



# Virtual Driving with Different Motion Characteristics

## Braking Manoeuvre Analysis and Validation

DSC Europe 06, 04.10.06

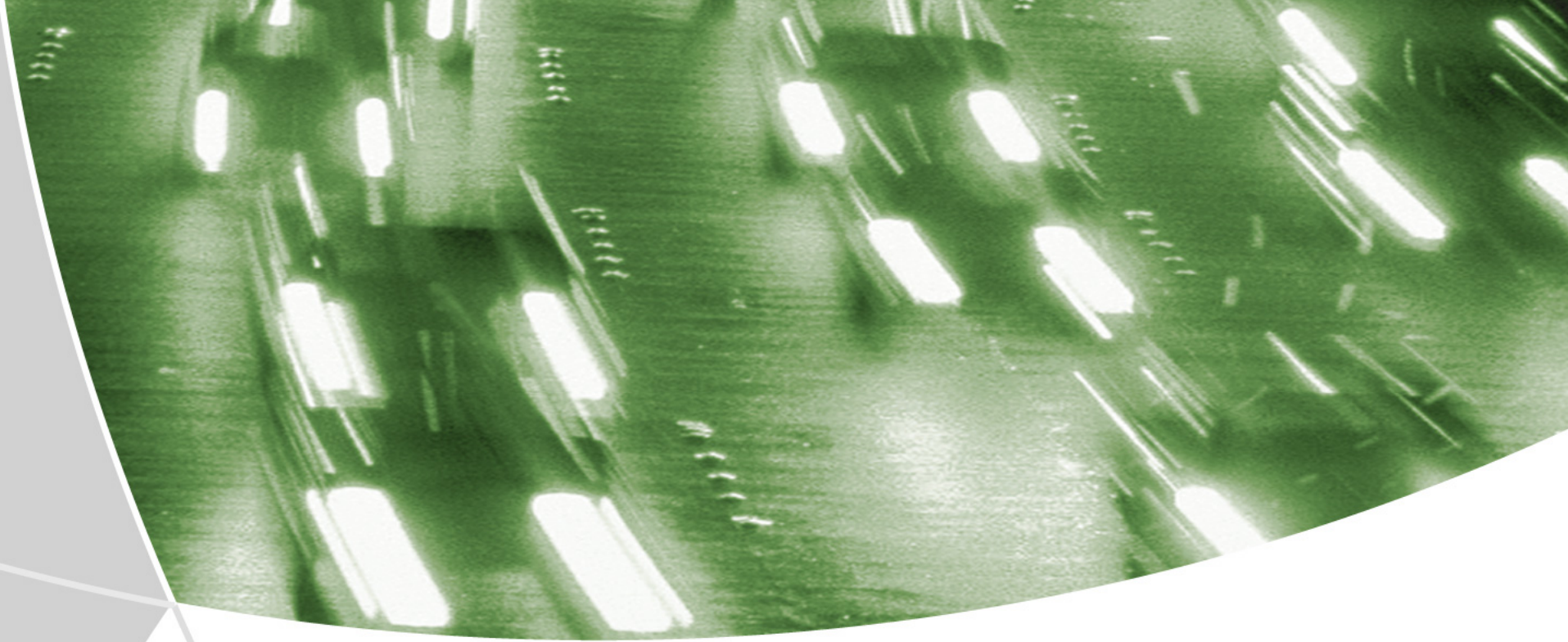
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Deutsches Zentrum  
für Luft- und Raumfahrt e.V.  
in der Helmholtz-Gemeinschaft

# 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

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

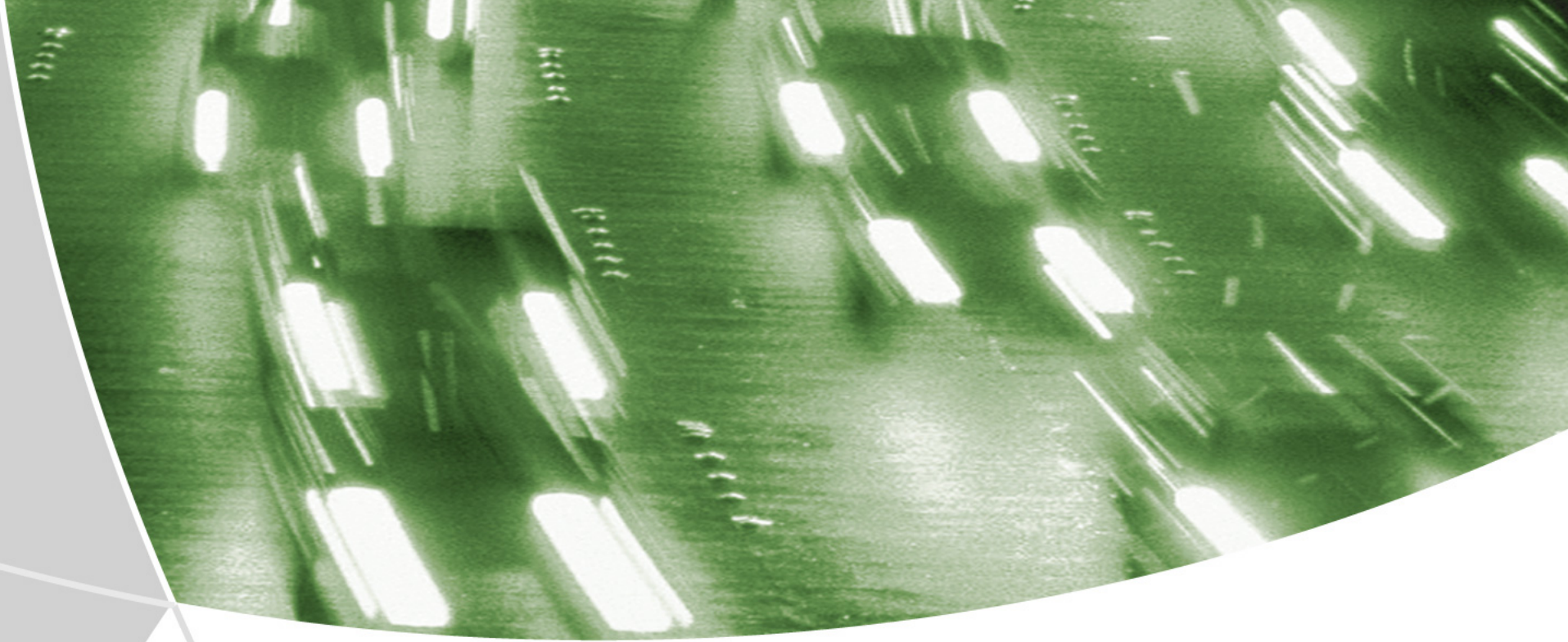
## ➤ Full cockpit

- 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

## ➤ ...



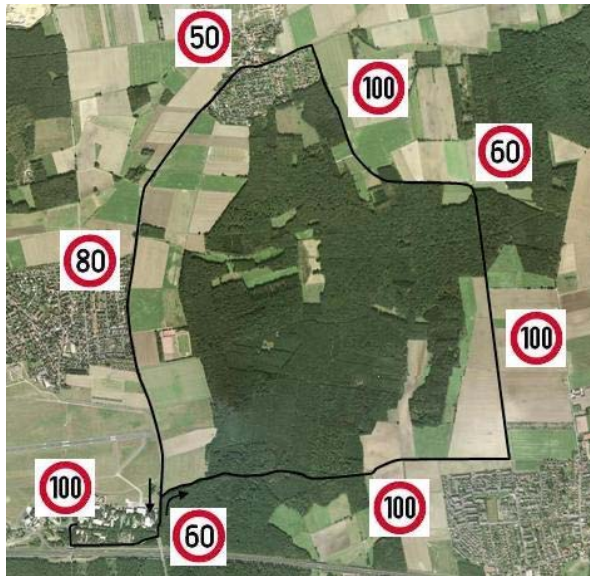
# Experiment Design



# Experiment Design

## Track S1, S3 and R

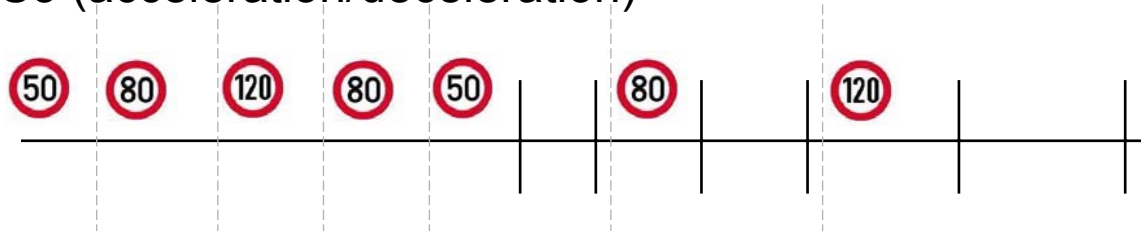
➤ S1 (virtual) vs. R (real)



➤ 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:

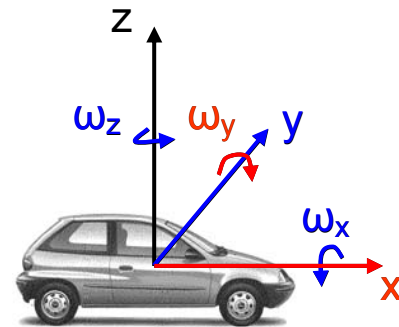
$$a_y, \omega_x, \omega_z$$

➤ 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
<b>Curve Driving</b>			
<b>Braking</b>			

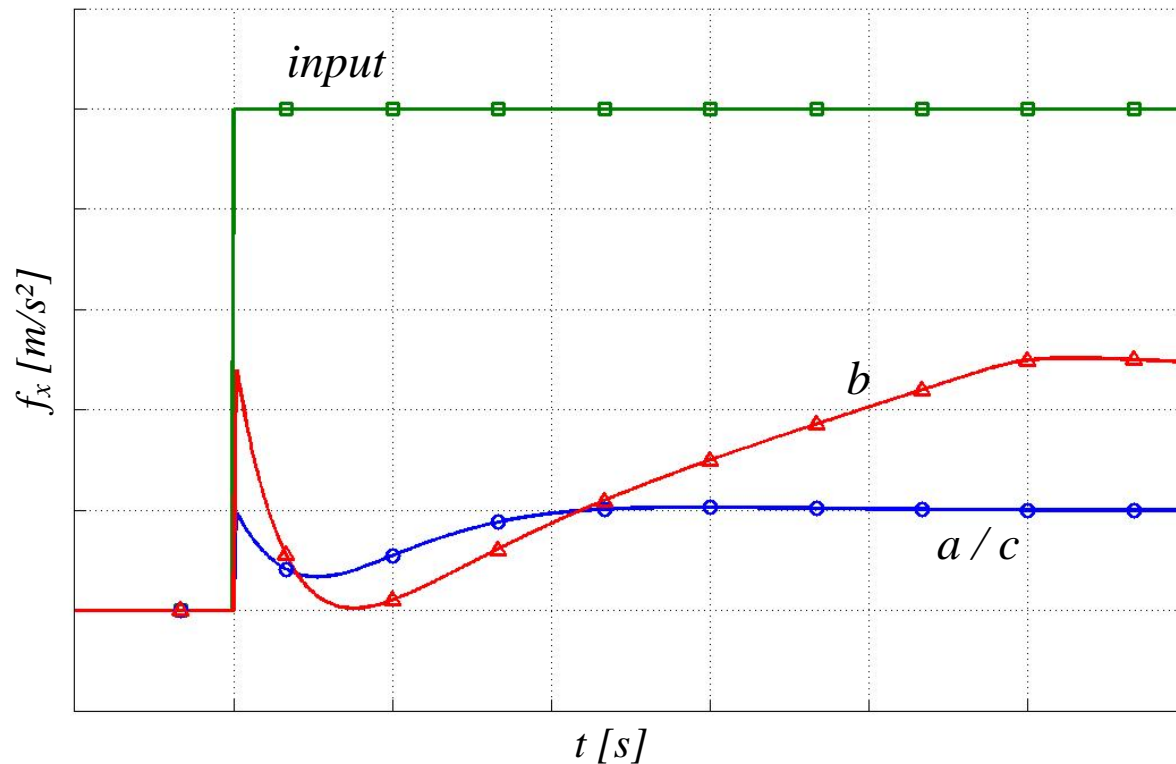
**hypothesis:  
b is bad for  
braking**



# Experiment Design

## Effect of Parameter Sets II

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





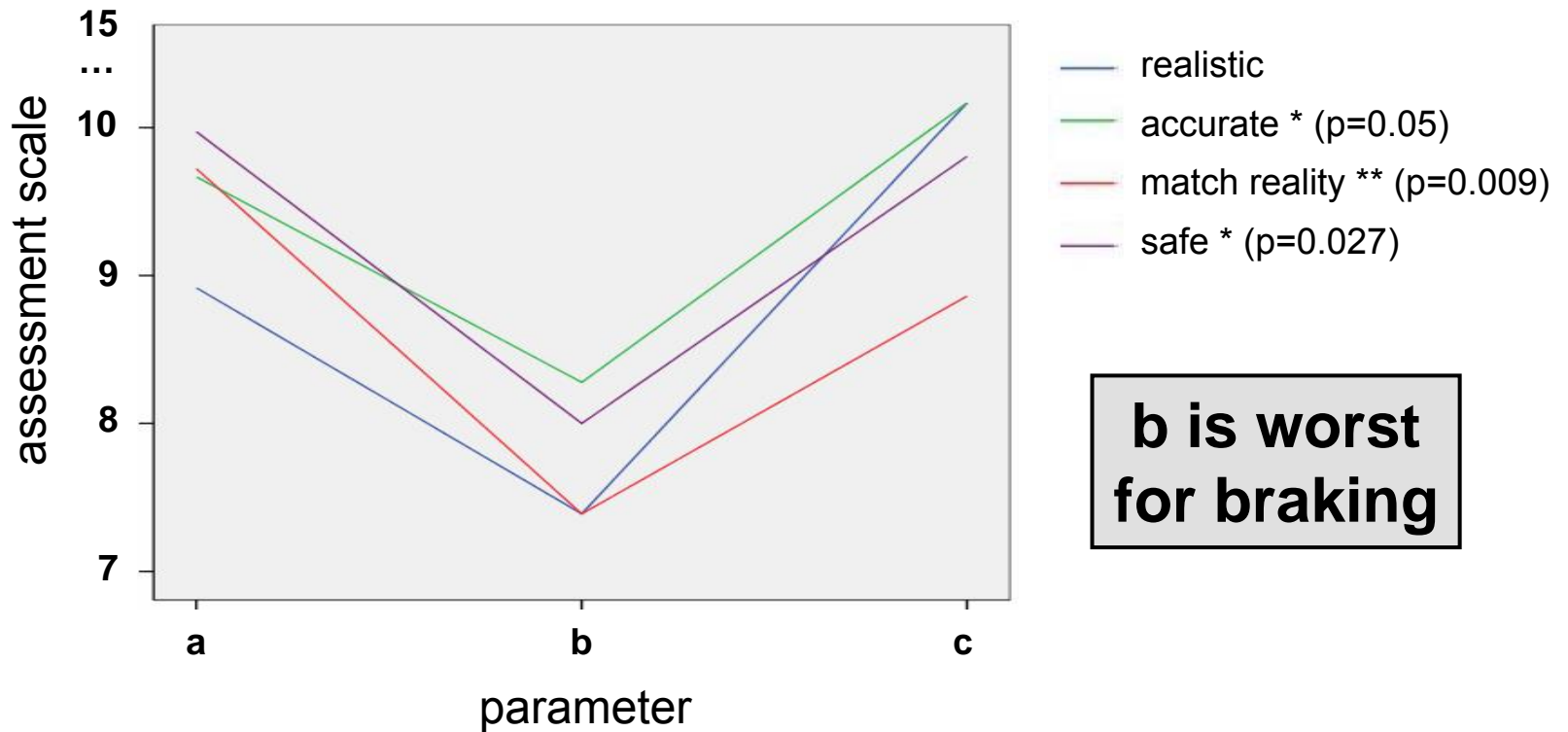
# Experiment Results I

## Analysing Parameter Effects



# Experiment Results

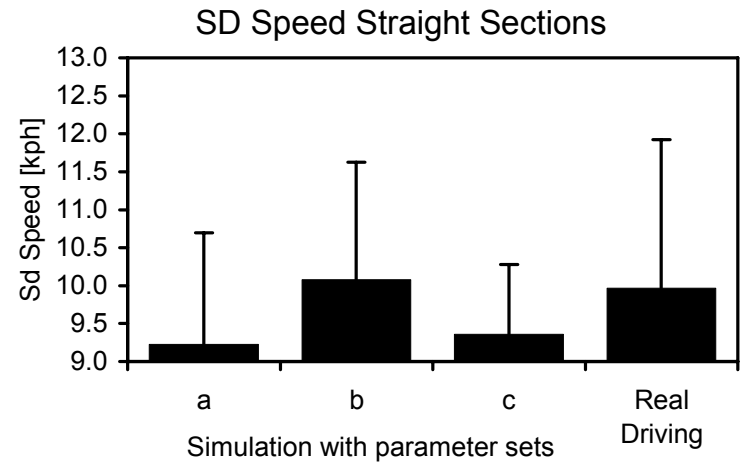
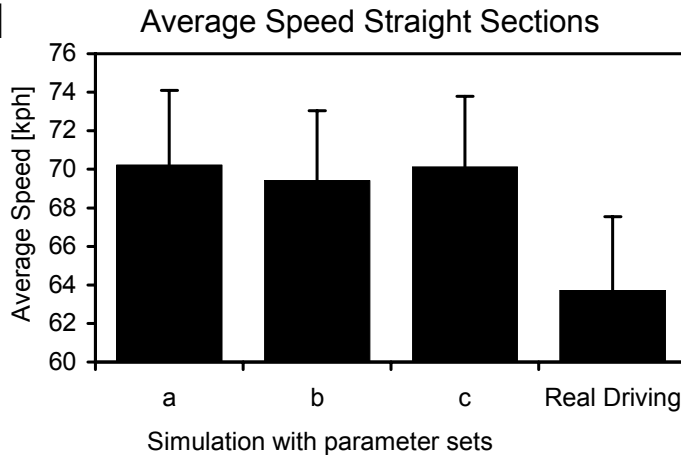
## Braking – main effect parameter



# Experiment Results

## Track Statistics

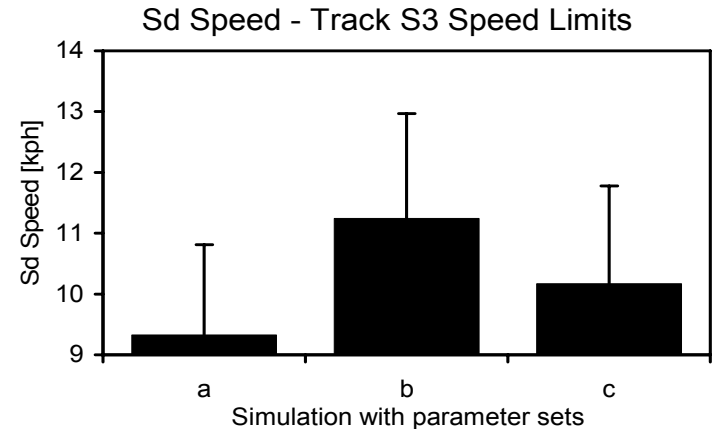
➤ S1



➤ S3

**in virtual driving speed is underestimated**

**b leads to more speed changes**



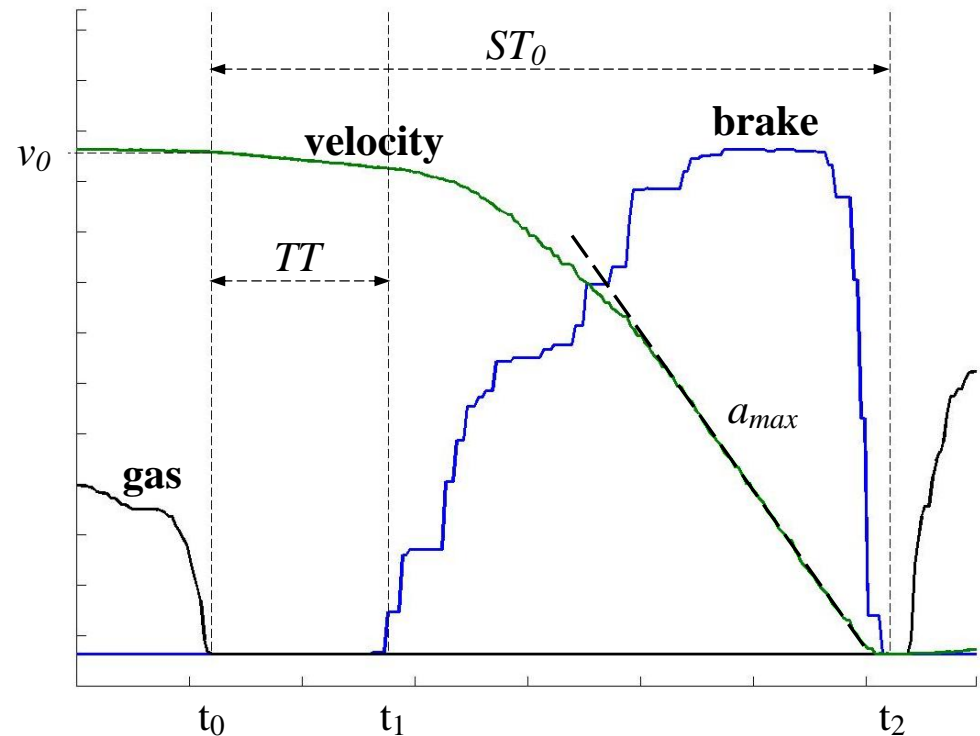
# Braking Manoeuvres

## 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

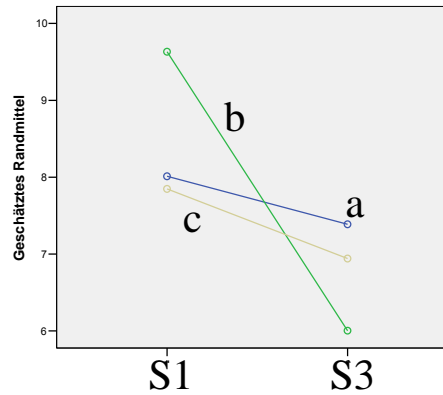
  - S3c vs. R

# Braking Manoeuvres

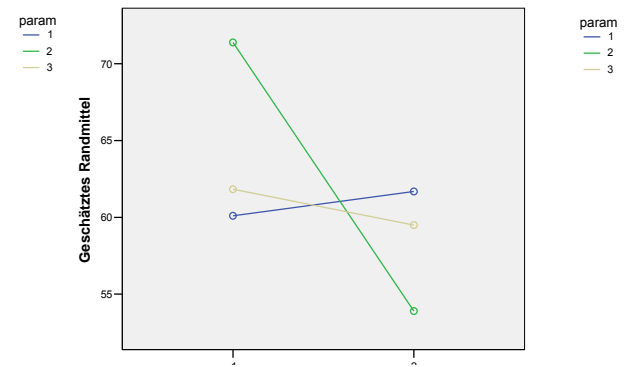
## Analysis of Variance (ANOVA)

	track	track* parameter
$v_0$	.060	.134
→ $ST_0$	<b>.008</b>	<b>.008</b>
→ $SD_0$	.120	<b>.046</b>
→ $TTC_0$	.074	.203
TT	.424	.160
→ $a_{max}$	<b>.000</b>	<b>.000</b>

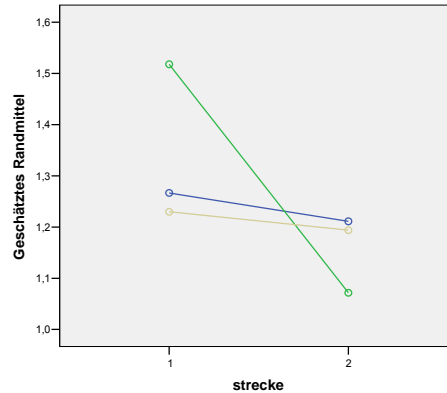
**ST<sub>0</sub>** Geschätztes Randmittel von MEASURE\_1



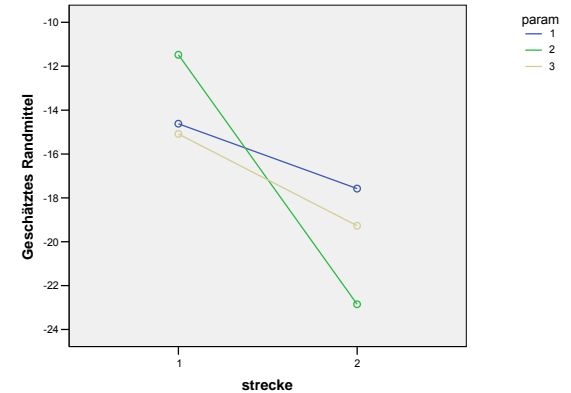
**SD<sub>0</sub>** Geschätztes Randmittel von MEASURE\_1



**TTC<sub>0</sub>** Geschätztes Randmittel von MEASURE\_1

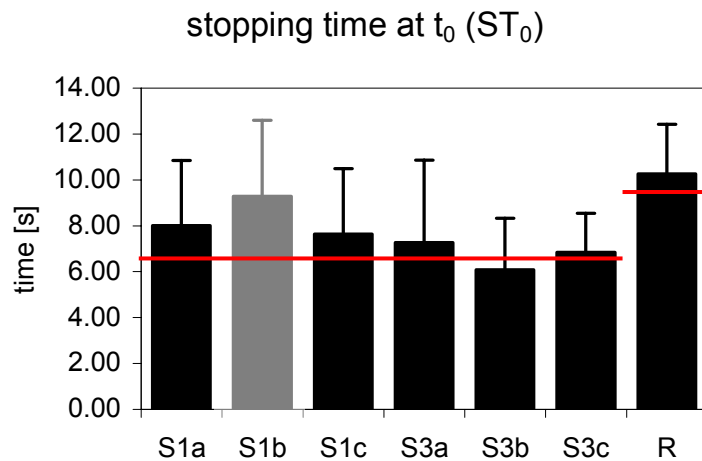
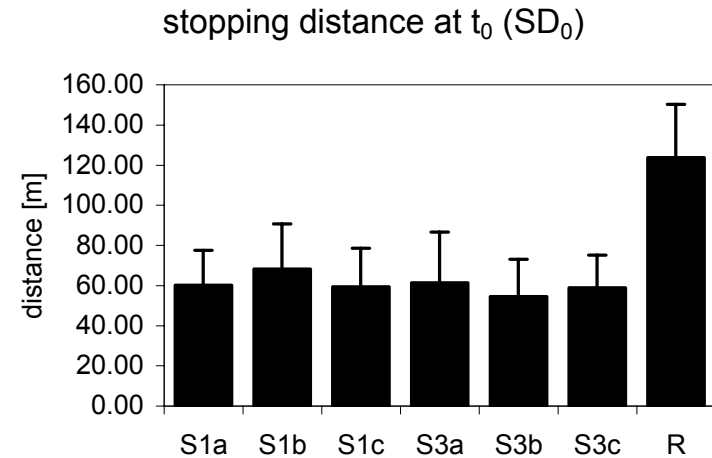
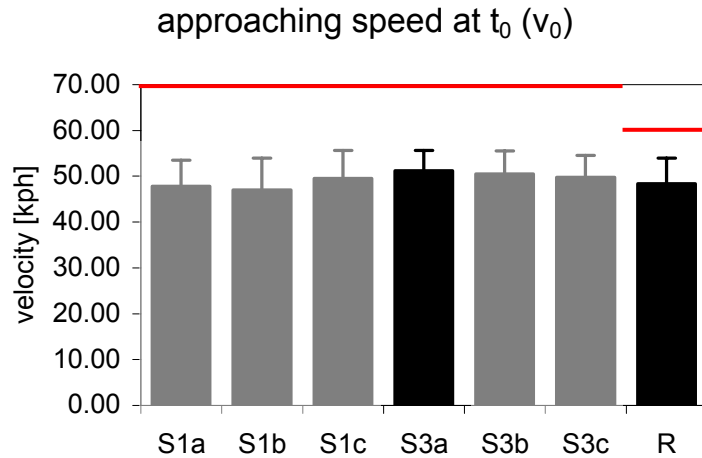


**a<sub>max</sub>** Geschätztes Randmittel von MEASURE\_1

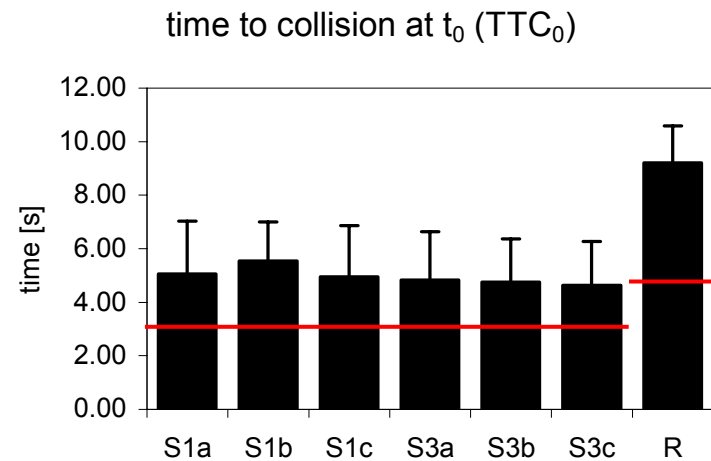


# Braking Manoeuvres

## Mean Values and T-Test Results I



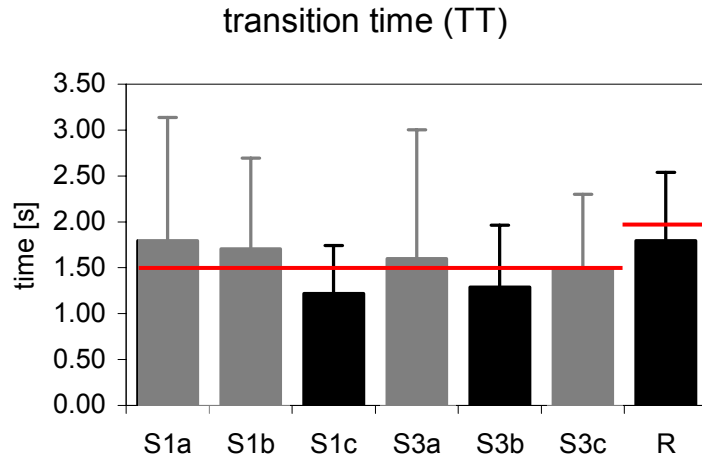
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et al.



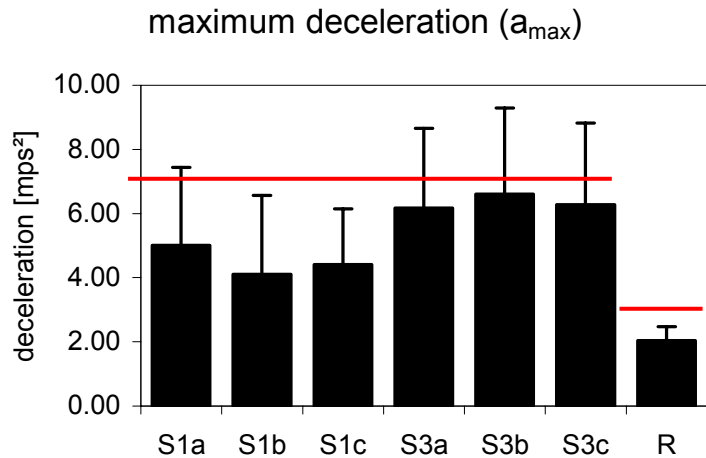


# Braking Manoeuvres

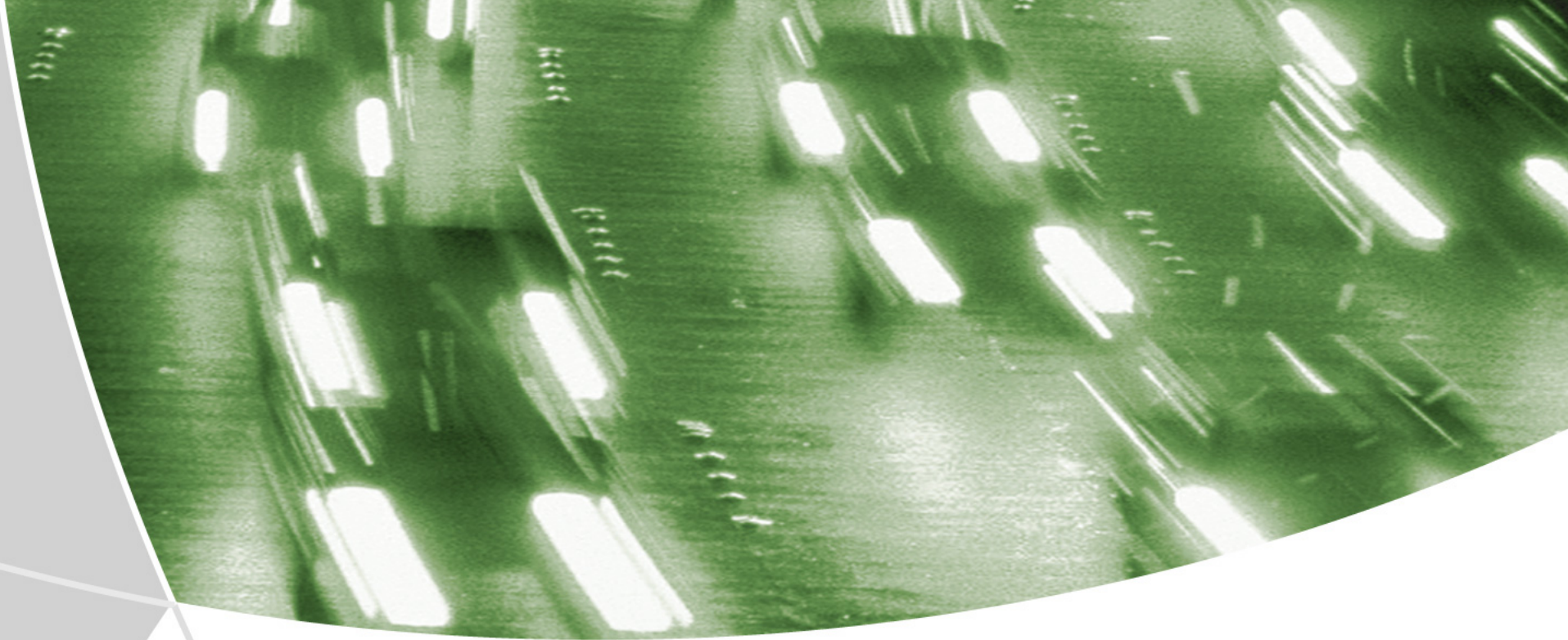
## Mean Values and T-Test Results II



**underestimation of speed  
+  
overestimation of distance  
=  
overestimation of TTC**



**overestimated TTC leads  
to significantly higher  
maximum deceleration**



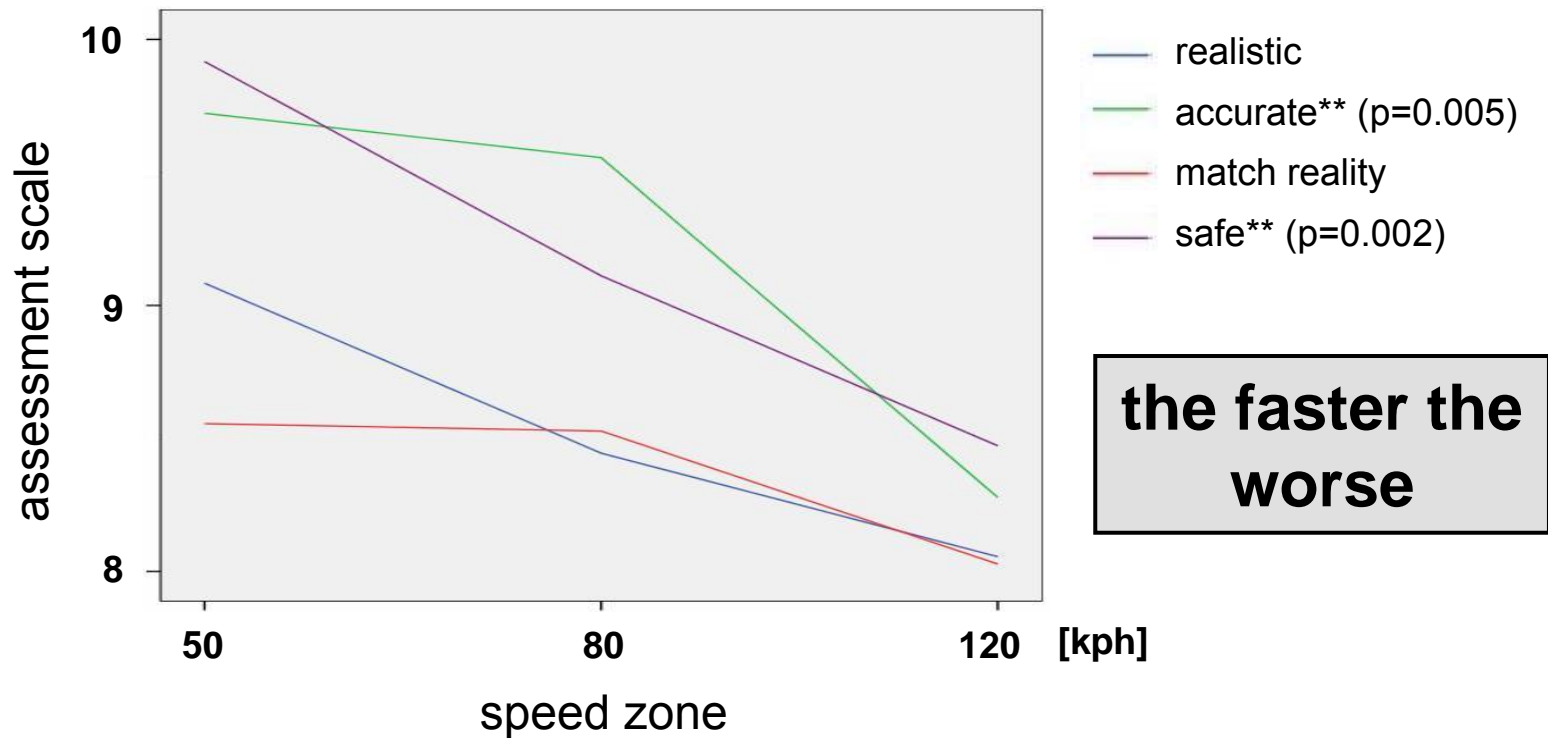
# Experiment Results II

## Analysing Speed Zone Effects



# Experiment Results II

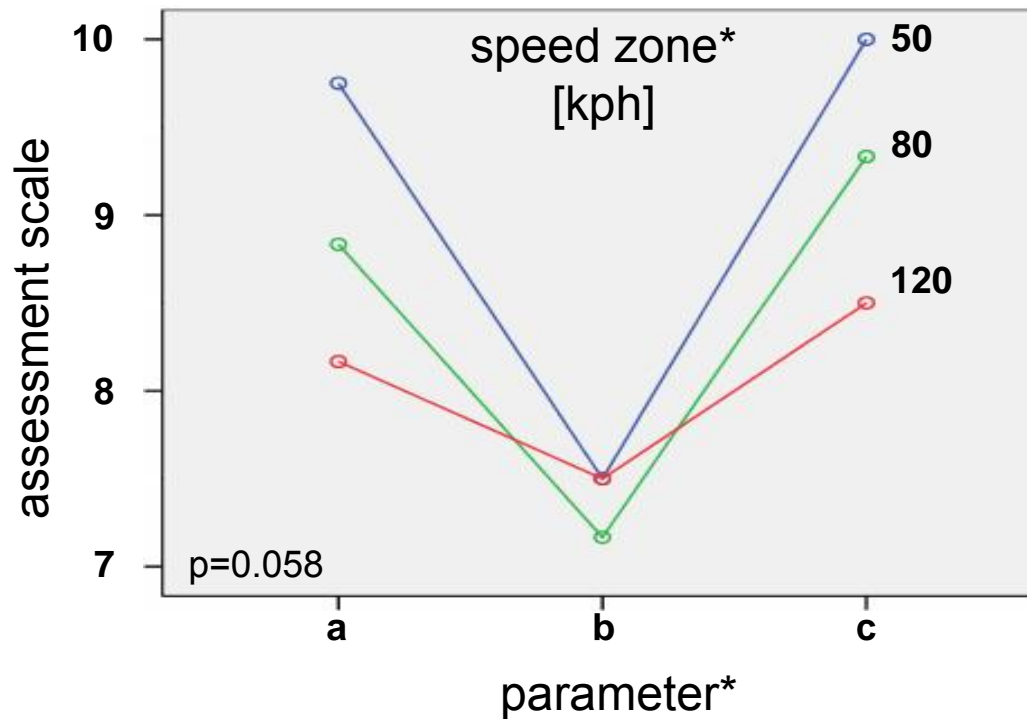
## Braking (S3) – main effect speed zone



# Experiment Results II

## Braking (S3) – interaction effect parameter-speed zone

How realistic is the feeling of driving?

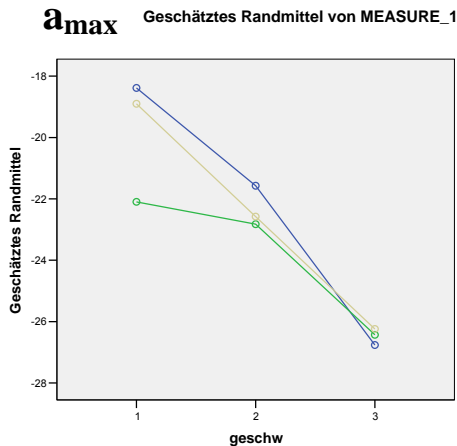
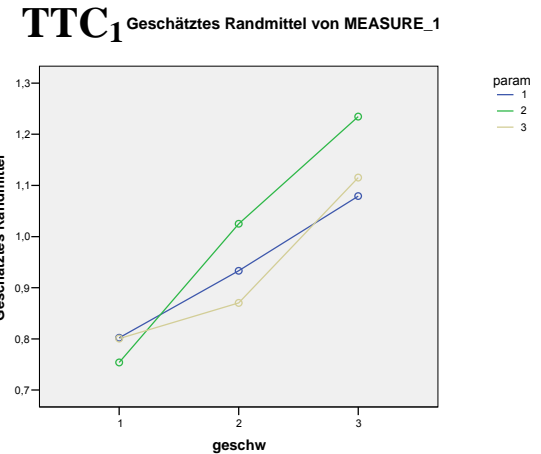
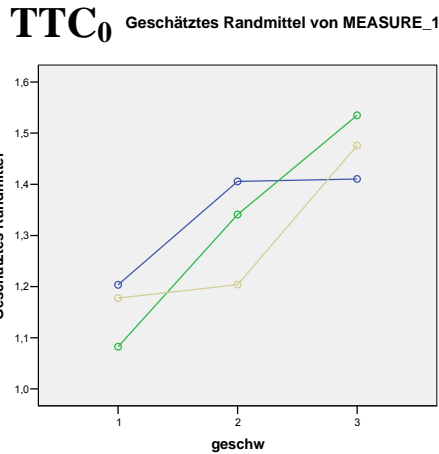
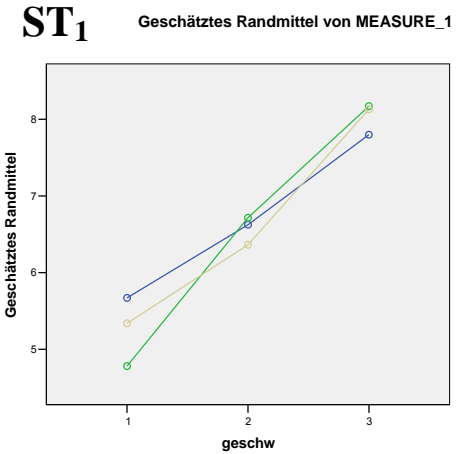
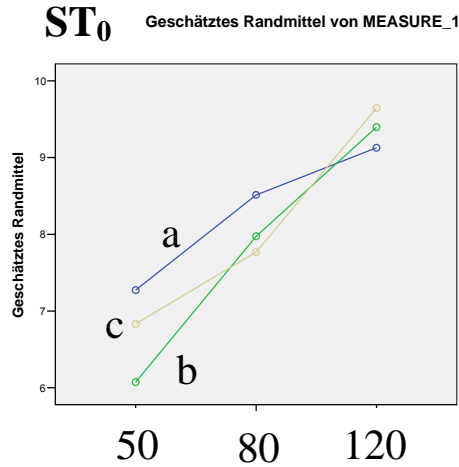


**b is equally worse for all driving speeds**

# Experiment Results II

## Analysis of Variance (ANOVA)

	speed	parameter
→ ST <sub>0</sub>	<b>.000</b>	.631
→ ST <sub>1</sub>	<b>.000</b>	.936
→ TTC <sub>0</sub>	<b>.000</b>	.797
→ TTC <sub>1</sub>	<b>.000</b>	.294
→ TT	.725	.271
→ a <sub>max</sub>	<b>.000</b>	.598





## Conclusion & Future Tasks





# Conclusion

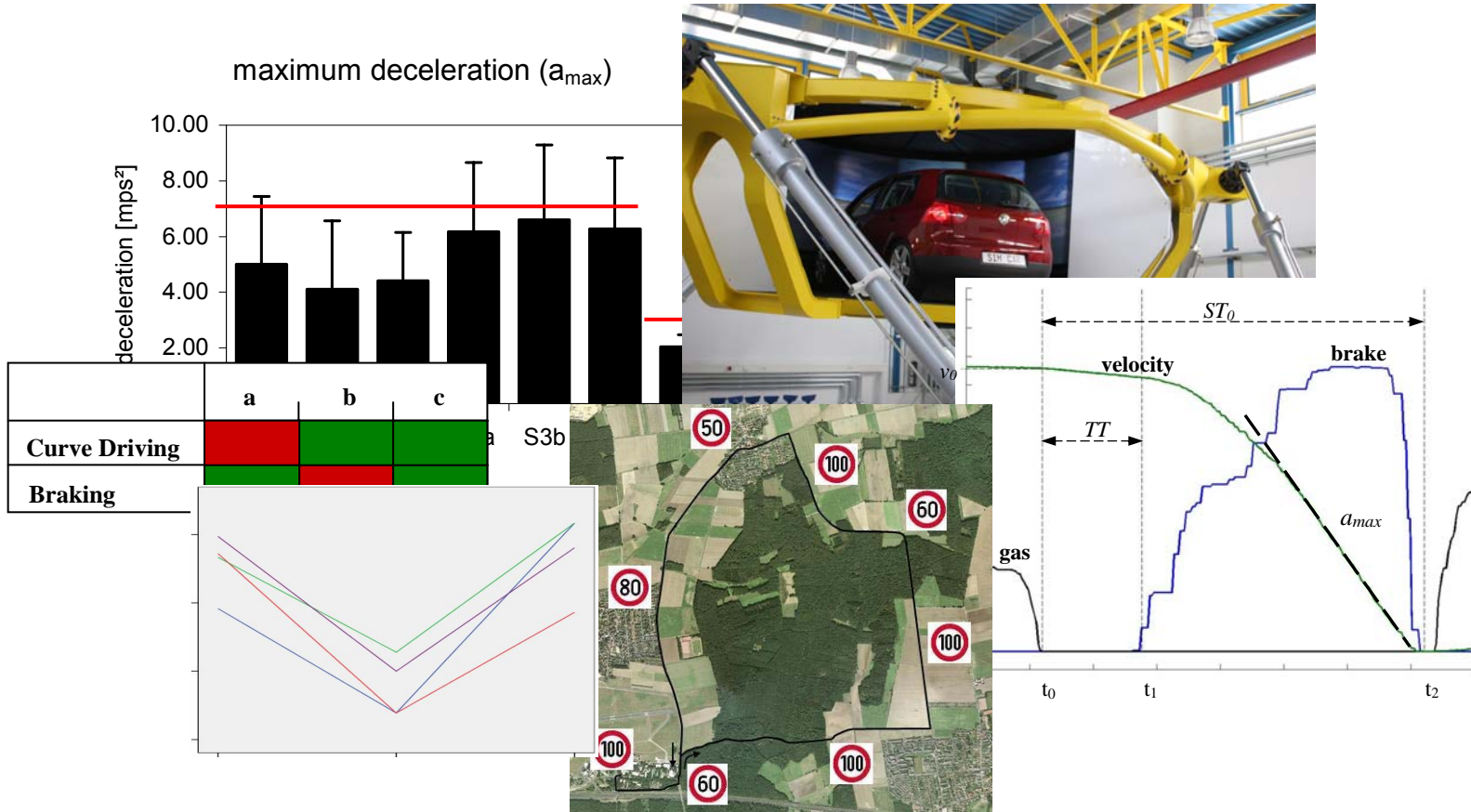
- Estimation of speed, distance and TTC is difficult in virtual driving
- Subjective ratings and objective driving data analysis results correspond
- Driving behaviour in simulators is repeatable
- Systematically varying speed is not essential for tuning the motion

# 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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