



Virtual Driving with Different Motion Characteristics

Braking Manoeuvre Analysis and Validation

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Agenda

- The DLR Dynamic Simulator
- Experiment Design
- Experiment Results
 - Analysing Parameter Effects
 - Analysing Speed Zone Effects
- Conclusion and Future Tasks



The DLR Dynamic Simulator



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The Simulator



Simulator Facts

➤ Motion Capabilities

	Position	Acceleration		Position	Acceleration
Surge	±1,5 m	±10 m/s ²	Roll	±21 °	±250 °/s ²
Sway	±1,4 m	±10 m/s ²	Pitch	±21 °	±250 °/s ²
Heave	±1,4 m	±10 m/s ²	Yaw	±21 °	±250 °/s ²

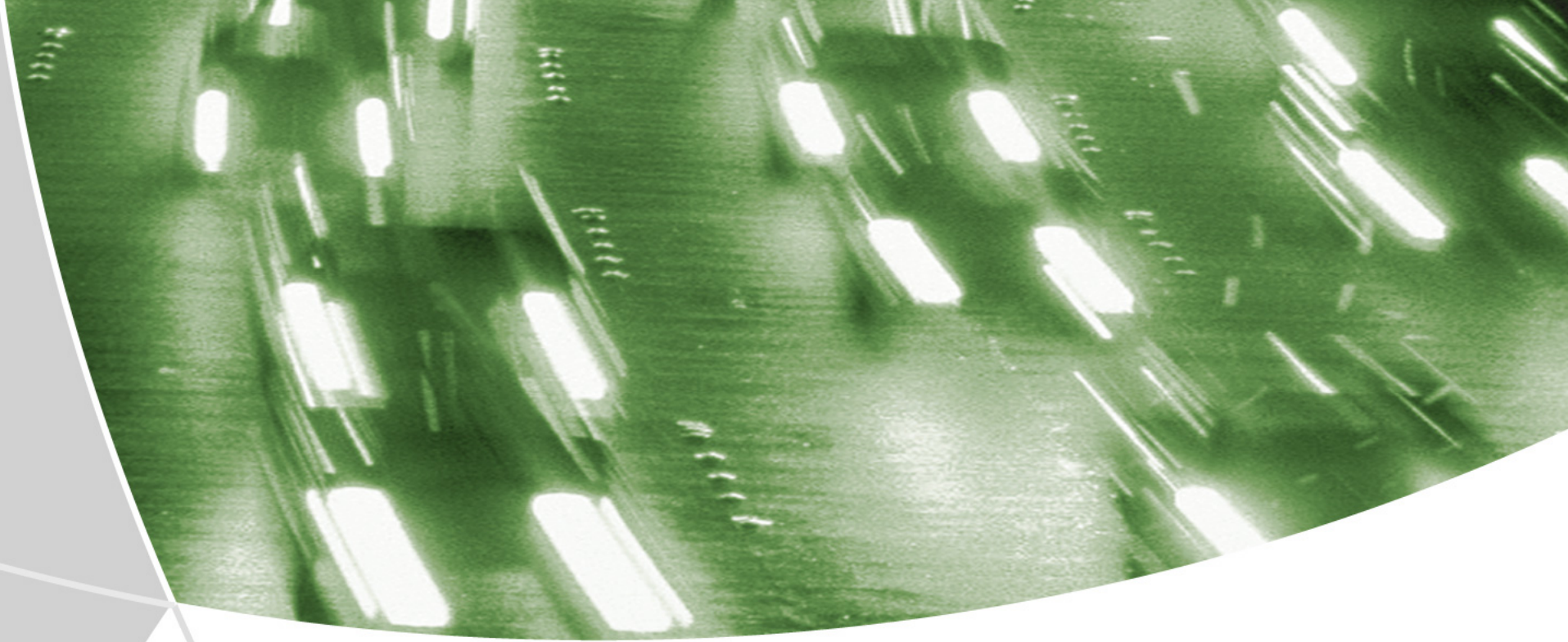
➤ Full cockpit

- force feedback steering
- active brake pedal

➤ Visual system

- 270° x 40° field of view
- TFT-displays in outside mirrors
- Large LCD-screen on backseat as rear view mirror

➤ ...



Experiment Design

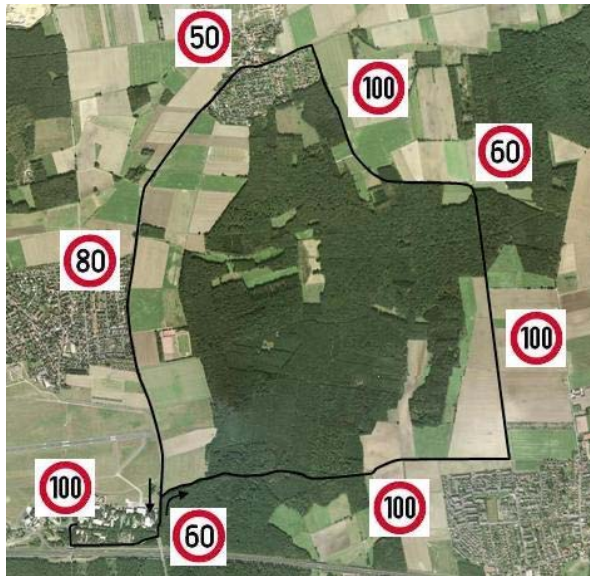


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Experiment Design

Track S1, S3 and R

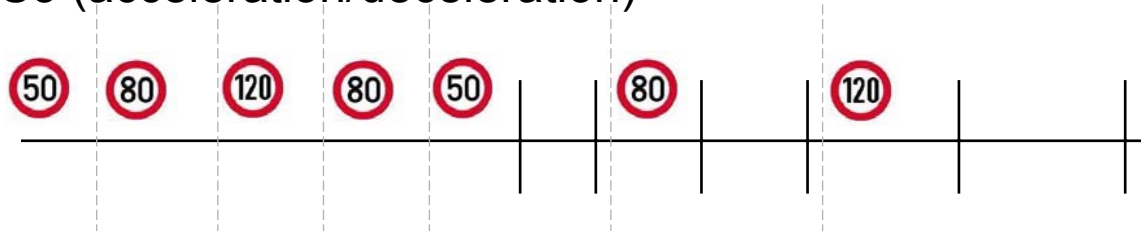
➤ S1 (virtual) vs. R (real)



➤ 12 Subjects

- 8 male, 4 female
- aged 25 – 50
- average driving experience

➤ S3 (acceleration/deceleration)



Experiment Design

Parameter Variation

➤ Acceleration vector for different manoeuvres

➤ Curve driving:

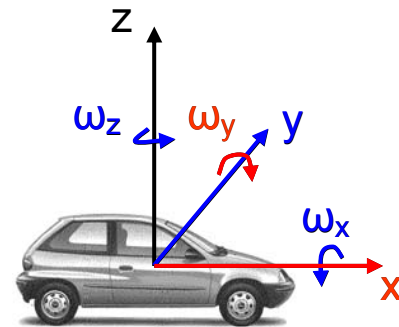
$$a_y, \omega_x, \omega_z$$

➤ Braking:

$$a_x, \omega_y$$

$$\bar{a} = \begin{bmatrix} a_x \\ a_y \\ a_z \end{bmatrix}$$

$$\bar{\omega} = \begin{bmatrix} \omega_x \\ \omega_y \\ \omega_z \end{bmatrix}$$



➤ Here: no common components (DoF).

⇒ Different parameters for tuning

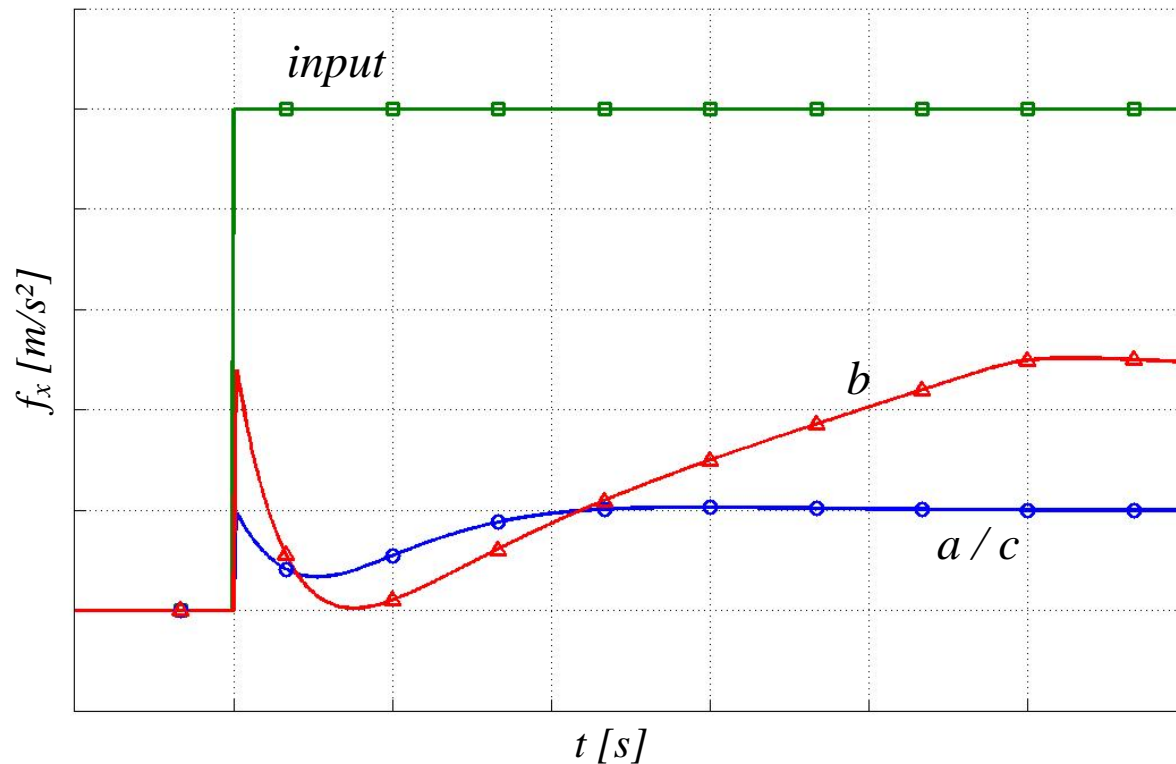
<i>Manoeuvre</i>	<i>Parameter Set-up</i>		
	a	b	c
Curve Driving			
Braking			

**hypothesis:
b is bad for
braking**

Experiment Design

Effect of Parameter Sets II

➤ Set a and c vs. b – step input response (f_x)





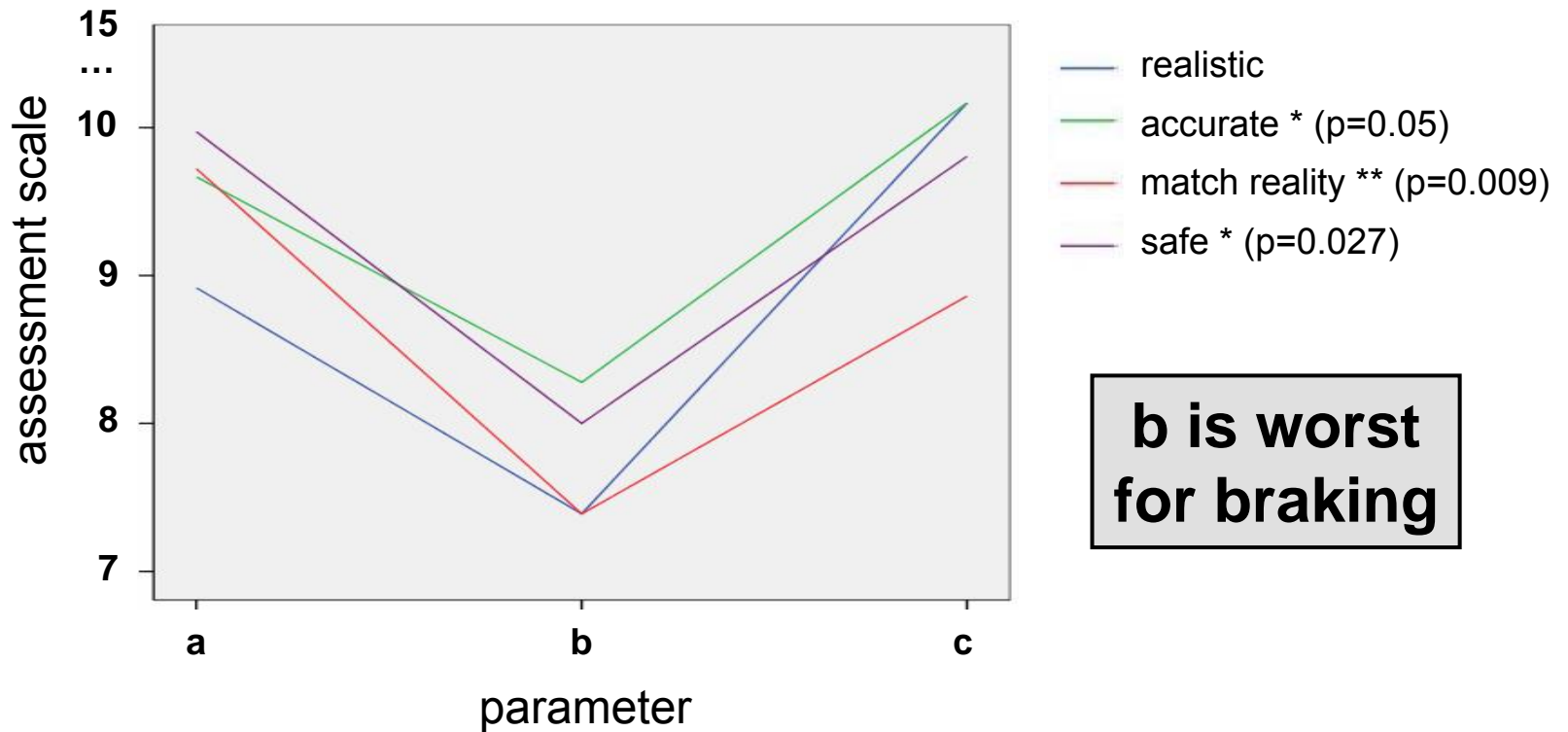
Experiment Results I

Analysing Parameter Effects



Experiment Results

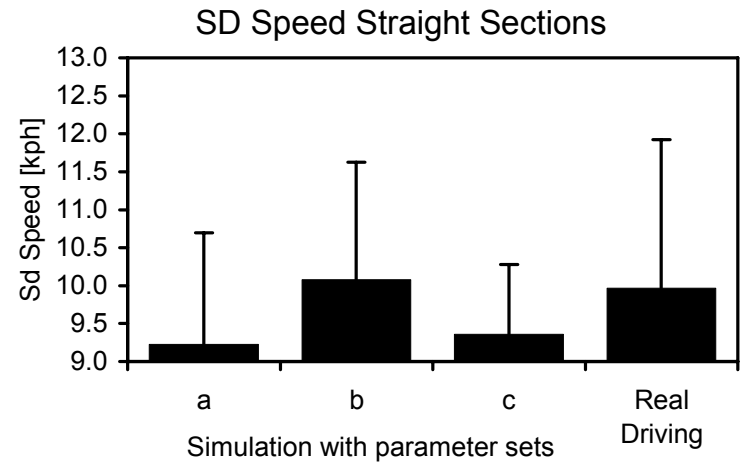
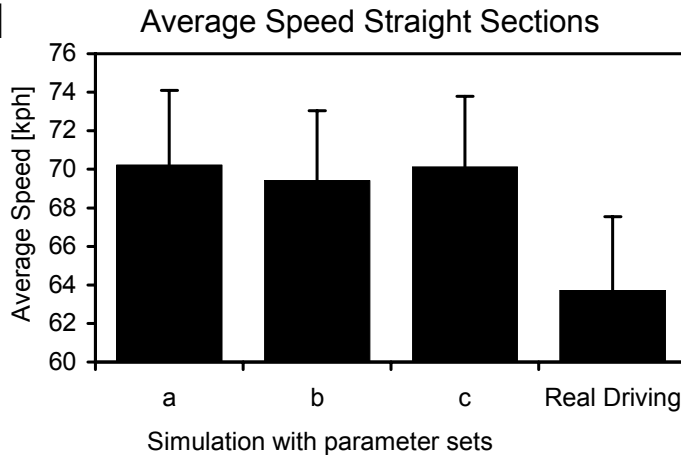
Braking – main effect parameter



Experiment Results

Track Statistics

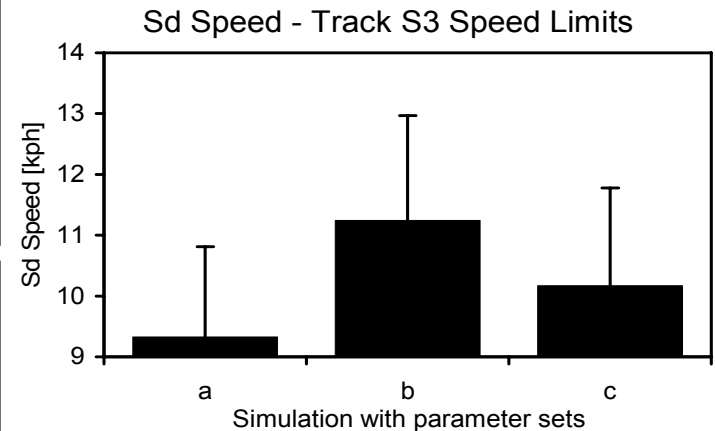
➤ S1



➤ S3

in virtual driving speed is underestimated

b leads to more speed changes



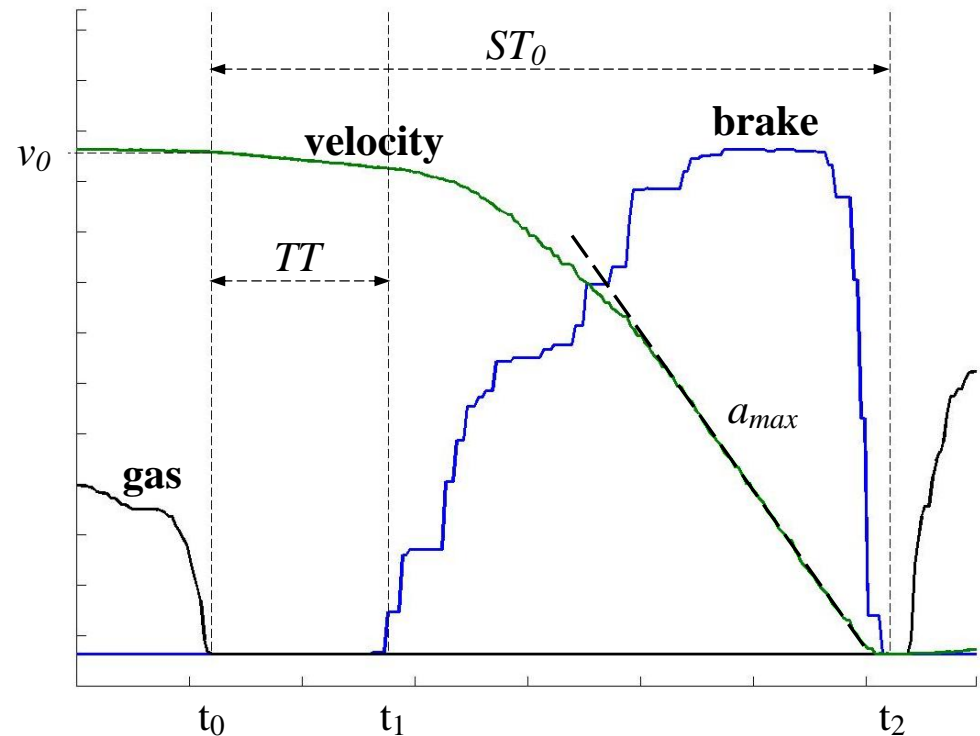
Braking Manoeuvres

Characteristic Values

- t_0 – foot off gas
- t_1 – foot on brake
- t_2 – car stopped

at t_0 and t_1

- v – velocity
- ST – stopping time
- SD – stopping distance
- TTC – time to collision
- TT – transition time
- a_{max} – maximum deceleration



Braking Manoeuvres

Analytic Method

- Analysis of Variance (ANOVA)

- S3/S1 vs. a/b/c

- T-Test

- S1a vs. R

- S1b vs. R

- S1c vs. R

- S3a vs. R

- S3b vs. R

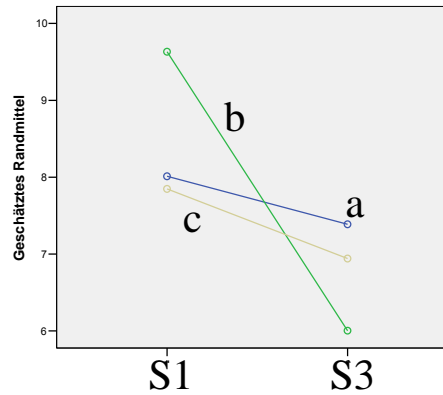
- S3c vs. R

Braking Manoeuvres

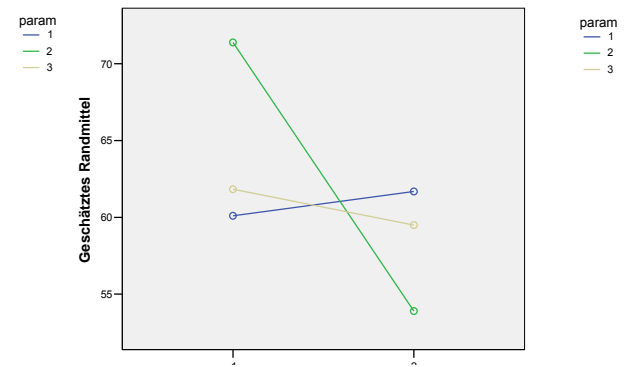
Analysis of Variance (ANOVA)

	track	track* parameter
V_0	.060	.134
→ ST_0	.008	.008
→ SD_0	.120	.046
→ TTC_0	.074	.203
TT	.424	.160
→ a_{max}	.000	.000

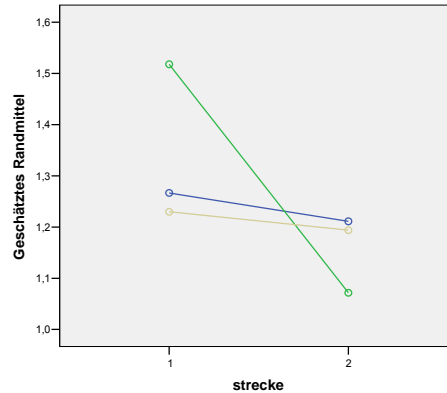
ST₀ Geschätztes Randmittel von MEASURE_1



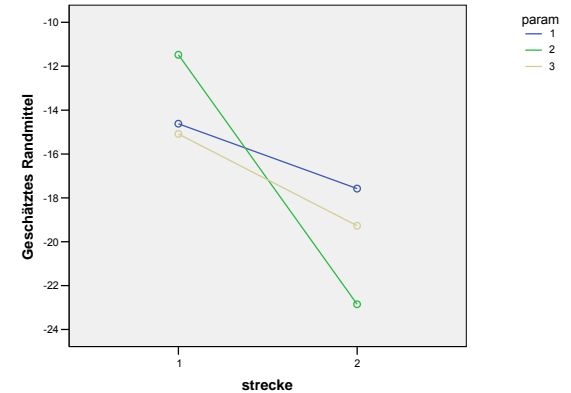
SD₀ Geschätztes Randmittel von MEASURE_1



TTC₀ Geschätztes Randmittel von MEASURE_1

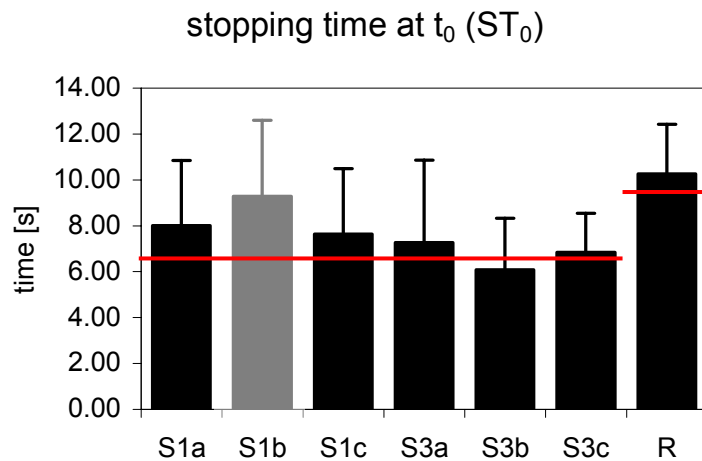
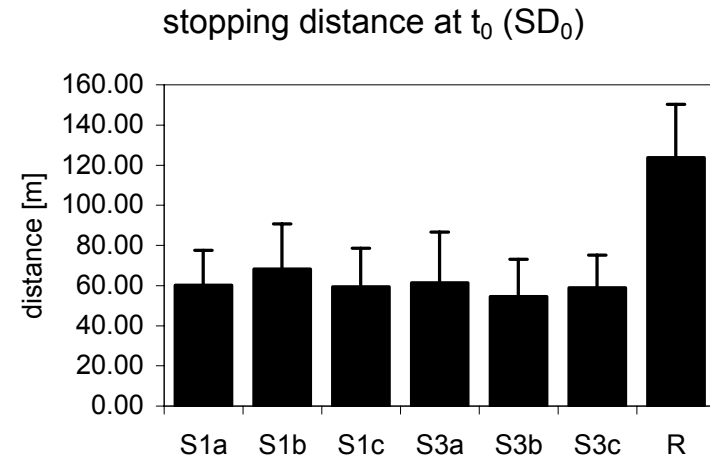
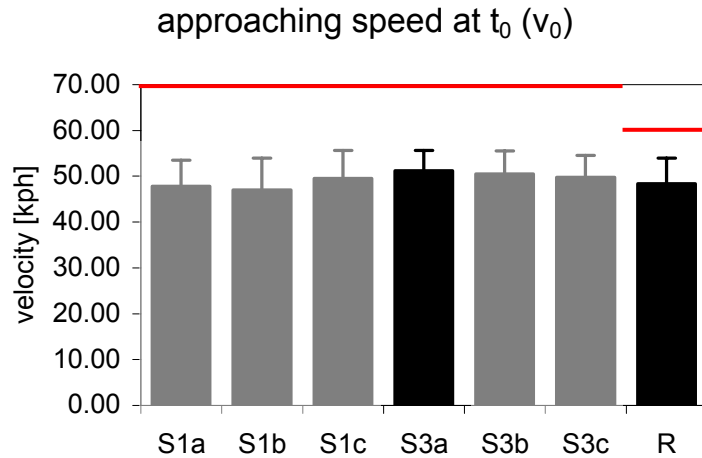


a_{max} Geschätztes Randmittel von MEASURE_1

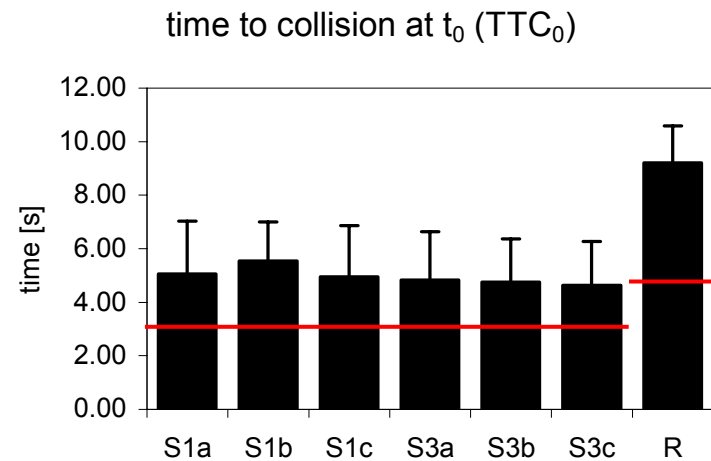


Braking Manoeuvres

Mean Values and T-Test Results I

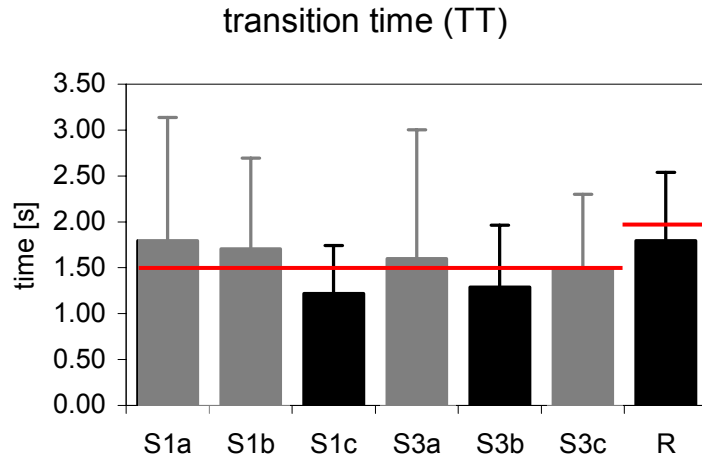


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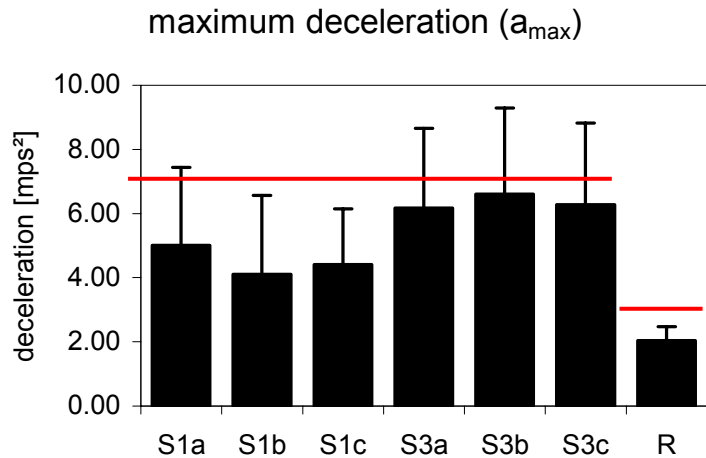


Braking Manoeuvres

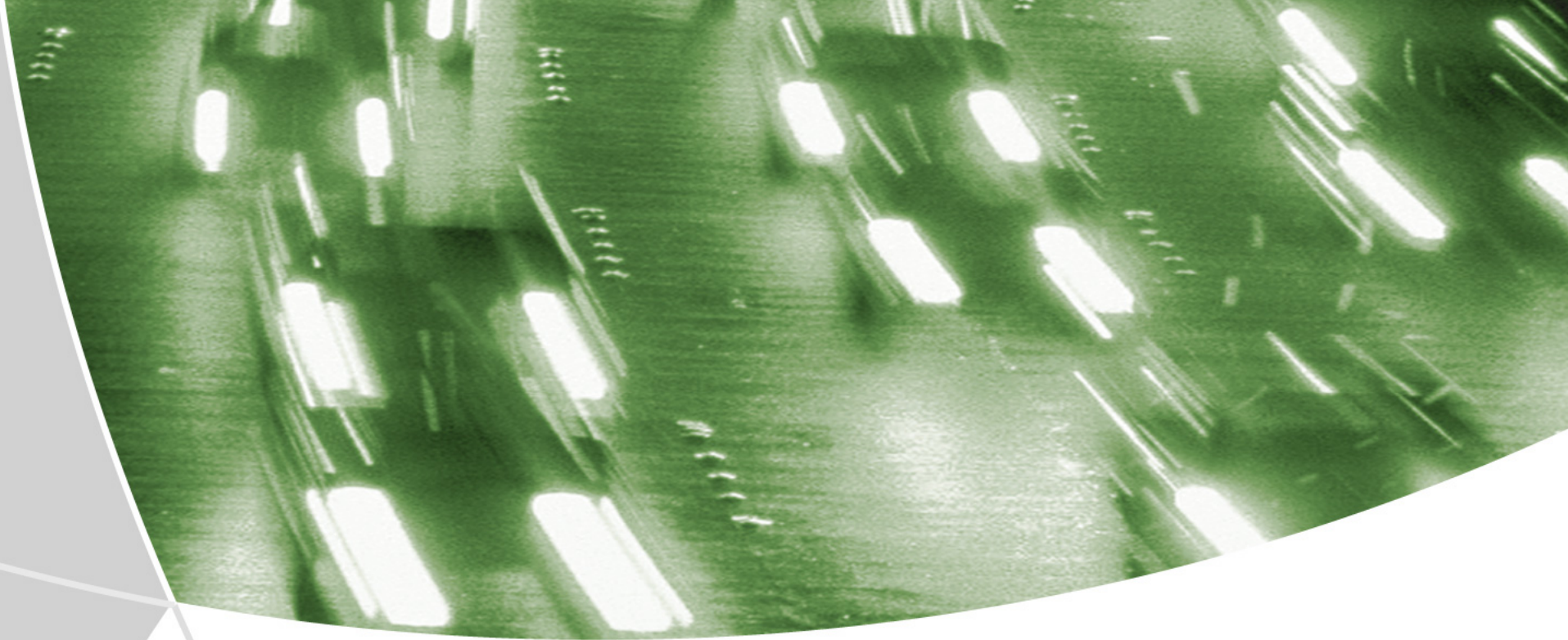
Mean Values and T-Test Results II



underestimation of speed
+
overestimation of distance
=
overestimation of TTC



overestimated TTC leads to significantly higher maximum deceleration



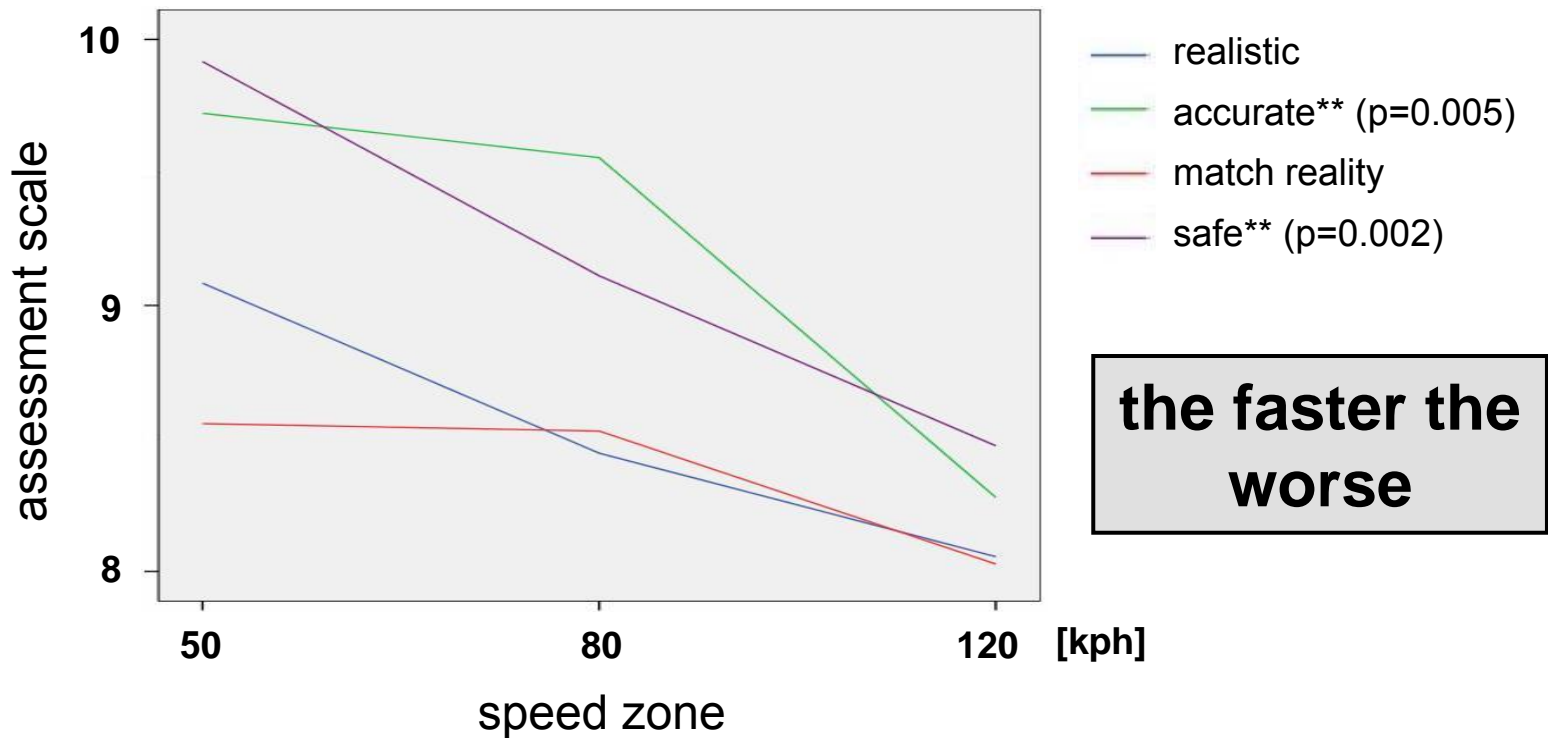
Experiment Results II

Analysing Speed Zone Effects



Experiment Results II

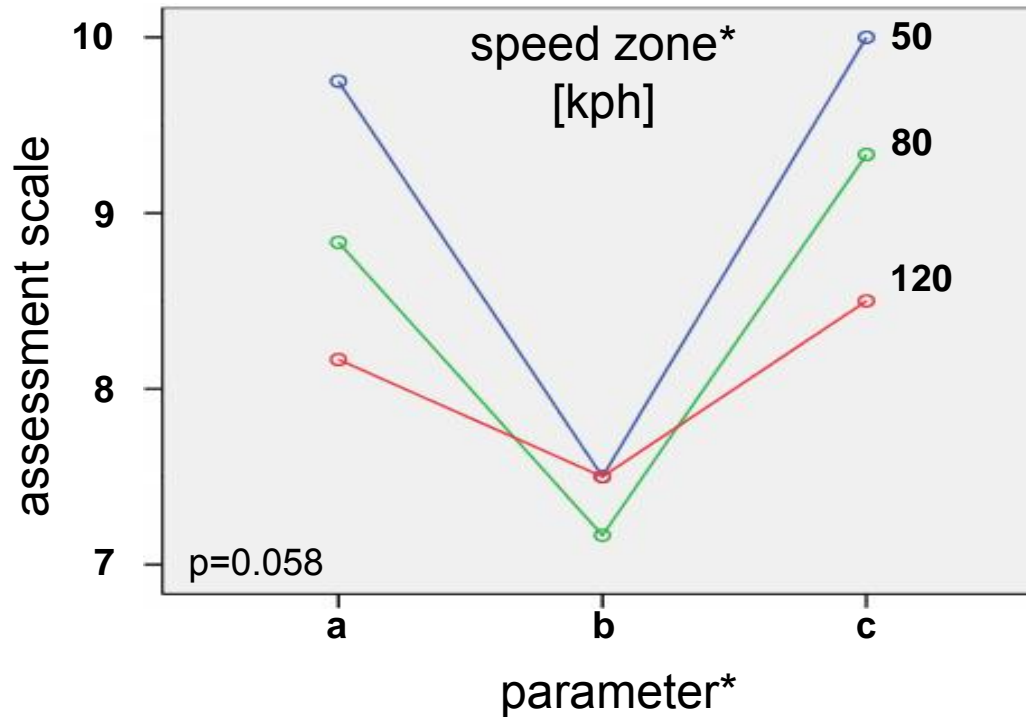
Braking (S3) – main effect speed zone



Experiment Results II

Braking (S3) – interaction effect parameter-speed zone

How realistic is the feeling of driving?

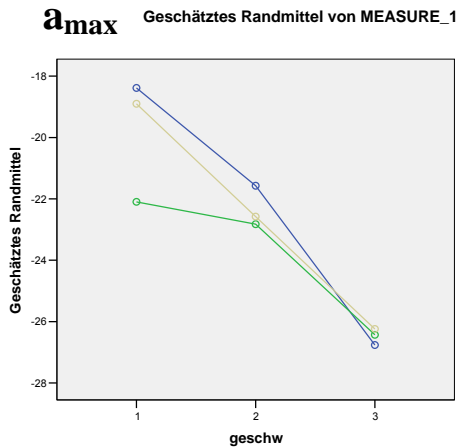
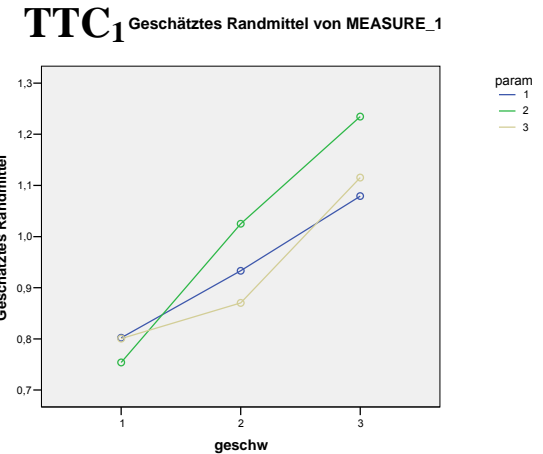
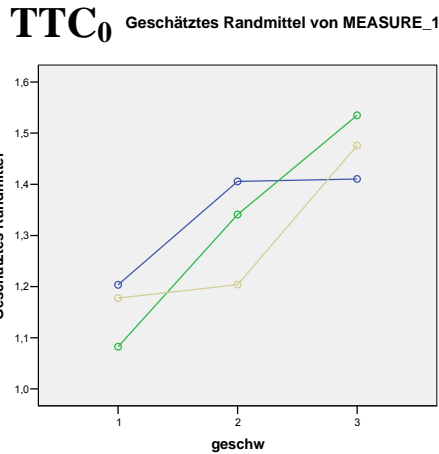
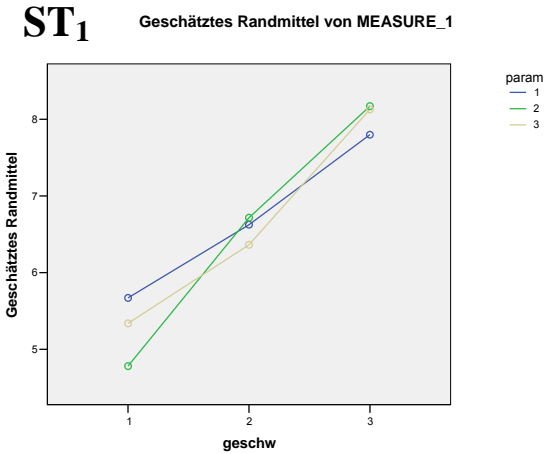
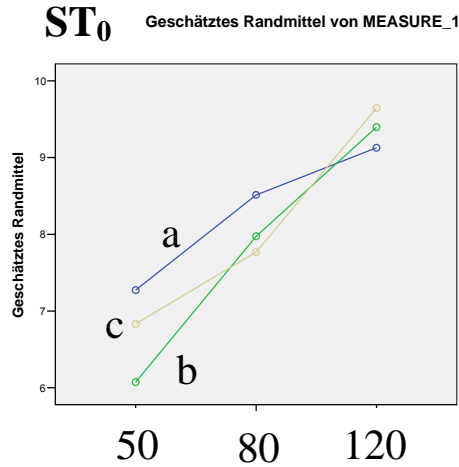


b is equally worse for all driving speeds

Experiment Results II

Analysis of Variance (ANOVA)

	speed	parameter
→ ST ₀	.000	.631
→ ST ₁	.000	.936
→ TTC ₀	.000	.797
→ TTC ₁	.000	.294
→ TT	.725	.271
→ a _{max}	.000	.598





Conclusion & Future Tasks





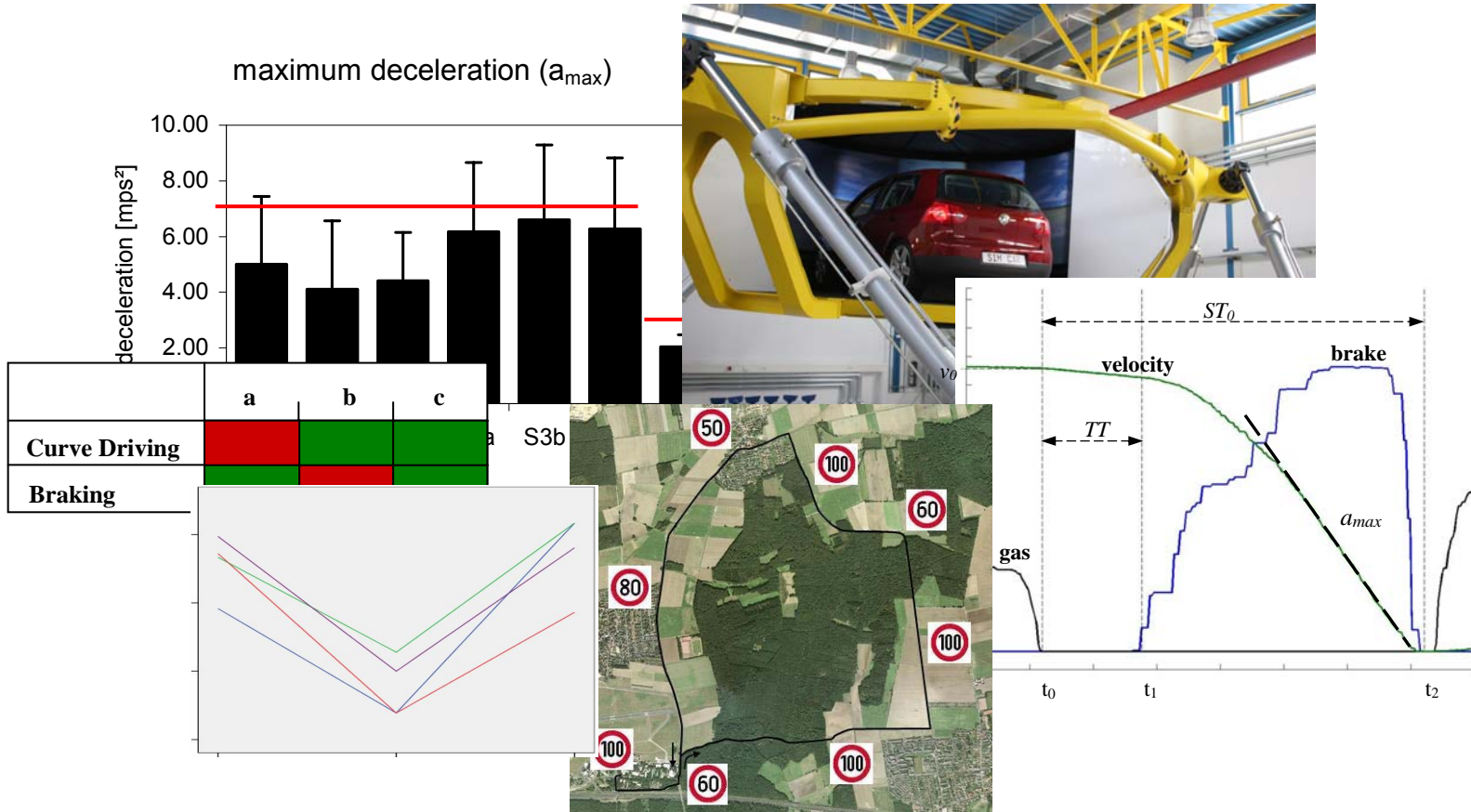
Conclusion

- Estimation of speed, distance and TTC is difficult in virtual driving
- Subjective ratings and objective driving data analysis results correspond
- Driving behaviour in simulators is repeatable
- Systematically varying speed is not essential for tuning the motion

Future Tasks

- Manoeuvre dependant tuning
 - with experts and normal drivers
 - different manoeuvre (braking, curving, cornering, lane change, ...)
- Adaptive Motion Cueing Algorithm
 - Time variant motion parameters (manoeuvre dependant)
- Manoeuvre prediction

Questions?



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