The New Time-Variant Motion Cueing Algorithm For The DLR Dynamic Driving Simulator
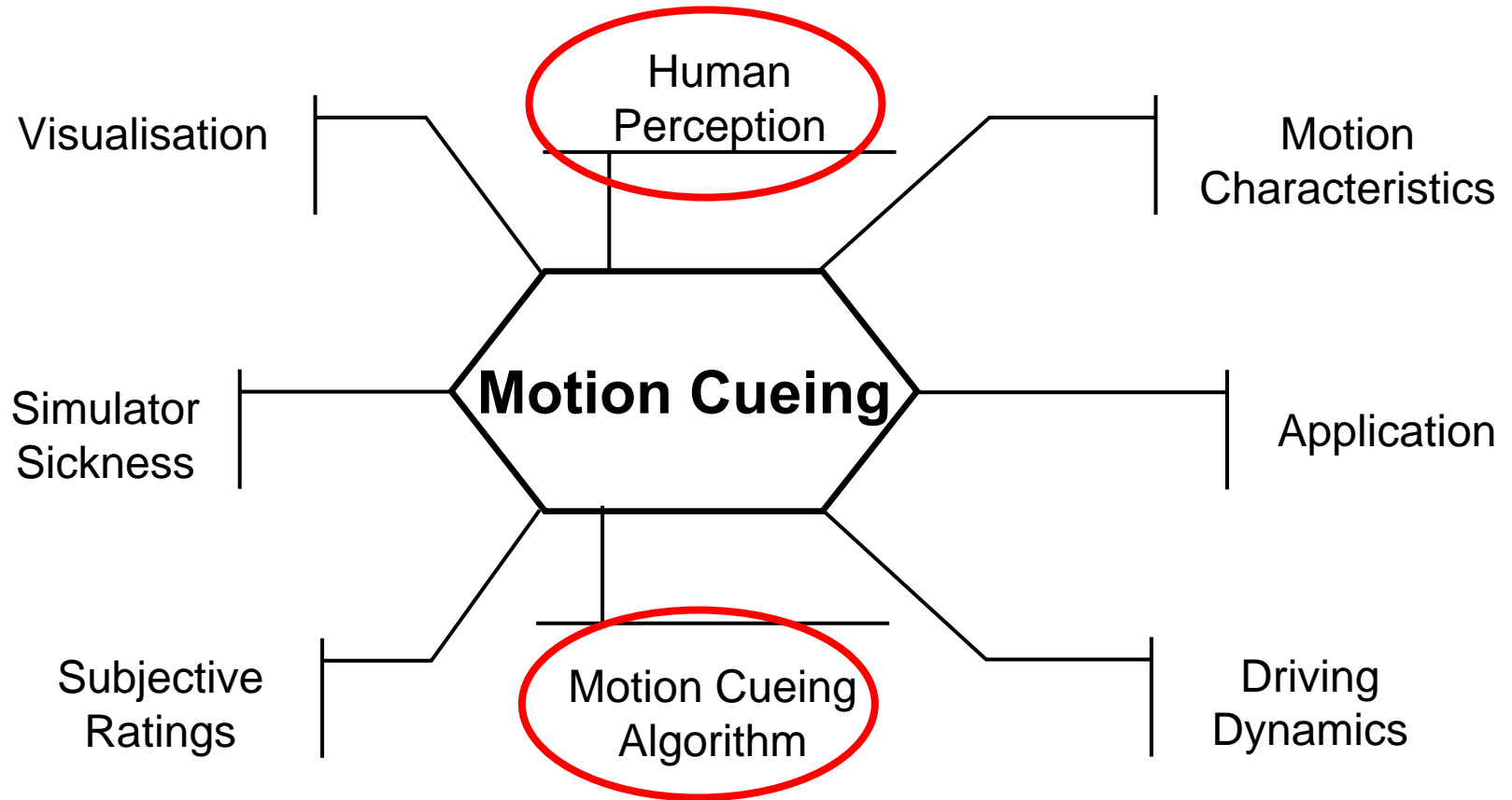DSC 2008, 31st January

Martin Fischer, Julia Werneke

Important Motion Cueing Factors

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

The Simulator

- Motion Capabilities

	Position	Acceleration		Position	Acceleration
Surge	±1,5 m	±10 m/s²	**Roll**	±21 °	±250 °/s²
Sway	±1,4 m	±10 m/s²	**Pitch**	±21 °	±250 °/s²
Heave	±1,4 m	±10 m/s²	**Yaw**	±21 °	±250 °/s²

- Full cockpit
  - force feedback steering
- Visual system
  - 270° x 40° field of view
  - TFT-displays in outside mirrors
  - Large LCD-screen on backseat as rear view mirror

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

New Time-Variant Motion Cueing Algorithm > 20 February 2008 > 3
Institute of Transportation Systems > Aerospace technology for road and railway

Tilt Study

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

Human Perception

visual vs. motion cue

otoliths

adaptation

cueing errors

sensory integration

optical flow

acceleration resolution
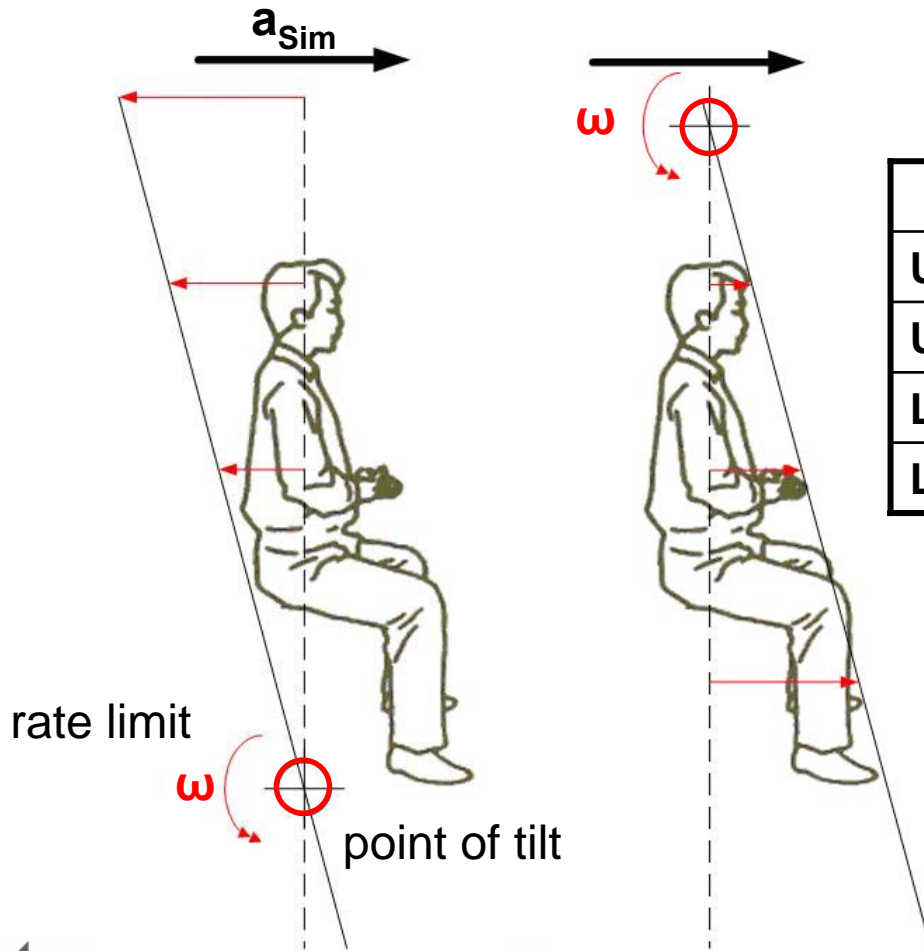
tilt rate limit

perception thresholds

yaw vs. lateral cue

jerk perception

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

Tilt Study
Experimental Design

		point of tilt	rate limit [°/s]
UpL	△	**Up**per	**L**imited (3)
UpU	▲	**Up**per	**U**nlimited (30)
LowL	▽	**L**ower	**L**imited (3)
LowU	▼	**L**ower	**U**nlimited (30)

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

New Time-Variant Motion Cueing Algorithm > 20 February 2008 > 6
Institute of Transportation Systems > Aerospace technology for road and railway
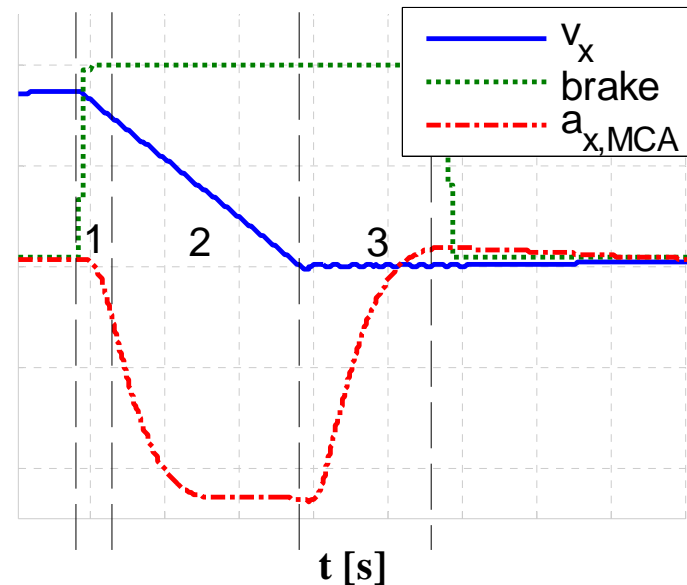
Tilt Study
Phase Definition of Braking Maneuver

➤ Task:

- Accelerate up to 80 km/h

- Keep speed a few seconds

- Initiate an emergency stop

Tilt Study
Questionnaires

➤ Rating the Perceived Force
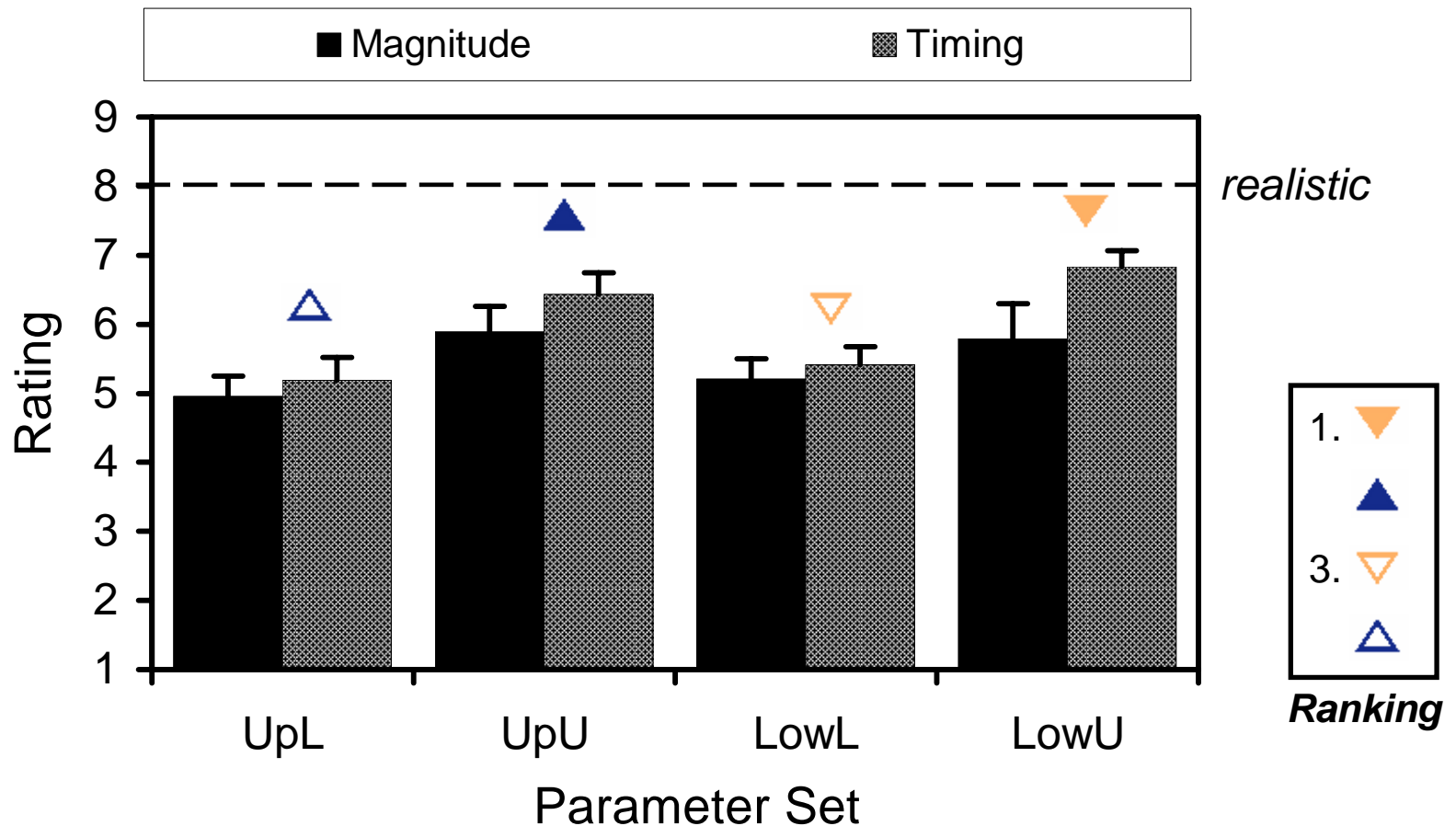
    ➤ Magnitude

    ➤ Timing

➤ Related to

    ➤ Phase   *1, 2, 3*

    ➤ Parameter set   △ ▲ ▽ ▼

much to low			to low			realistic			to high			much to high		
-1	0	1	-1	0	1	-1	0	1	-1	0	1	-1	0	1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

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

New Time-Variant Motion Cueing Algorithm > 20 February 2008 > 8
Institute of Transportation Systems > Aerospace technology for road and railway

Rating the Perceived Force
Related to the Parameter sets

Rating the Perceived Force
Related to the Phases

Motion Cueing Quality Criterion

Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft
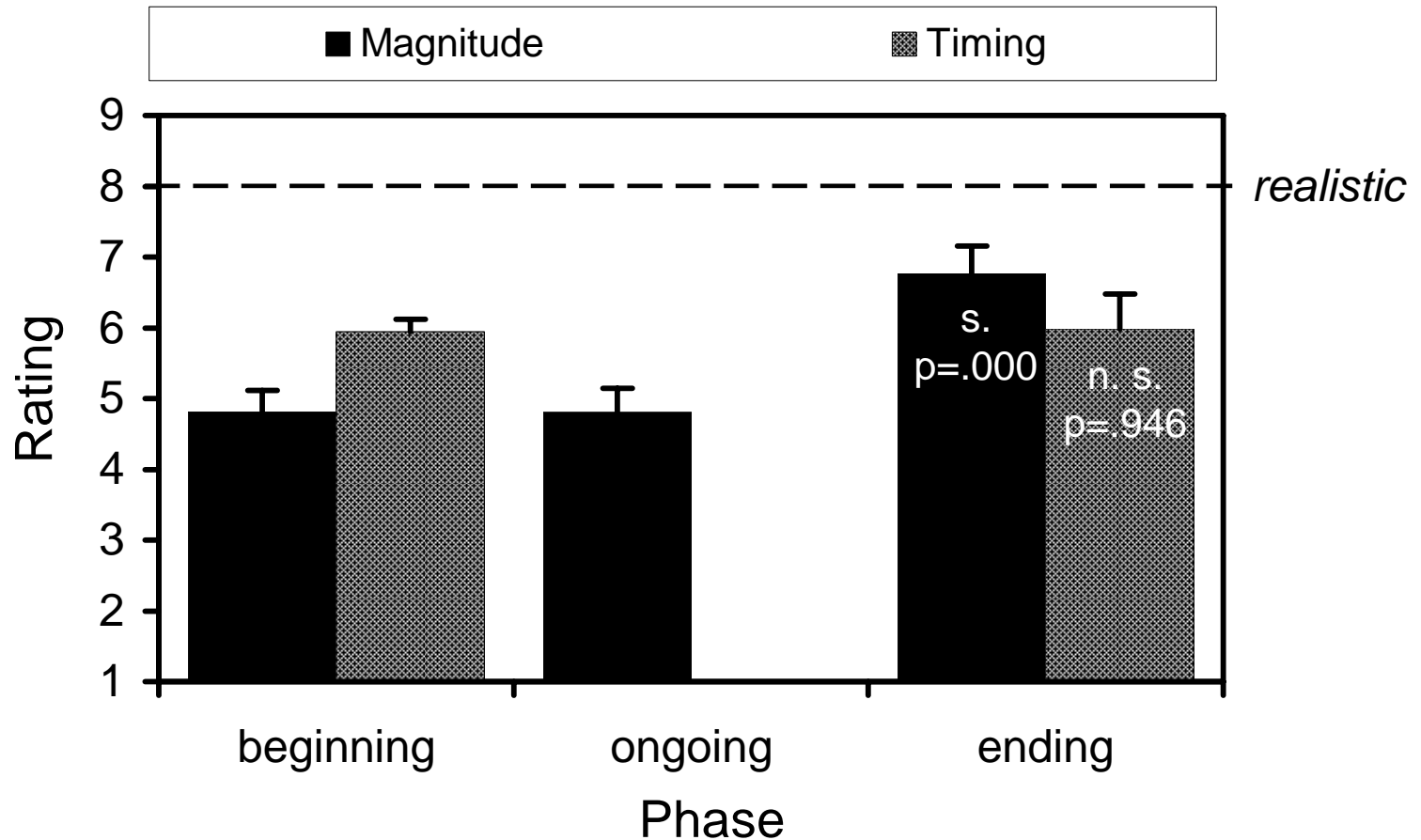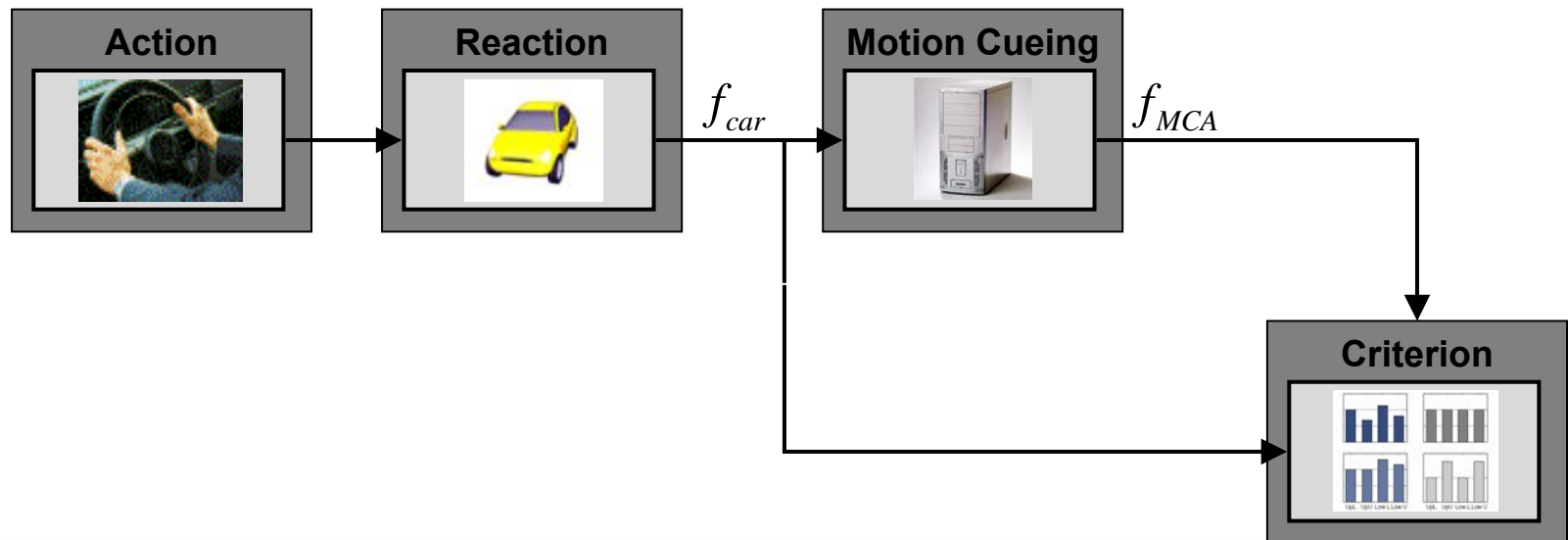
Why Do We Need Such a Criterion?

- ➐ Offline assessment of motion cueing algorithms
    - ➐ Fast
    - ➐ Low cost
- ➐ Enables objective comparison

f_{car} f_{MCA}

| Action | Reaction | Motion Cueing | Criterion |

Motion Cueing Quality Criterion
Definition (Pouliot et al 1998, Journal of Aircraft)
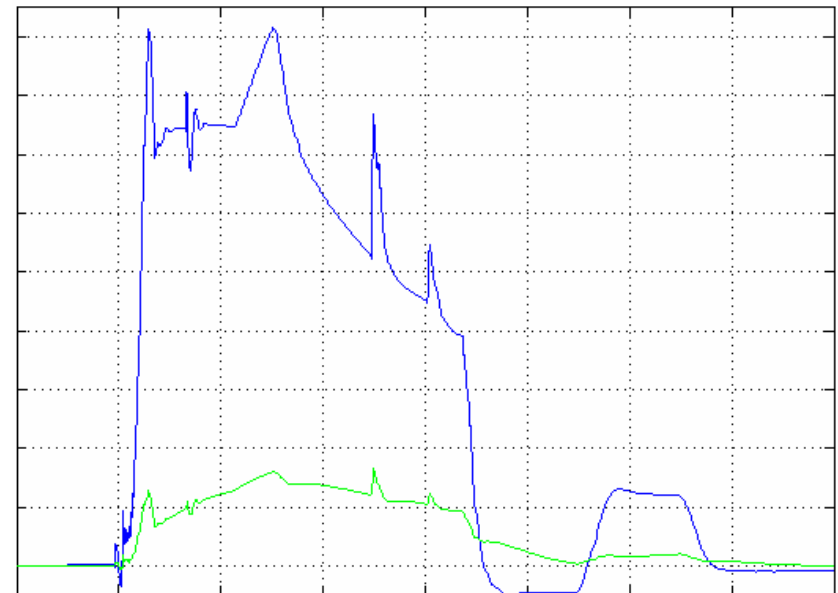
➢ Two performance indicators

  ➢ λ and $\Delta\lambda$

$$\lambda_f = \frac{1}{N} \sum_{j=0}^{N} \sqrt{\Delta f_{xj}^2 + \Delta f_{yj}^2 + \Delta f_{zj}^2}$$

$$\Delta f = f_{car} - f_{MCA}$$

$$\Delta\lambda_f = \frac{1}{N-1} \sum_{j=1}^{N} \sqrt{\delta f_{xj}^2 + \delta f_{yj}^2 + \delta f_{zj}^2}$$

$$\delta f = \dot{f}_{car} - \dot{f}_{MCA}$$

blue	$\rightarrow$	f_{car}
green	$\rightarrow$	f_{MCA}

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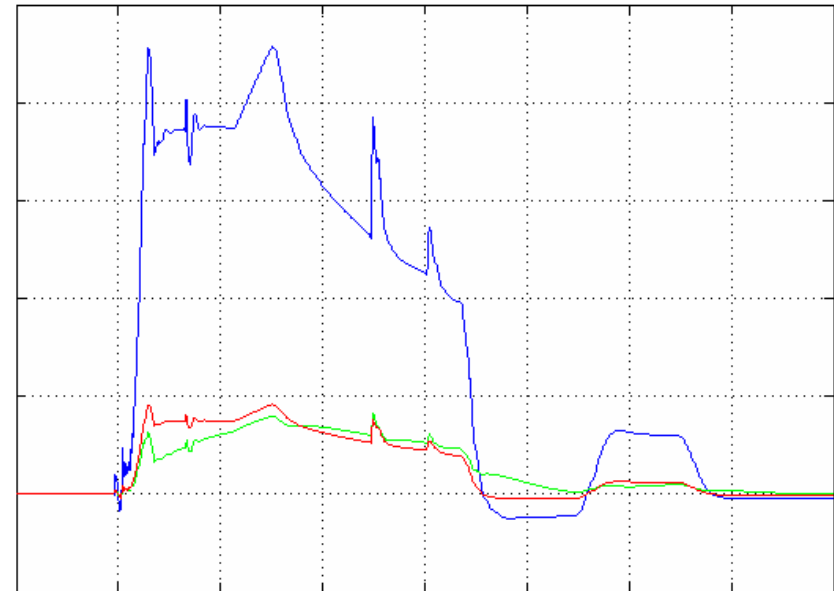in der Helmholtz-Gemeinschaft

Motion Cueing Quality Criterion
Extension

➤ splitting of the indicators
  ➤ shape error (sh)
  ➤ scale error (sc)
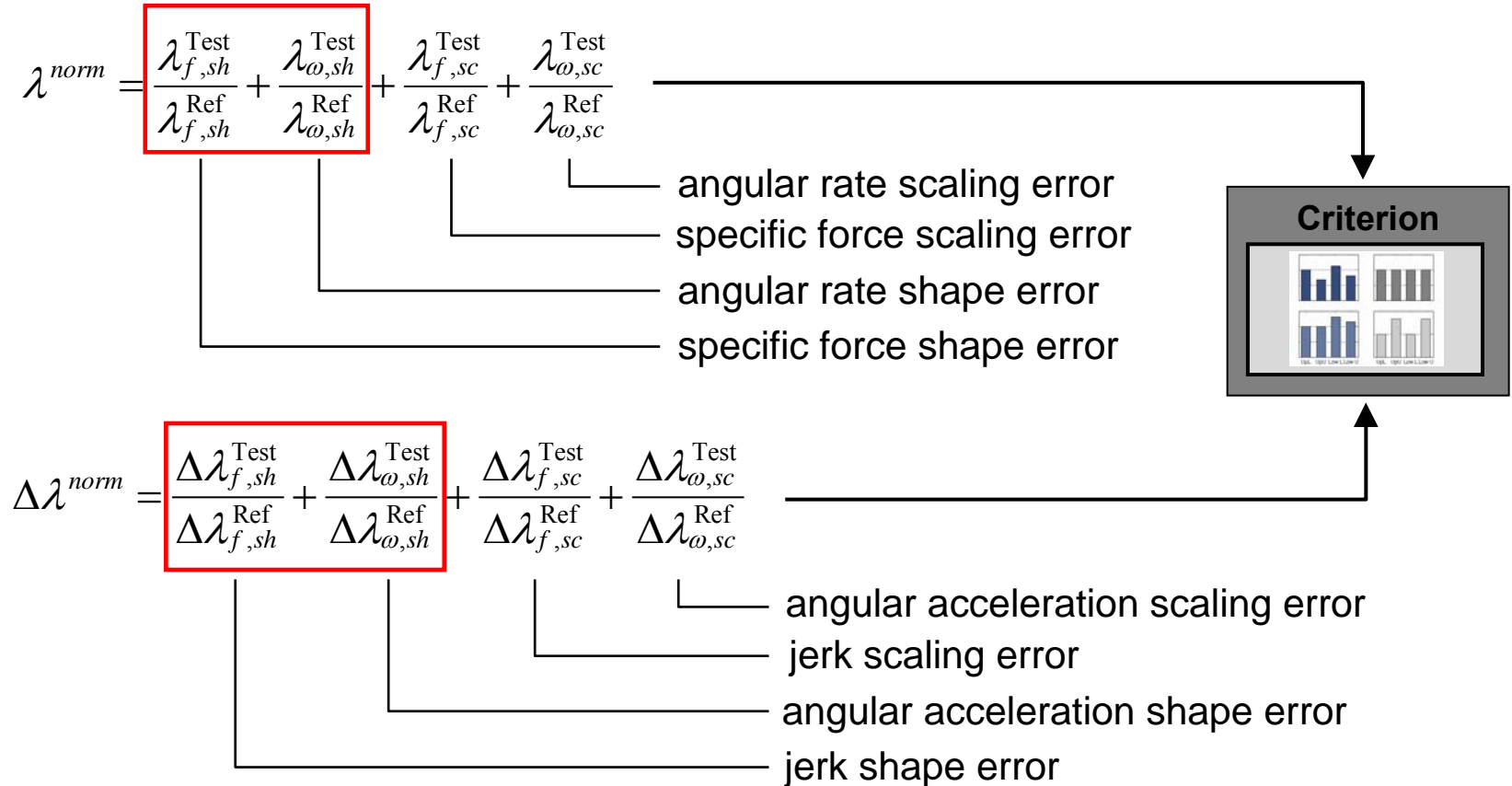
$$\Delta f = \Delta f_{sh} + \Delta f_{sc}$$

$$\Delta f_{sh} = f_{car,sc} - f_{MCA}$$

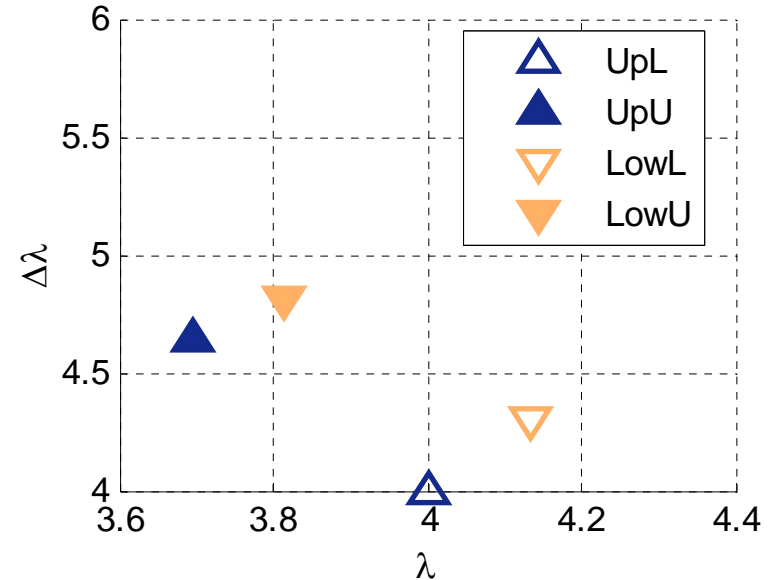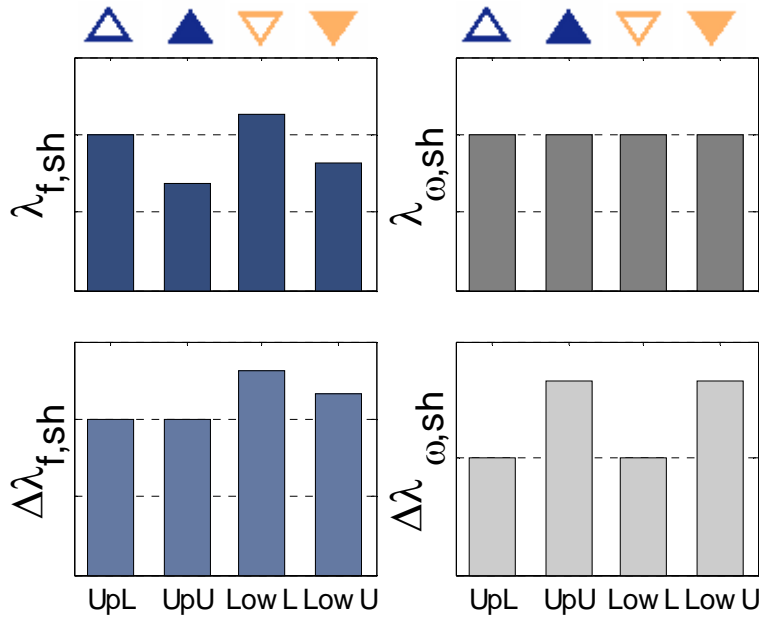$$\Delta f_{sc} = f_{car} - f_{car,sc}$$

blue	→	f_{car}
red	→	$f_{car,sc}$
green	→	f_{MCA}

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

Motion Cueing Quality Criterion
Components

$$\lambda^{norm} = \boxed{\frac{\lambda_{f,sh}^{\text{Test}}}{\lambda_{f,sh}^{\text{Ref}}} + \frac{\lambda_{\omega,sh}^{\text{Test}}}{\lambda_{\omega,sh}^{\text{Ref}}}} + \frac{\lambda_{f,sc}^{\text{Test}}}{\lambda_{f,sc}^{\text{Ref}}} + \frac{\lambda_{\omega,sc}^{\text{Test}}}{\lambda_{\omega,sc}^{\text{Ref}}}$$

angular rate scaling error

specific force scaling error

angular rate shape error

specific force shape error

Criterion

$$\Delta\lambda^{norm} = \boxed{\frac{\Delta\lambda_{f,sh}^{\text{Test}}}{\Delta\lambda_{f,sh}^{\text{Ref}}} + \frac{\Delta\lambda_{\omega,sh}^{\text{Test}}}{\Delta\lambda_{\omega,sh}^{\text{Ref}}}} + \frac{\Delta\lambda_{f,sc}^{\text{Test}}}{\Delta\lambda_{f,sc}^{\text{Ref}}} + \frac{\Delta\lambda_{\omega,sc}^{\text{Test}}}{\Delta\lambda_{\omega,sc}^{\text{Ref}}}$$

angular acceleration scaling error

jerk scaling error

angular acceleration shape error

jerk shape error

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

New Time-Variant Motion Cueing Algorithm > 20 February 2008 > 15
Institute of Transportation Systems > Aerospace technology for road and railway

Motion Cueing Quality Criterion
Results I

Subjective Rating   λ Indicator   Δλ Indicator

Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft
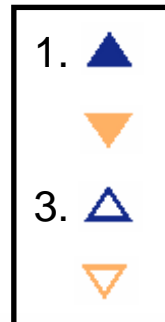
Motion Perception Toolbox (TNO)

Input | Sensors | Visual / Vestibular Interaction | Animation

http://www.desdemona.eu/

Action → Reaction f_{car} → Motion Cueing $\frac{f_{MCA}}{f_{car,sc}}$ → Perception

Perception $\tilde{f}_{car}$ → Criterion

$\tilde{f}_{MCA}$ $\tilde{f}_{car,sc}$

Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft
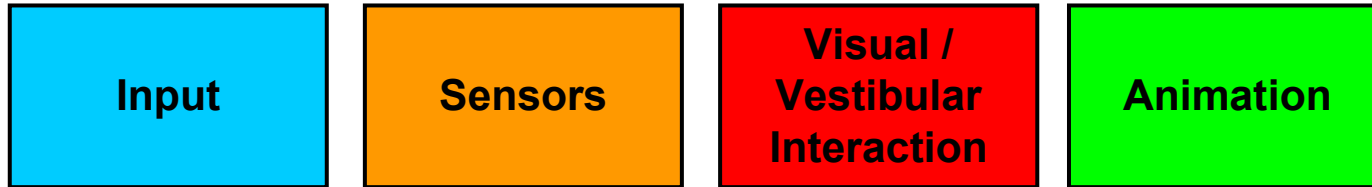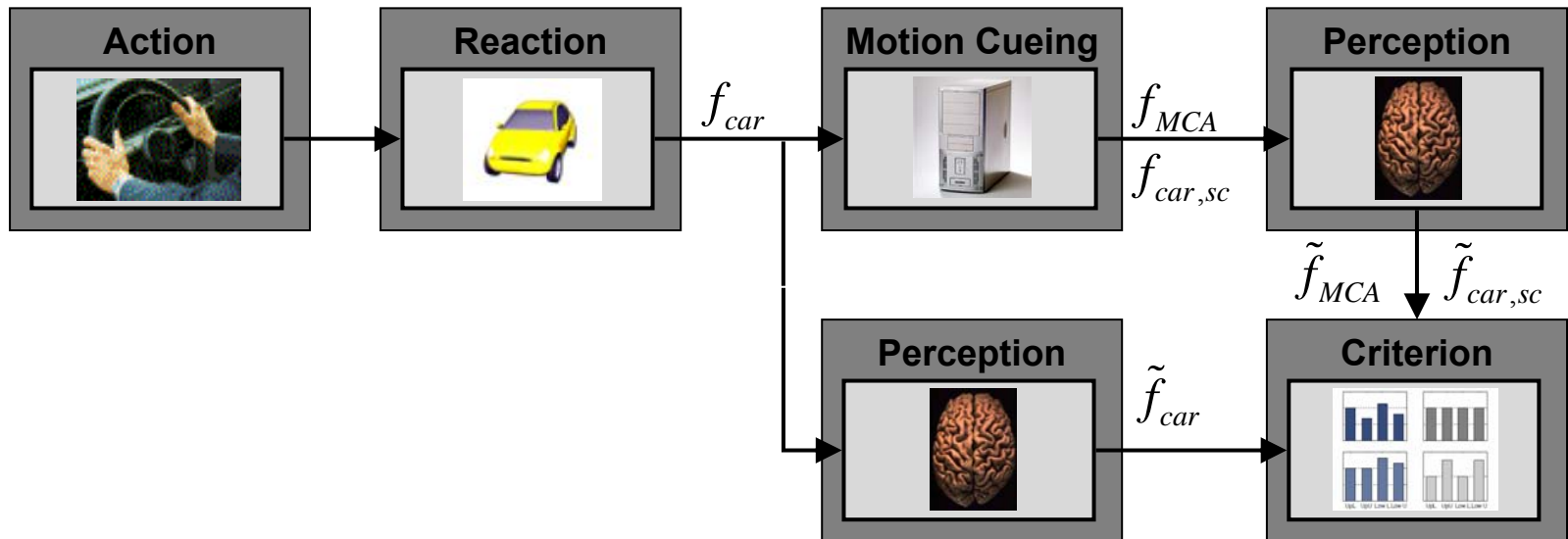
Motion Cueing Quality Criterion
Results II – Perception Model

Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft
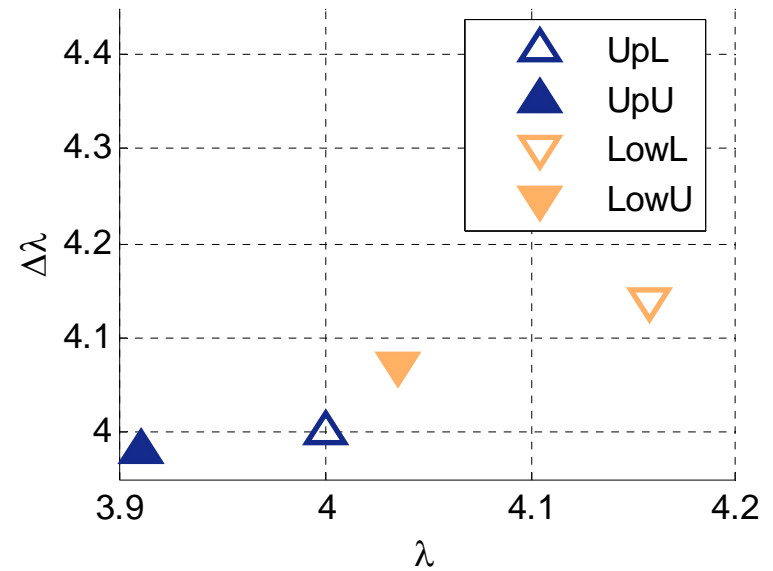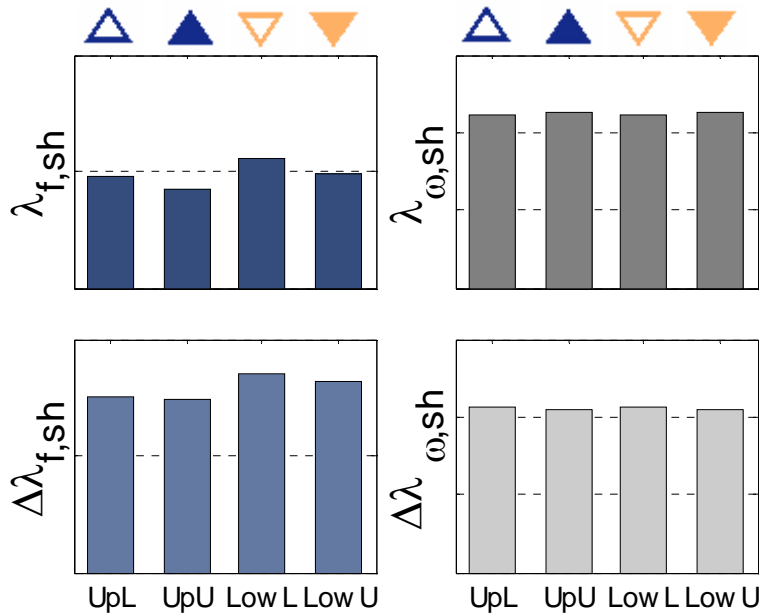
Motion Cueing Quality Criterion
Future Improvements

> Increase knowledge about human perception

$$\Rightarrow$$
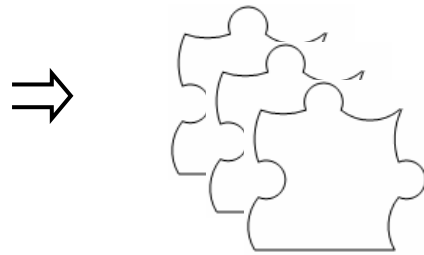
> Determine weighting factors

$$\Rightarrow \quad \lambda = \sum_i \sum_j W_{i,j} \cdot \lambda_{i,j} \Big|_{\substack{i=\{f;\omega\} \\ j=\{sc;sh\}}}$$

$$\Rightarrow \quad \Delta\lambda = \sum_i \sum_j W_{i,j}^{\Delta} \cdot \Delta\lambda_{i,j} \Big|_{\substack{i=\{f;\omega\} \\ j=\{sc;sh\}}}$$
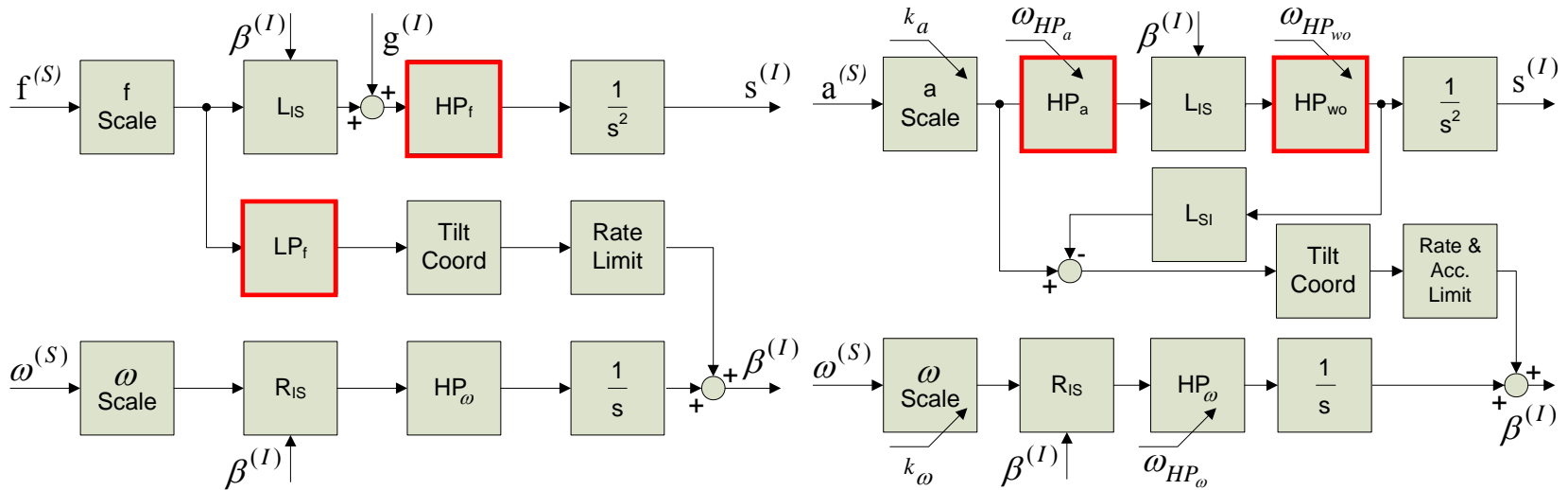
> Work together!!

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

New Time-Variant Motion Cueing Algorithm > 20 February 2008 > 19
Institute of Transportation Systems > Aerospace technology for road and railway

Time-Variant Motion Cueing

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

Fast Tilt Coordination
Specific Force vs. Acceleration Signals

Classical Washout Filter (CWA)
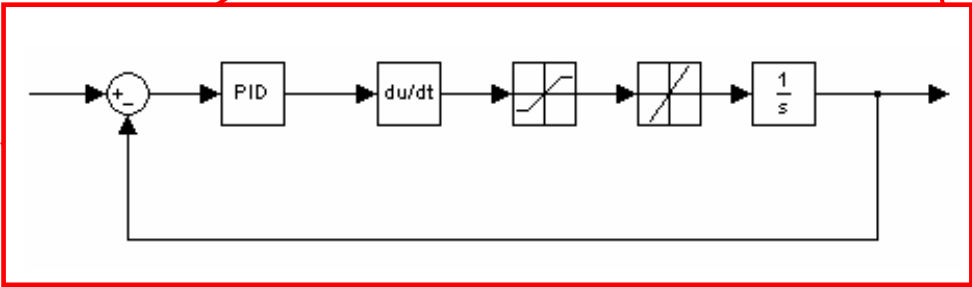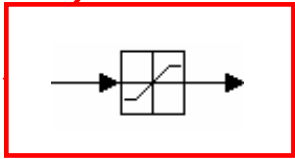
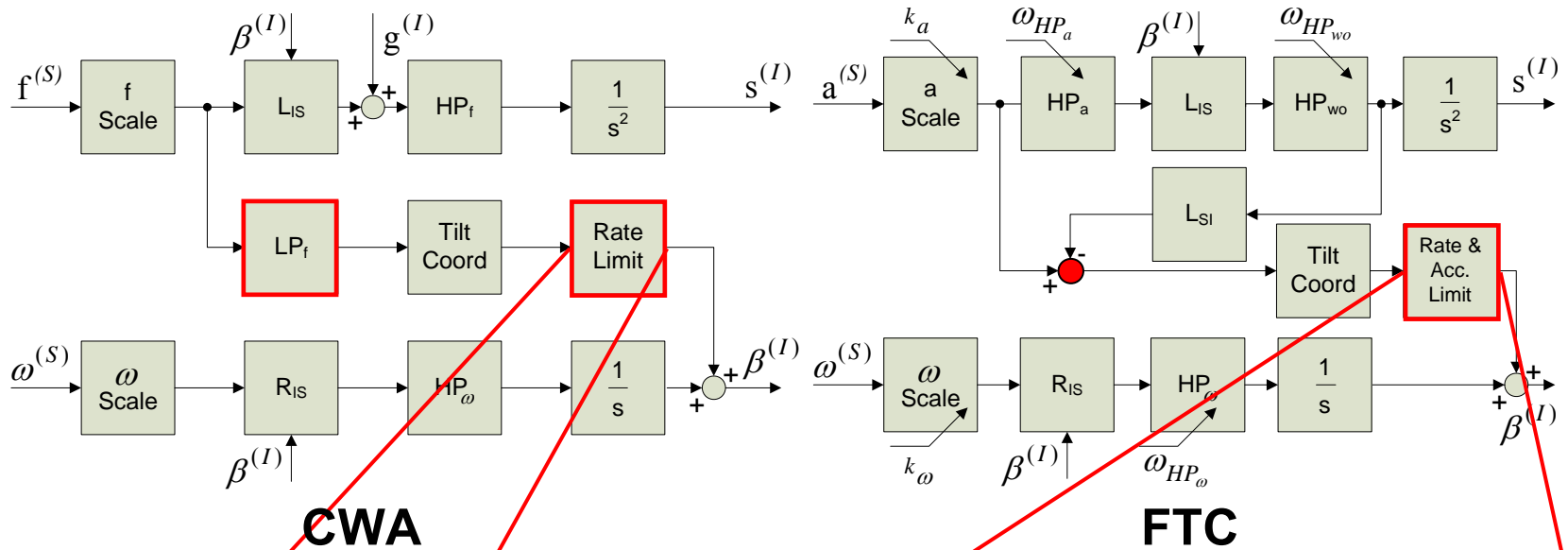**Fast Tilt Coordination (FTC)**

$$\underline{f} = \underline{a} - \underline{g}$$

$$\frac{\ddot{s}^{(I)}}{f^{(S)}} = (1 - LP_f) \cdot HP_f$$

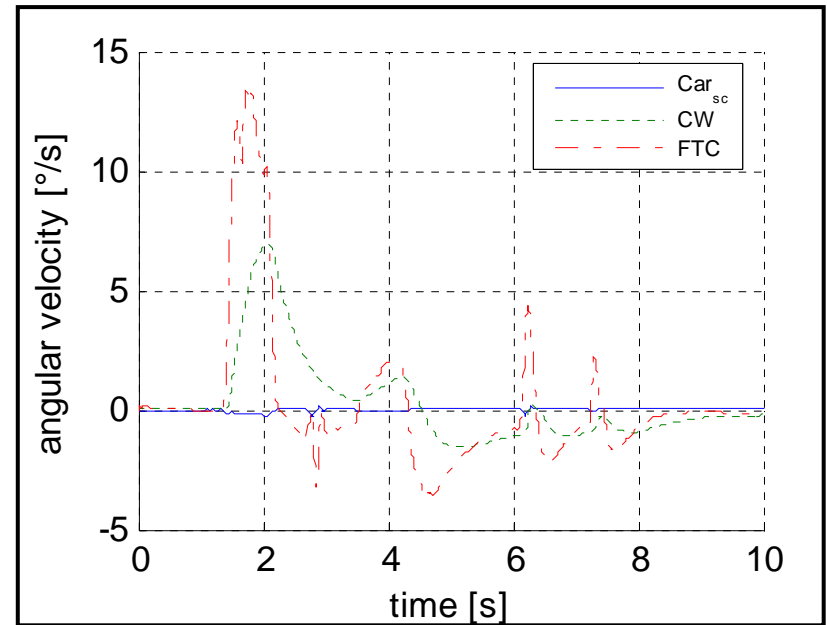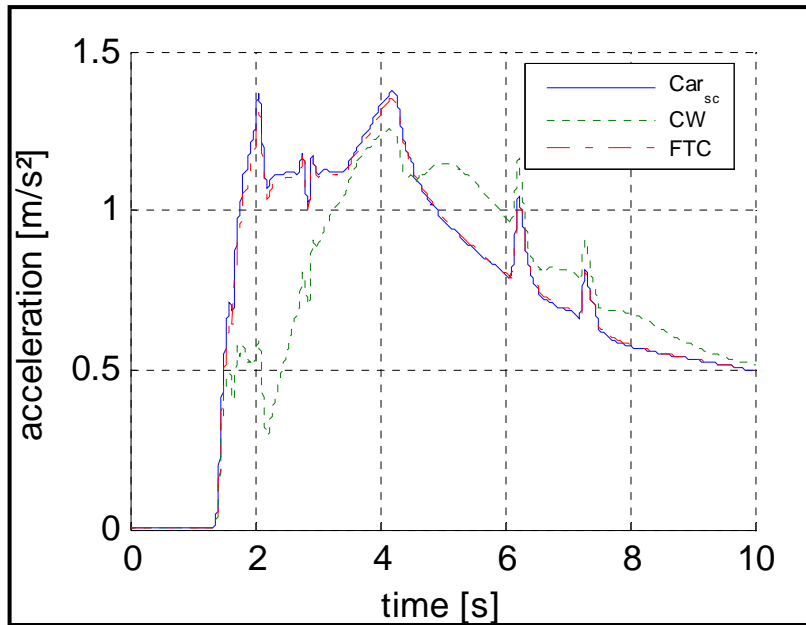$$\frac{\ddot{s}^{(I)}}{a^{(S)}} = HP_a \cdot HP_{wo}$$

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

New Time-Variant Motion Cueing Algorithm > 20 February 2008 > 21
Institute of Transportation Systems > Aerospace technology for road and railway

Fast Tilt Coordination (FTC)
Fast Tilting

CWA

FTC

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

Fast Tilt Coordination (FTC)
Fast Tilting

Fast Tilt Coordination (FTC)
Time Variant Switching

CWA

FTC
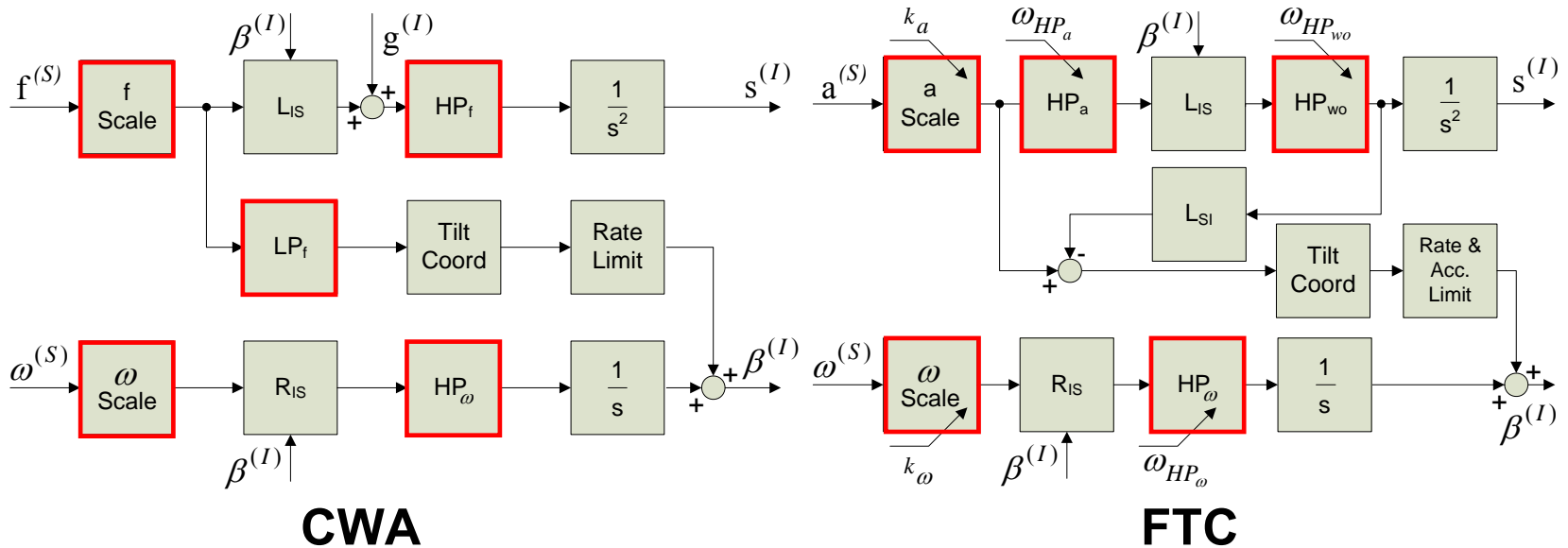
➤ "Maneuver" specific tuning instead of worst-case tuning

    ➤ rural road, city road, highway

➤ Choice of switching strategy

    ➤ Soft scaling

    ➤ No change of scale factors during sustained acceleration

Future Tasks

- Increase knowledge about human motion perception
  - More studies

- Further develop the motion cueing quality criterion
  - Include related published results

- Test FTC-Algorithm
  - subjective assessment

- Explore influence of parameter switching