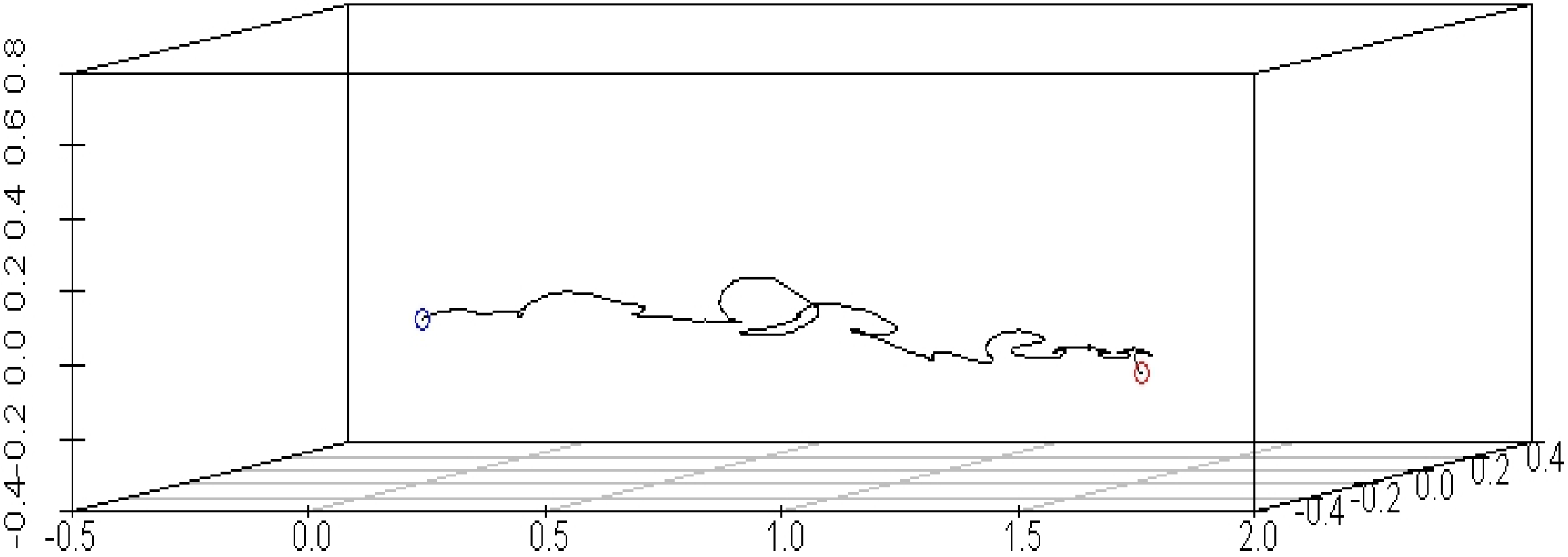


Time to approach the target

- survival analysis (Cox regression)
- proportional hazard OK
- blatant effect of sex-pheromone
- small effect of HAc background
- small interaction

Example for the obtained trajectories

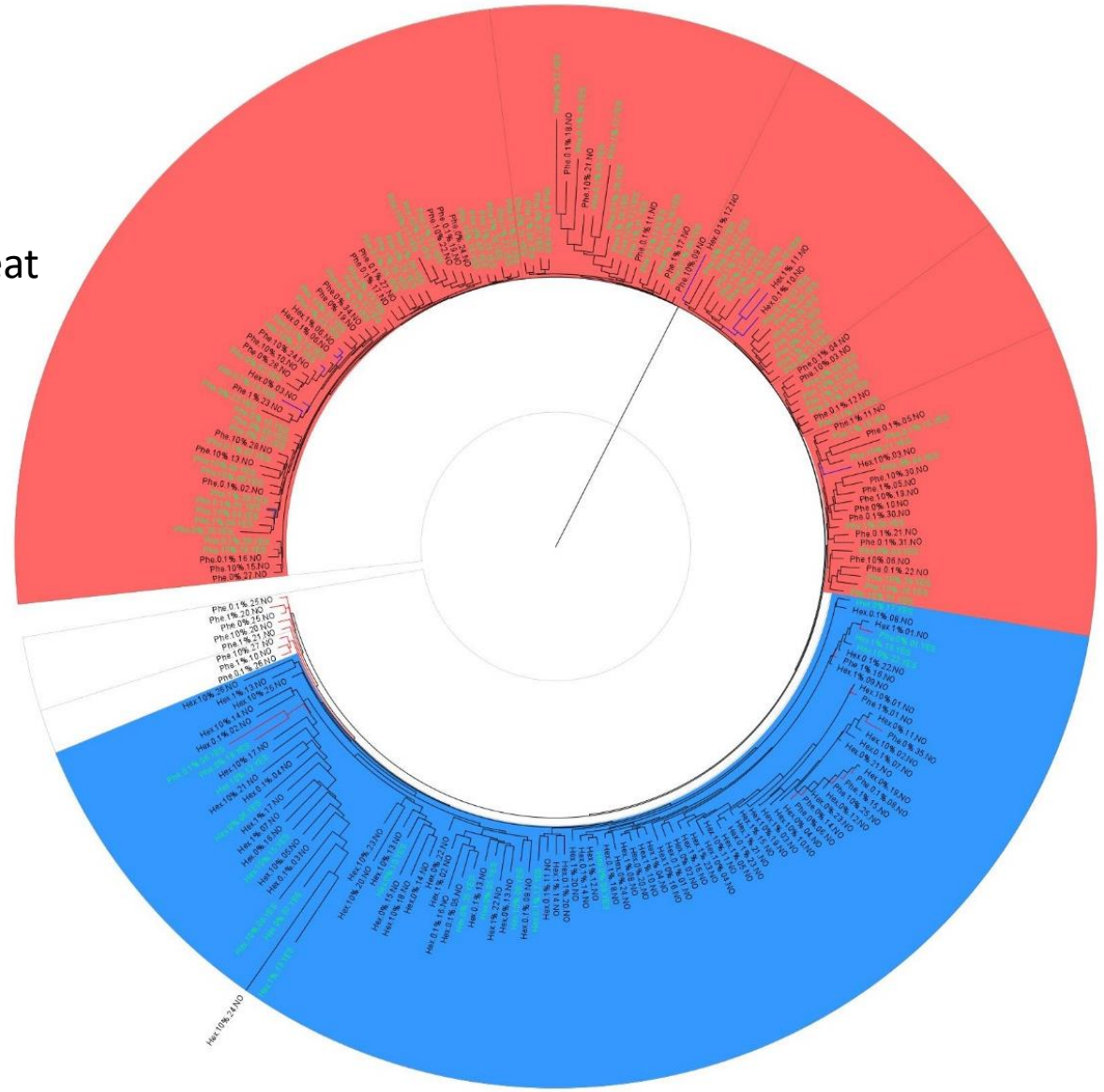
- Trajectories are corrected for artifact (tigmotactism, duplication …) and smoothed



Is target-finding connected to the trajectories?

Physical index: dynamic time warping = similarity index between trajectories

Phylogenetic classification: neat clustering of pheromone and non-pheromone trajectories (target approach in green)



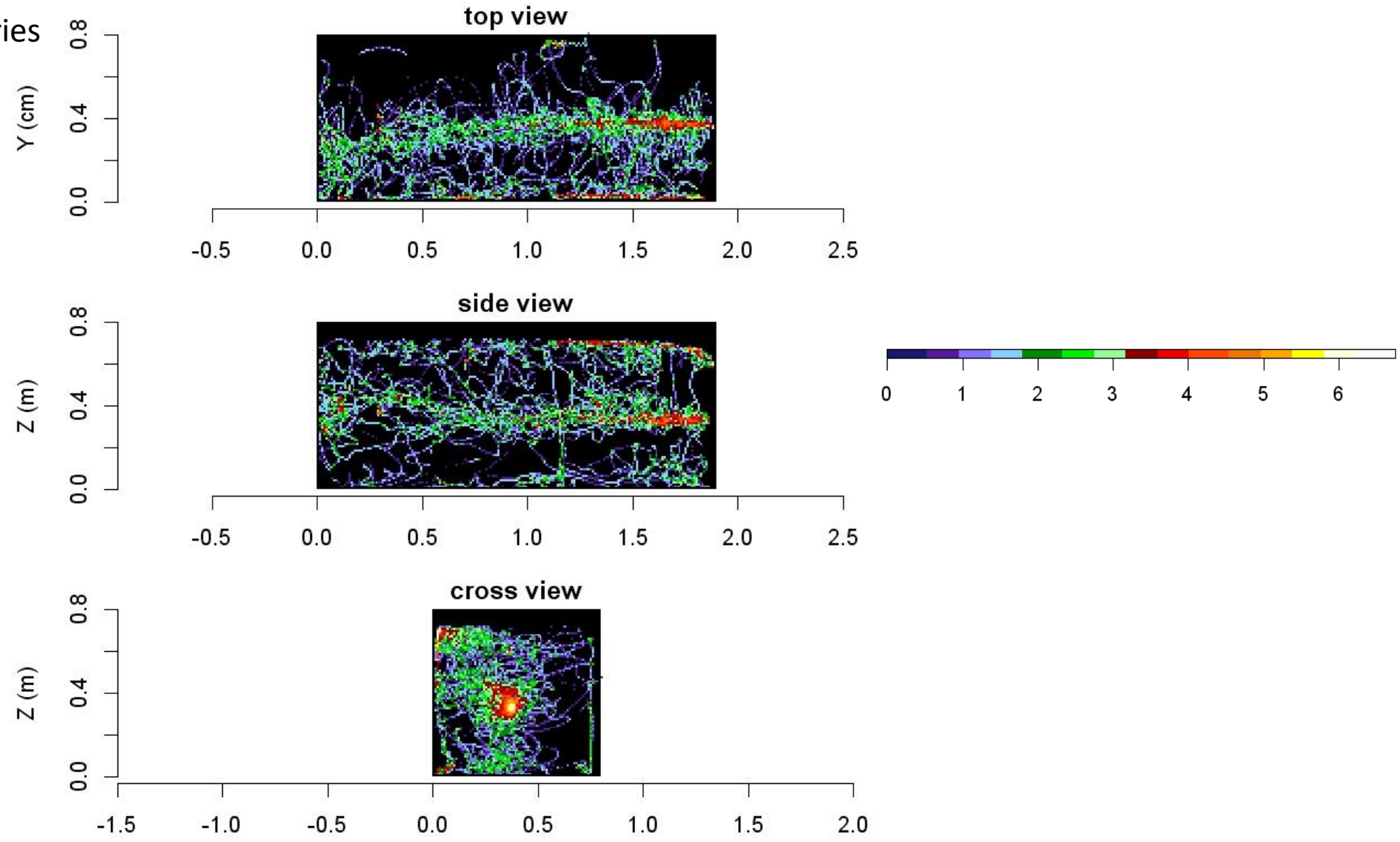
Hypotheses

1. Odours elicit differing flight strategies = trajectories

2. Trajectories reach (or not !) the target

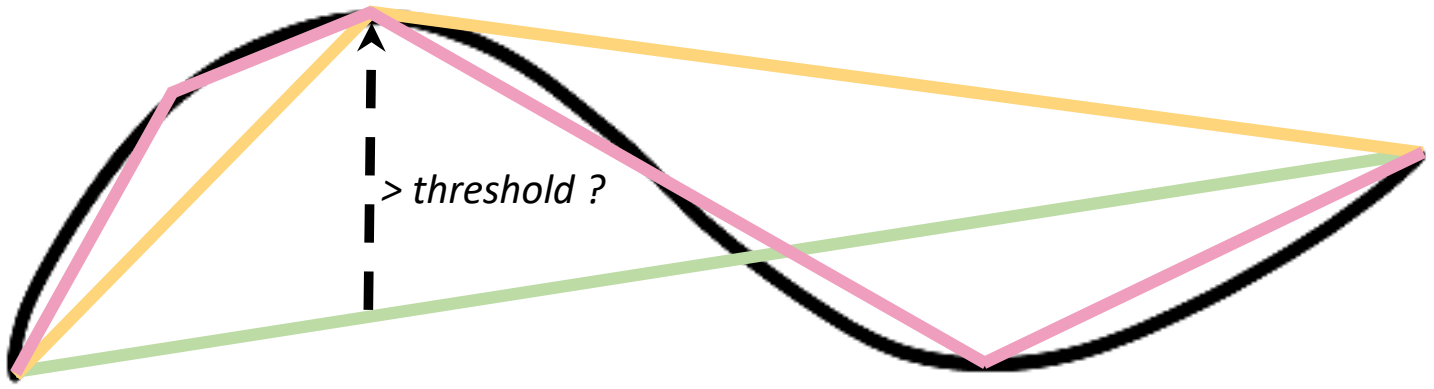
But trajectories are hardly analysable by themselves …

Density map of trajectories



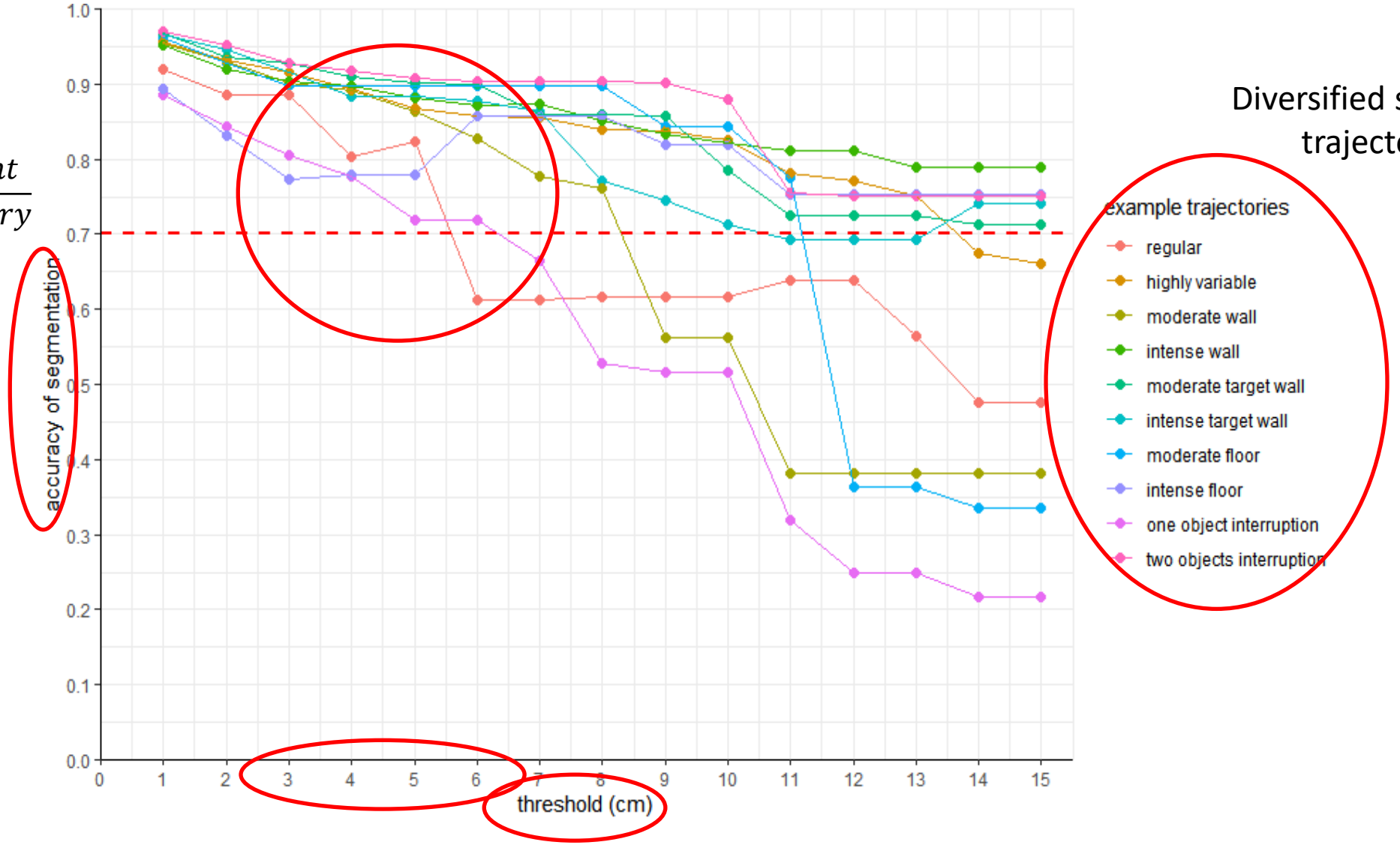
Solution: creating segments as units of analysis

1. Initial trajectory
2. Assume there is a single segment
3. Is the most remote point beyond a given threshold ?
4. If no: stop
5. If yes: separate the segment at this point
6. Repeat until no more cutting can be done



Setting the threshold (1/2)

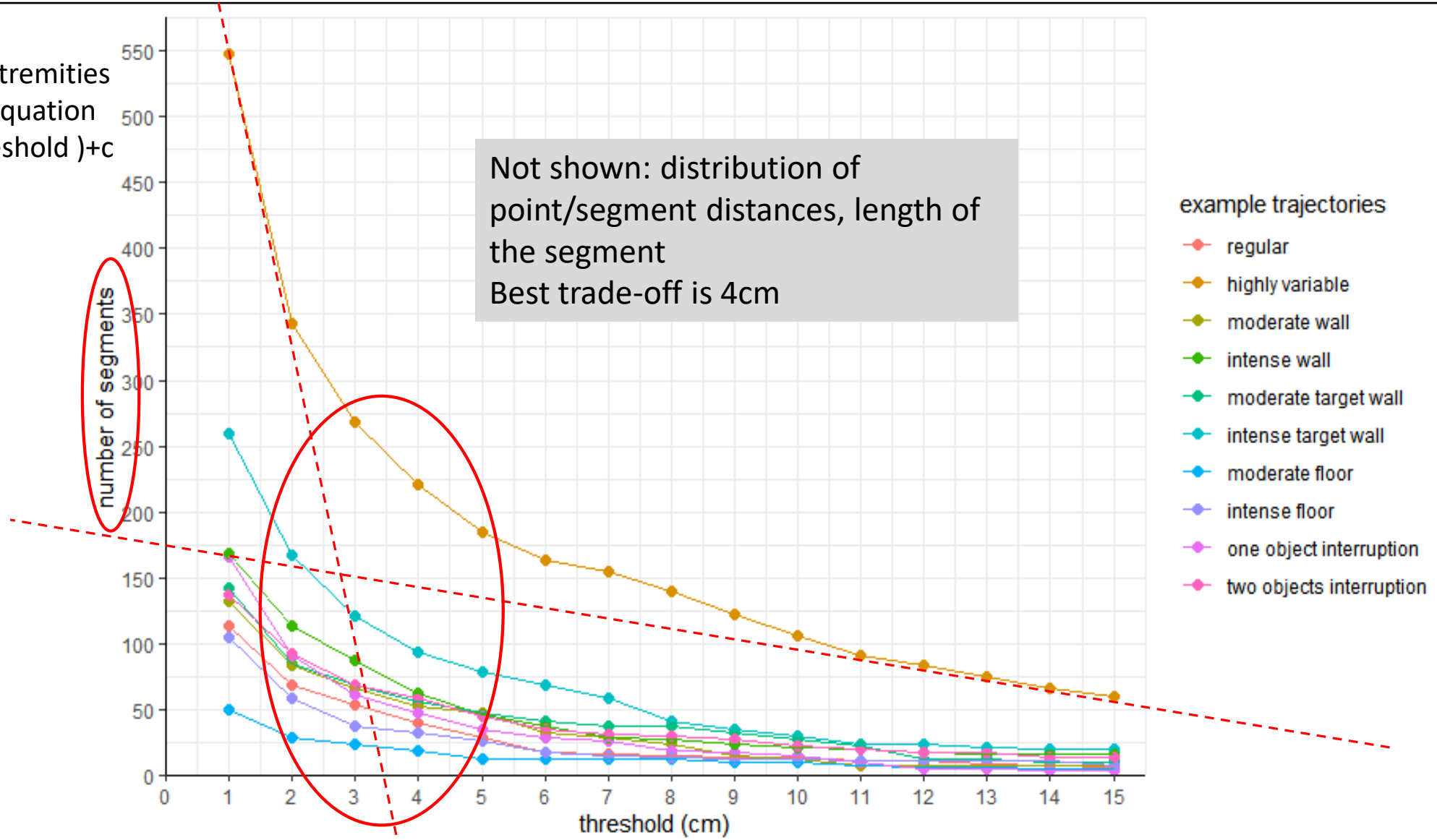
Straightness : $\frac{length\ of\ segment}{length\ of\ trajectory}$ (1 is perfection)



Diversified sample of trajectories

Setting the threshold (2/2)

Tangent of extremities for a fitted equation a*exp(b*threshold)+c



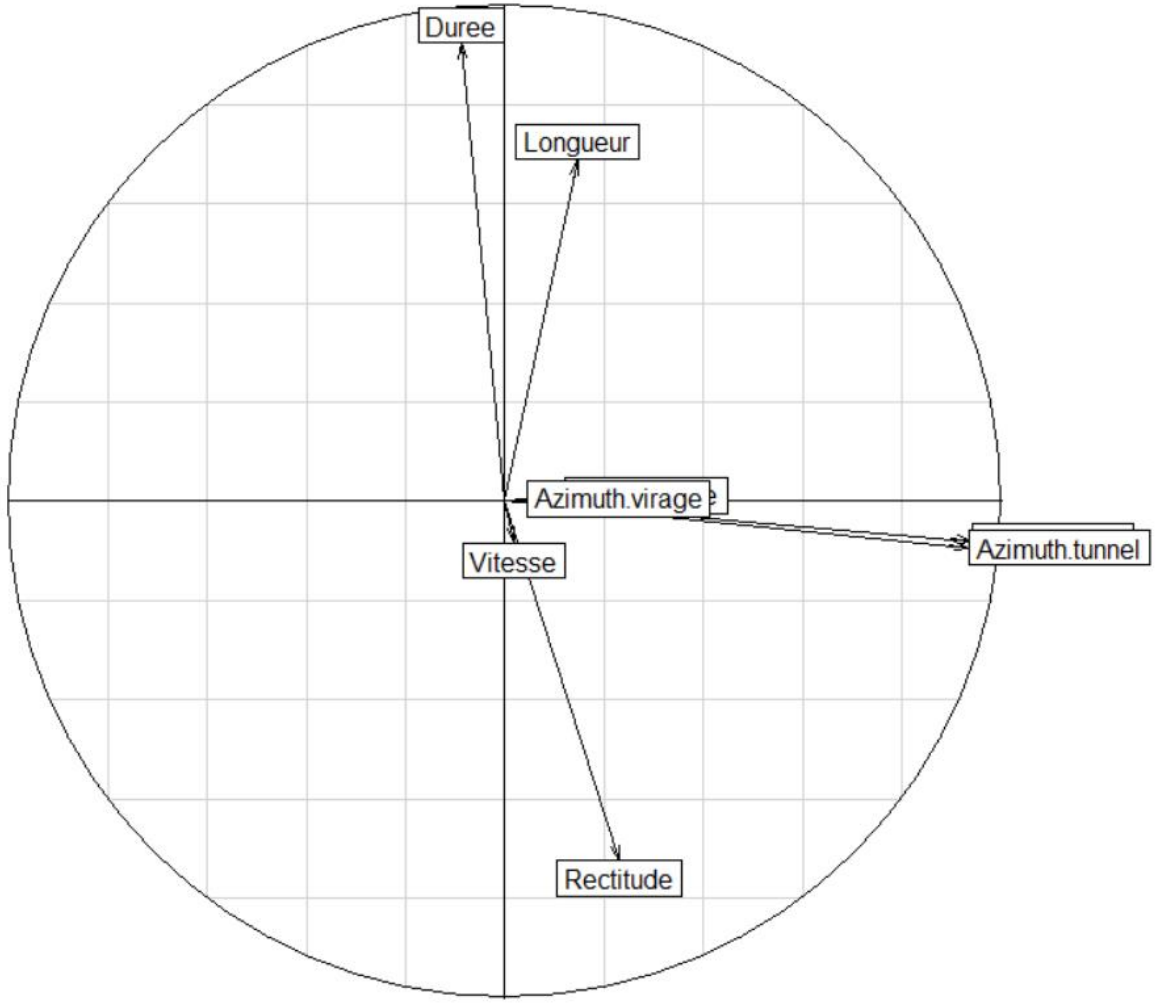
Not shown: distribution of point/segment distances, length of the segment
Best trade-off is 4cm

What to do with the segments?

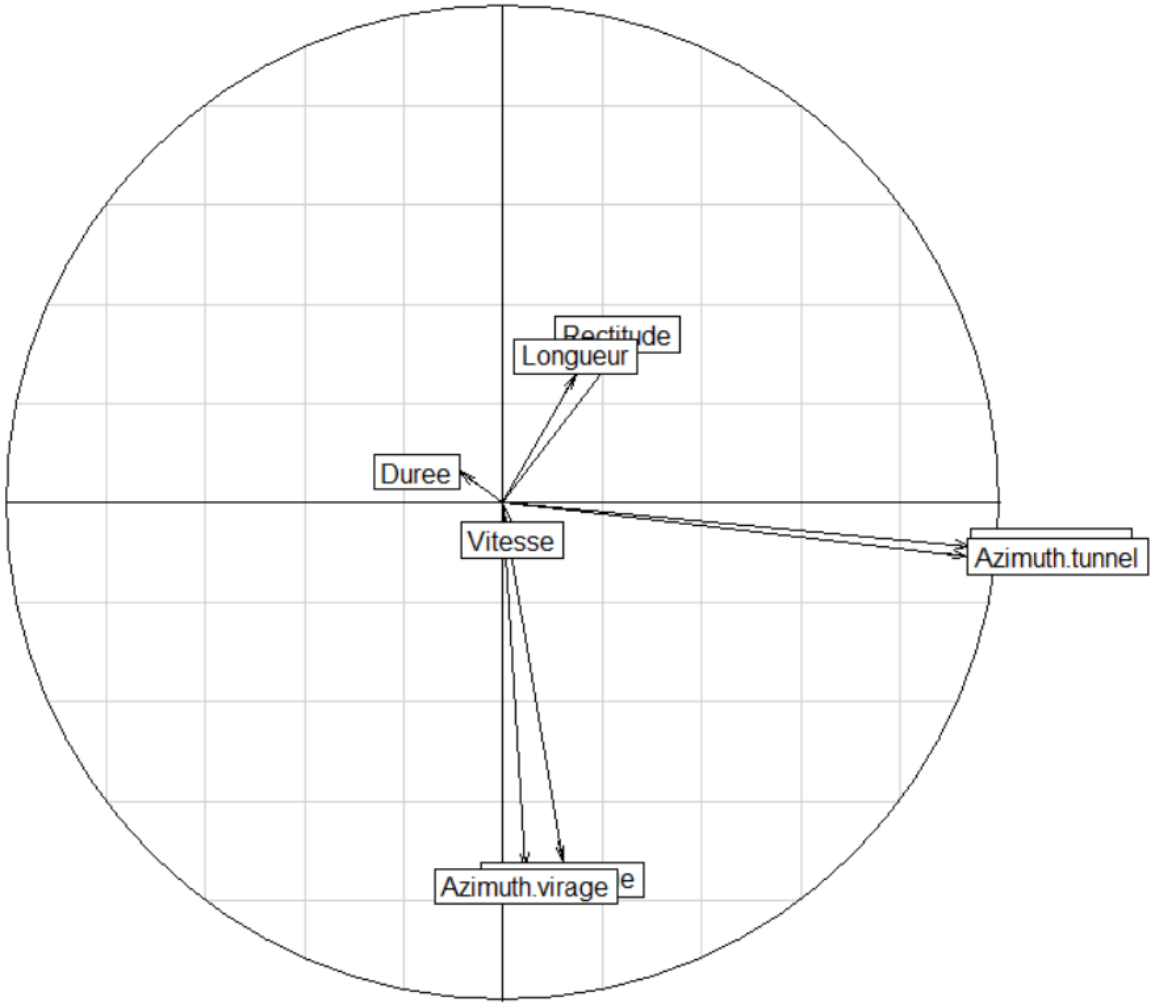
- 9805 segments in 220 trajectories (repeated measurements: mixed models)
- Parameters:
  - Speed (local speed in the segments)
  - Duration (latency before changing direction = before a new segment)
  - Length (=distance flown before turning, redundant with the previous)
  - Straightness
  - Azimuth and zenith against the wind (angle with the wind)
  - Azimuth and zenith between two segments
- Principal component analysis
  - 77.3% explained with 4 components

PCA (1/2)

Component 1: angles (azimuth and zenith) with the wind
Component 2: duration and straightness (and length)

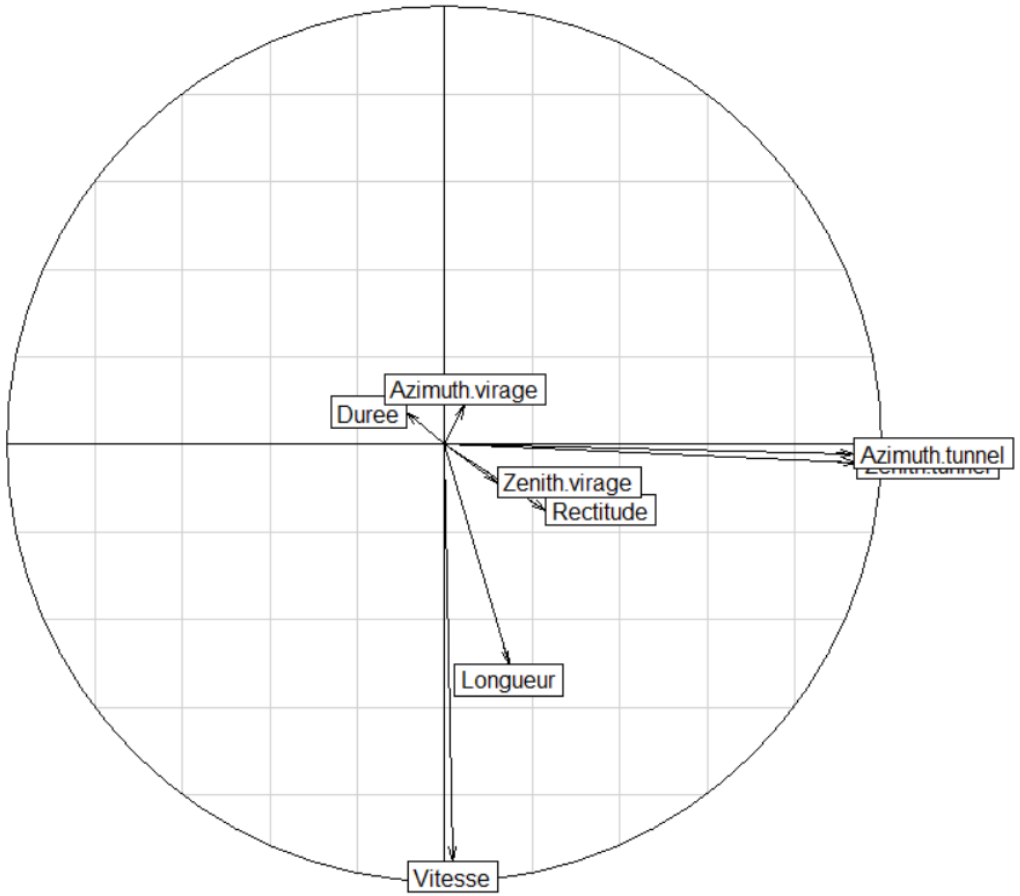


Component 1: angles (azimuth and zenith) with the wind
Component 3: angles (azimuth and zenith) between segments



PCA (2/2)

Component 1: angles (azimuth and zenith) with the wind
Component 4: speed (and length)



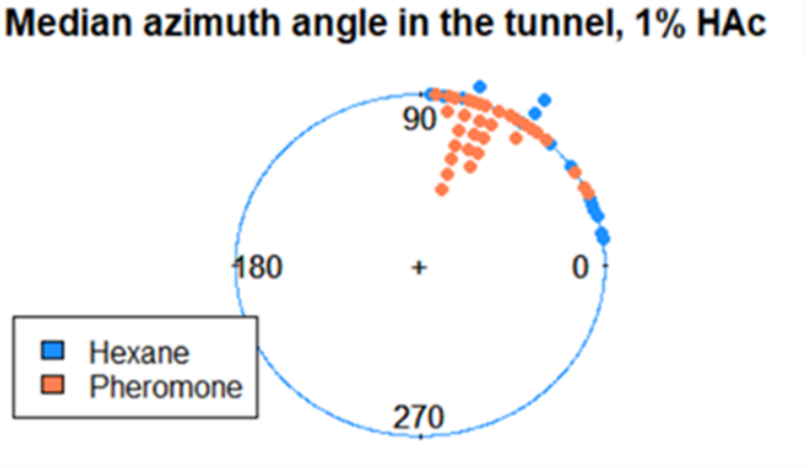
Parameters retained for the analysis

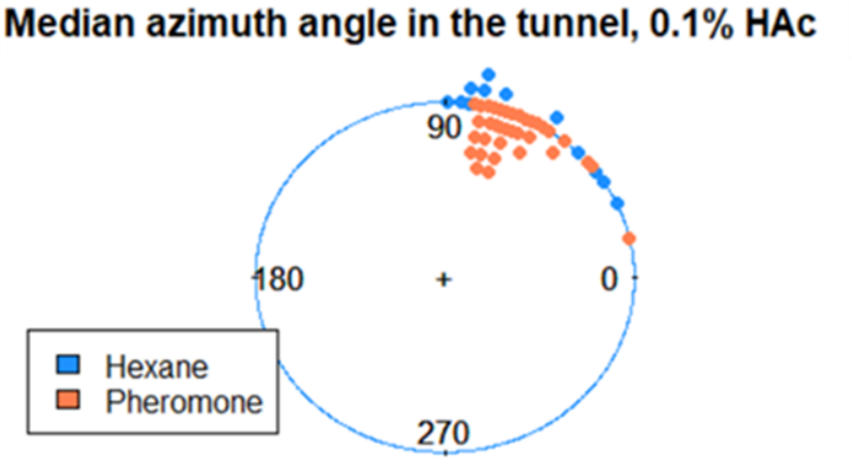
- Azimuth with the wind
- Turning angle (azimuth)
- Latency before turning (= segment duration)
- Speed

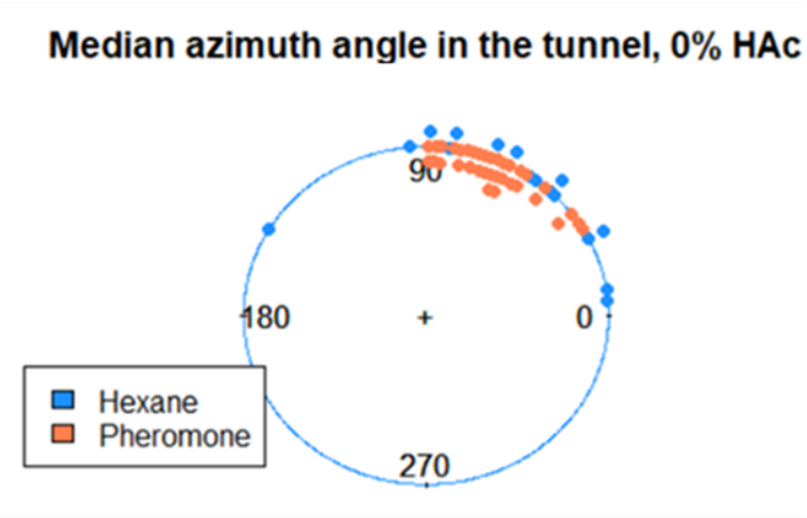
We can now address the first hypothesis:
Odours elicit differing flight strategies

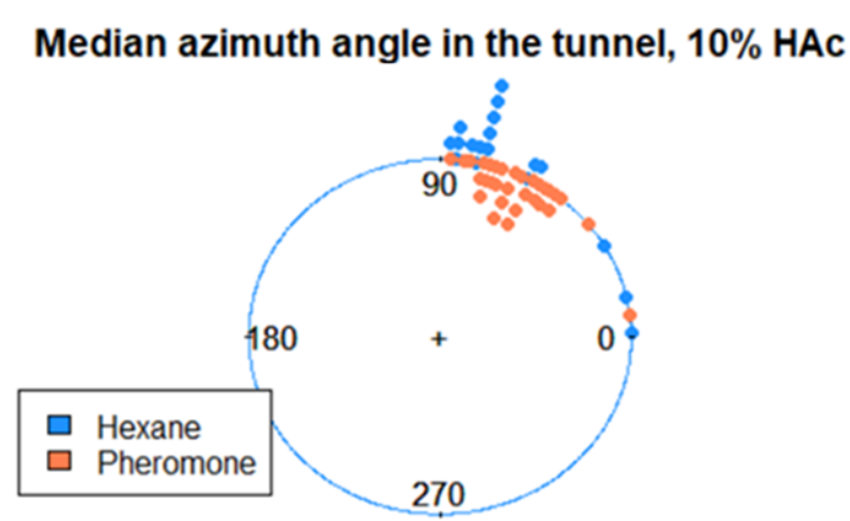
1st factor is presence/absence of sex-pheromone
2nd factor is background concentration
We will test the 4 parameters above
Mixed effect: segment within each trajectory

Azimuth with the wind









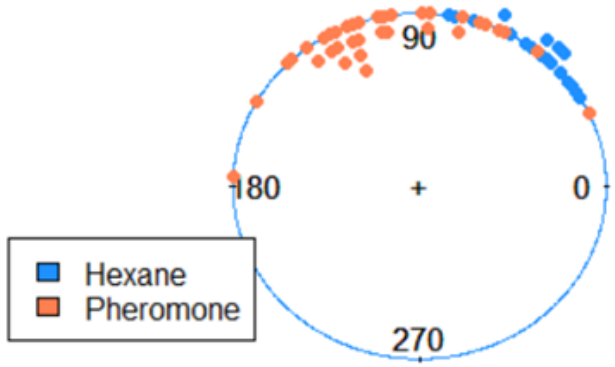
Analysis tool:
Bayesian circular mixed-effects model, with the R package bpnreg
(very convenient, slow!)

No effect, no interaction

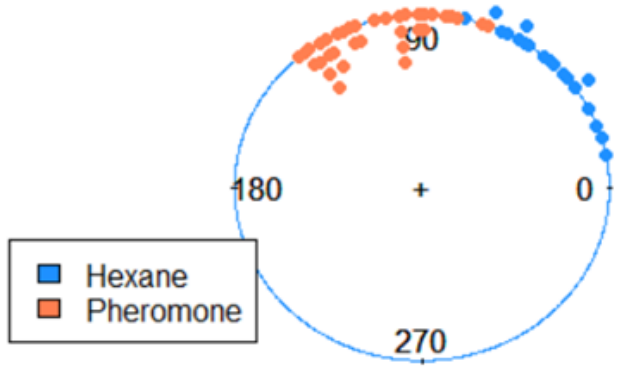
Odours are is irrelevant for wind angle

Turning angle (azimuth between segments)

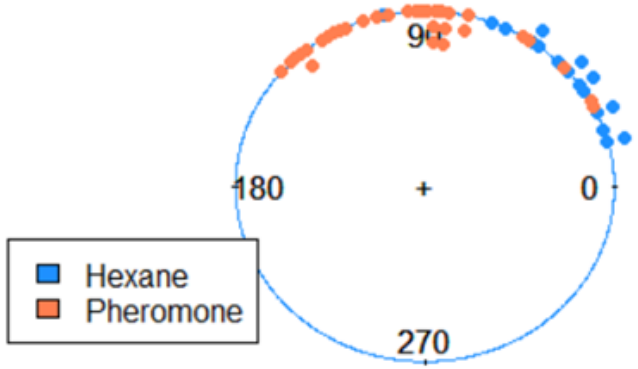
Median azimuth angle in turning, 0% HAc



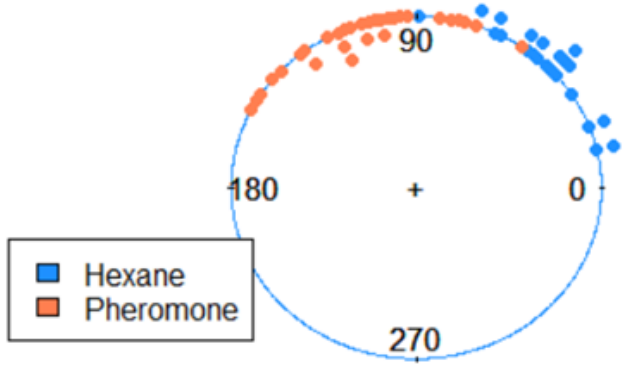
Median azimuth angle in turning, 0.1% HAc



Median azimuth angle in turning, 1% HAc



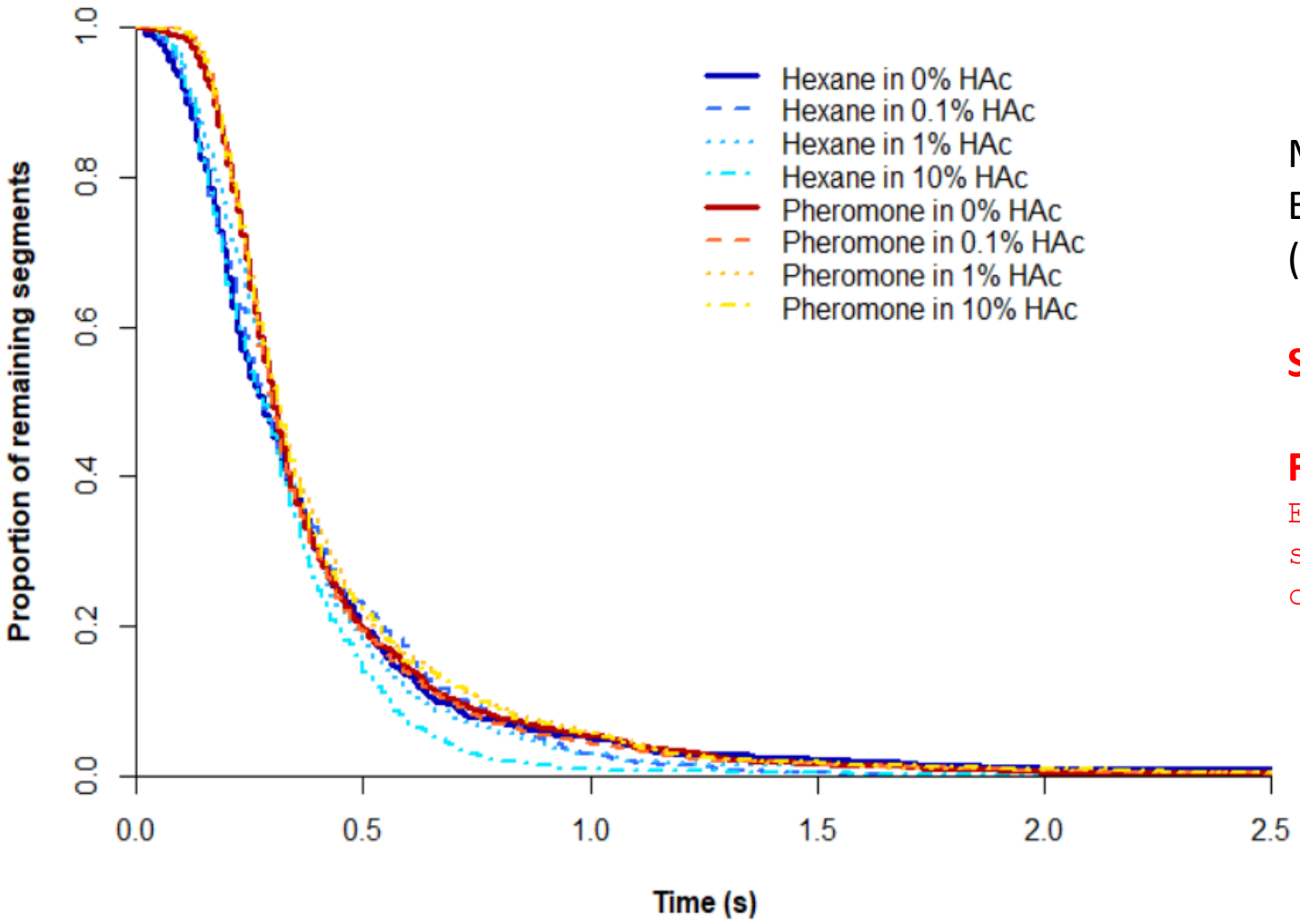
Median azimuth angle in turning, 10% HAc



Bayesian circular mixed-effects model
Effect of sex-pheromone (CI: 98.1-112.2°)
but not background (CI: 46.7-58.2°)

Sex-pheromone affects turning angle

Latency before turning (segment duration)



Mixed survival analysis (coxme)
Effect of sex-pheromone but not of background (interaction was dropped)

Sex-pheromone slightly increases turning latency

Failure to test proportional hazard ?!?

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Error in solve.default(imat, u):
system is computationally singular: reciprocal
condition number = 1.41019e-22
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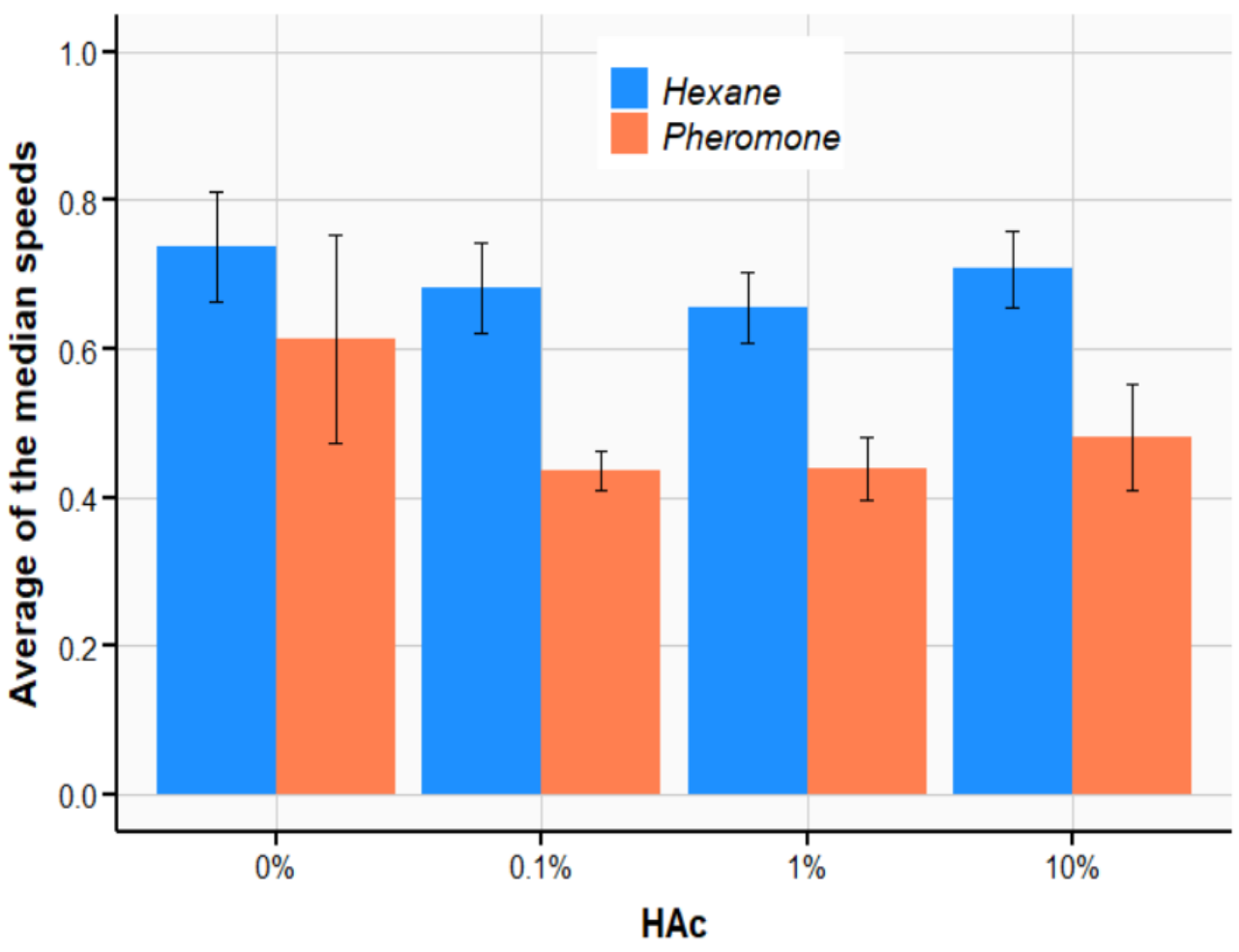
Speed



Mixed linear model on the speed
Problem of heteroscedasticity, solved with a mixed generalized least square (1 variance per cell, interaction dropped)
Effect of sex-pheromone and background

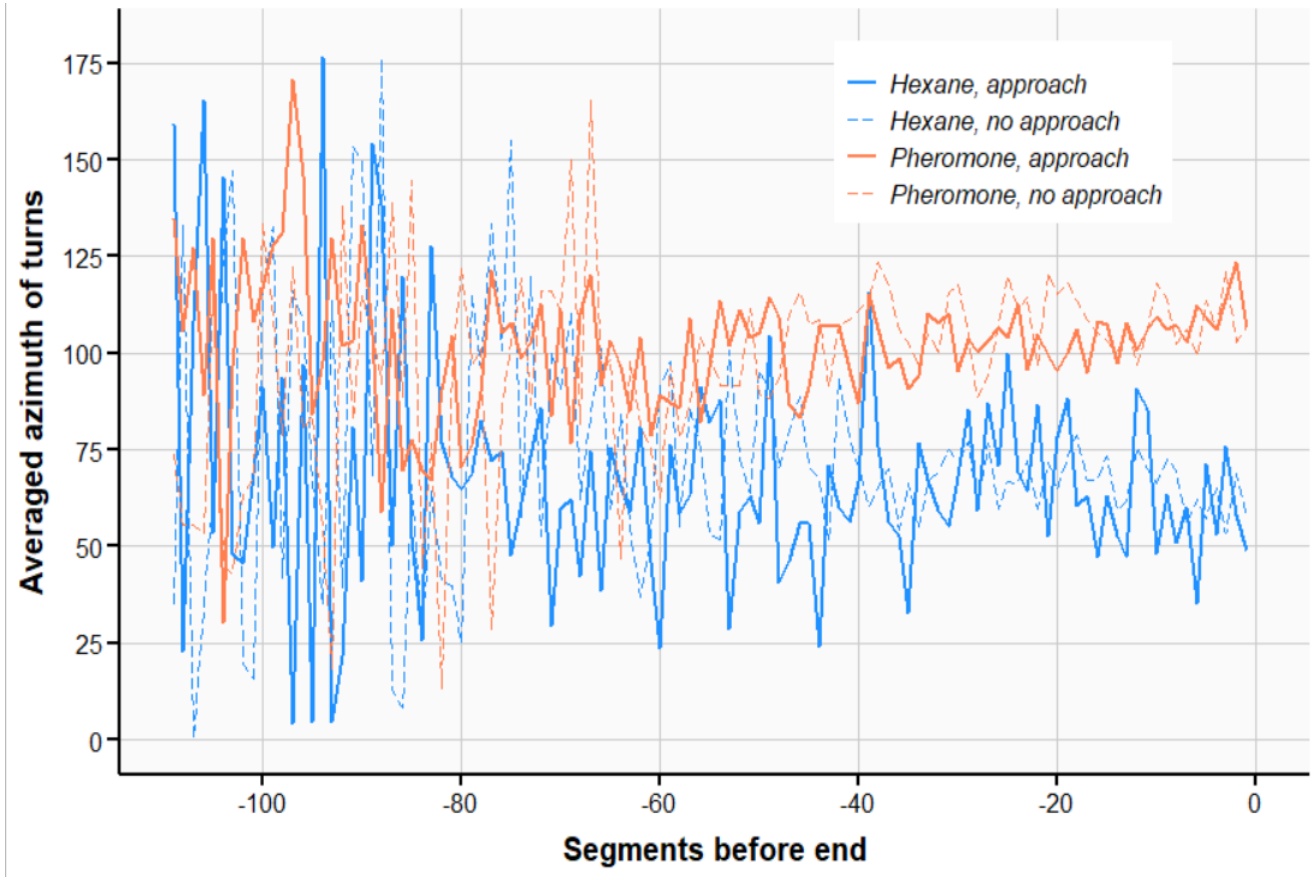
The presence of an odour makes the animal slower (especially the sex-pheromone)

Hypothesis 2:
do speed and turning angle explain target-reaching?

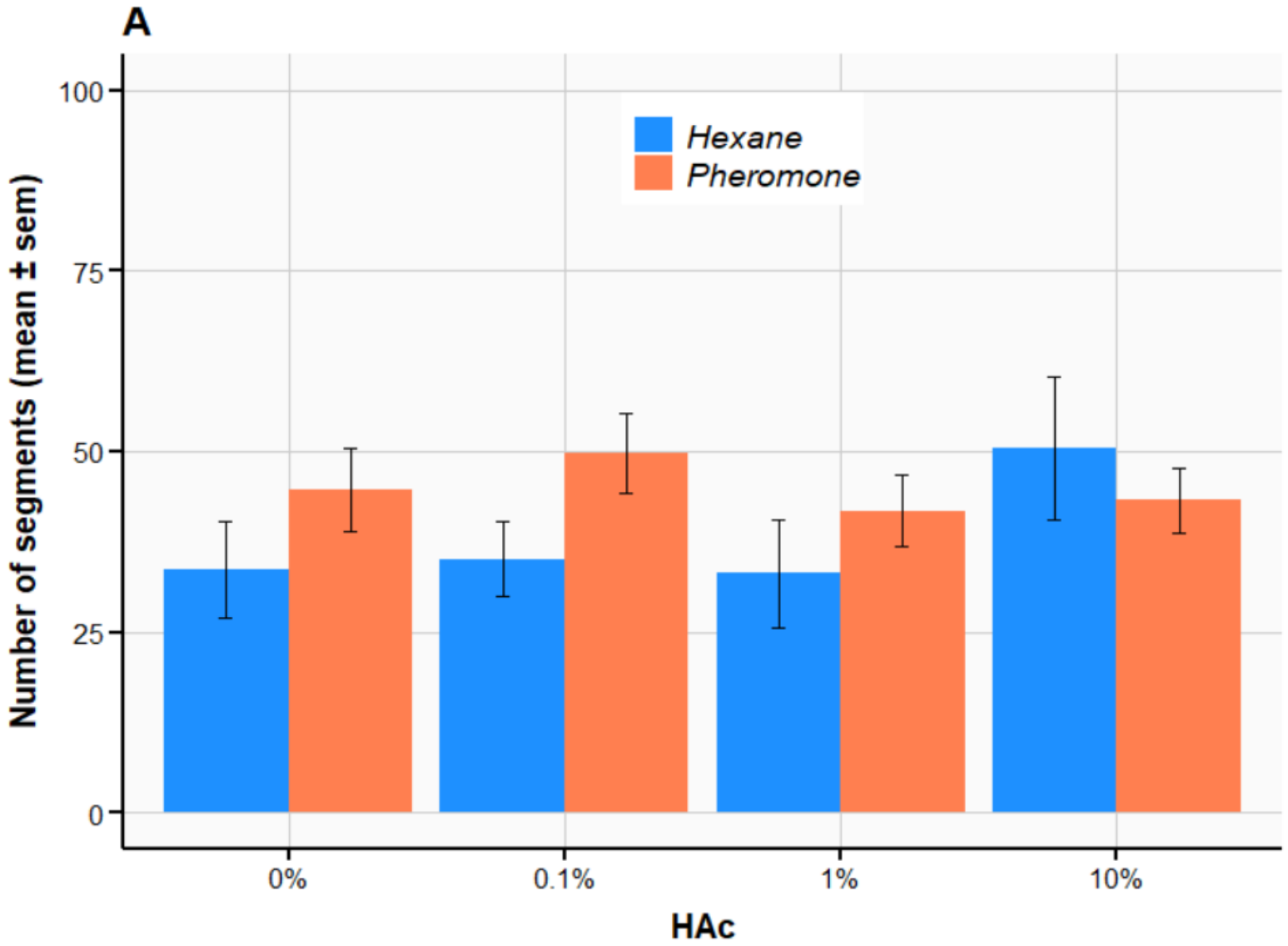
Geeglm (quicker and stabler than glmm)
Speed factor dropped
Only turning angle significantly explains the probability of finding the target

The same test performed restricted to either control or sex-pheromone do not reveal any angle effect. This indicate pheromone and turniong angle are in fact redundant.
This is consistent to the litterature and what can be seen by observers.

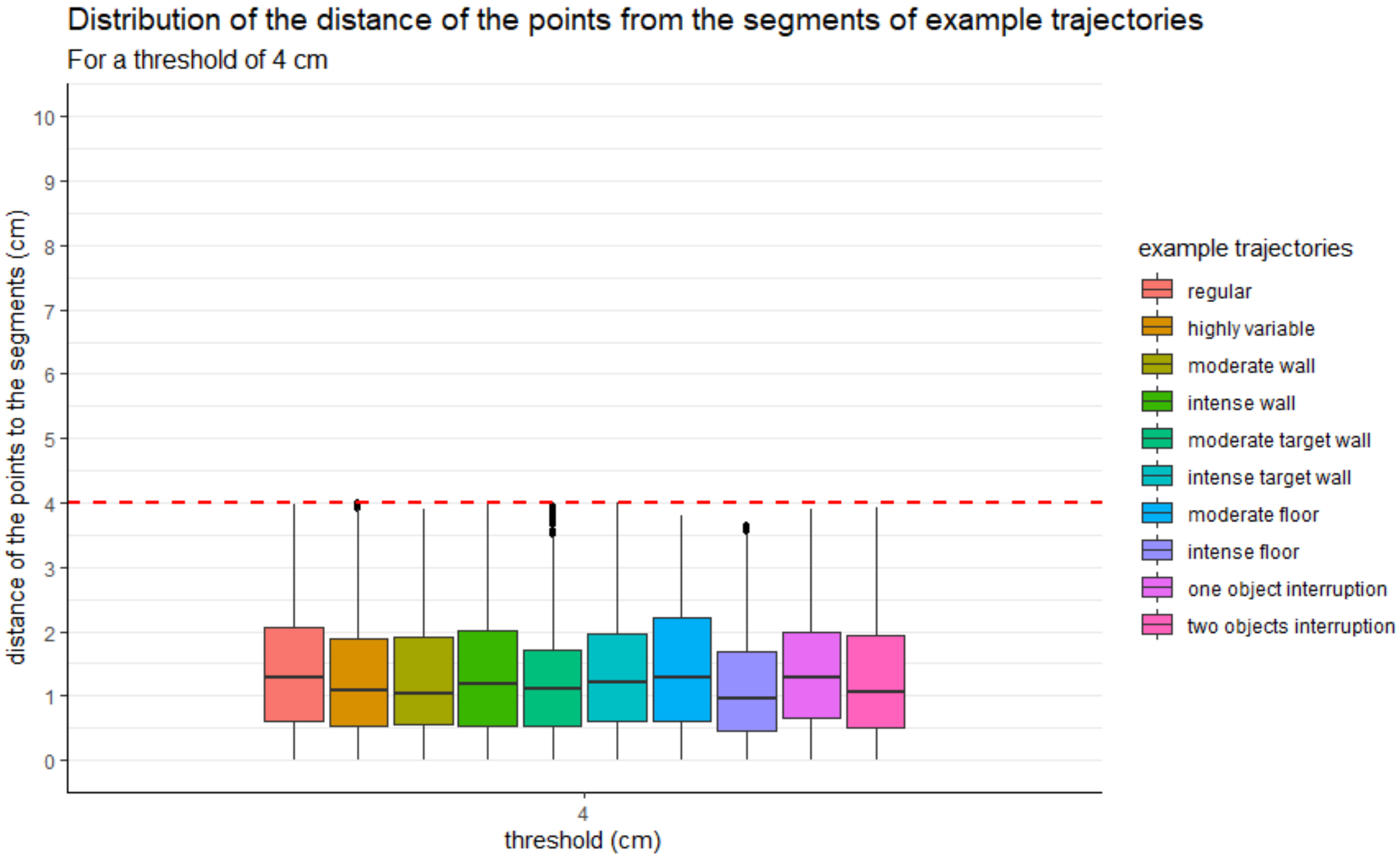
An attempt to plot the angle before the end reveals an interesting pattern. (end is defined as the moment when the animal approaches the target or when it is the closest to it)

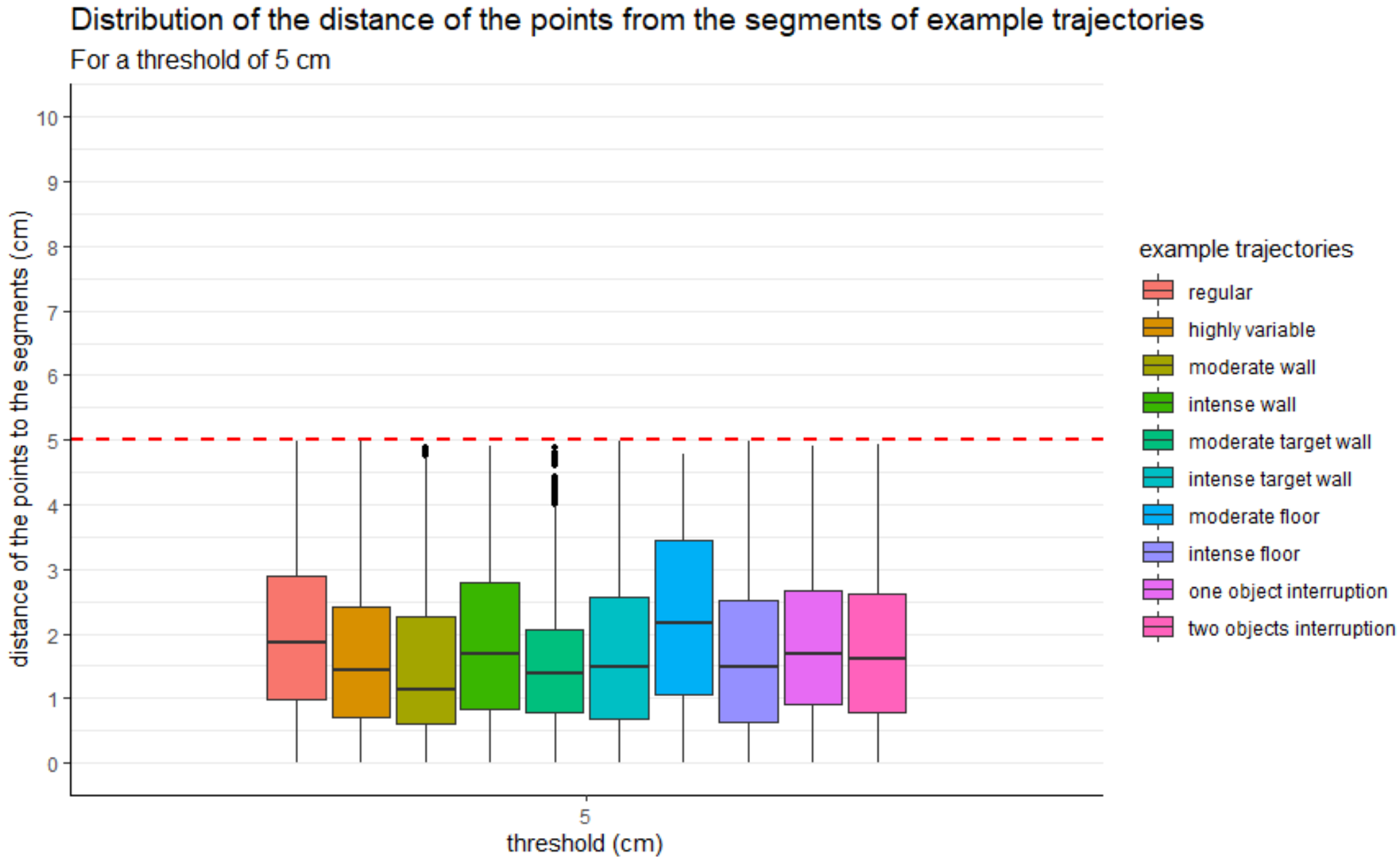


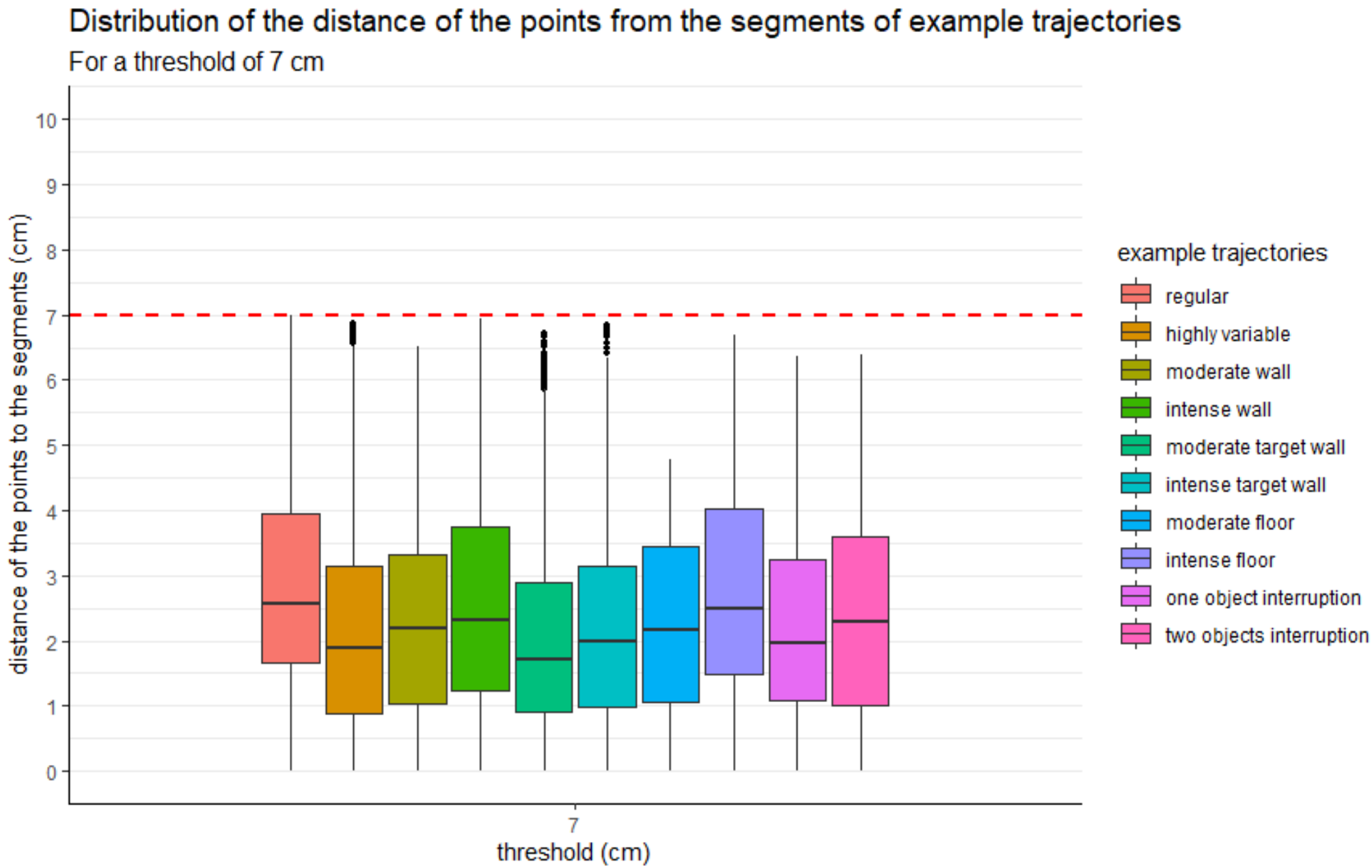
Supplementary data

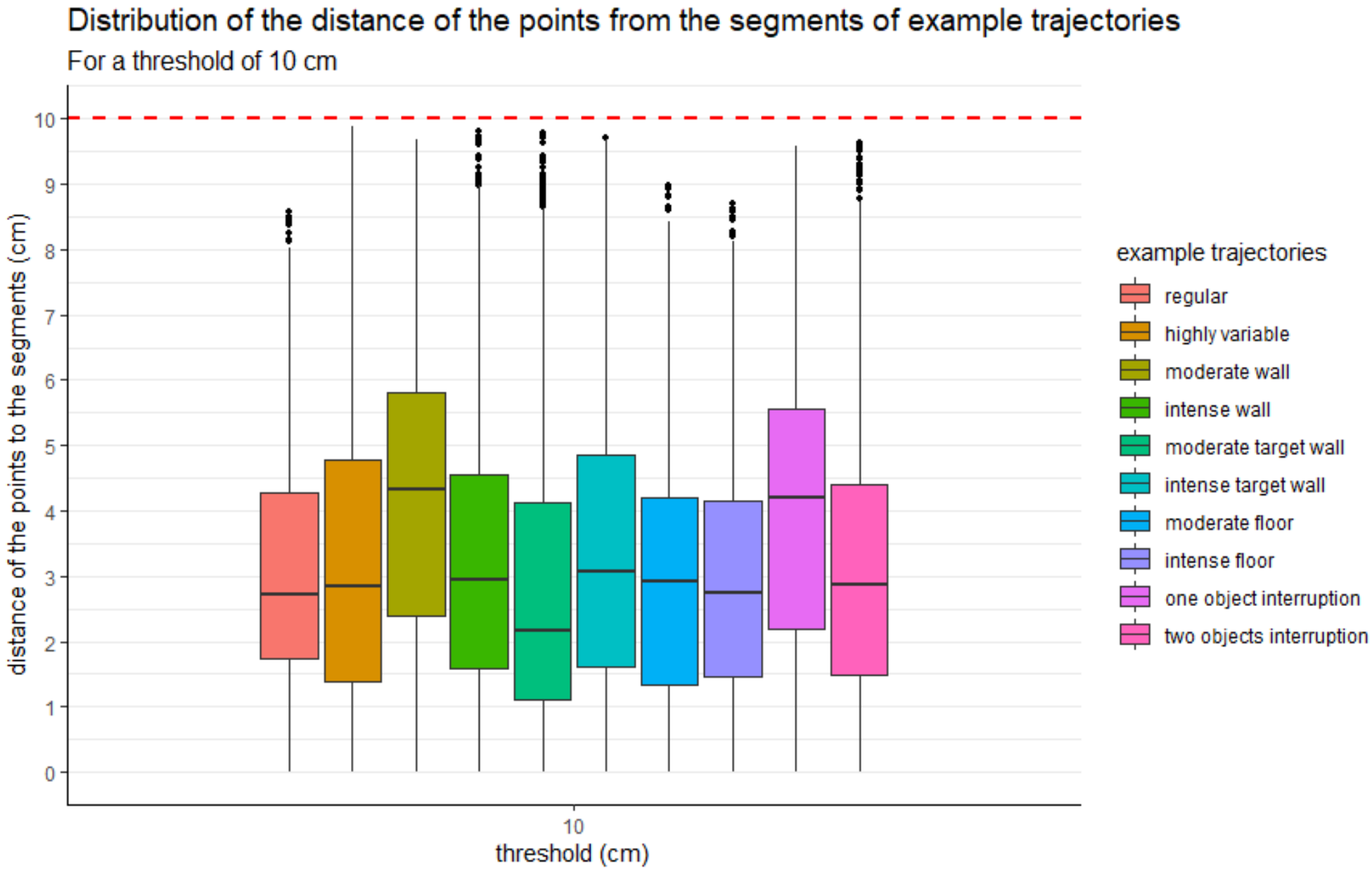


No significant effect on the number of segments


Distribution of the distance of the points from the segments of example trajectories
For a threshold of 4 cm
distance of the points to the segments (cm)
10
9
8
7
6
5
4
3
2
1
0
4
threshold (cm)
example trajectories
regular
highly variable
moderate wall
intense wall
moderate target wall
intense target wall
moderate floor
intense floor
one object interruption
two objects interruption


Distribution of the distance of the points from the segments of example trajectories
For a threshold of 5 cm
distance of the points to the segments (cm)
10
9
8
7
6
5
4
3
2
1
0
5
threshold (cm)
example trajectories
regular
highly variable
moderate wall
intense wall
moderate target wall
intense target wall
moderate floor
intense floor
one object interruption
two objects interruption


Distribution of the distance of the points from the segments of example trajectories
For a threshold of 7 cm
distance of the points to the segments (cm)
10
9
8
7
6
5
4
3
2
1
0
7
threshold (cm)
example trajectories
regular
highly variable
moderate wall
intense wall
moderate target wall
intense target wall
moderate floor
intense floor
one object interruption
two objects interruption


Distribution of the distance of the points from the segments of example trajectories
For a threshold of 10 cm
distance of the points to the segments (cm)
0
1
2
3
4
5
6
7
8
9
10
10
threshold (cm)
example trajectories
regular
highly variable
moderate wall
intense wall
moderate target wall
intense target wall
moderate floor
intense floor
one object interruption
two objects interruption

Length vs. threshold