

Skilled Visuomotor Control in a Real-world Task - *Explorations in the Cognitive Science of Driving*

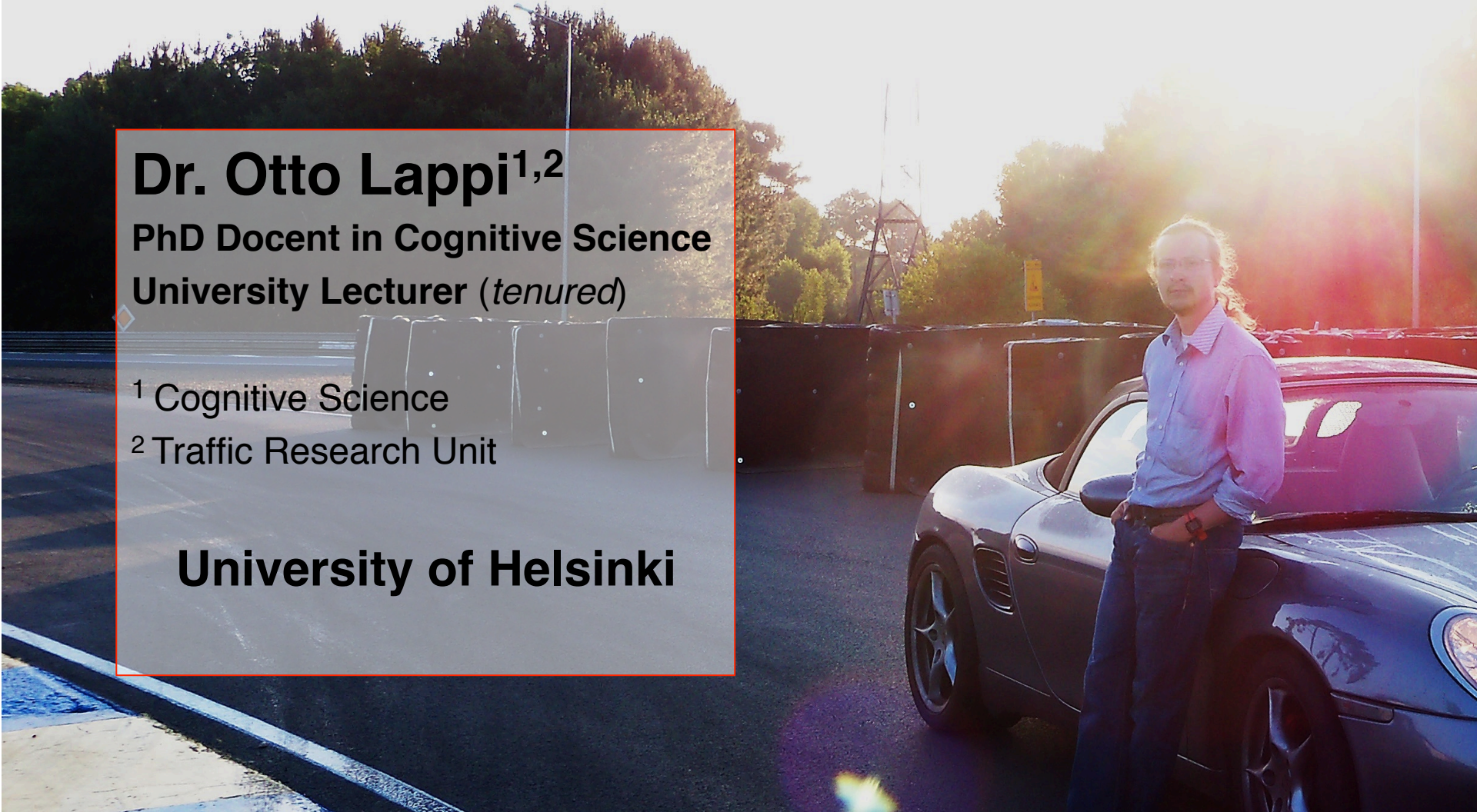
Dr. Otto Lappi^{1,2}

**PhD Docent in Cognitive Science
University Lecturer (*tenured*)**

¹ Cognitive Science

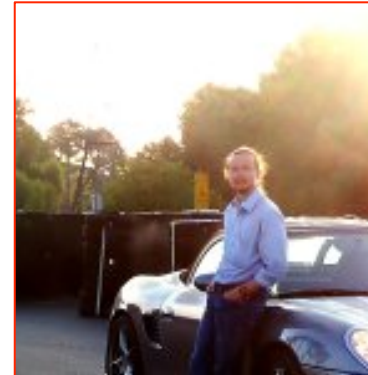
² Traffic Research Unit

University of Helsinki



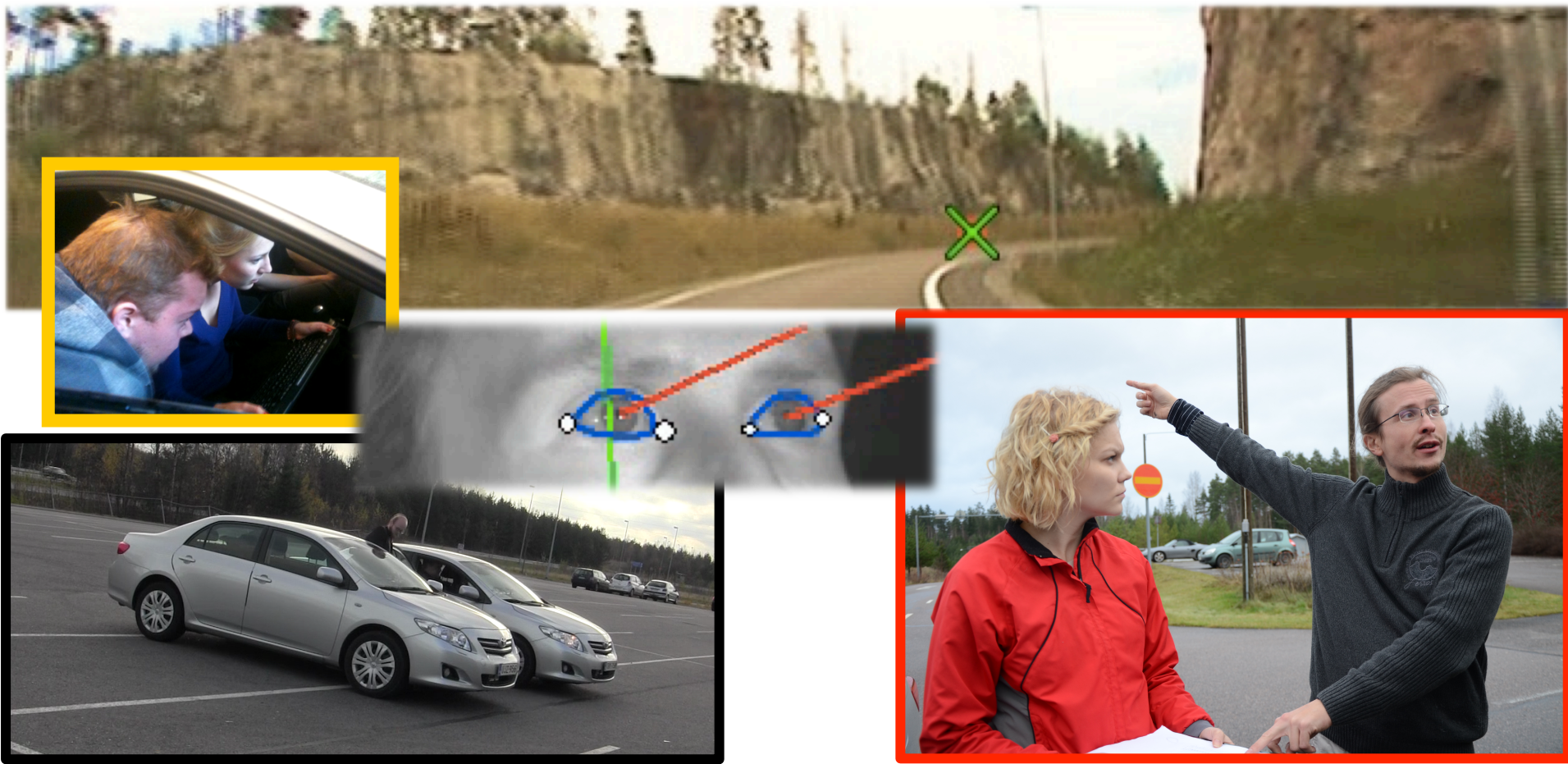
About me and my research

- Research interests:
 - **gaze behavior** in the real world
 - information processing in the **visual control of high speed locomotion**
 - ...especially in the domain of driving...



About me and my research

- Began experimental work on curve driving using on-road eye-tracking in 2009



"That looks like a nice enough road, let's go do some measurements!"

"Sure, how hard can it be?"



Representative Publications in the past five years

Pekkanen, J. & Lappi, O. (in press). A new and general approach to signal denoising and eye movement classification based on segmented linear regression. [Scientific Reports](#)

Itkonen, T., Pekkanen, J., Lappi, O., Kosonen, I. & Luttinen, T. (2017). Trade-Off Between Jerk and Time Headway as an Indicator of Driving Style. [PLOS ONE](#)

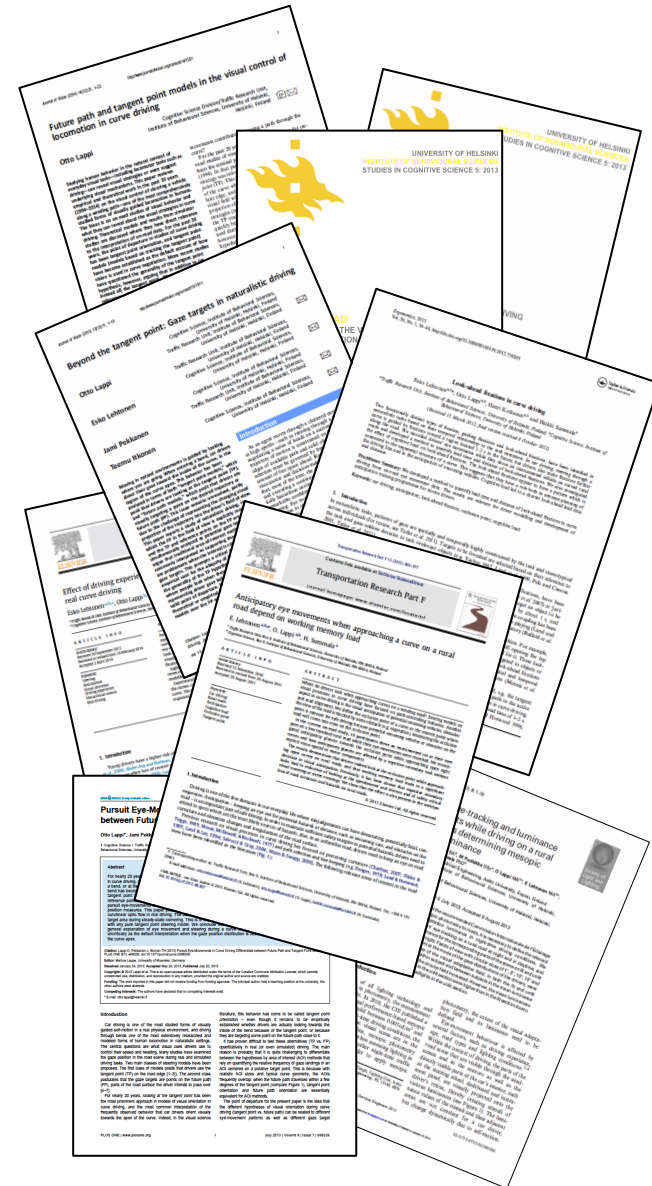
Lappi, O., Rinkkala, P. & Pekkanen, J. (2017). Systematic Observation of an Expert Driver's Gaze Strategies - An On-Road Case Study. [Frontiers in Psychology](#), 8:620. doi: 10.3389/fpsyg.2017.00620

Pekkanen, J., Lappi, O., Itkonen, T.H. & Summala, H. (2017). Task-Difficulty Homeostasis in Car Following Models: Experimental Validation Using Self-Paced Visual Occlusion. [PLOS ONE](#) 12(1): e0169704. doi:10.1371/journal.pone.0169704

Lappi, O. (2016). Eye Movements in the Wild: Oculomotor Control, Gaze Behavior and Frames of Reference. [Neuroscience & Biobehavioral Reviews](#). 69, 49-68. doi: 10.1016/j.neubiorev.2016.06.006

Lappi, O. (2015). The Racer's Brain: How Domain Expertise is Reflected in the Neural Substrates of Driving. [Frontiers in Human Neuroscience](#), 9:635. doi: 10.3389/fnhum.2015.00635

Continued...



Representative Publications in the past five years

Itkonen, T., Pekkanen, J., & Lappi, O. (2015). Driver Gaze Behavior Is Different in Normal Curve Driving and when Looking at the Tangent Point. *PloS ONE*, 10 (8), e0135505.

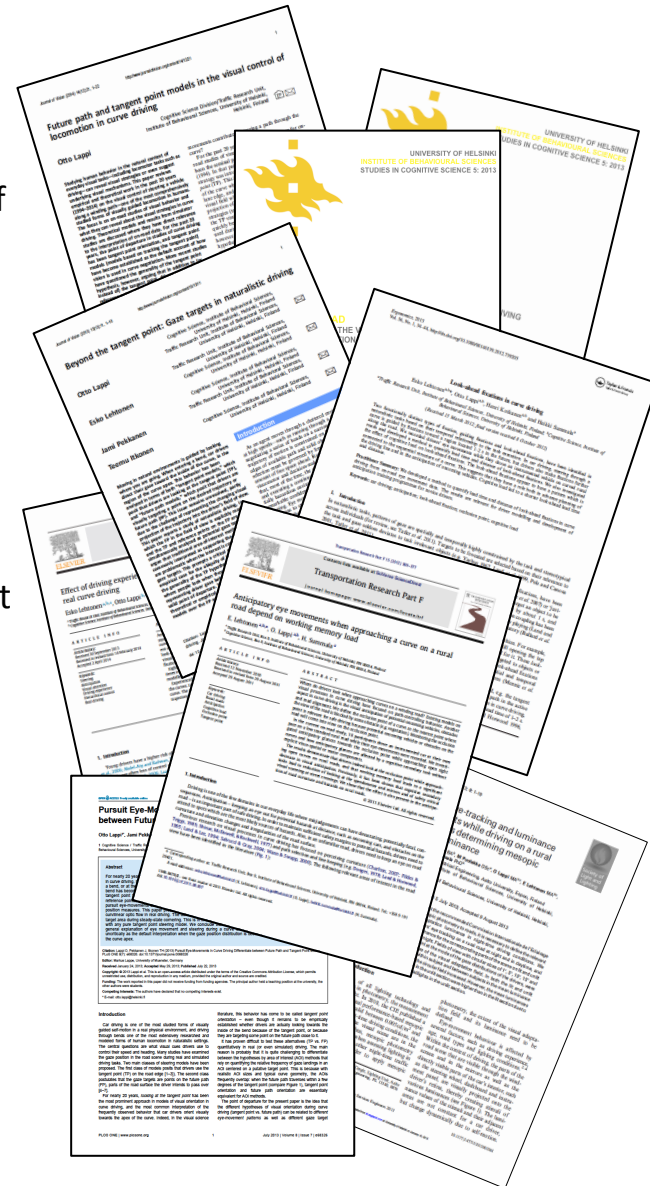
Lappi, O. (2014). Future path and tangent point models in the visual control of locomotion in curve driving. *Journal of Vision*, 14(12), 1–22.

Lehtonen, E., Lappi, O., Koirikivi, I. & Summala, H. (2014). Effect of driving experience on anticipatory look-ahead fixations in real curve driving, *Accident Analysis & Prevention*, 70, 195-208. doi:10.1016/j.aap.2014.04.002.

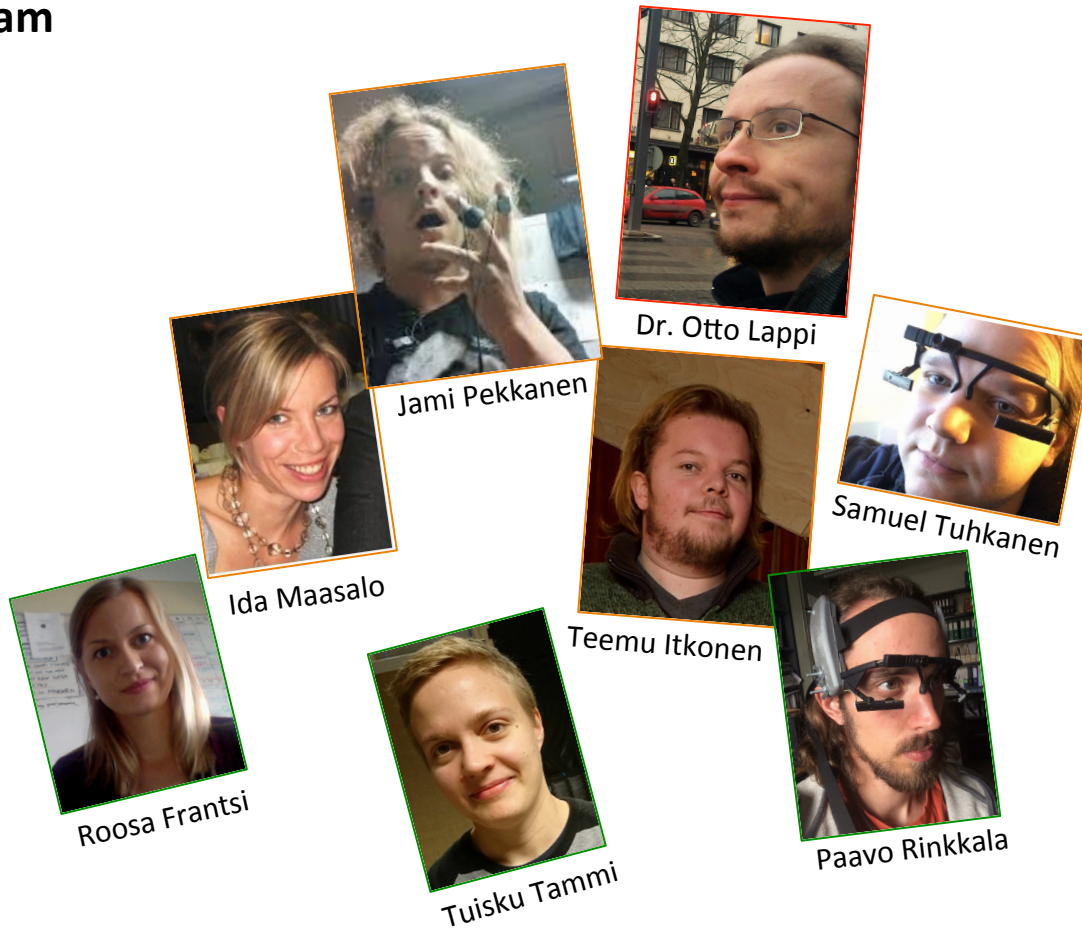
Lappi, O., Pekkanen, J. J. O., & Itkonen, T. (2013). Pursuit Eye-Movements in Curve Driving Differentiate between Future Path and Tangent Point Models. *PLOS ONE*, 7(8), e68326. doi:10.1371/journal.pone.0068326

Lappi, O., Lehtonen, E., Pekkanen, J., & Itkonen, T. (2013). Beyond the tangent point: Gaze targets in naturalistic driving. *Journal of Vision*, 13(13), 1-18

Lehtonen, E., Lappi, O., Kotkanen, H., & Summala, H. (2013). Look-ahead fixations in curve driving. *Ergonomics*, 56(1), 34–44. doi: 10.1080/00140139.2012.739205



The Team



Prof. emer. Heikki Summala

Collaboration



Dr. Esko Lehtonen
(Chalmers)



Dr. Callum Mole & Dr. Richard Wilkie
(Leeds)



Damien Schnebelen & Dr. Franck Mars
(Nantes)



Today's topic

Driving - a **ubiquitous real-world task**, and
in many ways an **attractive model system**
of skilled visuomotor action



basic



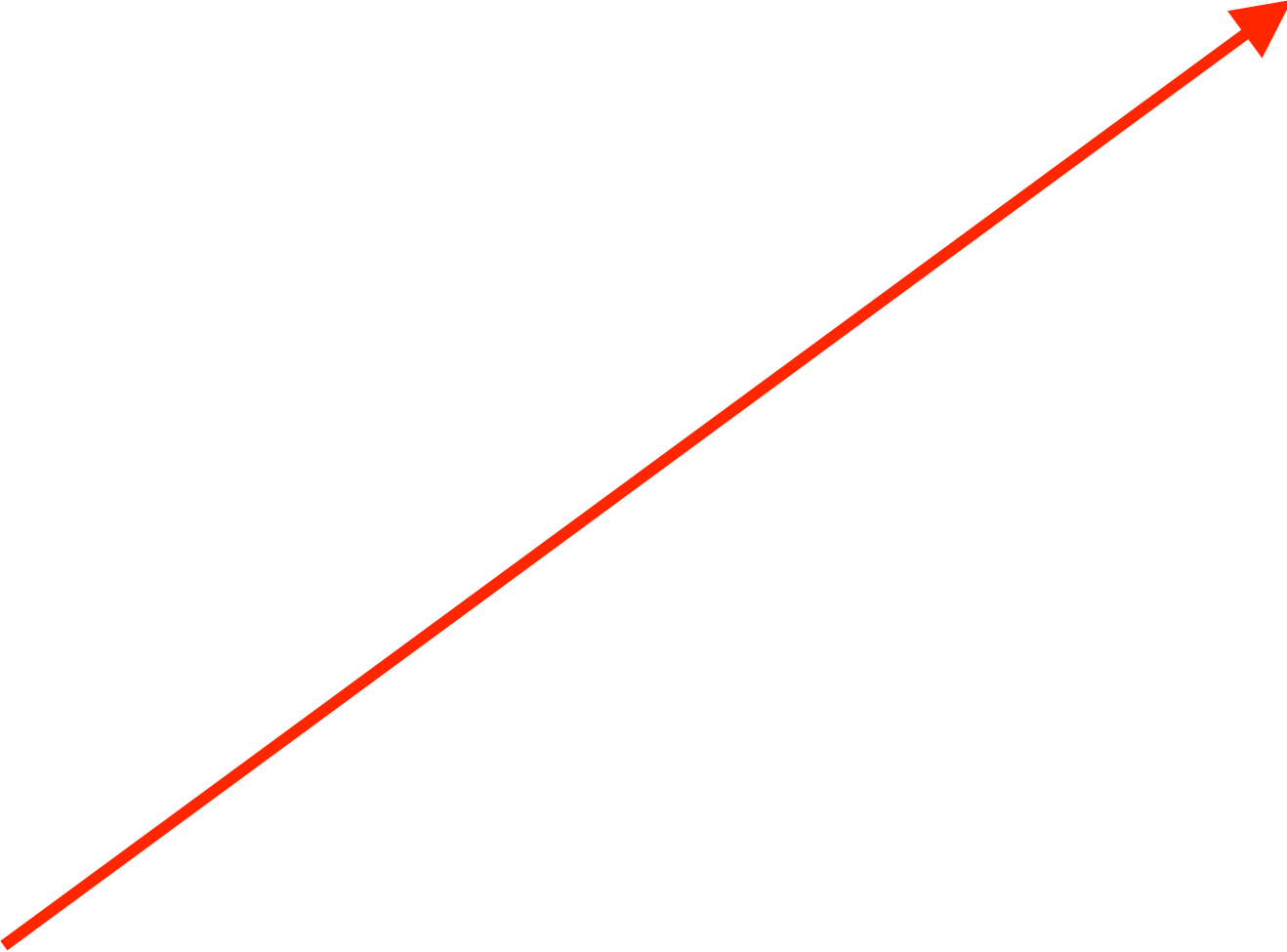
normative

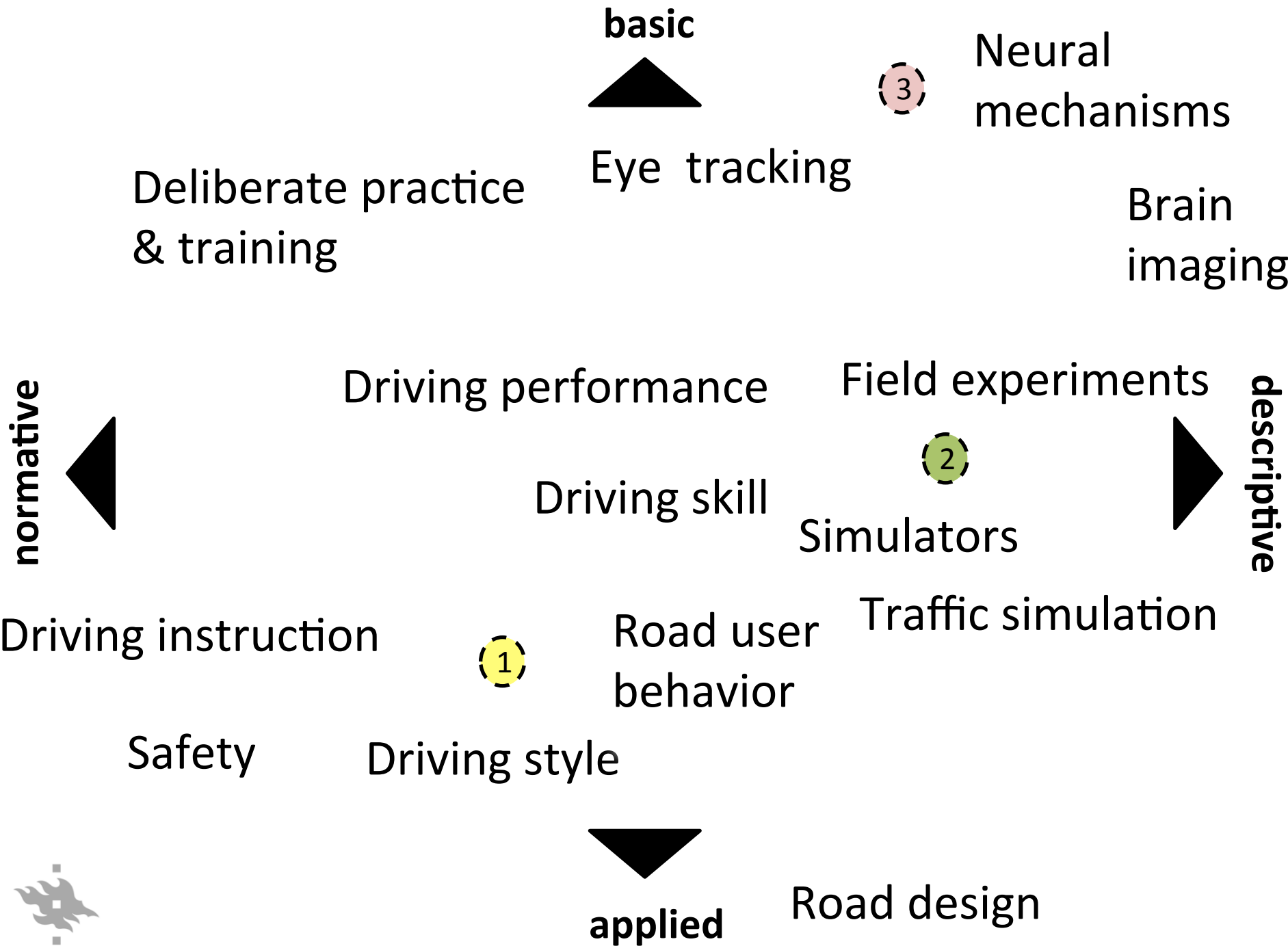


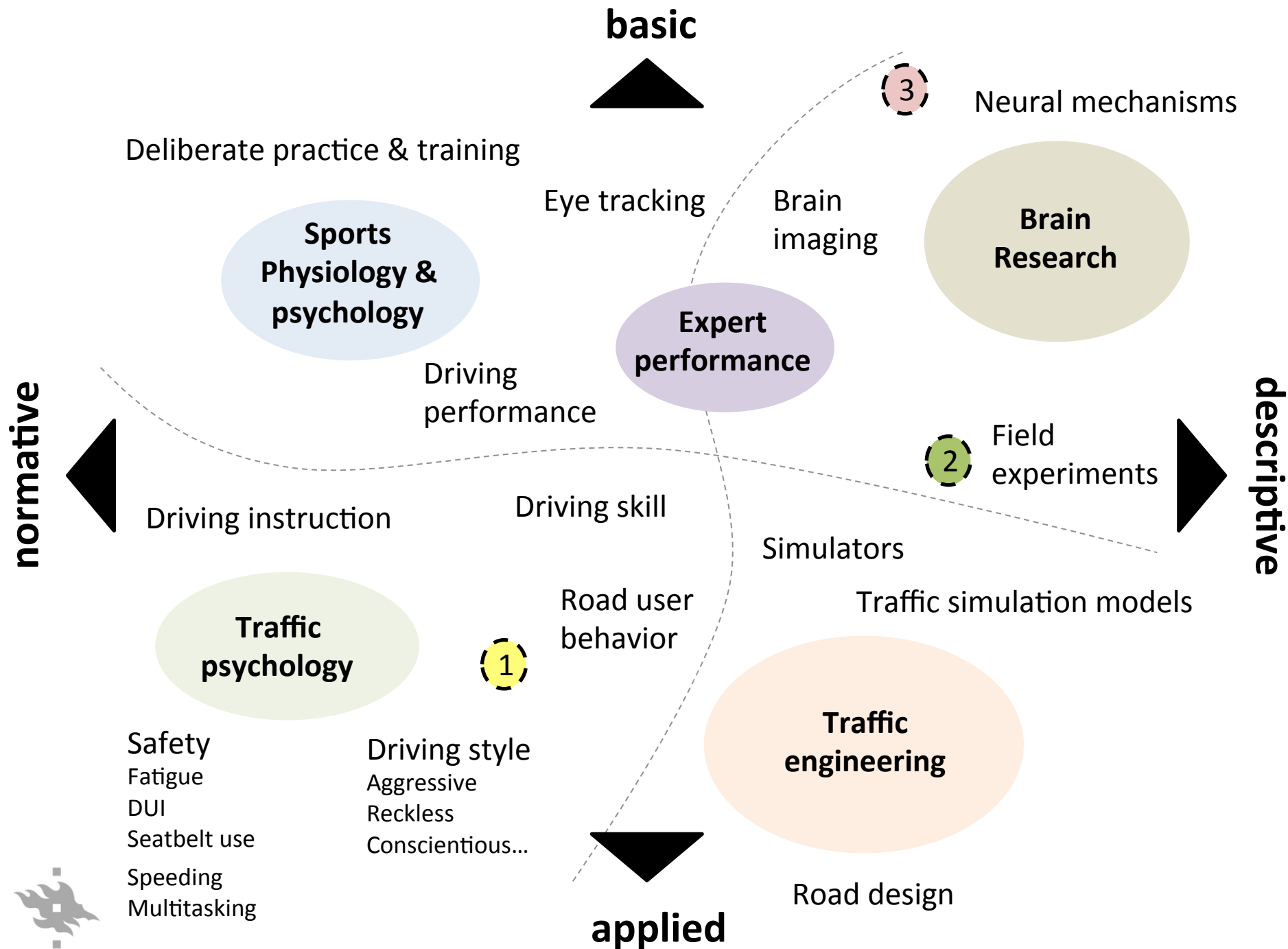
descriptive



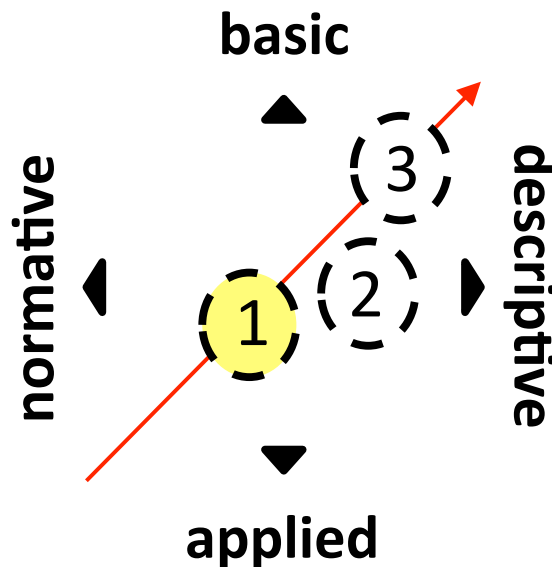
applied



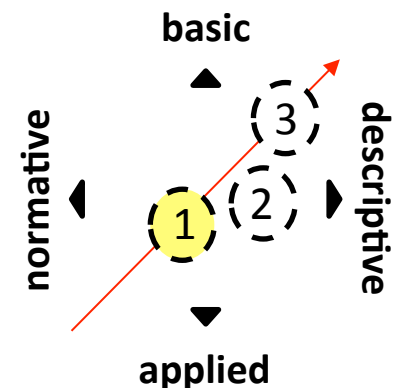




Integrating Traffic psychology and Traffic engineering

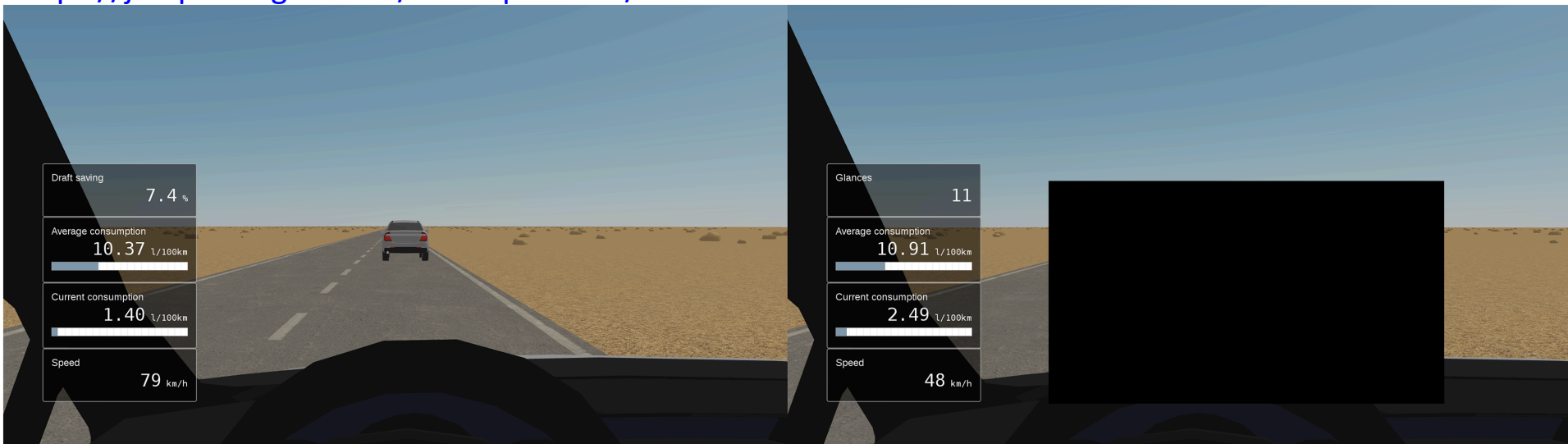


- Car following (CF) models in traffic engineering often criticized for not incorporating “human factors”
- Some recent work with the **Task-Capability Interface (TCI)** model
- We examined assumptions using a **self-paced visual occlusion paradigm**

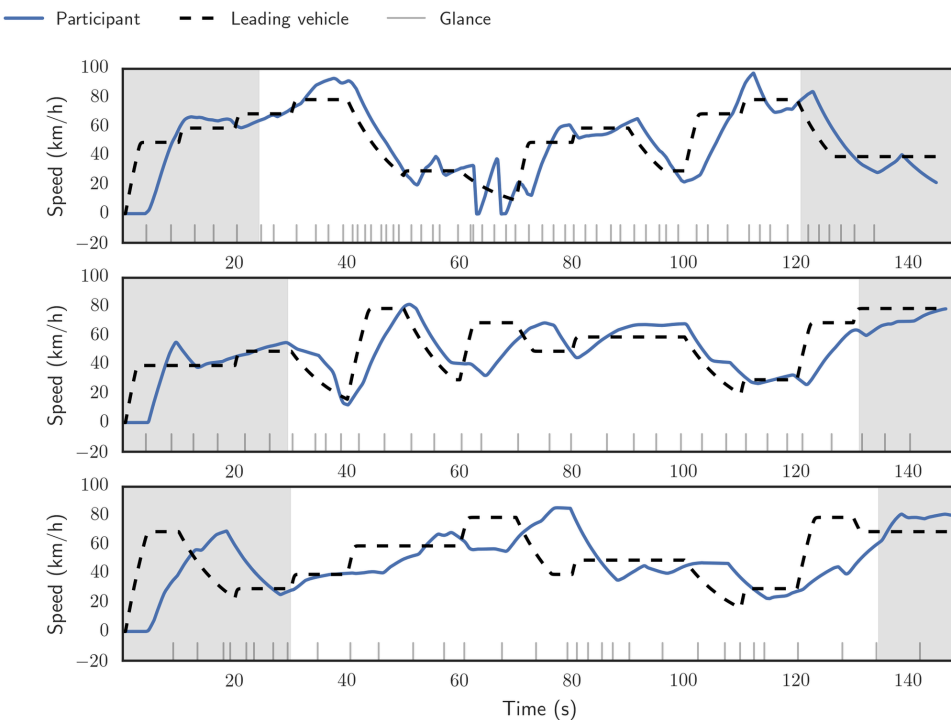


<https://doi.org/10.1371/journal.pone.0169704>





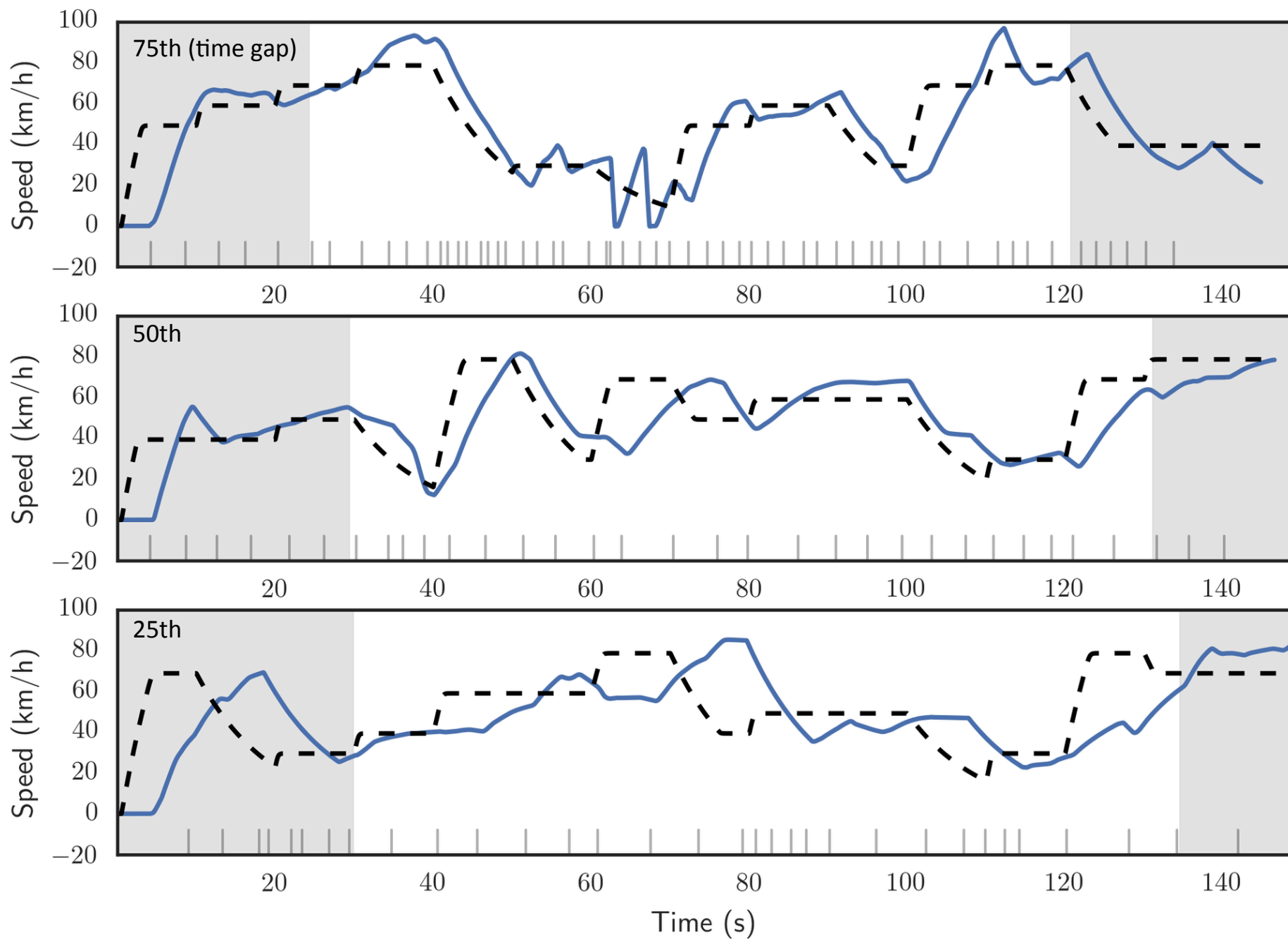
CF task



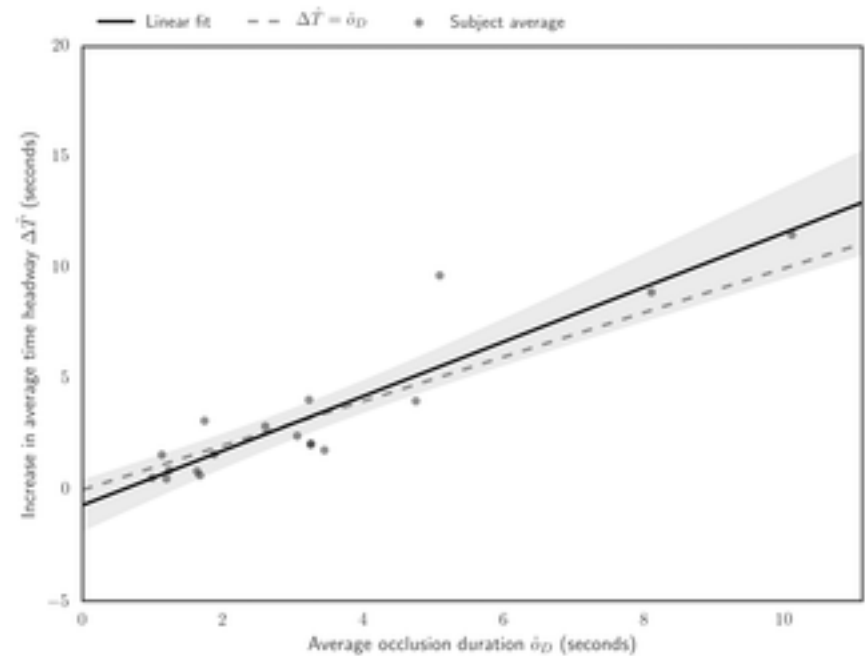
Visual occlusion

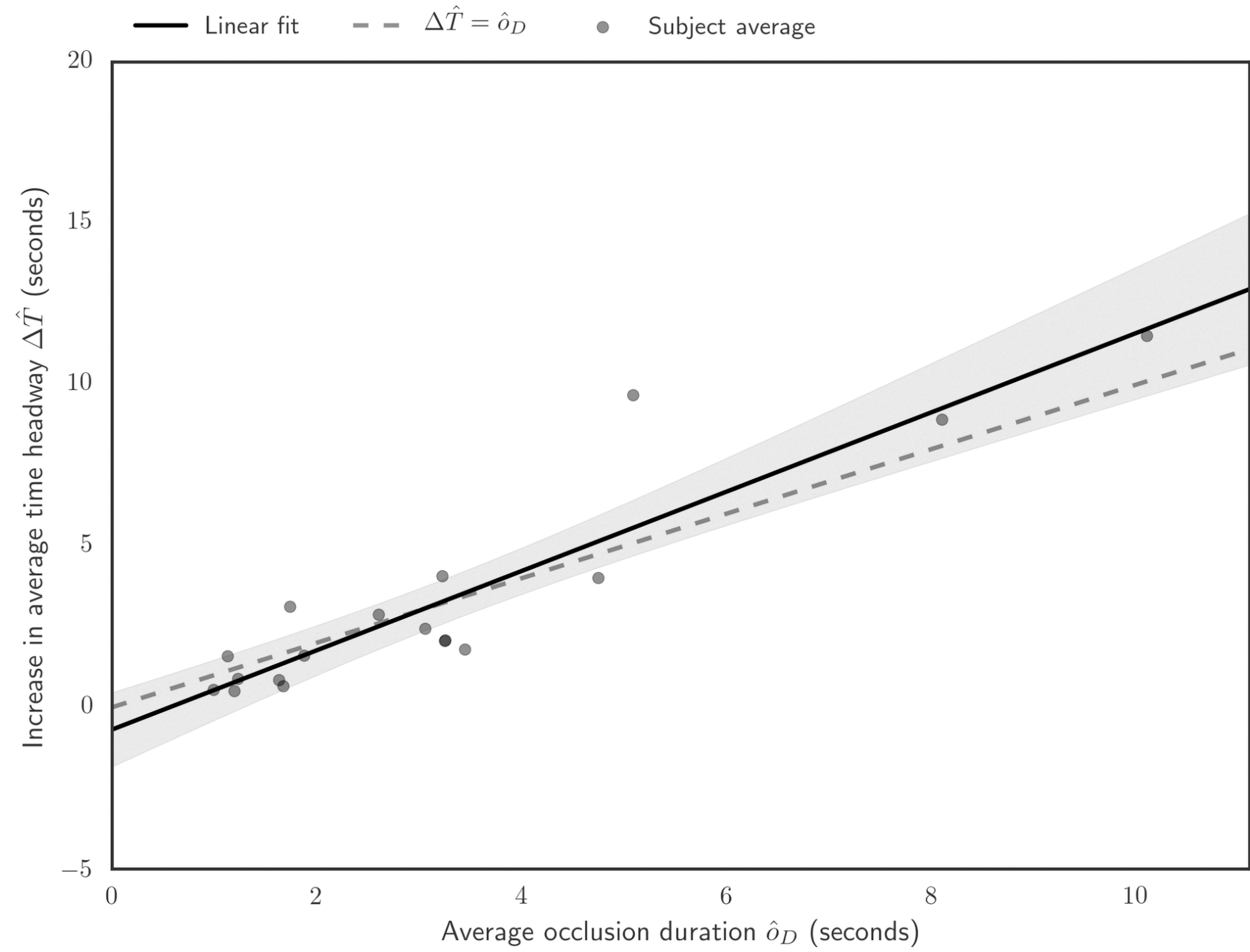
- Road scene only **intermittently** sampled
 - Blinder lifted on request for 0.5s
- Reduces capability
 - Infrequent sampling compensated by time gap/ short time gap requires more frequent sampling

— Participant - - - Leading vehicle — Glance



- Strong, approximately one-to-one, correspondence between occlusion duration and increase in time headway
- Support TCI-CF models that assume linear increase in time headway (*reduced demand*) in response to increased distraction (*reduced capability*)
- Between subjects and within subjects

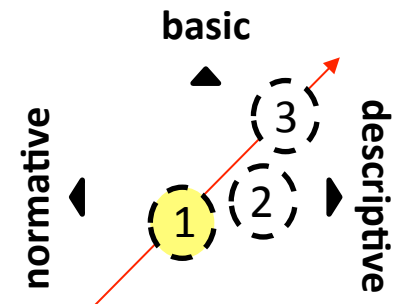




- The concept of variability in “driving style” (DS) well established in traffic psychology recognized in engineering but fields rarely overlap in concepts and methods



- Traditionally CF models in traffic simulation assume identical drivers following a simple rule
- Validation of model parameters done by modelling an “average” driver



“Definition” of driving style in traffic psychology:

1. **differs** across individuals or groups of individuals
2. is a **stable, habitual** feature in driving behaviour
3. is a **preference**, which many authors but not all equate with a conscious **choice**.

Accident proneness *“Young male syndrome”*

A-type personality *Violating drivers vs. error-prone drivers (DBQ)*

Conscientiousness,
agreeableness (Big Five) *Distractible vs. focussed drivers*

Anxious drivers *“Reckless” drivers*
(DUI, seat belts,
fatigue speed...)

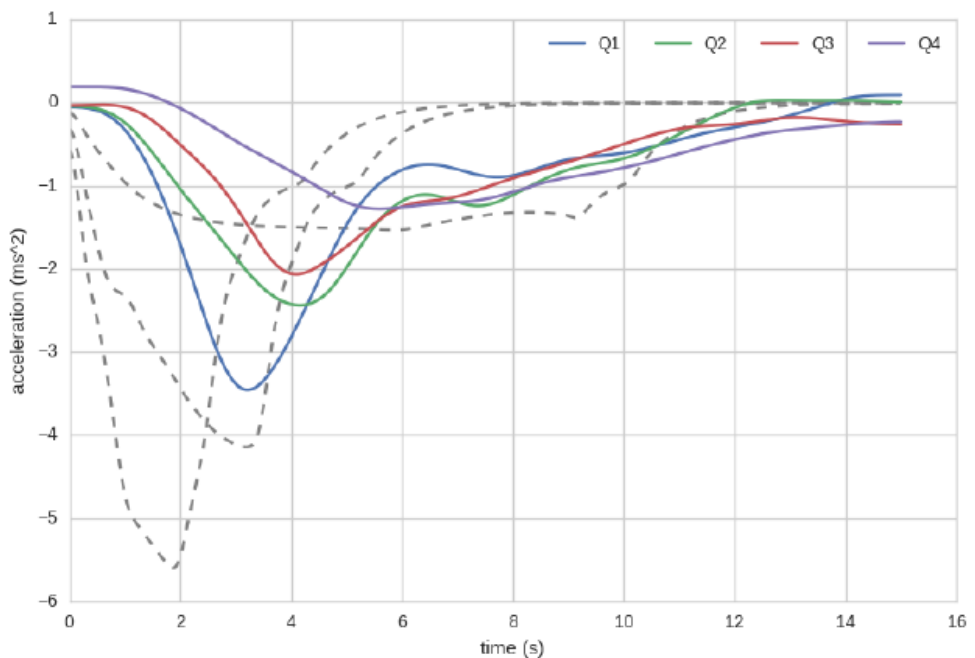
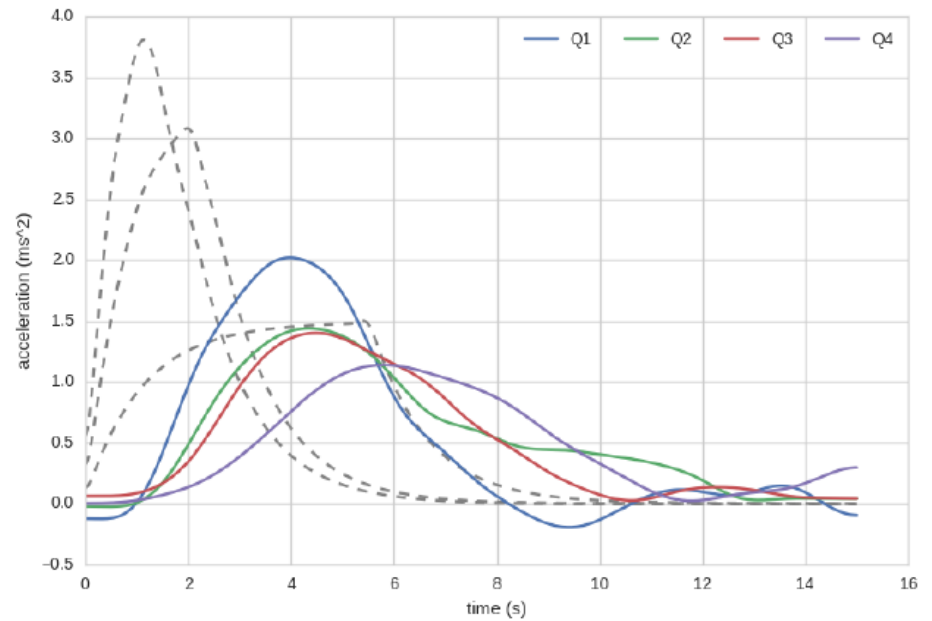
Hostility, “road rage” *Aggressive driving style*

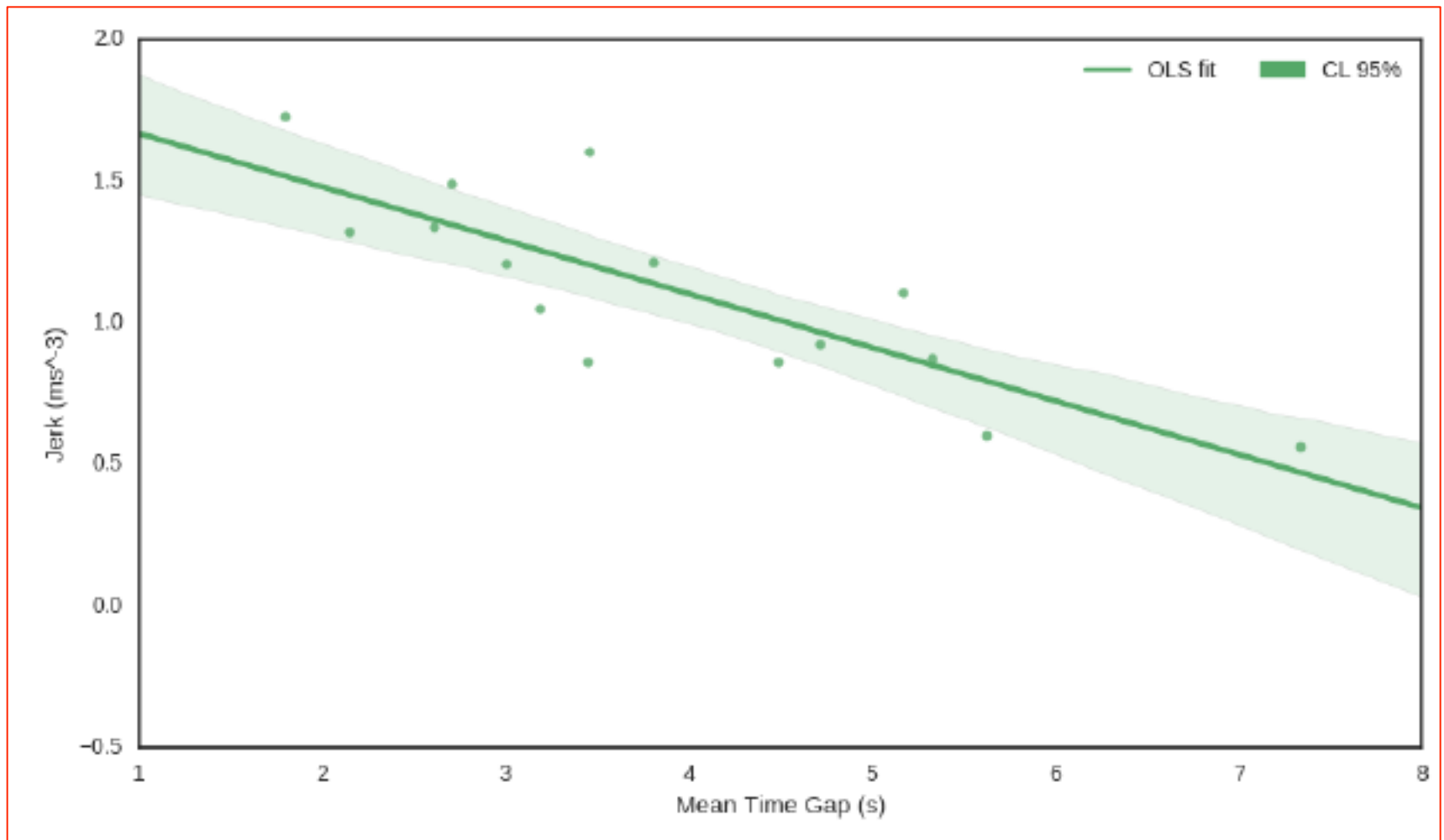
“Tailgating” drivers

“Jerky” driving style *“Speeders”*



- Habitual preference in the “style” of controlling safety margin
- CF longitudinal control
 - a core behavior for traffic simulation





“Jerky” (*intensive*) vs. “smooth” (*calm*)
preference/driving style?





CF task



Visual occlusion

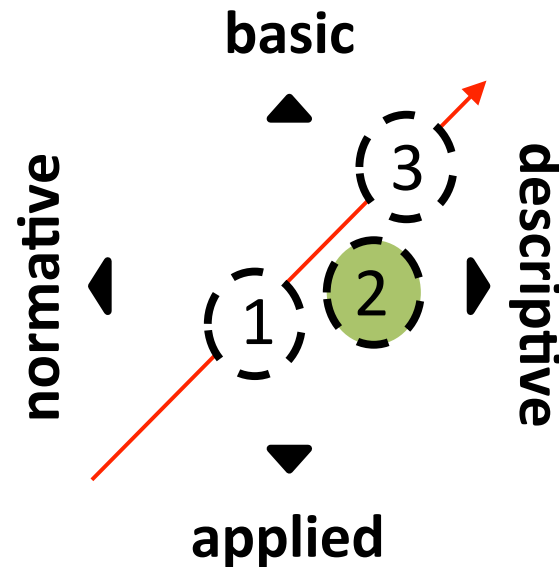
Validation experiments
Coming out soon!



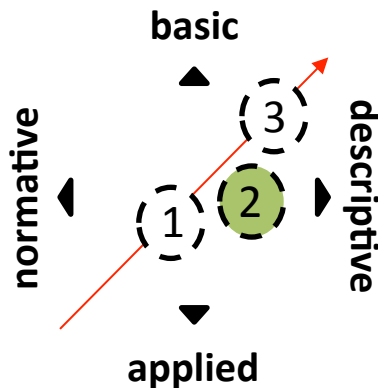
Pekkanen et al., in preparation



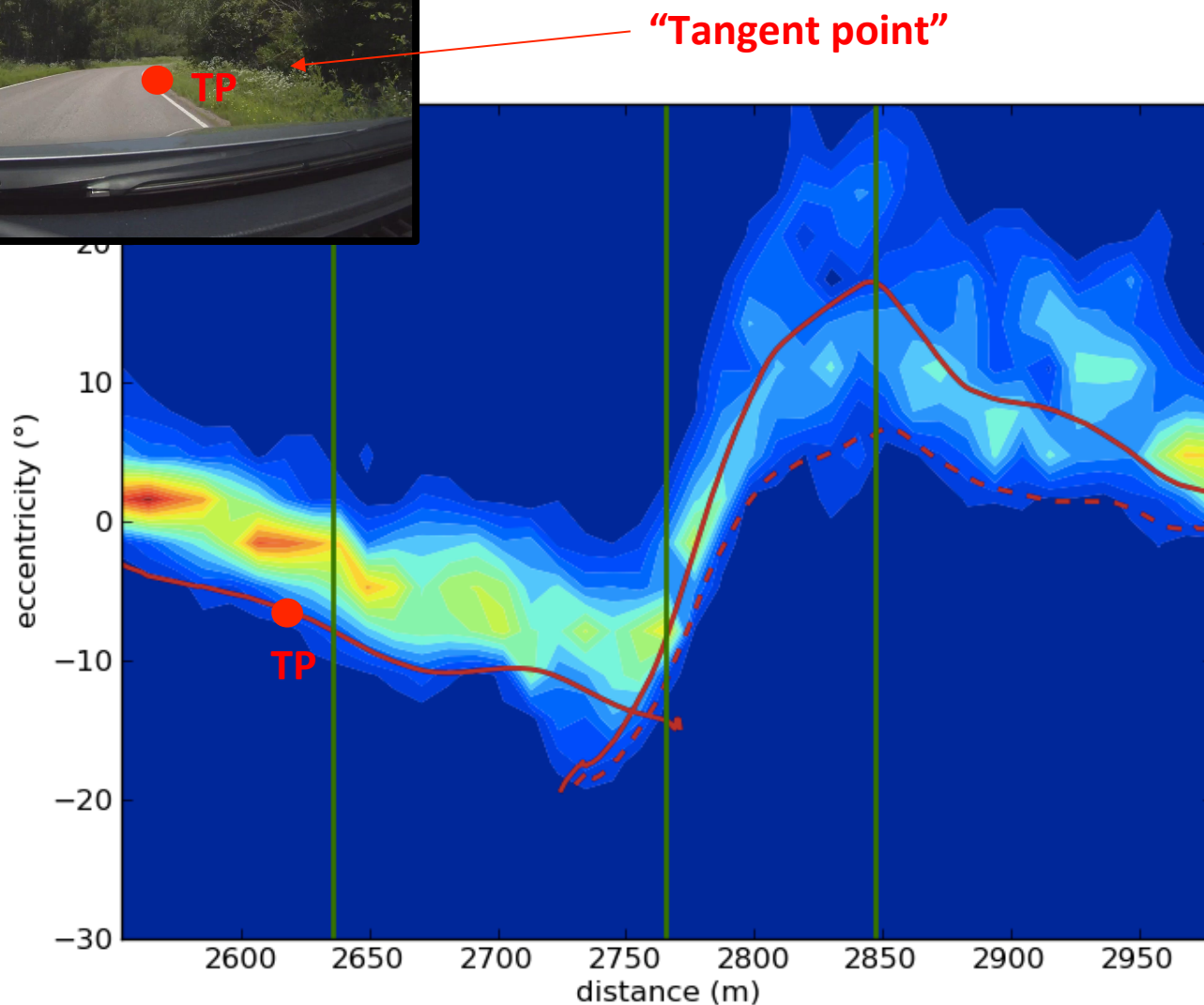
Fieldwork on driver eye movements

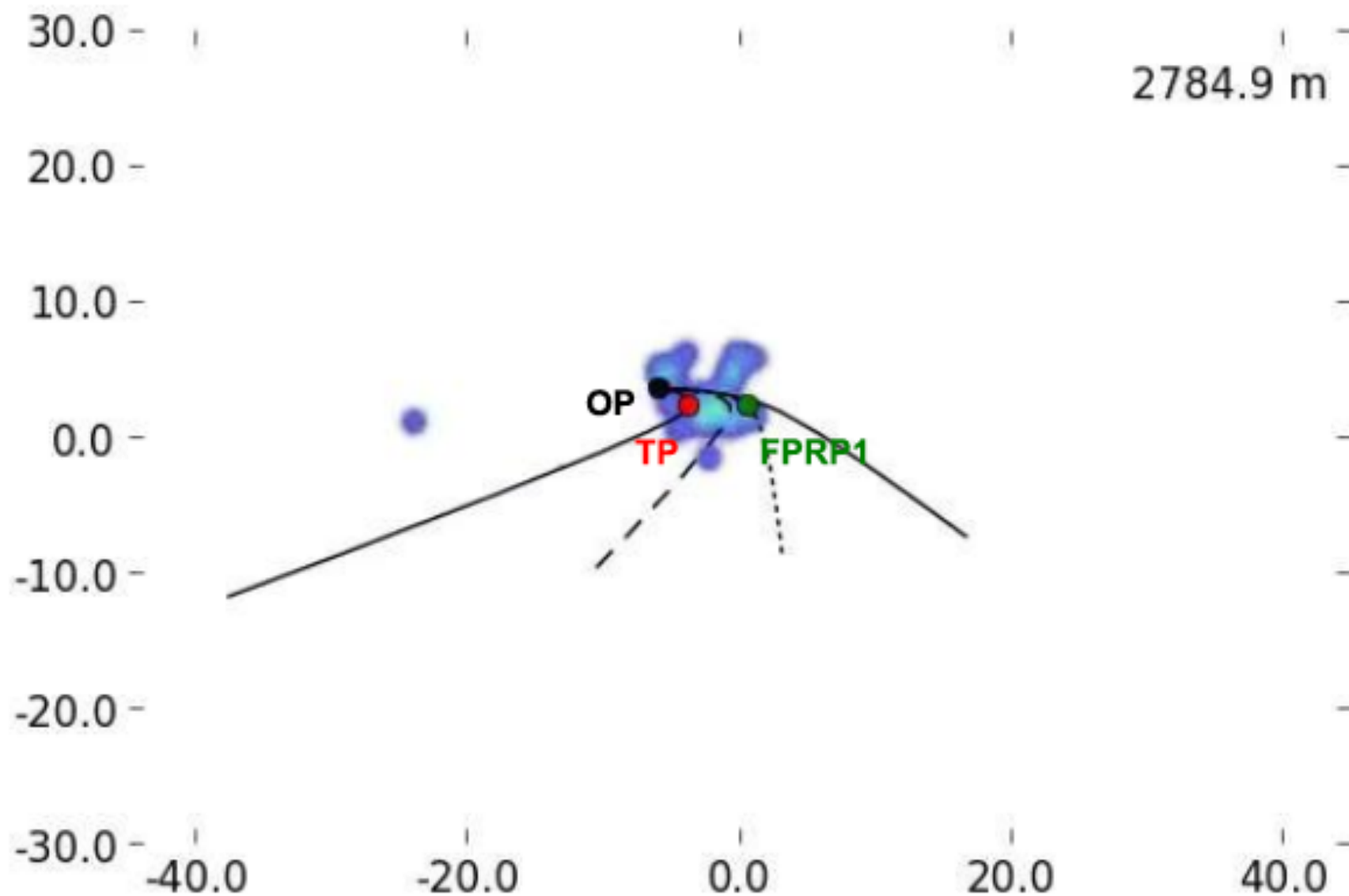


- On-road eye tracking of driver **eye movements in curve driving**
 - 2 camera SmartEye (2009-2015)
 - Pupil Labs (2016-)
- <https://pupil-labs.com/>



Steering (guiding fixations GF)





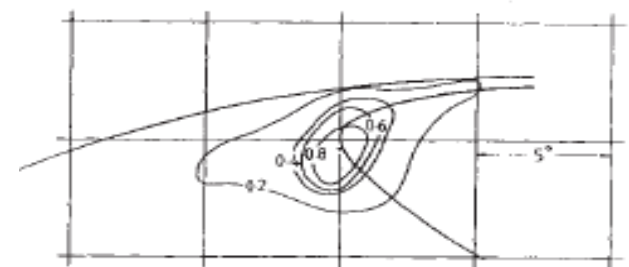
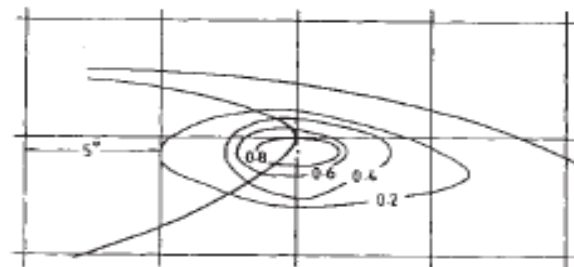
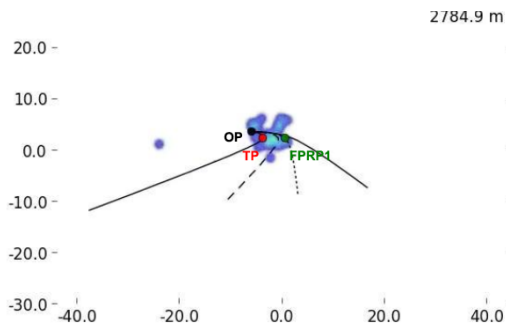
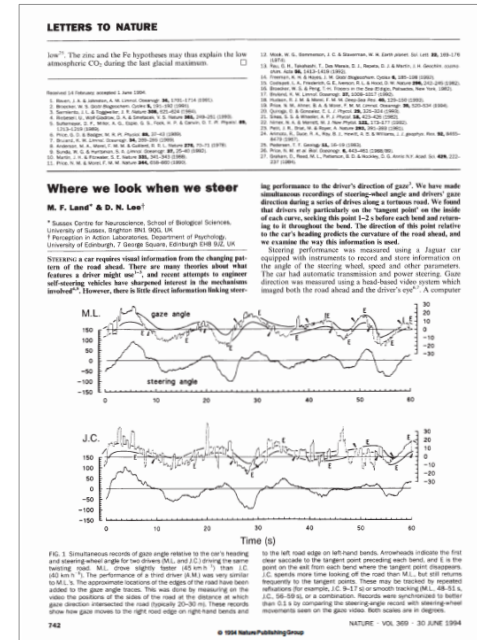
<http://jov.arvojournals.org/article.aspx?articleid=2193829>

(See supplementary Movies)

- For twenty years “steering by the tangent point” the dominant hypothesis for interpreting on-road gaze data and the textbook account of how vision is used for high-speed steering

“Tangent point orientation”

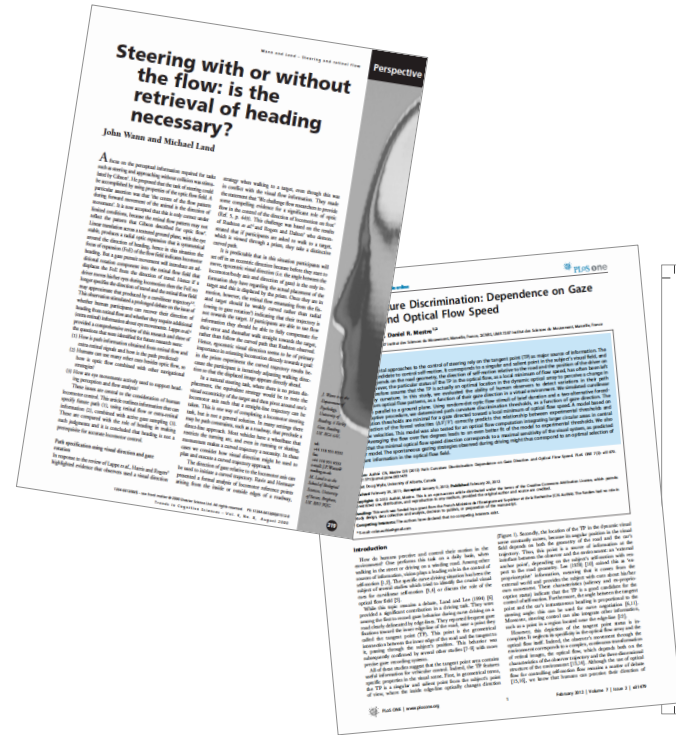
Land & Lee, Nature 1994





What I thought

Steering models and replication studies



"directing gaze to successive points along the intended future path ... a succession of saccades should be evident ... having a horizontal component shifting gaze in the direction of the bend. Such **sequences of saccades at corners are not present** ... rather we see fixation on the tangent point and smooth pursuit to keep it fixated." [Wil05]

"All drivers we have tested in a driving simulation naturally adopt **this optimal coordination**" [Wil07]

"because of its minimum flow speed, the **TP is indeed an optimal location in the visual field**" [Aut12]

"Our results confirm that subjects **normally look at the tangent point whereas they do not use gaze sampling** [i.e. tracking future path waypoints] of their own accord ... In contrast to virtual environment studies, the tangent-point thus wins out against gaze sampling in these real-world experiments"" [Kan09]

“subjects normally **look at the tangent point** on average for about three quarters of the time” [Kan09]

"Our data show that drivers rely heavily on the tangent point. Subjects spent more than half of the time on looks at the tangent point. In contrast, **we did not find any evidence for the use of the alternative gaze sampling method**. No subject showed the eye movement pattern of looking at a certain spot on the future path of the lane and tracking this spot as it approaches." [Kan10]

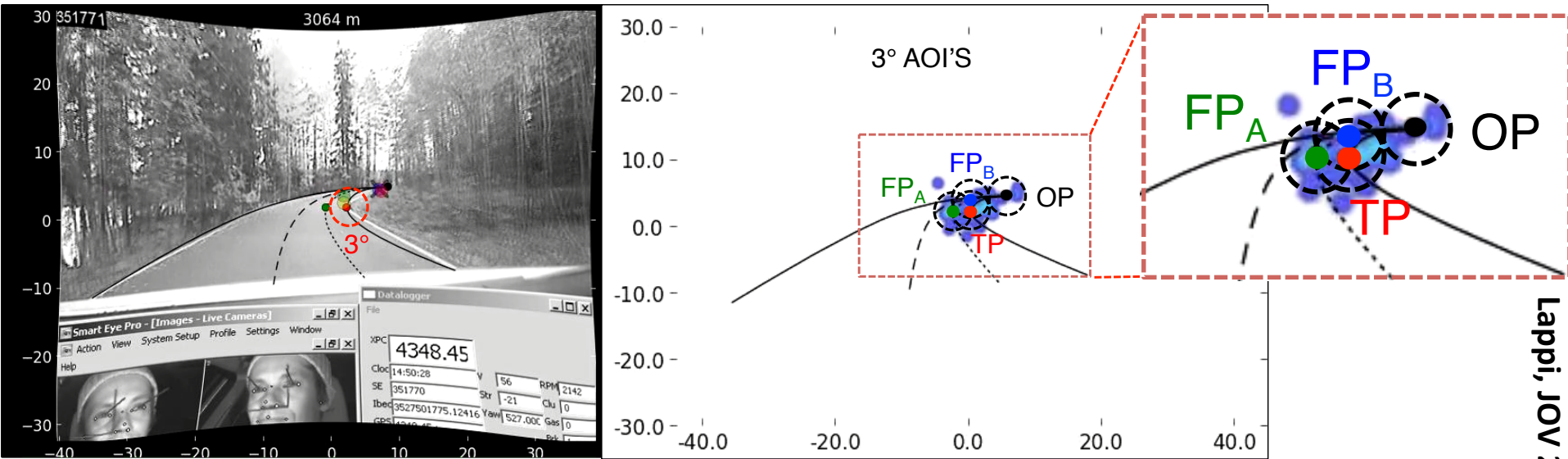




That can't be
quite right!

I STILL thought

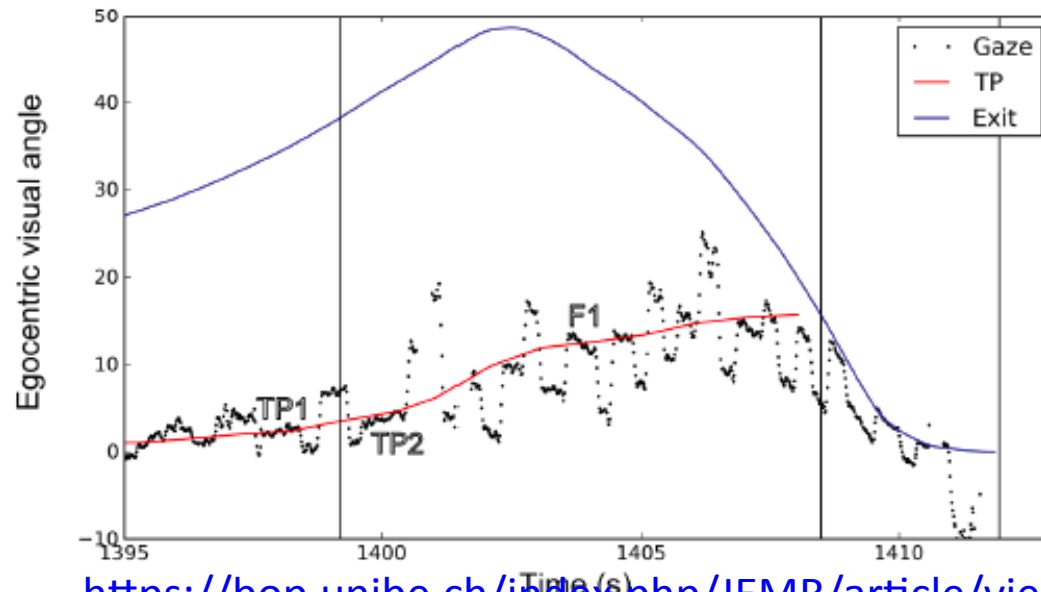
AOI overlap problem



- Results interpreted in support of the TP in fact **inconclusive!**
- A number of steering point models actually account for the way drivers orient gaze by assuming the target is **future path (FP)**, not the **tangent point (TP)**

Observation:

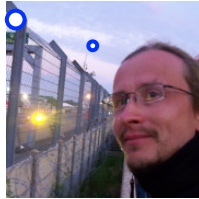
Optokinetic nystagmus elicited by visual flow while cornering



<https://bop.unibe.ch/index.php/JEMR/article/view/23>



Idea!



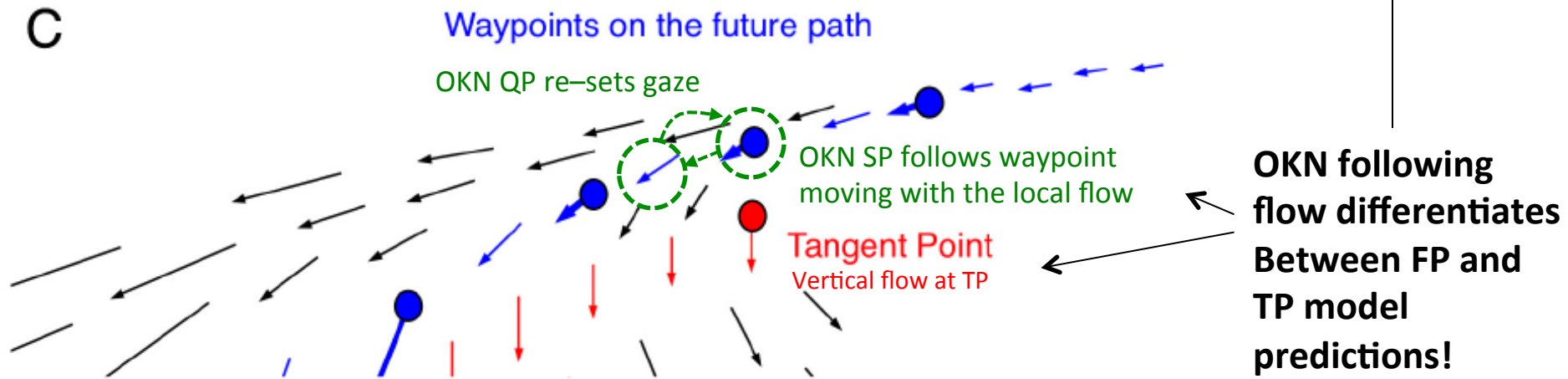
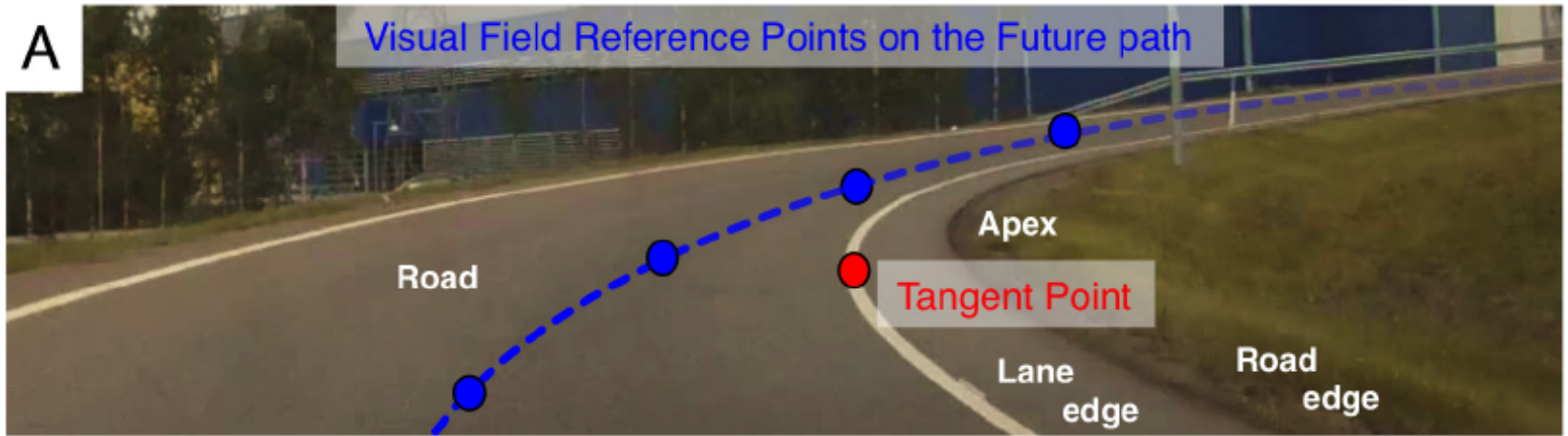
Why not use
the systematic OKN SP
gaze velocity to
differentiate between
TP and FP models'
predictions where gaze
position (AOI
methods) cannot?

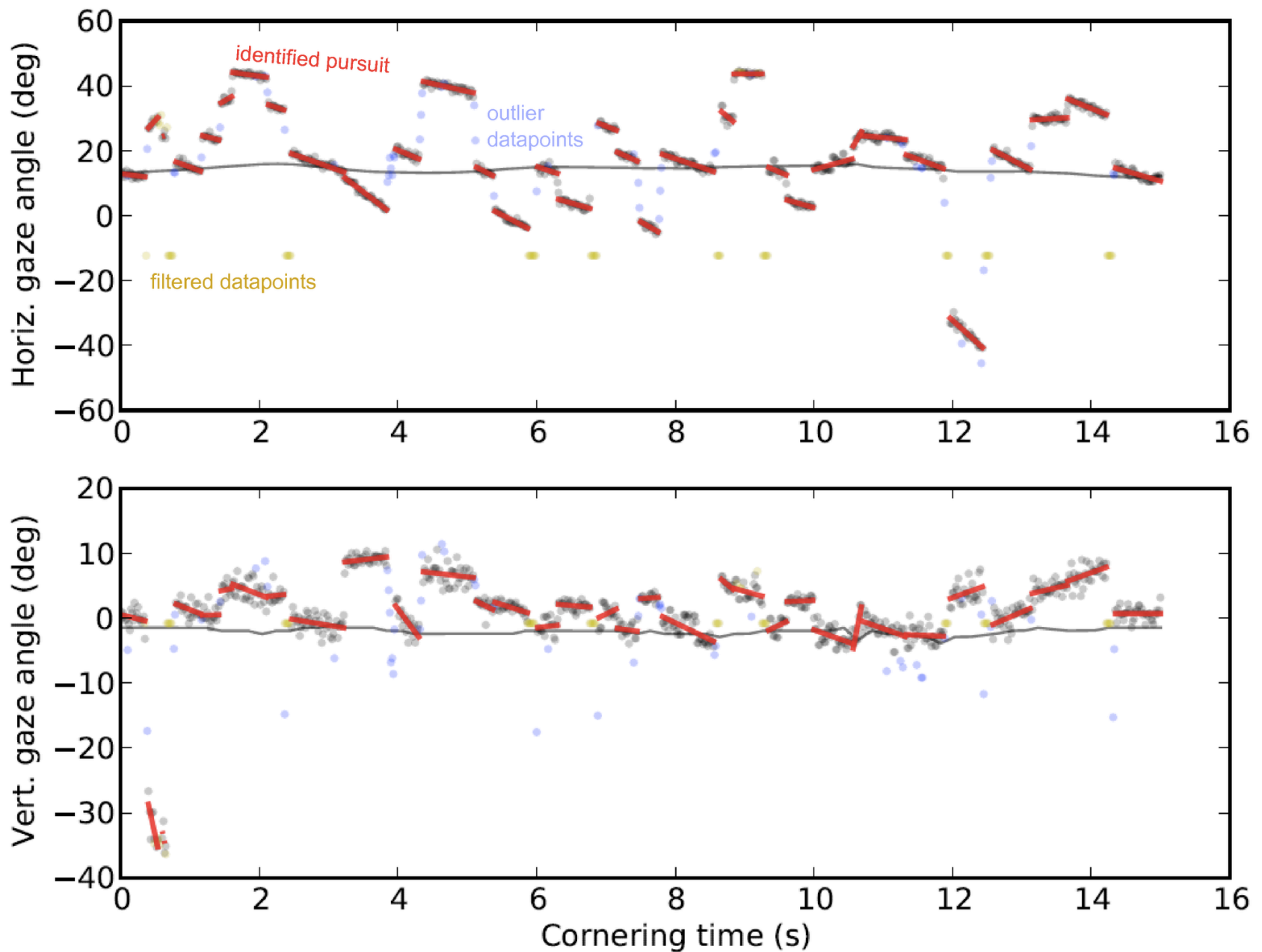


“Let’s do it in velocity-velocity space”!

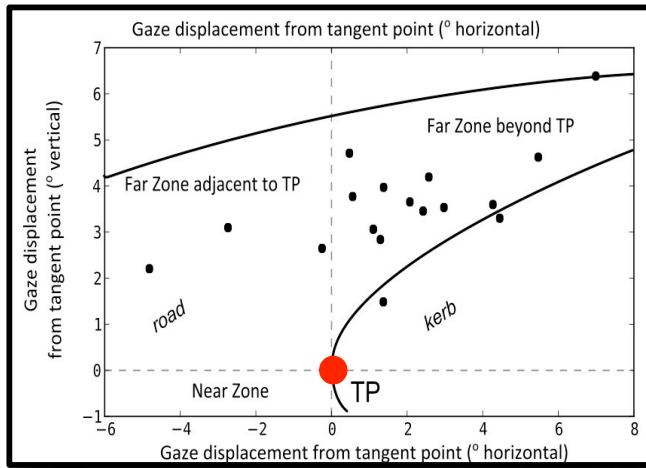
“November 5th
1955”







 Just the small matter of a new event parsing algorithm and...



$$\Delta WP_A = \frac{1}{2} \int d\varphi / dt$$

$$\rho_{\text{path}} = 1/R = 2 \sin VD_{\text{FPB}} / D_{\text{FPB}}$$

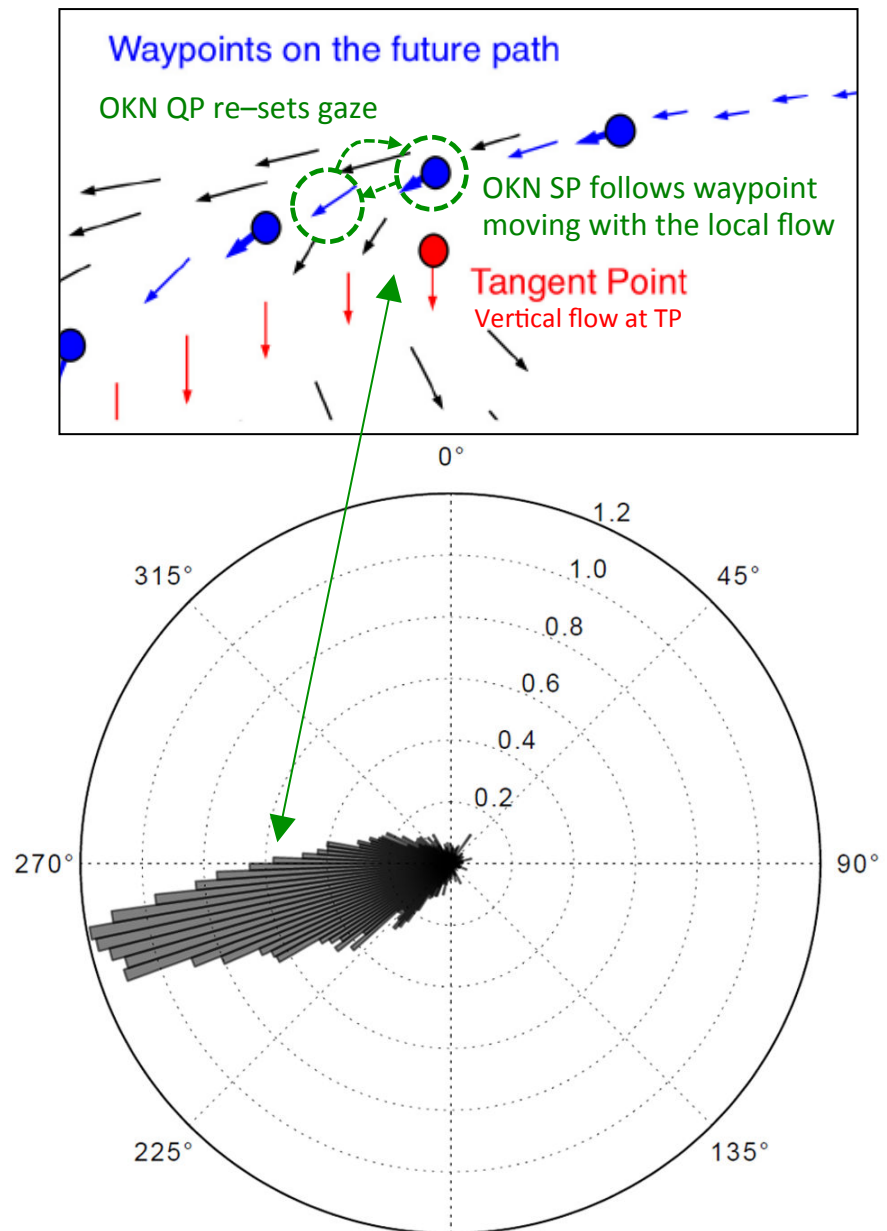
Some elementary maths and a bunch of new algorithms...

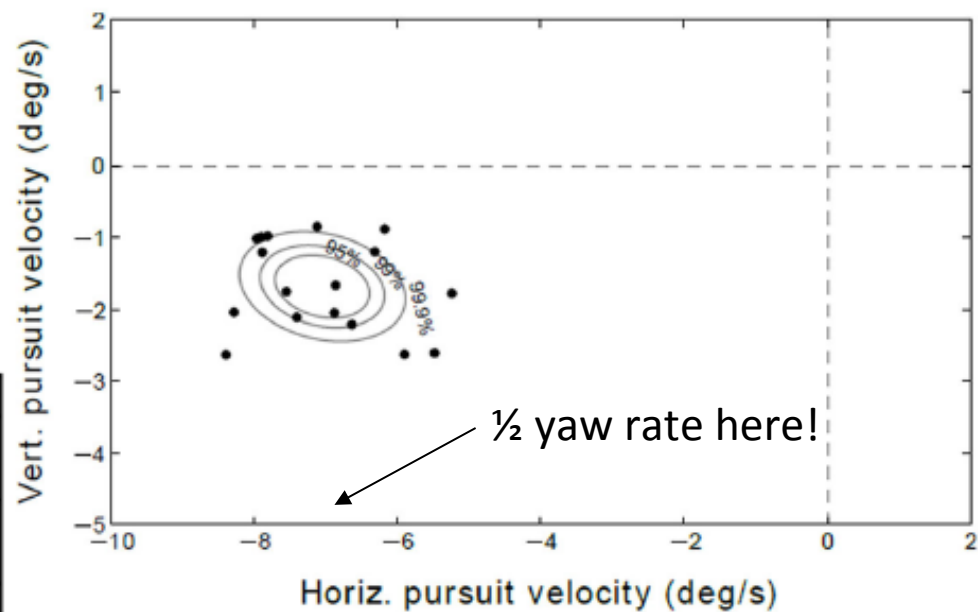
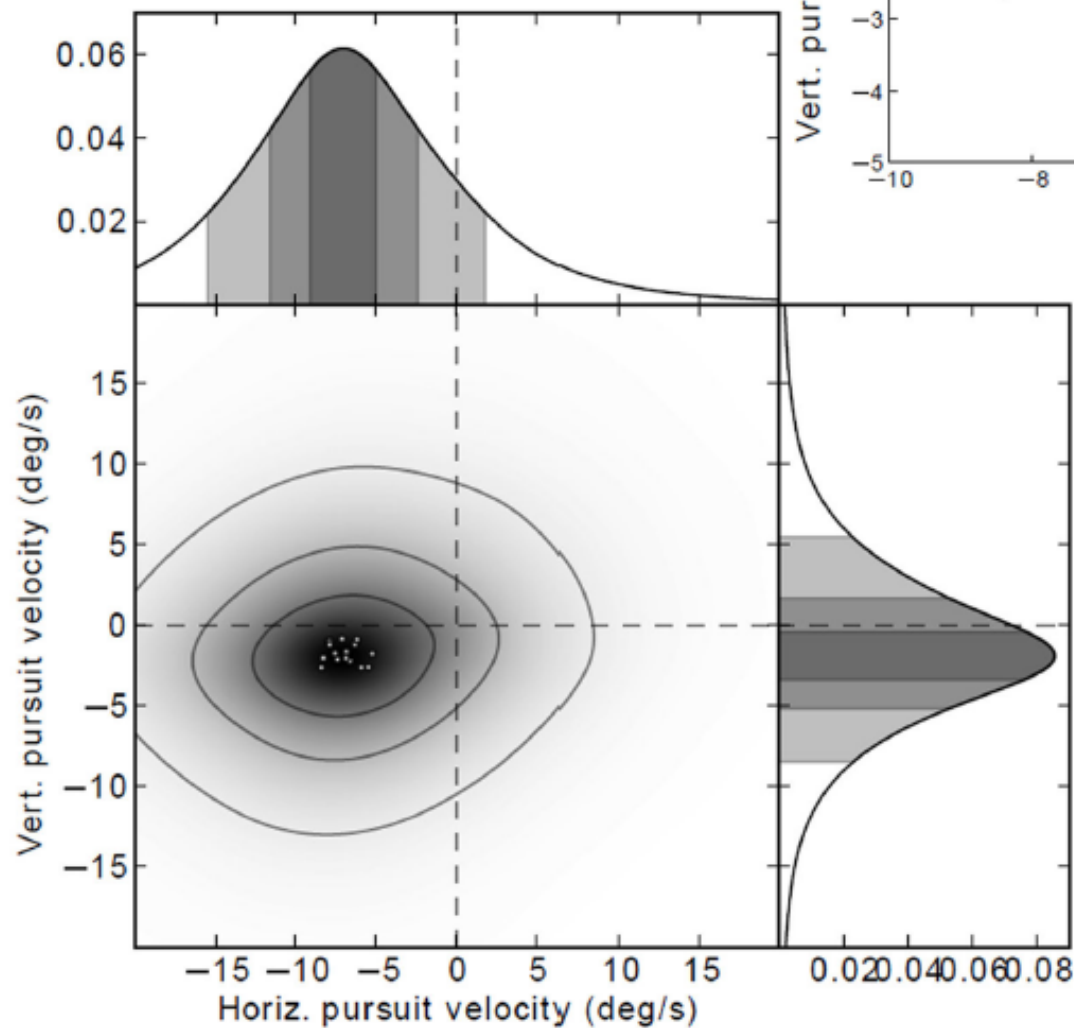
(and lots and lots of **coffee**, trial and error...)



- ...we were for the first time able to **differentiate between quantitative predictions from the TP and the FP models**

- Results supported FP models, undermining the plausibility of the TP models as a general account of steering





From a driver's perspective, the point on a road at which the direction of its inside edge appears to reverse.

How can we make sense of the apparently inconsistent findings? Lappi et al. (2013) argued that drivers fixate the tangent point when approaching and entering a bend but fixate the future path further into the bend. A detailed examination of the data from the study by Land and Lee (1994) revealed precisely this changing pattern of fixations as drivers proceeded through bends. Lappi et al. (2013) studied

H. Eysenck: Cognitive Psychology, A
Student's Handbook 7th ed. 2015 😊

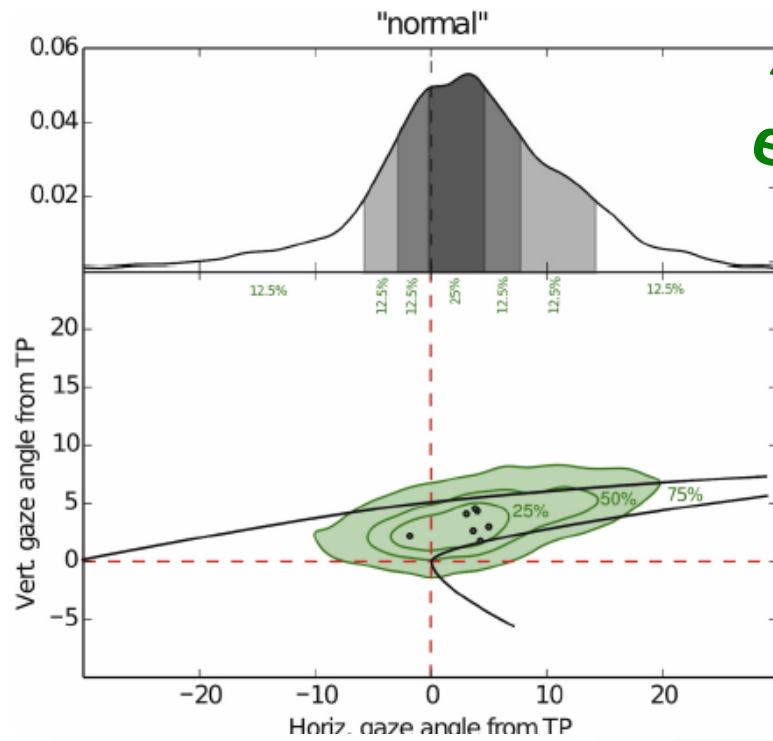
PERCEPTION, MOTION AND ACTION

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drivers' eye movements as they drove along a lengthy curve of constant radius formed by the slip road to a motorway. Drivers' fixations were predominantly on the path ahead rather than the tangent point after the first few seconds (short clips of drivers' eye movements performing this task can be found under supporting information for the article at [10.1371/journal.pone.0068326](https://doi.org/10.1371/journal.pone.0068326)).

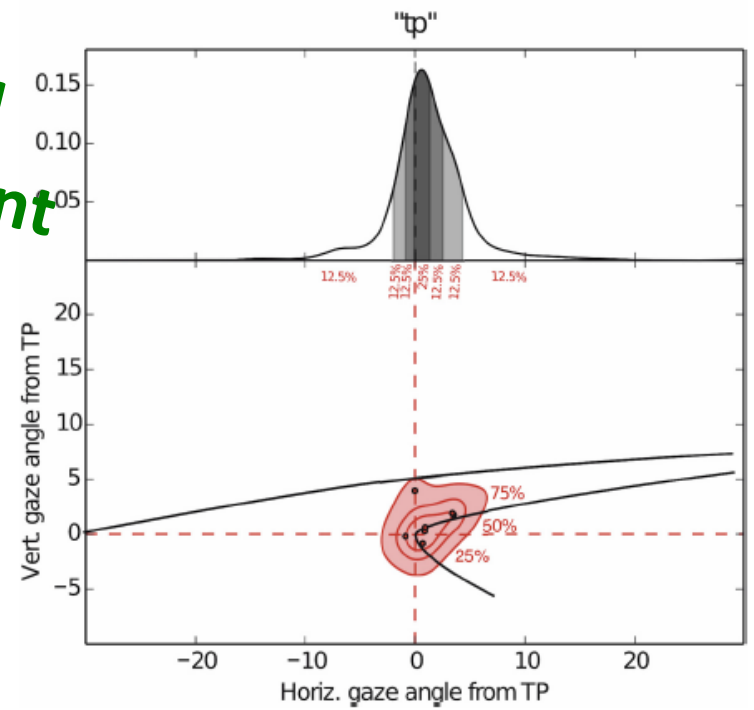
Why do drivers tend to switch from fixating the tangent point to fixating the path ahead as they negotiate curves? The tangent point provides relatively precise information. As a result, drivers may use it when uncertainty about the precise nature of the curve or bend is maximal (i.e., when approaching and entering it). Thereafter, drivers may revert to focusing on the future path.



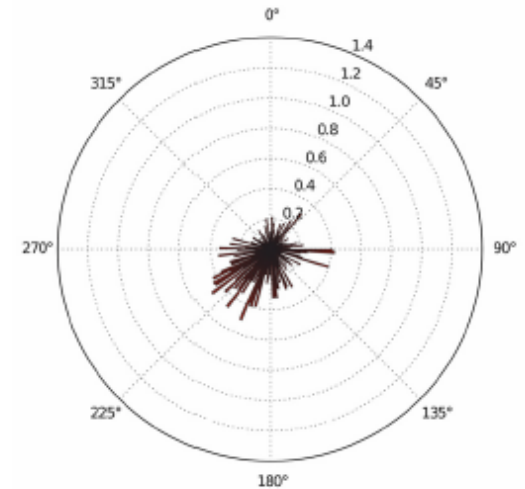
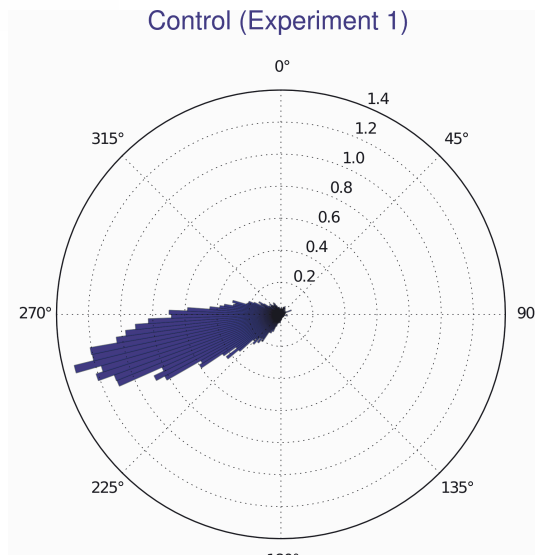
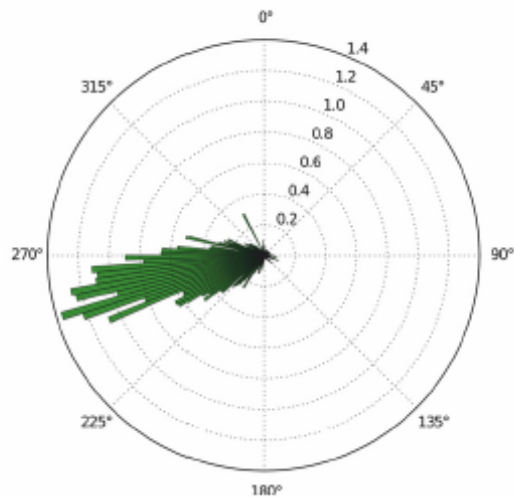


"normal" (Experiment 2)

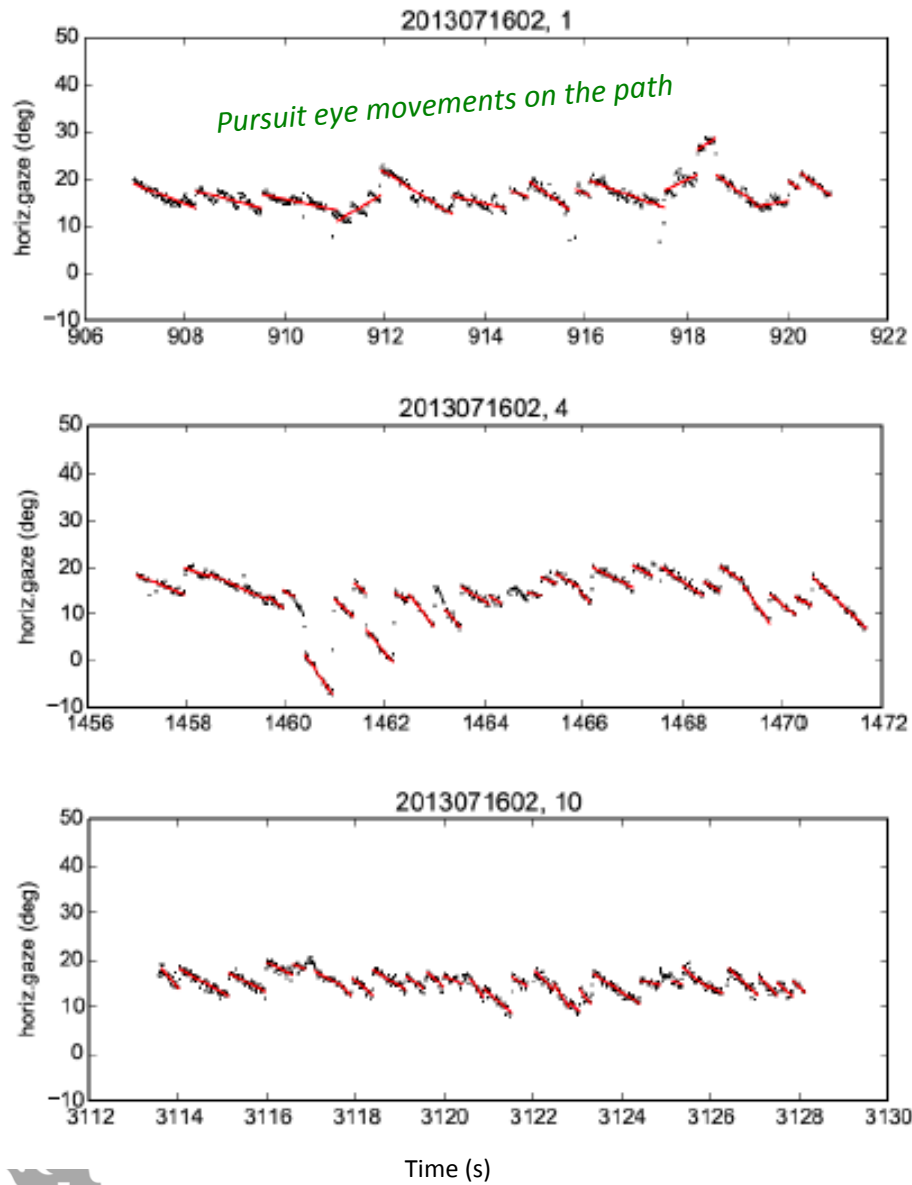
A control
experiment



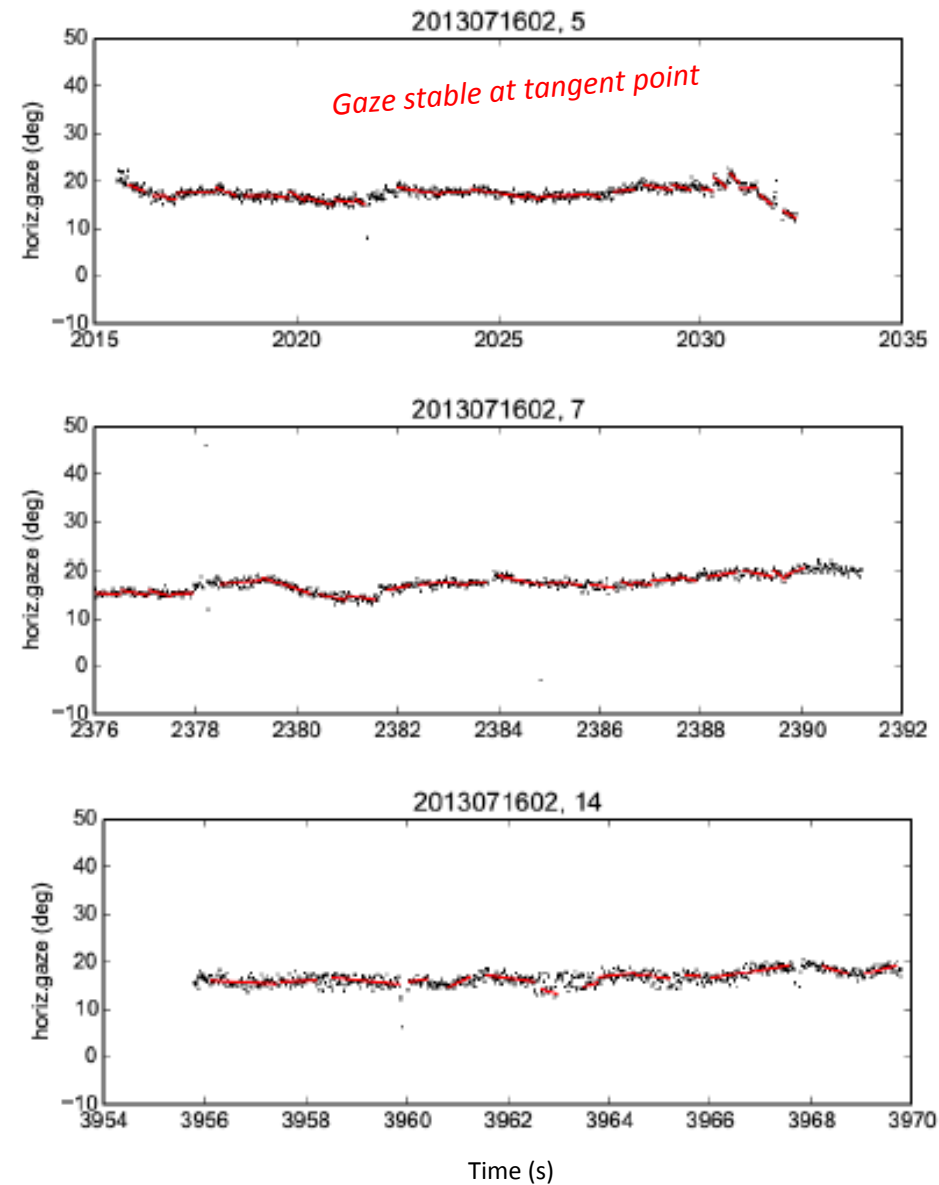
"tp" (Experiment 2)

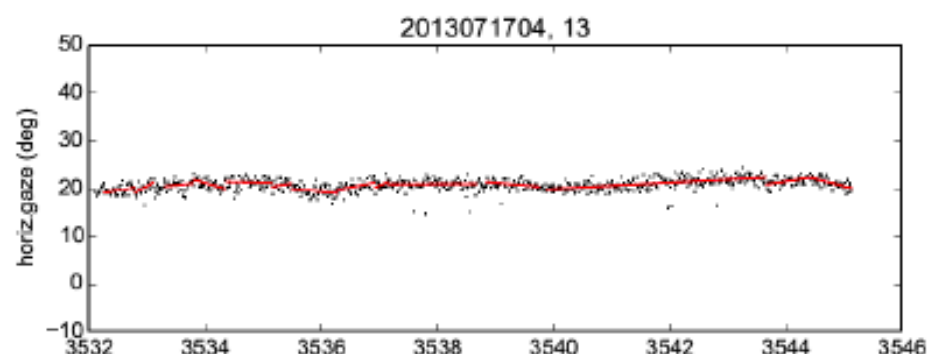
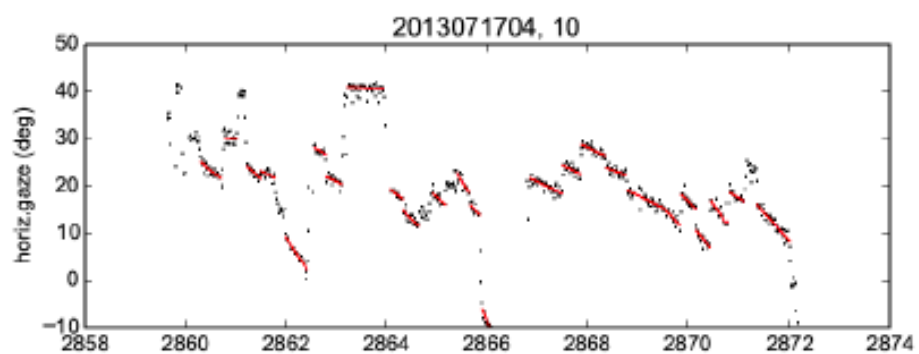
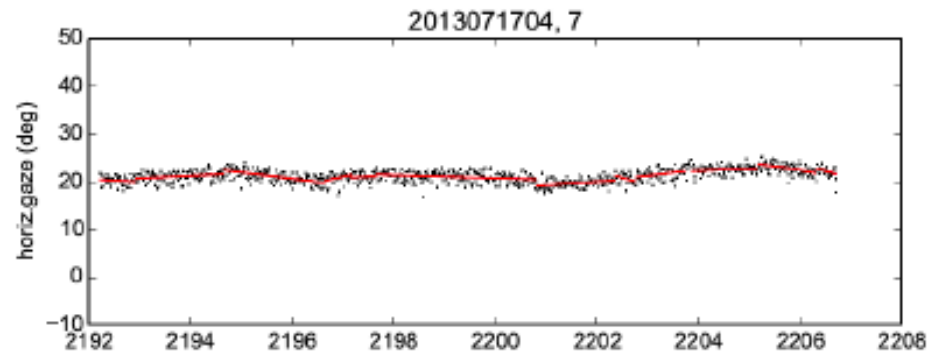
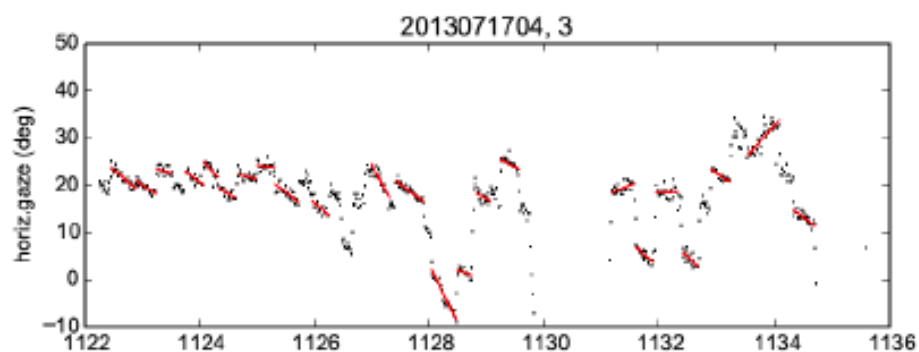
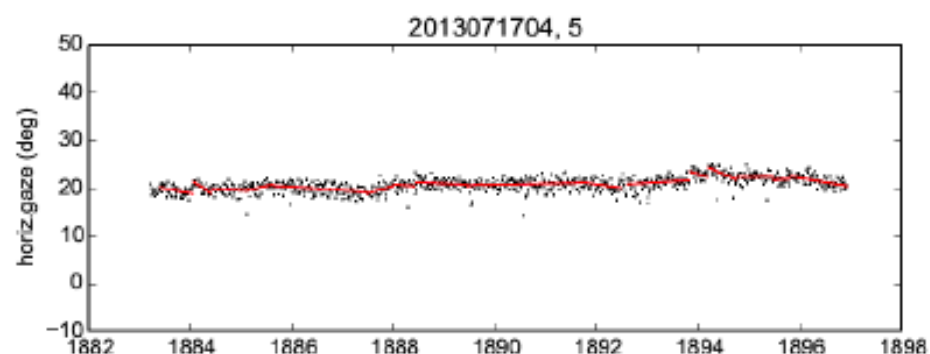
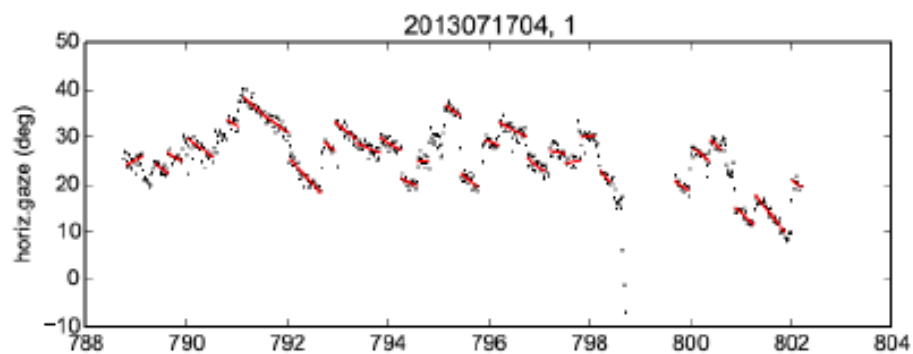


“Drive as you normally would”

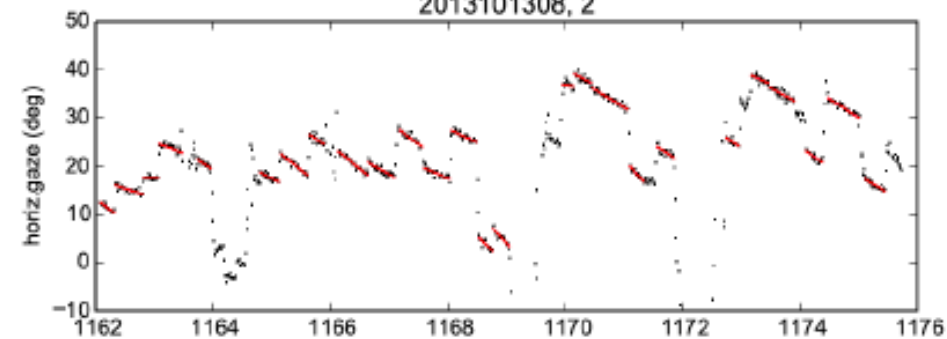


“Look at the tangent point”

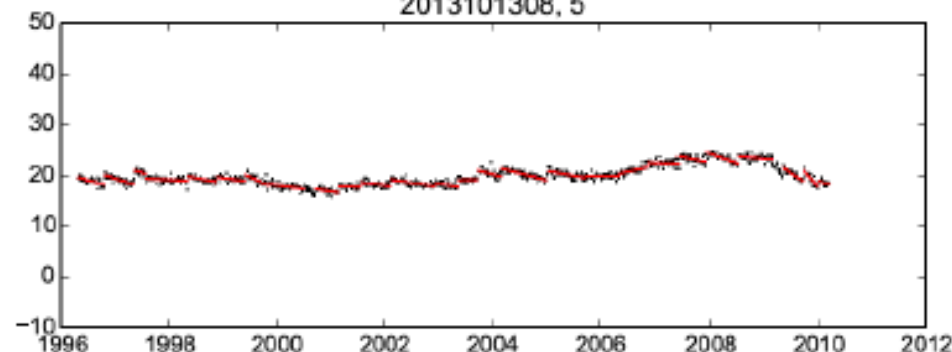




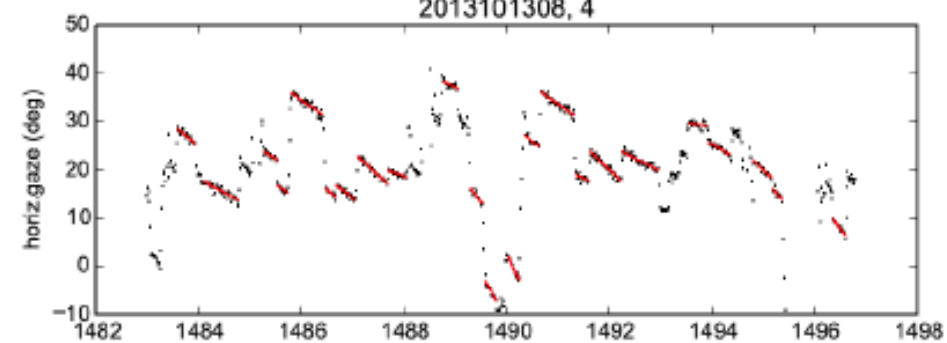
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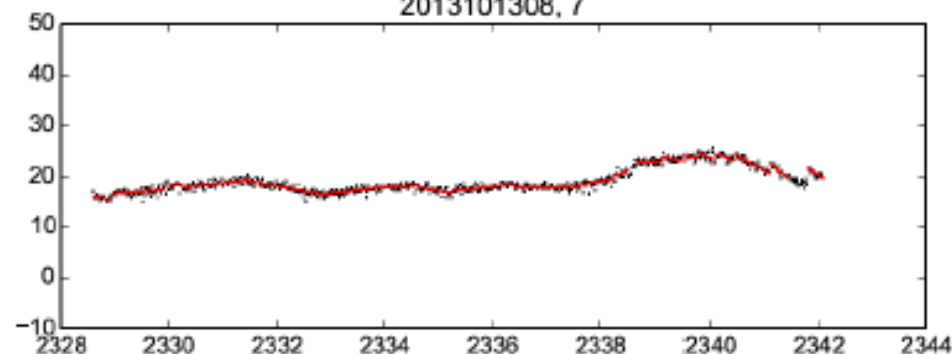
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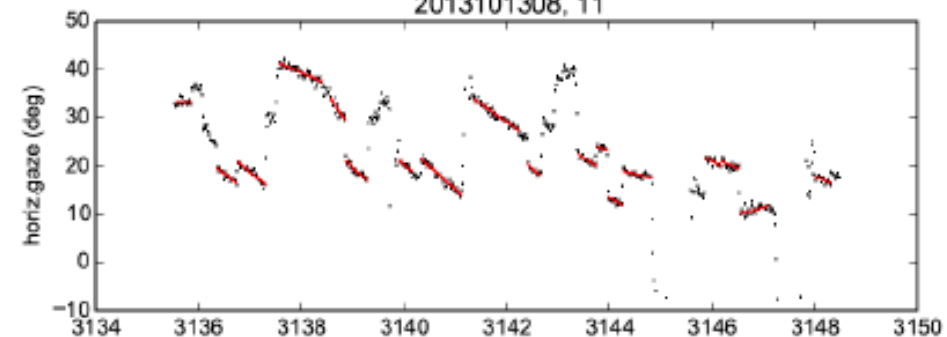
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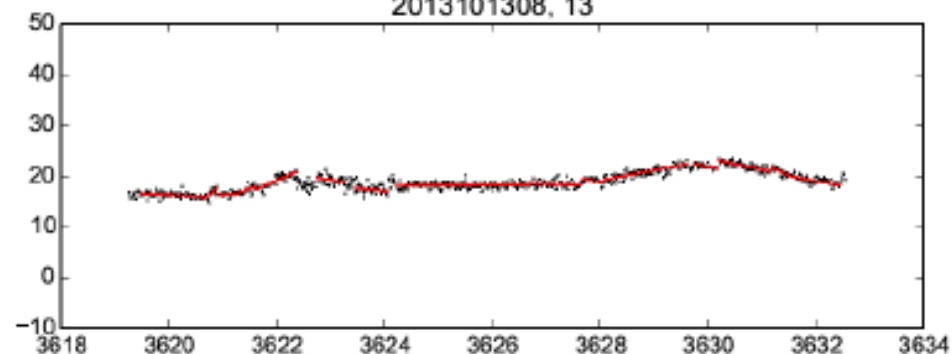
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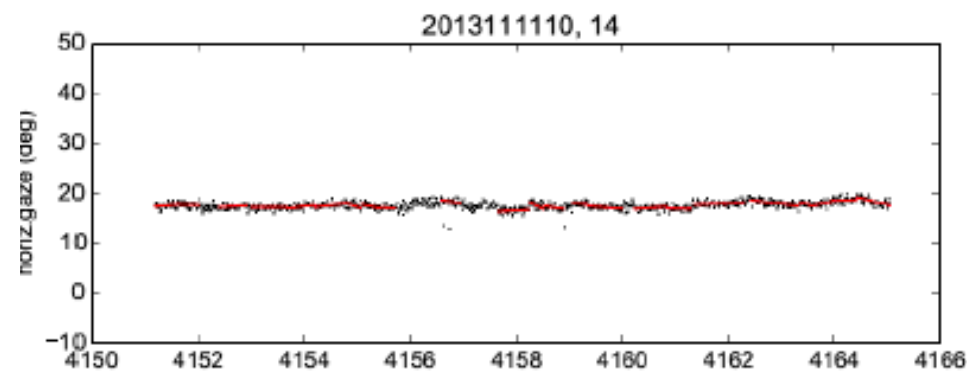
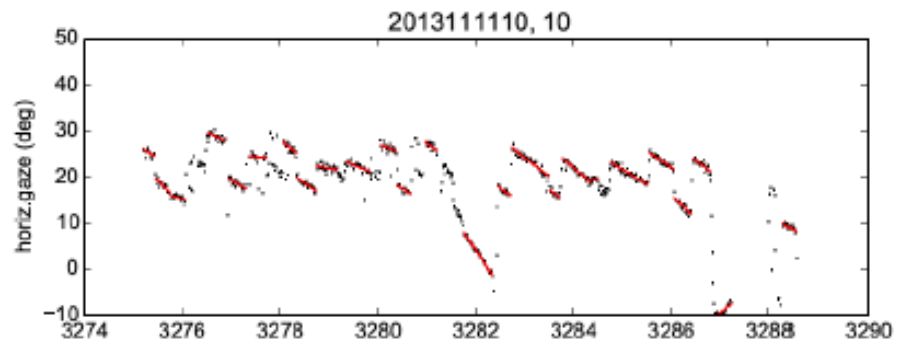
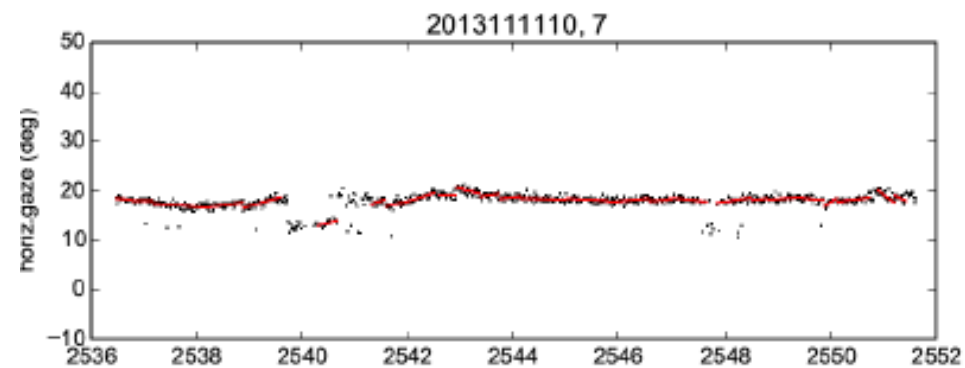
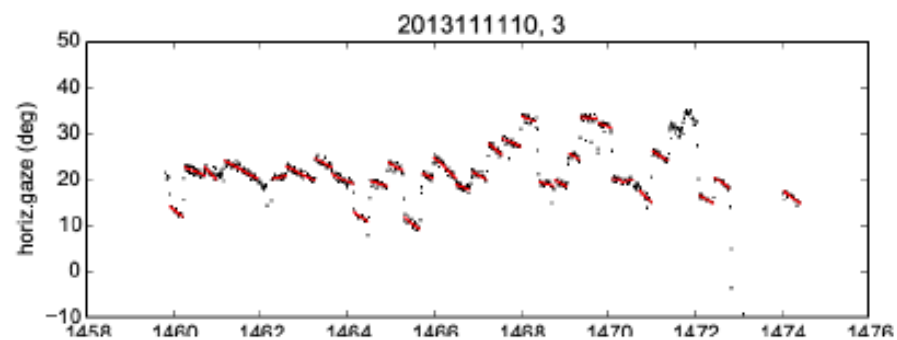
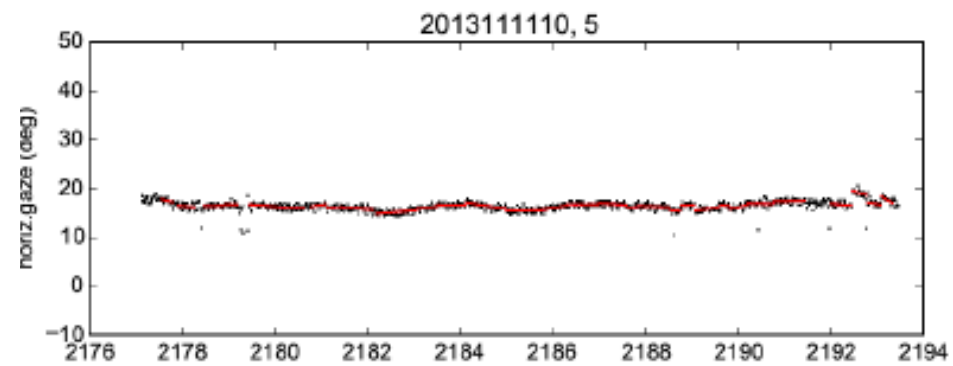
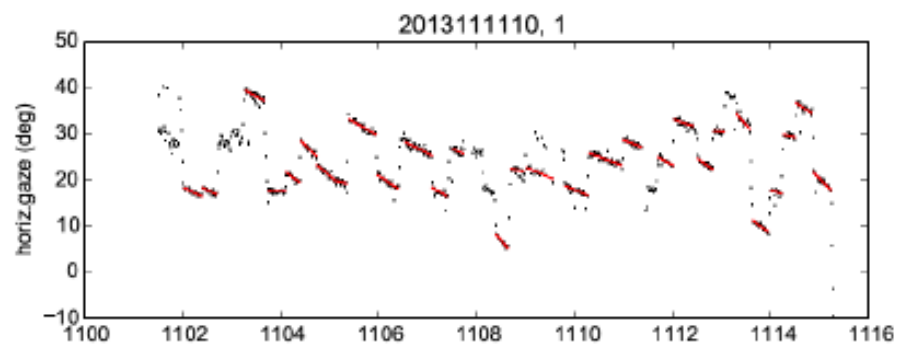


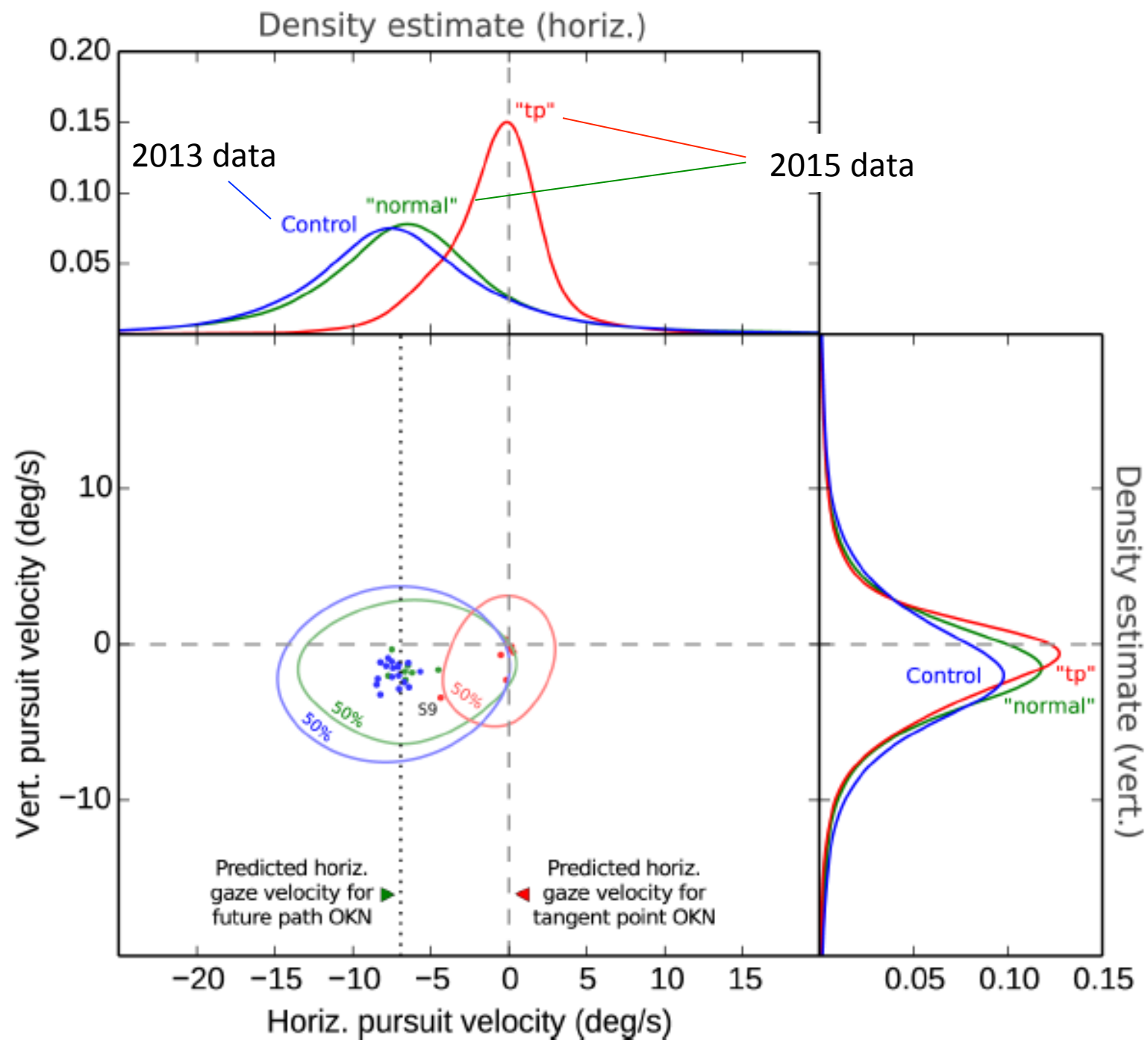
2013101308, 11



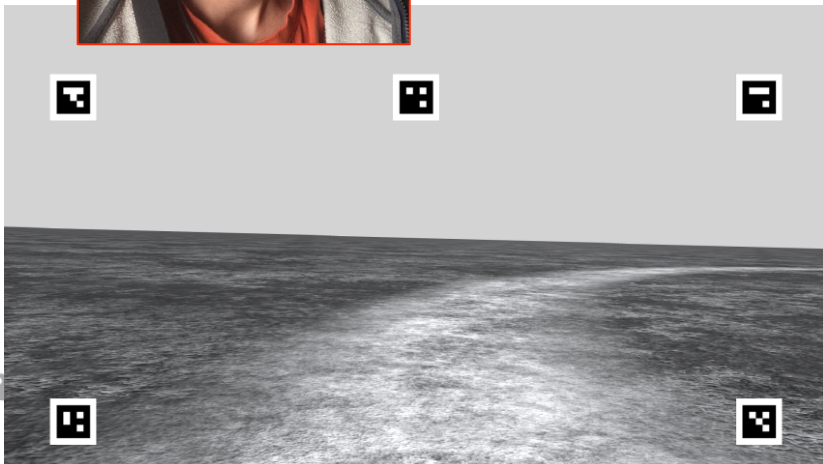
2013101308, 13







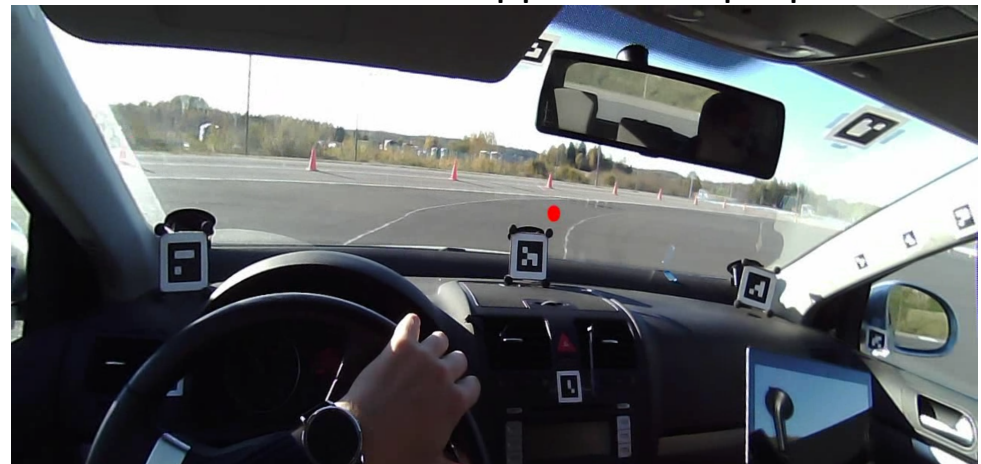
- **2016:** New head-mounted eye tracker
- Can be used in the sim and in real driving!

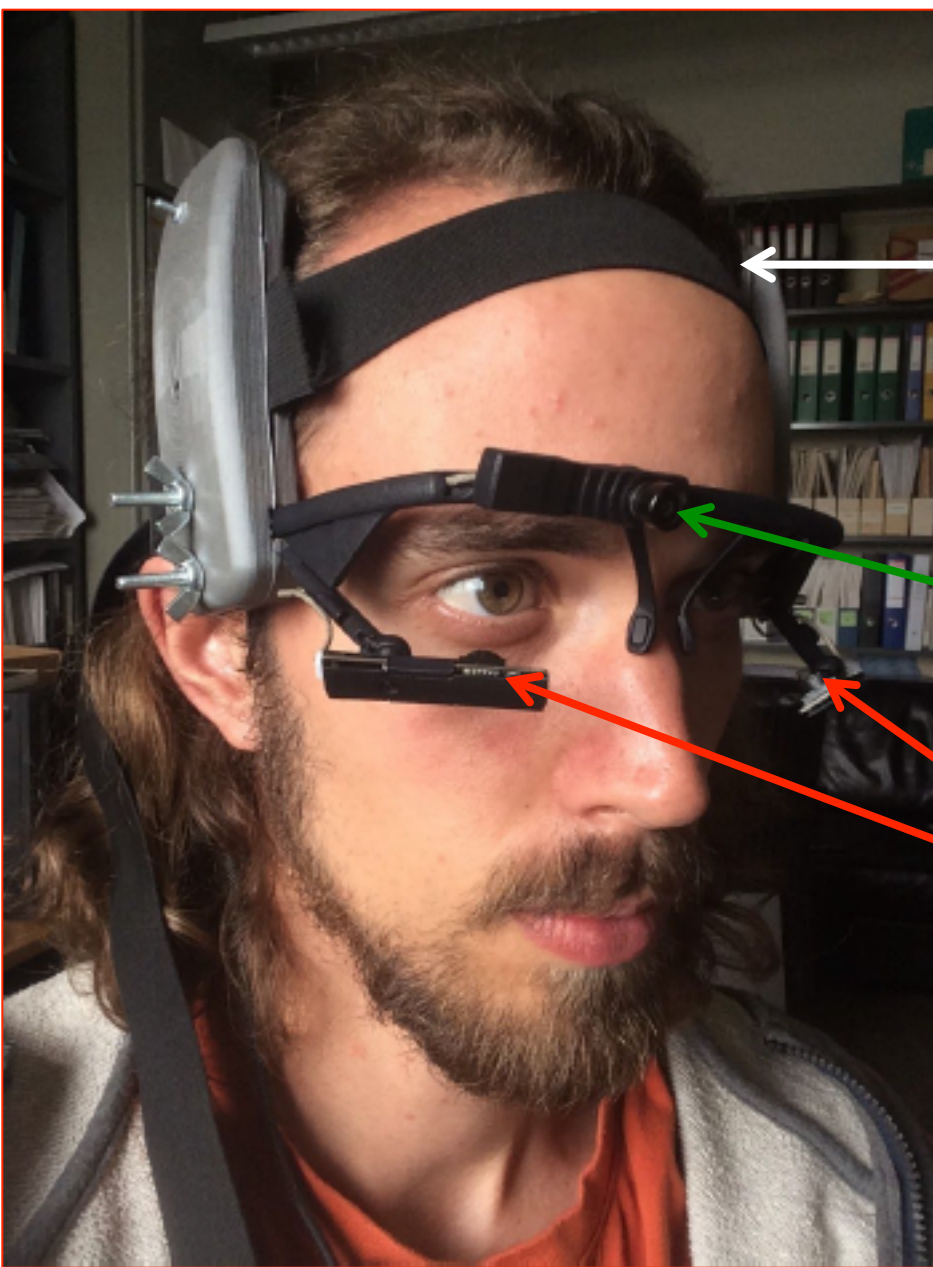


Tuhkanen et al. in preparation



Lappi et al. in preparation





Custom headband

Improve stability during longer measurement (parts CAD designed and 3D printed)

World camera

Eye cameras



Fieldwork: eye movements “in the wild”



<https://www.frontiersin.org/articles/10.3389/fpsyg.2017.00620/full>

https://figshare.com/articles/Supplementary_Movie_1_full_video_mp4/4498466

https://figshare.com/articles/Supplementary_Movie_2_17_21_31_r_mp4/4498613





“The simpler you make things, the more they can be understood”

- Jackie Stewart





Sim



Field

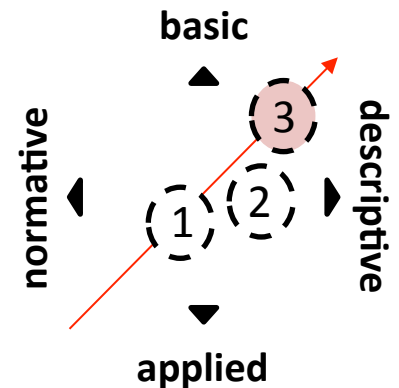
Coming out soon!



“The Big Picture”

So what?

“Driving - a **ubiquitous real-world task**, and in many ways an **attractive model system** of skilled visuomotor action”



Identify representative subtasks **Isolate** performance-relevant parameters **Infer** underlying mechanisms



Validate lab/simulator observations **Interpret** results in natural ecological context **Explain** by basic mechanisms

Constrain model assumptions by empirical data and theoretical insights gleaned from experiments

Neurocomputational model

Derive testable predictions that can be tested using multiple experimental techniques



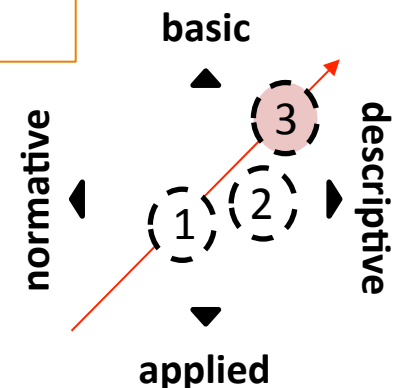
“The Big Picture”

On-road gaze targets:

- Do not travel with the observer (**fixed location**)
- **Anticipate** locomotion (fall on the “future path”)
- Have no obvious salient bottom-up features (**top-down** selection)

Emerging hypotheses:

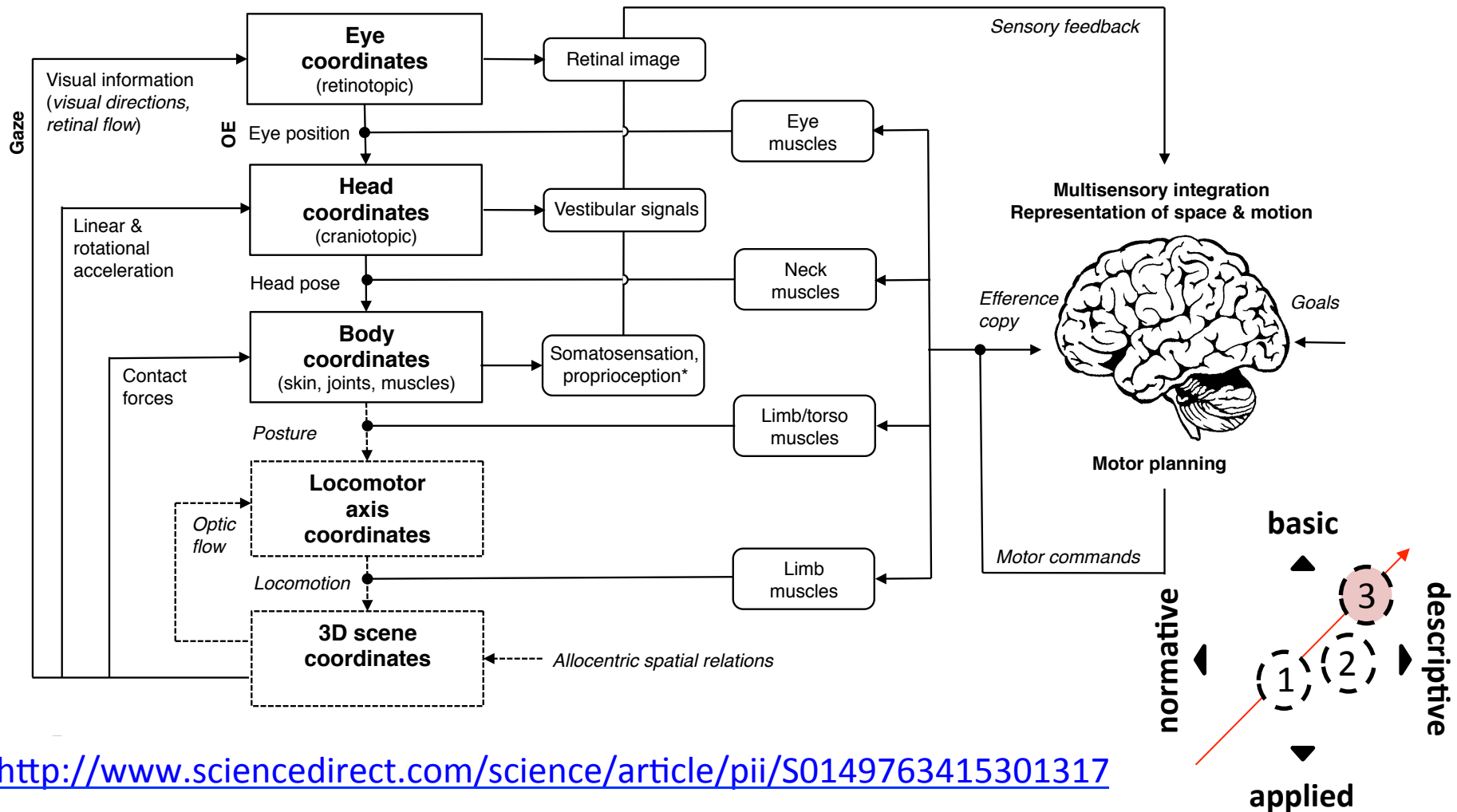
1. Locomotion uses multiple **waypoints** on the future path
2. Waypoints are **internally represented** in “psychological space”
3. Waypoints are the basis of **sequential motor planning**
4. These waypoints the **fixation targets** for steering-related eye movements as well as **locomotor targets**



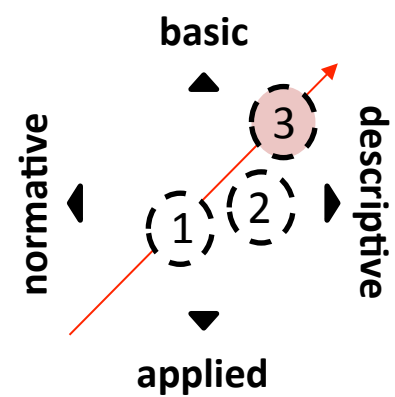
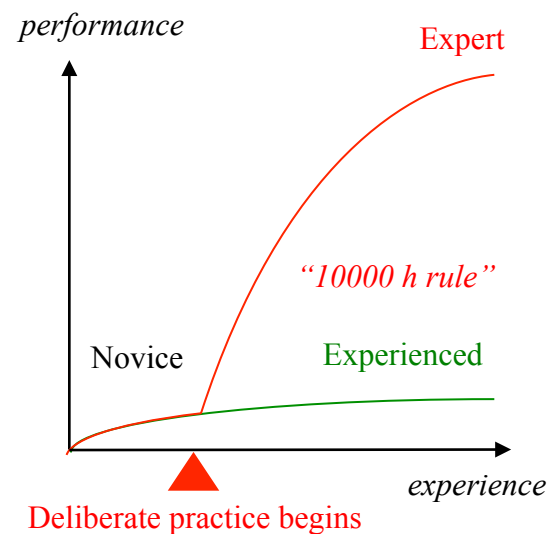
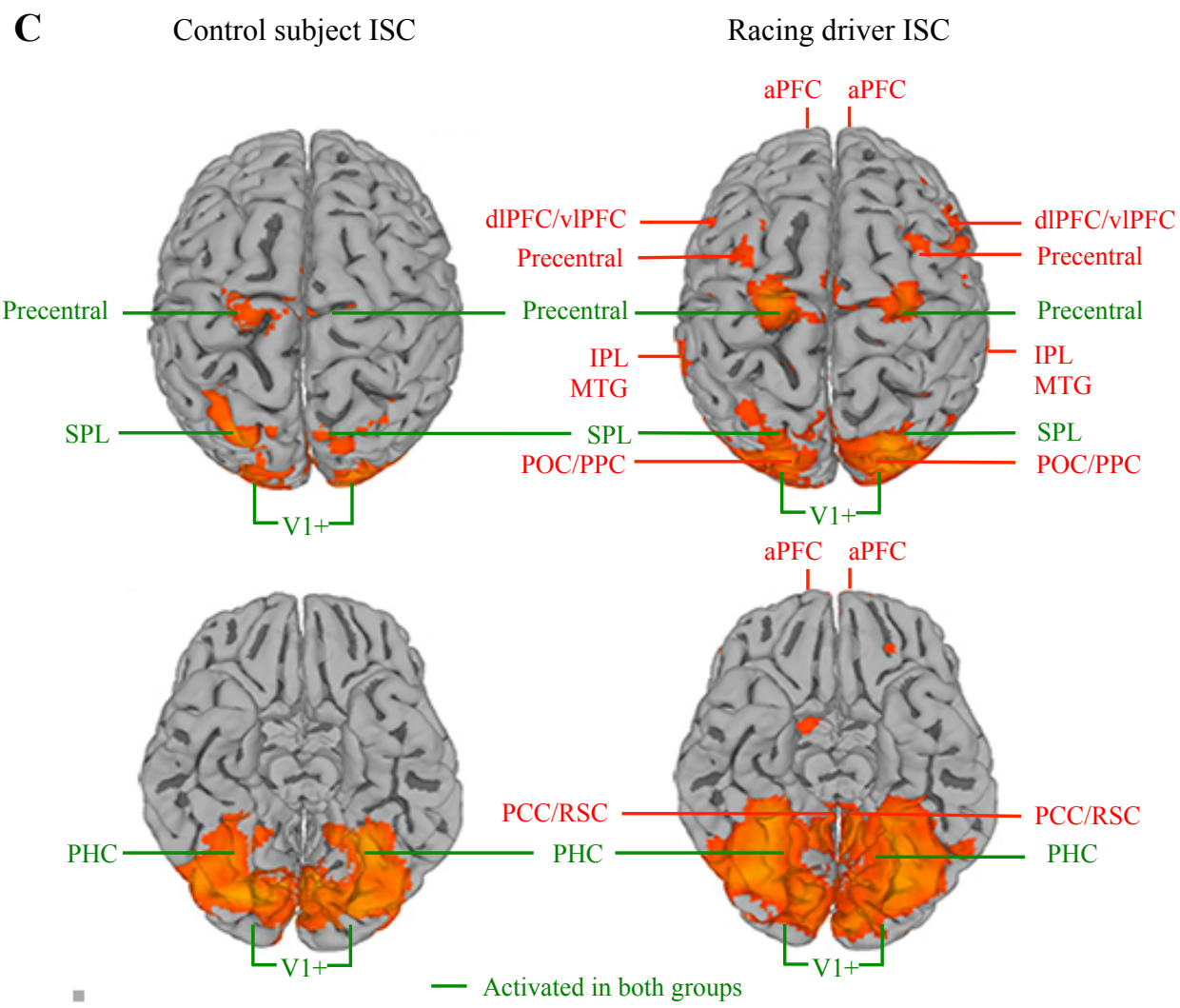
"The Big Picture"

3D FRAMES OF REFERENCE

SENSORIMOTOR TRANSFORMATIONS



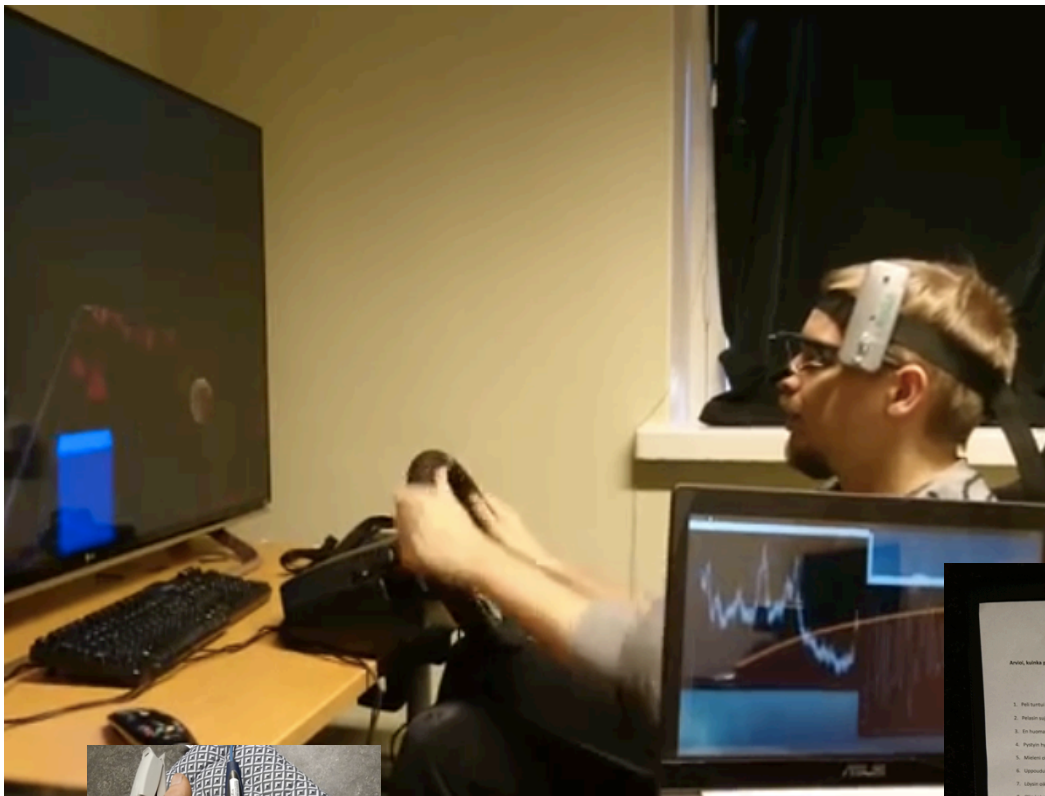
Next steps: Visual strategies and neural substrates of expert performance?



<https://www.frontiersin.org/articles/10.3389/fnhum.2015.00635/full>

Next steps: Visuomotor skill development?

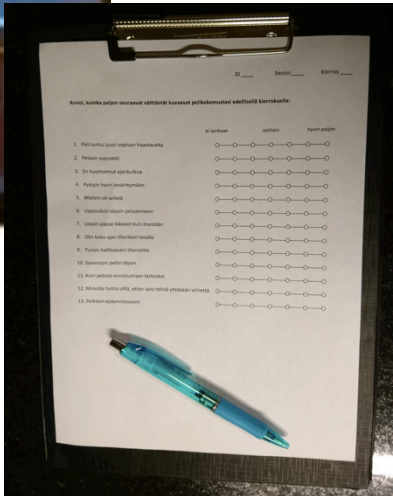
“Flow” in high performance cognition?



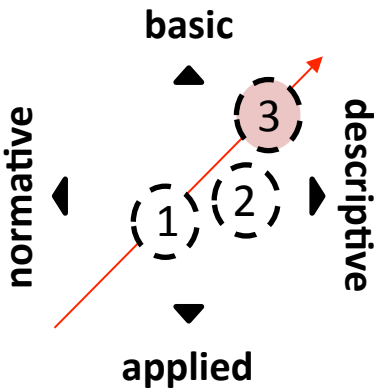
Eye tracking



Skin conductance and heart rate



Self report



normative

basic

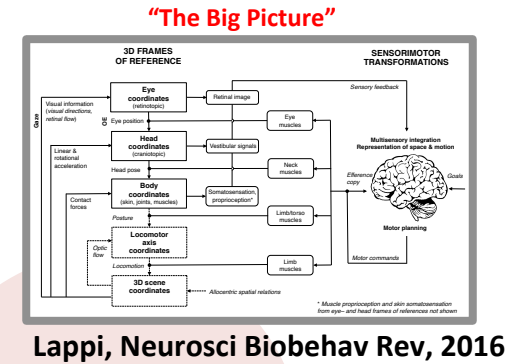
3

Lappi, Front Hum Neurosci, 2015

Sports
Physiology &
psychology

Lappi, JOV, 2014

Expert
performance

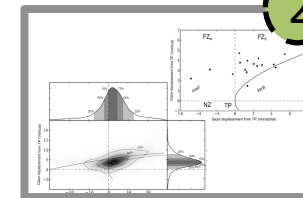


Brain
Research

Lappi, Rinkkala & Pekkanen (in review)

descriptive

2



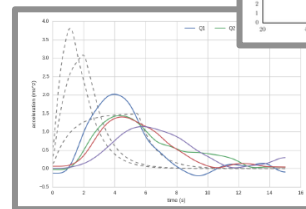
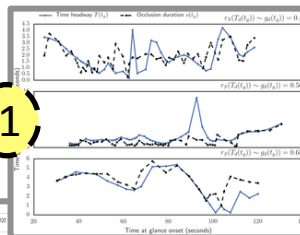
Lappi et al., 2013; Lehtonen et al., 2013/2014
Lappi, Pekkanen & Itkonen, PLOS ONE 2013
Itkonen et al. PLOS ONE 2015

Traffic
engineering

applied

Pekkanen et al PLOS ONE 2017
Itkonen et al (submitted)

1



Traffic
psychology

