Non-driving Related Tasks in Automated Driving – Implications for Driver's Take-over Performance and HMI Design

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In Conditional Automated Driving (CAD, SAE Type 3) the system performs longitudinal and lateral vehicle control.

- The human driver can engage in non-driving related tasks (NDRTs) as she/he is not required to monitor the system/environment.

- However, if the system detects a situation it can not handle, the human driver receives a Request to Intervene (Rti).

  Example video of short-term take-over situation:

  „Please take over vehicle control!“
Driver Availability Model

- An adequate driver state is the prerequisite for a successful take-over reaction of the driver:

Different NDRTs can affect different aspects of the driver state and thus take-over performance when it comes to an RtI.
Aspects of the driver state

- **Sensory**: what can currently be perceived with the sensory system; what information is required in a take-over situation?
- **Motoric**: position in the vehicle (turned around, lying, sitting) or the availability of the hands for steering (occupied or not?)
- **Cognitive**: reconfiguration of mental task sets or response rules
- **Arousal**: emergence of passive task related fatigue in automated driving
- **Motivation**: reduced willingness to instantly interrupt the NDRT

➢ In Ko-HAF these aspects were examined in several studies by different project-partners.
Effects of NDRTs: Sensory and motoric transition (1)

Method
- Wizard-of-Oz-Approach
- \( N = 34 \) participants
- RtI due to sensor failure on open road
- 5 vs. 15 minutes automation period

Main results: Take-over reaction

Non-driving related tasks (NDRTs)
- Baseline (no task)
- Listen to Audiobook
- Playing Tetris (mounted Tablet)
- Reading magazine (handheld)
- Search task (requires rotation of torso)

Conclusion
- Increased take-over times due to motoric unavailability
- Large inter-individual differences
Effects of NDRTs: Sensory and motoric transition (2)

Method: Driving simulator study ($N = 30$)

<table>
<thead>
<tr>
<th>NDRT</th>
<th>Resource demands</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conversation</td>
<td>Auditory-vocal (AV)</td>
</tr>
<tr>
<td>Reading out text</td>
<td>Visual-vocal (VV)</td>
</tr>
<tr>
<td>Texting (Tablet mounted)</td>
<td>Visual-manual (VM)</td>
</tr>
<tr>
<td>Texting (Tablet handheld)</td>
<td>Visual-manual (VMh)</td>
</tr>
</tbody>
</table>

Results: Take-over reaction

Take-over scenario: Obstacle with TTC = 6 sec.

Conclusion

- Significant effects of modalities.
- The handheld texting task degraded performance the most.
Effects of NDRTs: Cognitive transition

Method: Driving simulator study (N=53, age = 32 years, SD=16y)
Between subject factor: NDRTs

<table>
<thead>
<tr>
<th>Visual-motoric</th>
<th>Cognitive</th>
<th>Motoric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surrogate Reference Task</td>
<td>N-back Task (N = 2)</td>
<td>Shape-sorter ball</td>
</tr>
</tbody>
</table>

Within subject factors: take-over situation and instruction (free vs. instructed)

<table>
<thead>
<tr>
<th>Crash site</th>
<th>Construction site</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Image]</td>
<td>[Image]</td>
</tr>
</tbody>
</table>

Example Results: Take-over Time

<table>
<thead>
<tr>
<th>Time [s]</th>
<th>SuRT</th>
<th>N-back</th>
<th>Motoric task</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.66</td>
<td>2.71</td>
<td>2.88</td>
</tr>
</tbody>
</table>

Conclusion:
- NDRTs (different modalities) influence the driver state and can be detected using eye-tracking and seat pressure mats
- However, no significant differences were found regarding drivers’ take-over performance.
Effects of NDRTs: Arousal Level

Method:
- Motion Based Driving simulator study (N = 66)
- Between-subjects factor: NDRTs to affect fatigue
- Prolonged automated ride: 60 min
- A take-over situation with ttc = 7 s occurred after 50 min

Results: driver state (PERCLOS)

Results: Take-over time

- Significant effect on the driver state (subjective / objective fatigue).
- Significant differences in take-over reaction (reaction times).
Effects of NDRTs: Motivational Aspects (1)

Method: Driving simulator study (N=53)
NDRT: Playing Tetris® on tablet

Manipulation 1: Interruption Effort
→ Throwing tablet on co-driver’s seat vs. storing it in a box

Manipulation 2: Task Incentive
→ Playing as a simple pastime vs. playing for points and money

Results: First driver reaction*
*steering wheel button press, braking or steering wheel angle > 2°

Conclusion:
- High interruption effort (storing tablet in box) causes delayed driver reaction times (approx. 1.5 s latency)
- Motivational differences in the study were small and task incentive did not lead to significant differences in reaction times

Take-over scenario:
Obstacle with TTC = 9 sec.
Effects of NDRTs: Motivational Aspects (2)

**Method**
- Study in Daimler Driving Simulator
- \(N\text{(total)} = 96, \ N\text{(with all situations)} = 44\) participants
- NDR-tasks: Reading, Video, Item search
- **Mandatory vs. self-regulated** engagement
  - Mandatory = High Workload
  - Self-regulated = Free Workload

**Take-over Situation with RtI** (Request to Intervene)
- Missing lane markings & crosswind

**Main results**

- The differences in drivers' reaction times to RtI for different levels of workload are statistically significant, but practically irrelevant.
- The reaction times to RtI during self initiated NDRT are faster than during instructed NDRT.
Effects of NDRTs: Summary of Publications

Overall effects of different NDRTs. Not only Ko-HAF experiments are represented.

For a detailed description see:
Conclusion: NDRTs

The Ko-HAF experiments showed increased take-over times for NDRTs including:

- Strong rotations of the torso (> 90°)
- Manual interaction with handheld objects (e.g. tablet computer)
- High effort or steps needed to disengage from an NDRT

No clear / consistent results were found for:

- Visual or visual-manual tasks without occupation of hands
- NDRTs affecting the cognitive transition

Overall: Strong individual differences

- Natural behavior, self regulation and motivational aspects of NDRTs should be considered in the experimental design.
HMI Implications: How to support the driver?

Different types of take-over situations considered in Ko-HAF:

- Long-term transitions (based on Safety Server)
  - Known from maps / card material / online updates
  - Safety Server (Ko-HAF)
  - The human driver can be requested long time before he has to regain control

- Short-term transitions (based on Onboard Sensors)
  - Detected by onboard sensors
  - Short period of time – the human driver has to regain control within seconds
Example Concept for Long-term transitions (1)

Method: Driving simulator study ($N = 36$)

Tested HMI versions (selection)
- Basic HMI
- Adaptive HMI (staged pre-alerts)

What is the impact on NDRT disengagement and take-over times in predictable transitions?

Results: NDRT disengagement

- Pre-alerts facilitated NDRT disengagement and take-over time.
- Very good user experience and acceptance ratings for adaptive HMI.
Example Concept for Long-term transitions (2)

HMI for take-over requests

- "Upcoming work zone – please take over soon"
- "Please take over"
- "Take over!"

HMI for system maneuvers (no driver intervention required)

- "Upcoming lane splitting"
- "Preparing lane change..."
- "Changing lane..."

Results: Usability

- Take-over requests followed a multi-step escalation scheme
- Take-over requests and system maneuvers displayed different HMIs
- Additional speech output increased overall system usability

N=17
Example Concept for Short-term transitions

Method: Driving simulator study (N = 64) 3x2 between-within design

- Three different HMI concepts for RtI
  - Speech output
  - LED – light signal
  - Baseline: Text

- Take-over scenarios

  Scenario 1:
  required reaction of driver: Lane change maneuver

  Scenario 2:
  required reaction of driver: Braking maneuver

Results: Take-over reaction

Gaze-reaction time (in s)

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<thead>
<tr>
<th>1. Scenario</th>
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</thead>
<tbody>
<tr>
<td>Speech</td>
</tr>
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<td>LED</td>
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<tr>
<td>Text</td>
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Hands-on times (in s)

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<tr>
<td>Text</td>
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- Eyes-on road time was lowest in the LED group.
- In the LED group reaction times were faster compared to the other HMI concepts (hands-on time, braking reaction).
Conclusion: HMI

**Long-term transitions**

- **Multi-stage transition concepts** have been shown to accelerate the disengagement from NDRTs and take-over time.

- A preview of planned requests to intervene along the route (based on safety server information) helps **drivers to self-regulate their engagement** in NDRTs.

**Short-term transitions**

- The **request to intervene (RtI)** should be designed to be **multi-modal** and needs to explicitly convey the necessity for taking over control of the vehicle.

- An „**NDRT lockout“** simultaneously with the request to intervene (RtI) can accelerate the driver response.
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References


