Assessment of Cognitive Workload Estimation Metrics for Younger & Older Drivers in a Driving Simulator

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Contents

- Backgrounds
- Research Method
- Sensitivity of Cognitive Workload Measures
- Discussion and Summary
Challenges in Auto UI

- Distraction Management
  - Restricted Glance Time
  - Limited Resources
- Integration with Smartphone
- More older drivers

Balance between Safety & Functionality
Challenges in automotive for older drivers

• Innovation Paradox
  • At least 25% of automobile buyers will be over age 50.
  • Ex) BMW iDrive
    ➔ Criticism from the consumers, predominantly age of 45+

• Different Learning Behavior
  • Older drivers:
    Distracted from the driving task when the cause of a warning was not clearly evident.
  • Younger drivers:
    Trust in warning systems often choosing to rely on.

Need to understand Older Drivers for Better Interface Design
Increasing traffic accident fatality as getting older

**Driver Fatality Rate**
(Per 100 Million Vehicle Miles Traveled)

**Driver Age Group**
(Source: FARS 2001 and NHTSA 2001)
Age-induced Limitation

- Sensation & Perception
  - Audition
  - Vision
- Movement Control
- Cognition
  - Working Memory (Short-term)
  - Multiple Task Demands
  - Visual Attention
  - Spatial Cognition
In-Vehicle Systems need to know driver’s states

- To activate assistant system when a driver needs assistance
- To provide in-vehicle information timely and affordable
Backgrounds

Research Objective

- Understanding the sensitivity of the cognitive workload measures
- Considering age differences

Driving Performance

Physiological Arousal

Eye Behavior
Contents

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- Research Method
- Sensitivity of Cognitive Workload Measures
- Discussion and Summary
## Research Method

### Participants

- **Screening Criteria:**
  - Driving on average more than twice a week
  - Self-reported good health
  - Free from major medical conditions
  - Not take medications for psychiatric disorders
  - Score 27 or greater on the mini mental status exam
  - Not previously participated in a simulated driving study

<table>
<thead>
<tr>
<th>Group</th>
<th># of Subjects</th>
<th>Gender</th>
<th>Mean Age (S.D.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Younger (25-35)</td>
<td>15</td>
<td>M</td>
<td>27.9 (3.13)</td>
</tr>
<tr>
<td>Older (60-69)</td>
<td>15</td>
<td>M</td>
<td>63.2 (1.74)</td>
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</tbody>
</table>
Research Method
Experimental Setup

- Fixed-base Driving Simulator
  - STISIM Drive™ software with force feedback (30 Hz)
  - Physiological data (200Hz)
    - MEDAC System/3 unit (NeuroDyne Medical Corp., Cambridge, MA)
  - Eye behavior data (60Hz)
    - FaceLAB® 4.6 (Seeing Machines Ltd., Canberra, Australia)
  - A display beside the rear-view mirror
    - Elapsed time & Distance remaining
An auditory delayed recall task (N-Back Tasks)

- Each 2-min task consisted of a set of four 30s trials
- 0-Back (Non-delayed)

<table>
<thead>
<tr>
<th>Present</th>
<th>2</th>
<th>3</th>
<th>5</th>
<th>6</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recall</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>6</td>
<td></td>
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</tbody>
</table>

- 1-Back (1 digit delayed)

<table>
<thead>
<tr>
<th>Present</th>
<th>2</th>
<th>3</th>
<th>5</th>
<th>6</th>
<th>...</th>
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</thead>
<tbody>
<tr>
<td>Recall</td>
<td></td>
<td>x</td>
<td>2</td>
<td>3</td>
<td>5</td>
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</tbody>
</table>

- 2-Back (2 digit delayed)

<table>
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<tr>
<th>Present</th>
<th>2</th>
<th>3</th>
<th>5</th>
<th>6</th>
<th>...</th>
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</thead>
<tbody>
<tr>
<td>Recall</td>
<td></td>
<td></td>
<td>x</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
Secondary task performance
- Significantly impacted by the difficult level and age

Engagement was high for all participants
- Attention did not appear to be withdrawn from the task

<table>
<thead>
<tr>
<th>Workload</th>
<th>Age</th>
<th>0-back</th>
<th>1-back</th>
<th>2-back</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>25~35</td>
<td>0%</td>
<td>0.74%</td>
<td>6.25%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0)</td>
<td>(2.87)</td>
<td>(8.35)</td>
</tr>
<tr>
<td>Non driving</td>
<td>60~69</td>
<td>2%</td>
<td>3%</td>
<td>33.13%</td>
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<tr>
<td></td>
<td></td>
<td>(7.75)</td>
<td>(4.86)</td>
<td>(20.86)</td>
</tr>
<tr>
<td>Dual Task</td>
<td>25~35</td>
<td>0%</td>
<td>4.63%</td>
<td>7.08%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0)</td>
<td>(7.47)</td>
<td>(6.83)</td>
</tr>
<tr>
<td></td>
<td>60~69</td>
<td>0.67%</td>
<td>6.48%</td>
<td>37.29%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.14)</td>
<td>(6.70)</td>
<td>(17.46)</td>
</tr>
</tbody>
</table>
Research Methods
Procedure

Subject Arrives (5 min)
- Consent & Overview (5 min)
- Physio. Sensor Attach. (5~10 min)
- Survey (Pre sim) (10 min)
- Set up (FaceLab, etc) (10 ~ 20 min)
- Sim. Training (10 min)
- Rest & Physio. Baseline (10 min)

Main Experiment
- N-Back Task Training (10 ~ 20 min)
- N-Back Task Baseline (10 min)
- Rest (5 min)
- Driving & N-Back Experiment (20 ~ 25 min)
- Exit Car & Rest (5 min)

Post Survey (10 min)
- Subject Departs
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- Backgrounds

- Research Method

- Sensitivity of Cognitive Workload Measures

- Discussion and Summary
# Cognitive Workload Measures: Overall Sensitivities

<table>
<thead>
<tr>
<th>Methods</th>
<th>Measures</th>
<th>Descriptions</th>
<th>Main Effect</th>
<th>Pair-wise Sensitivity</th>
<th>Age Effect</th>
<th>Level*Age</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>BL-0B</td>
<td>0B-1B</td>
<td>IB-2B</td>
<td>RC-0B</td>
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<tr>
<td>Secondary Task</td>
<td>ER</td>
<td>Error rate of secondary task scores</td>
<td>0.000</td>
<td>-</td>
<td>0.068</td>
<td>0.000</td>
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<tr>
<td>Driving Performance</td>
<td>SPD</td>
<td>Mean speed</td>
<td>0.000</td>
<td>0.000</td>
<td>0.598</td>
<td>0.589</td>
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<tr>
<td></td>
<td>SDSPD</td>
<td>Standard deviation of speed</td>
<td>0.005</td>
<td>0.002</td>
<td>0.504</td>
<td>0.713</td>
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<tr>
<td></td>
<td>SRR</td>
<td>Steering wheel reversal rate</td>
<td>0.000</td>
<td>0.000</td>
<td>0.008</td>
<td>0.193</td>
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<tr>
<td></td>
<td>SDLP</td>
<td>Standard deviation of lane position</td>
<td>0.000</td>
<td>0.662</td>
<td>0.001</td>
<td>0.022</td>
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<tr>
<td>Physiology</td>
<td>IBI</td>
<td>Mean inter-beat interval</td>
<td>0.000</td>
<td>0.001</td>
<td>0.002</td>
<td>0.001</td>
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<tr>
<td></td>
<td>HR</td>
<td>Mean heart rate</td>
<td>0.000</td>
<td>0.002</td>
<td>0.001</td>
<td>0.001</td>
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<tr>
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<td>SDHR</td>
<td>Standard deviation of heart rate</td>
<td>0.002</td>
<td>0.651</td>
<td>0.090</td>
<td>0.121</td>
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<td>HRV</td>
<td>Heart rate variability</td>
<td>0.018</td>
<td>0.476</td>
<td>0.019</td>
<td>0.538</td>
</tr>
<tr>
<td></td>
<td>SCL</td>
<td>Mean skin conductance level</td>
<td>0.000</td>
<td>0.015</td>
<td>0.007</td>
<td>0.140</td>
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<tr>
<td></td>
<td>SDSCL</td>
<td>Standard deviation of skin conductance level</td>
<td>0.172</td>
<td>0.957</td>
<td>0.713</td>
<td>0.008</td>
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<tr>
<td></td>
<td>ST</td>
<td>Mean skin temperature</td>
<td>0.586</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td></td>
<td>SDST</td>
<td>Standard deviation of skin temperature</td>
<td>0.562</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Eye Behavior</td>
<td>SDHG</td>
<td>Standard deviation of horizontal gaze</td>
<td>0.000</td>
<td>0.000</td>
<td>0.013</td>
<td>0.409</td>
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<tr>
<td></td>
<td>SDVG</td>
<td>Standard deviation of vertical gaze</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.099</td>
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<tr>
<td></td>
<td>HG</td>
<td>Mean horizontal gaze</td>
<td>0.000</td>
<td>0.000</td>
<td>0.892</td>
<td>0.347</td>
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<tr>
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<td>VG</td>
<td>Mean vertical gaze</td>
<td>0.001</td>
<td>0.377</td>
<td>0.076</td>
<td>0.653</td>
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<tr>
<td></td>
<td>PD</td>
<td>Pupil Diameter</td>
<td>0.291</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td></td>
<td>BF</td>
<td>Blink Frequency</td>
<td>0.387</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>BD</td>
<td>Blink Duration</td>
<td>0.727</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>PERCLOS</td>
<td>Percentage of eyelid closure over the pupil over time</td>
<td>0.245</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>
## Cognitive Workload Measures: Driving Performance

### Driving Performance Metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Reference</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SPD</strong> (Mean speed)</td>
<td>0.000</td>
<td>0.000</td>
<td>0.598</td>
<td>0.589</td>
<td>0.002</td>
</tr>
<tr>
<td><strong>SRR</strong> (Steering wheel reversal rate)</td>
<td>0.000</td>
<td>0.000</td>
<td>0.008</td>
<td>0.193</td>
<td>0.000</td>
</tr>
<tr>
<td><strong>SDLP</strong> (Standard deviation of lane position)</td>
<td>0.000</td>
<td>0.662</td>
<td>0.001</td>
<td>0.022</td>
<td>0.465</td>
</tr>
</tbody>
</table>
Cognitive Workload Measures: Physiological Arousal

<table>
<thead>
<tr>
<th>Physiology</th>
<th>HR</th>
<th>Mean heart rate</th>
<th>0.000</th>
<th>0.002</th>
<th>0.001</th>
<th>0.001</th>
<th>0.000</th>
<th>0.251</th>
<th>0.371</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRV</td>
<td></td>
<td>Heart rate variability</td>
<td>0.018</td>
<td>0.476</td>
<td>0.019</td>
<td>0.538</td>
<td>0.695</td>
<td>0.340</td>
<td>0.396</td>
</tr>
<tr>
<td>SCL</td>
<td></td>
<td>Mean skin conductance level</td>
<td>0.000</td>
<td>0.015</td>
<td>0.007</td>
<td>0.140</td>
<td>0.358</td>
<td>0.467</td>
<td>0.150</td>
</tr>
</tbody>
</table>
Cognitive Workload Measures: Eye Behavior

<table>
<thead>
<tr>
<th>Eye Behavior</th>
<th>SDHG</th>
<th>Standard deviation of horizontal gaze</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>SDVG</td>
<td>Standard deviation of vertical gaze</td>
<td></td>
</tr>
<tr>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>VG</td>
<td>Mean vertical gaze</td>
<td></td>
</tr>
<tr>
<td>0.001</td>
<td>0.377</td>
<td>0.076</td>
</tr>
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Discussion
Measures for Detecting Cog. Load

• No measure was significant affected by age
  • Older drivers have lower mean values in physiological data, But not significant
  • Measures can be applied for both of younger and older drivers
• The best measures for detecting cognitive demands
  • Heart rate: Sensitive & Independent indicator of changes in cognitive workload
  • Brookhuis and De Waard
    • Heart rate increased with heightened task demand, such as entering a traffic circle, and dropped as task demands decreased, for instance, driving on a two-lane highway.
  • Mehler et al.
    • A near linear increase in heart rate and skin conductance appeared across the demand levels. The most useful measure in estimating the difficult level of cognitive workload in a driving environment.
Discussion

Measures for Detecting Cog. Load

• Eye Movement Measures
  • Can detect relatively high cognitive workload
  • Horizontal gaze variation
    • Concentration of gaze with added cognitive demand
    • Not only cognitive demand with reasonable sensitivity but also visual distraction with high accuracy
  • Limitation of FaceLAB
    • Pupil diameter & Blink characteristics were not affected by cog. load

• Driving Performance Measures
  • Can detect relatively high cognitive workload
  • Steering wheel reversal rate has shown good sensitivity
    • Distinguish most levels of cognitive demand except the highest cognitive workload
    • Sensitivity of SRR might be degraded on road environment, because the results of SRR were conducted from straight highway driving
Multiple Tasks

- Characteristics of Older Adults
  - More poorly performing two tasks at once
  - The magnitude of the age difference increases with the task difficulty
  - Where tasks are relatively simple, older adults perform as well as younger

- Designing for Older Adults
  - Not to require the combined performance of tasks.
Sensitive measures for detecting cognitive workload

- Best performance and sensitivity
  - Heart Rate (HR)
- Physiological Domain
  - Skin Conductance Level (SCL)
    - Good performance with slightly lower sensitivity than HR
- Eye Behavior Domain
  - S.D. of Horizontal Gaze
- Driving Performance Domain
  - Steering reversal rate
    - Useful measure by combining with the other domains’ measures
Thank You For Your Attention!
(Contact: json@dgist.ac.kr)