Monitoring Driver’s Mental Workload for User Adaptive Aid

Promotor
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2001 – 2006 Psychology

2008-2014 PhD Student

2012 – 2014 (postdoctoral) researcher;
• Fitness to drive (dementia, borderline, chronic medicine use)
• Pay As You Drive Insurance
• Assisting older drivers with entering the highway
• Factsheets on DRIPS, behavioural adaptations due to Intelligent Transport Systems

Computer Idee, augustus
REsponsive FLExible Collaborating ambient

Goal: develop a software framework with a set of practical tools which can be used for building pervasive, adaptable, self-organized systems that seamlessly collaborate with users and control their environments.
Emotional Loop
Physical Loop
Cognitive Loop

Demonstration in Maranello
Rationale

Human operates machine/tools

Better:
Technology capable of recognizing our mental state is better able to help us achieve goals by adapting to our changing wishes and needs.
Sensor data

Human

Machine/Computer

Machine intervention
Task Demands/Task Environment

Task Performance

Biometrics

Sensor data

Human

Machine/Computer

Machine intervention
Central concepts

- Adaptive Automation
- (Brain-Computer interface)
- Mental Workload
- Lane keeping task
Adaptive automation (AA)

- Automation / Artificial Intelligence (‘70)
- Minimise ‘out of the loop’ automation problems.
- Tasks shift between human and computer
- Stabilise levels of work (workload/comfort/output)
- Implicit vs. Explicit control loop
## Level of Automation

<table>
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<tr>
<td>1  human does the whole job up to the point of turning it over to the computer to implement</td>
<td>1  Manual control</td>
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<td>2  computer helps by determining the options</td>
<td>2  Action support (computer assists performing action, e.g., teleoperator)</td>
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<td>3  computer helps determine options and suggests on, which human need not follow</td>
<td>3  Batch processing (computer performs tasks automatically as selected by the operator)</td>
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<td>4  computer selects action and human may or may not do it</td>
<td>4  Shared control (computer and operator generate options, the operator selects, performance shared)</td>
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<td>5  computer selects action and implements it if human approves</td>
<td>5  Decision support (computer and operator generate options, the operator selects, computer performs)</td>
</tr>
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<td>6  computer selects action, informs human in plenty of time to stop it</td>
<td>6  Blended decision making (computer generates options, computer selects option, operator consents, computer performs)</td>
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<td>7  computer does whole job and necessarily tells human what it did</td>
<td>7  Rigid System (computer generates limited number of options, operator consents, computer performs)</td>
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<tr>
<td>8  computer does whole job and tells human what it did only if human explicitly asks</td>
<td>8  Automated decision making (computer and operator generate options, computer selects and performs)</td>
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<tr>
<td>9  computer does whole job and tells human what it did and it, the computer, decides he should be told</td>
<td>9  Supervisory control (computer generates, selects and performs. Operator monitors and might intervene by shifting the system to a lower LOA).</td>
</tr>
<tr>
<td>10 computer does whole job if it decides it should be done, and if so tells human, if it decides he should be told</td>
<td>10 Full automation (the human is completely out of the control loop)</td>
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Flexible, dynamic task allocation
What to support?

Fig. 1. Simple four-stage model of human information processing.*

Figure 2.1. Levels of automation for independent functions of information acquisition, information analysis, decision selection, and action implementation. Examples of systems with different levels of automation across functional dimensions are also shown (From Parasuraman et al., 2000, © 2000 IEEE).
Mental workload:
The proportion of capacity that is allocated for task performance.

Mental workload = \frac{\text{Task demands}}{\text{Available capacity}}

Inter-intra individual differences
- talent, training
- fatigue, time of day, moods, motivation

De Waard, 1996
Lane keeping task

› Major part of driving

› Ca. 1/3 of accident involving personal injury or death related to inadequate steering*

Central goal thesis:

Monitor changes in mental workload levels as elicited from the lane-keeping task when driving on rural roads

(and connect these changes to automated driver support actions)
Traditional statistics:
- **Offline** studies at the group level

Classification studies:
- **Offline** studies at the individual level

Classification studies:
- *(Pseudo)*Online studies at the individual level

Test applications. Which interventions could influence the mental state of the user?

Online studies at the individual level AND ‘closing the loop’
Thesis Outline

• Steering demand and mental workload
• A performance based adaptive driver support system
• The potential of music selection for adaptive driver support
• Classifying visuomotor workload from brainwaves
• A brain and performance based adaptive cruise control
Study 1

Offline, group study:

Associations with steering demand levels

(sensitivity to workload changes)

**Design**  \( (N=30) \)

- **Lane width:**
  - 3.00, 2.75, 2.50, and 2.25 m

- **Oncoming traffic density:**
  - Low and High density
    - Low: 6 cars/minute for 6 minutes
    - High: 40 cars/minute for 2 minutes

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*Including 27.5 cm (edge and central) lines*
Variables

Driving parameters
- Lateral Position
- SD Lateral Position
- Time over lines

Physiology
- Heart Rate
- Heart Rate Variability

Subjective
- Mental Effort
- Risk
Results/Conclusions

• SDLP was sensitive to all levels of steering demand
  - Behavioural adaptation to maintain safety margins (reflects changes in mental workload)
• Mental effort ratings sensitive to changes in lane width, but only in high density oncoming traffic
  - Threshold effect of awareness
• Heart rate variability sensitive to traffic density
• **Using multiple types of measures is probably required for reliable mental workload assessment over a wide range of task demands when designing a support system.**
Study 2

Test Application

A performance based support system

• Monitoring three vehicle parameters,
• over a 30 seconds period,
• continuously updating,

• HUD was triggered by passing thresholds
• 10 sec deadband
Design (N=32)

- Support mode (3);
  1: Continuously off
  2: Adaptive
  3: Continuously on

- Lane width (2);
  1: Narrow (2.25 m)
  2: Wide (3.00 m)

- Oncoming traffic density (2); (nested into the each condition)
  1: Low (6 cars/minute for 7 minutes)
  2: High (40 cars/minute for 1 minute)
Results

• Lateral Position: Effects of the adaptive HUD small but significant.

• Lateral Position: Adaptive HUD caused more central driving when on a wide lane and in dense traffic.

• SDLP: Adaptive HUD caused less swerving when on a wide lane and in dense traffic.
Results

How did you mainly used the HUD?

- Information: 15%
- Warning Signal: 15%
- Ignore: 35%
- Different: 5%
Conclusions

• Effect of HUD small compared to other manipulations

• An adaptive system may be used differently than anticipated

• Purely adaptive support on the information acquisition level may be impossible
Study 4

 offline, individual study:

 **EEG associations with steering demand levels**

(sensitivity to workload changes)

Individual approach!

• Traditional statistics, even RM ANOVA’s rely on group behaviour.
  • Effect direction consistency
• An individual application calls for individual data analysis.
• BCI!
Brain-computer interface (BCI)

- **Input:** brain activity
- **Central processing:** classification / decision algorithm
- **Output:** control signal / action
Common Spatial Pattern (CSP)

- Not a classifier but a filter.
- Filter or transforms two data sets
  - EEG
- To maximise difference in a chosen frequency band.
- Illustration
- The actual classifying can be done by a Linear Discriminant Analysis.
Common Spatial Pattern (CSP)
Offline classifications

Select two levels of lane keeping demand of a participant (two data classes)

Frequency band filter

Segment all data into 1 s epochs

Randomly select 75% epochs for training

Determine CSP filters

Determine discriminant function (LDA)

Classify the remaining 25% test epochs

Repeated 50 times to avoid selection bias
Design (n=34)

- Task:
  Rural driving: easy curves.
  Automatic speed control
- Manipulation:
  Speed and ‘Lateral Performance Target’.
    - Speed:
      - [-40, -20, 0, 20, 40] km/h
      - Speed relative to initial/baseline speed
    - Performance Target:
      - Normal, hard, very hard
      - Current SDLP calculated over 15 sec. time frame / updated at 2 Hz.
      - Target SDLP relative to initial ride
- Design:
  Speed (5) x Target (3)
Measurements: EEG

- 21 EEG electrodes
- Reference A1-A2
- EOG to correct for eye-movements
- Several subsets of electrodes
- A lot of frequencies
- A lot of condition pairs
Classification results

- High frequencies do better
- More electrodes give higher accuracy
- Frontal set outperformed the posterior set
Conclusions

• This technique is highly sensitive to changes in mental workload / task demand

• High accuracy for high frequencies suggest classification on muscular activity

• Promising for developing driver support systems
Study 5

Test applications

A brain and performance based adaptive cruise control
Adaptive cruise control

- Detect low, comfortable and high mental workload of the driver
- Maintain workload by changing speed

- Expanding from a binary approach to a multiclass approach
- Multiple pairwise classifications, then a vote.
Select two levels of lane keeping demand of a participant.

Frequency band filter

Segment all data into 1 s epochs

Randomly select 75% epochs for training

Determine CSP filters

Determine discriminant function (LDA)

Classify the remaining 25% test epochs

Repeated 50 times to avoid selection bias

Calibration phase
Select two levels of lane keeping demand of a participant (two data classes)

Frequency band filter

Segment all data into 1 s epochs

Determine CSP filters

Determine discriminant function (LDA)

CALIBRATION PHASE

LOW VS. COMF

COMF VS. HIGH

LOW VS. HIGH
Feedback phase; for each new epoch a vote:

- **LOW VS. COMF**: Low = 60%, Comf = 40%
- **LOW VS. HIGH**: Low = 70%, High = 30%
- **COMF VS. HIGH**: Comf = 55%, High = 45%

Low = 130, Comf = 95, High 75
Feedback phase

- Classifications at 10 Hz
- 1 second, overlapping EEG epochs

Workload classification probabilities further filtered using an exponentially weighted moving average
- Weighted classifications then advised to speed-up, maintain speed, or slow down.
Feedback Phase

• 3 levels of lane keeping demand (curve length)
• 3 system versions
  – Low frequency (4-20 Hz)
  – High frequency (20+ Hz)
  – driving without BCI
• Initial driving speed set at comfortable speed.
Feedback phase: system behaviour

• Huge individual differences
• Stable and oscillating speed setting behaviour

EEG classifications continually advised ‘slow-down’

EEG classifications continually advised ‘speed-up’, but the driving performance loop intervened (conflict).

EEG classifications continually advised ‘maintain speed’
Conclusions

- Functional BCI for some periods of time.
- Misclassifications were commonplace.
- Dramatic decrease in accuracy from the calibration phase to the feedback phase (not an unique observation!)

- The classifier was TOO task specific
Considerations for future research

• High accuracies for offline studies are a long way removed from creating a well-functioning system

• Substantial improvements of classification accuracy transferability are required.
  • E.g. adaptive classifiers

• Even a highly reliable classifier may necessitate safety protocols (e.g. from task performance)

• Consider different support actions (limited to information, warnings, and suggestions).
Take home messages

• Psychophysiological measures of mental states require considerable research before they can be applied to real life systems, especially in safety critical tasks.
  • An approach aimed at avoiding extreme levels may be worthwhile
• Be very careful in extrapolating conclusions from offline and group level studies to online, interactive systems; things may get ‘lost in translation’
• Multiple sources of information should be combined for a more reliable assessment of e.g. mental workload
• Users of adaptive systems may not always behave as expected; expect behavioural adaptations.
That’s it!

Questions?

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