Modeling and Tracking Brain Nonstationarity in a Sustained Attention Task

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Toward real-time **alert** and **drowsy** states assessment



Drowsy Driving

National Sleep Foundation (2005)

- 60% drowsy driving (past year)
- 37% fall asleep at the wheel
- 10-30% of all crashes[1]

Problems:

- No test to determine drowsiness
- Self-reporting is unreliable

Brain Activities: EEG
(Electroencephalogram)
Biosignals, Behaviors

Alert / Drowsy
State Assessment

Real-time feedback:
Intervention (alarm)

[1]source: http://drowsydriving.org/about/facts-and-stats/

Challenges

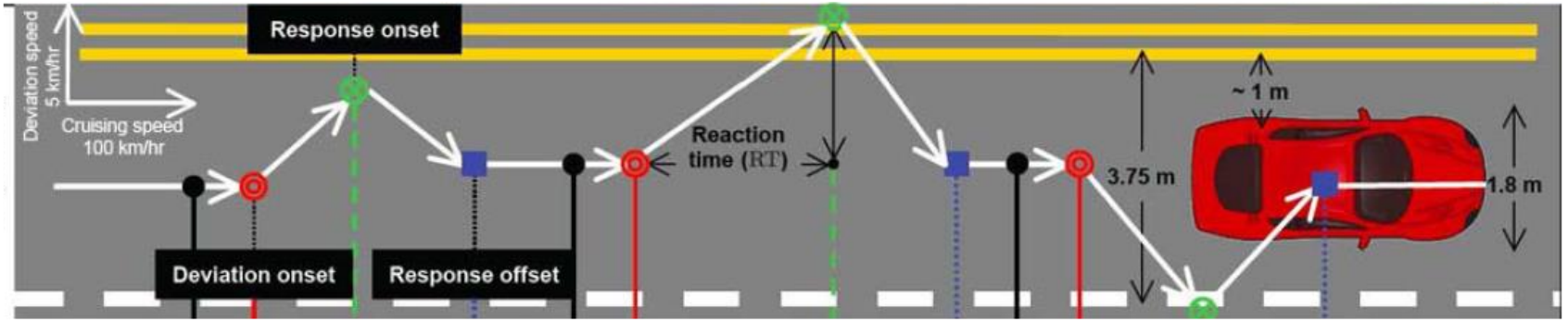
- What are the differences in brain activities when the brain is alert vs. drowsy?
- How to quantitatively assess the level of alertness? Tracking in real-time?

Study	Modality	Features
Wierwille et al., 1994	Video, EOG	eye closure
Makeig et al., 1993	EEG	coherence in power spectra
Jung et al., 1997	EEG	α and θ band power
Golz et al., 2007	EEG, EOG, pupil size	power spectra
Peiris et al., 2011	EEG	power spectra, approximate entropy, fractal dimension

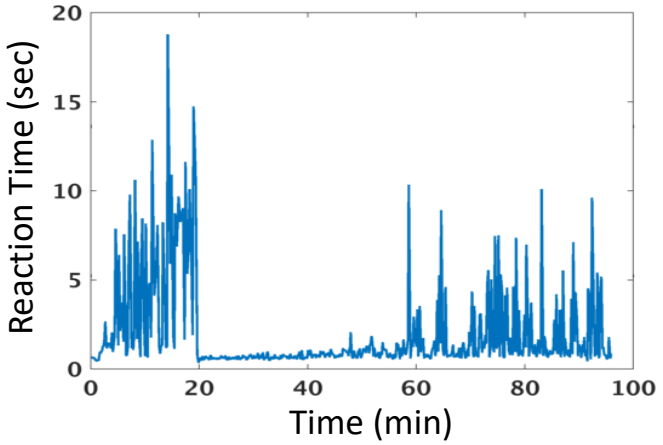
Sustained-attention task for studying alertness fluctuation







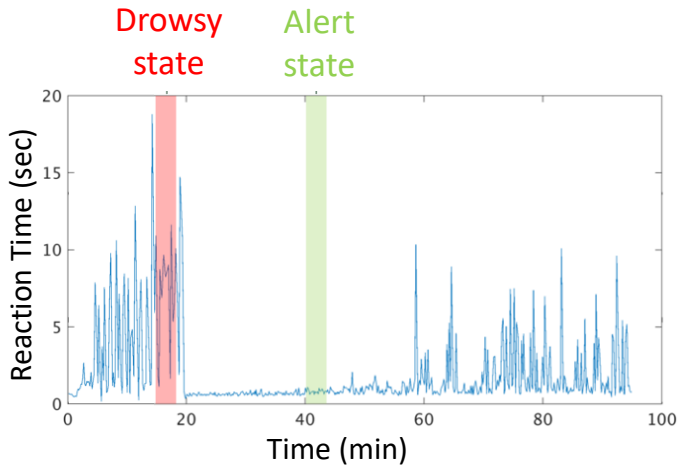
Reaction Time (RT)



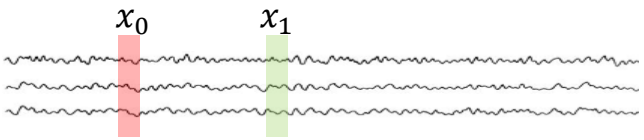
Adapted from Chuang et al., IEEE TNSRE, 2014

Hypothesis:
different states involve different active EEG sources

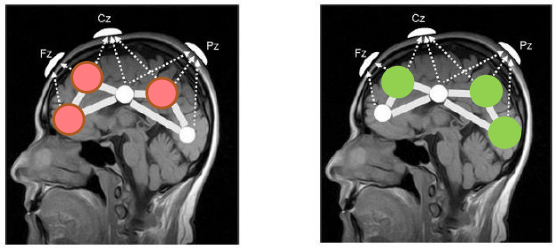
Alert/Drowsy State Change



EEG channel-space ($\boldsymbol{x}$)

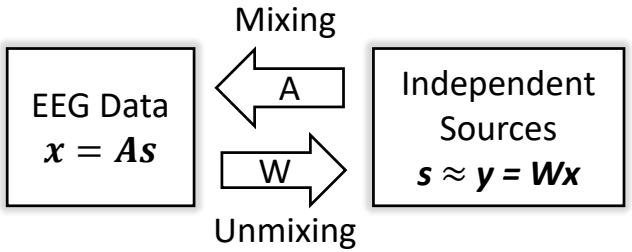


EEG Source-space ($\boldsymbol{s}$)



$x_0 = A_0 s_0$ $x_1 = A_1 s_1$

Independent Component Analysis (ICA)

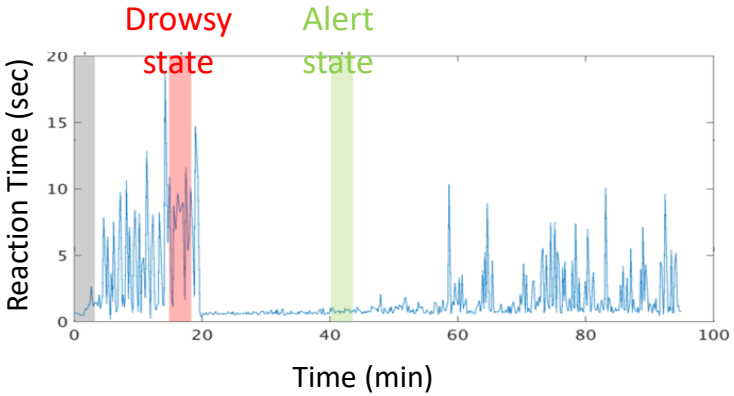


ICA models:

Source composition and activation

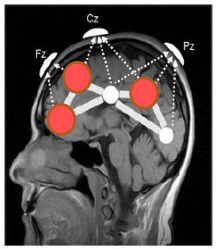
$$x(t) = A_k \cdot s_k(t)$$

Methods

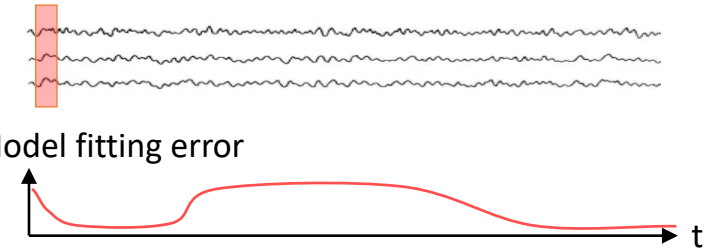


Drowsiness ICA Model

$y_0 = W_0 x_0$

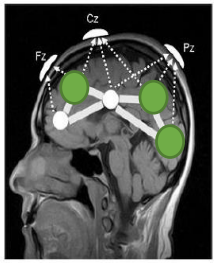


$y(W_0) = W_0 x_{test}$

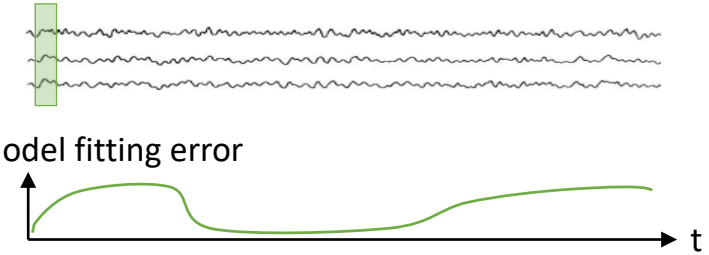


Alertness ICA Model

$y_1 = W_1 x_1$



$y(W_1) = W_1 x_{test}$



Infomax ICA [Lee et al. 1999]:

$$\boldsymbol{W} \leftarrow \boldsymbol{W} + \eta[\boldsymbol{I} - \boldsymbol{f}(\boldsymbol{y}) \cdot \boldsymbol{y}^{\boldsymbol{T}}]\boldsymbol{W}$$

Model Deviation Index (MDI)

$$MDI\ (\boldsymbol{W}_0) = \frac{\left\| \langle \boldsymbol{f}_i \cdot \boldsymbol{y}_j^T \rangle_{i \neq j} \right\|_F}{\left\| \langle \boldsymbol{y} \cdot \boldsymbol{y}^{\boldsymbol{T}} \rangle \right\|_F}$$

$$\boldsymbol{y} = \boldsymbol{W}_0 \boldsymbol{x}$$

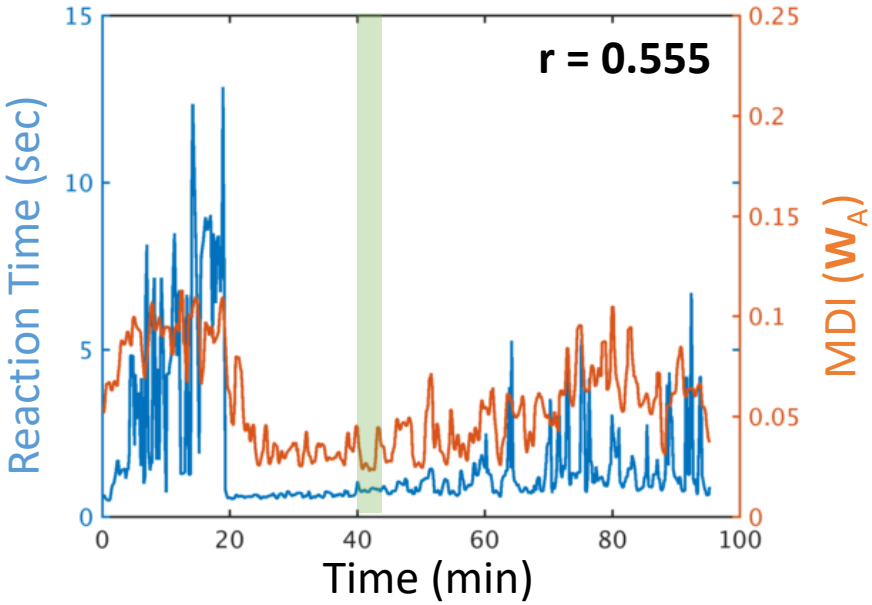
$$\boldsymbol{f}(\boldsymbol{y}) = tanh(\boldsymbol{y}) + y$$

Notation:

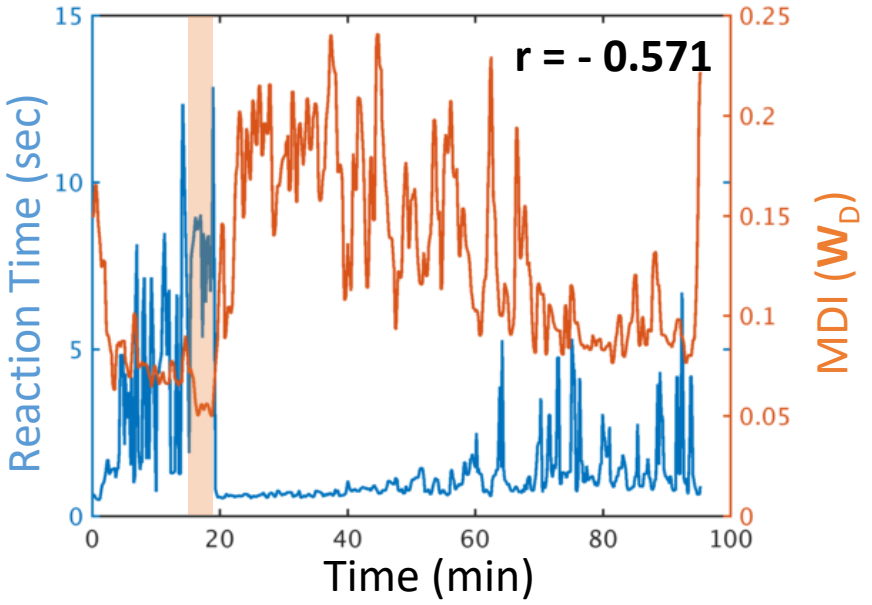
- $\boldsymbol{x}$: EEG data
- $\boldsymbol{y}$: source activity
- $\boldsymbol{f}$: nonlinear function
- $\boldsymbol{W}_0$: ICA filter / model
- $\langle \cdot \rangle$: window average
- $\|\cdot\|_F$: Frobenius norm
- η : learning rate
- $\boldsymbol{I}$: identity matrix

Results

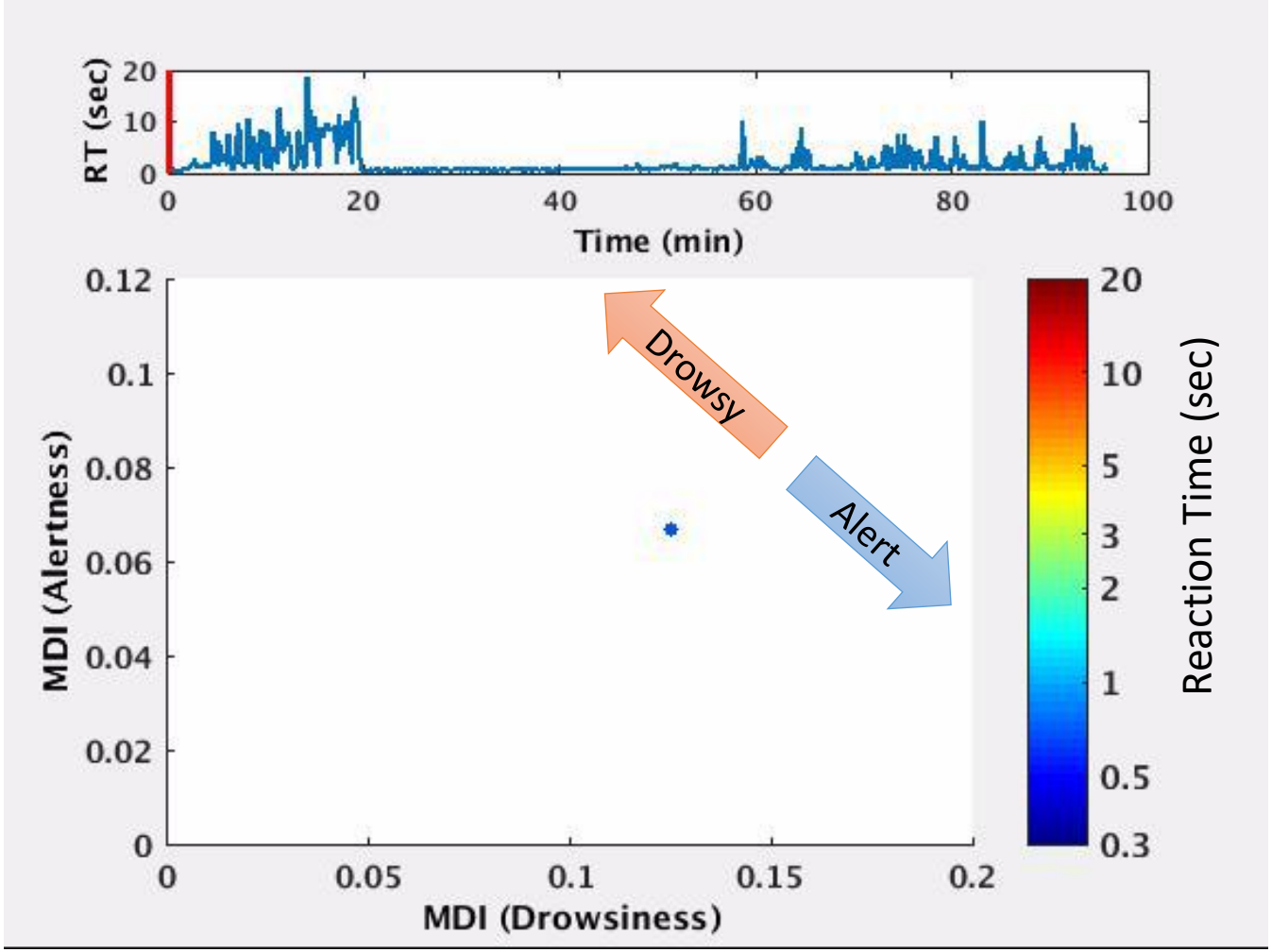
Alertness ICA Model



Drowsiness ICA Model

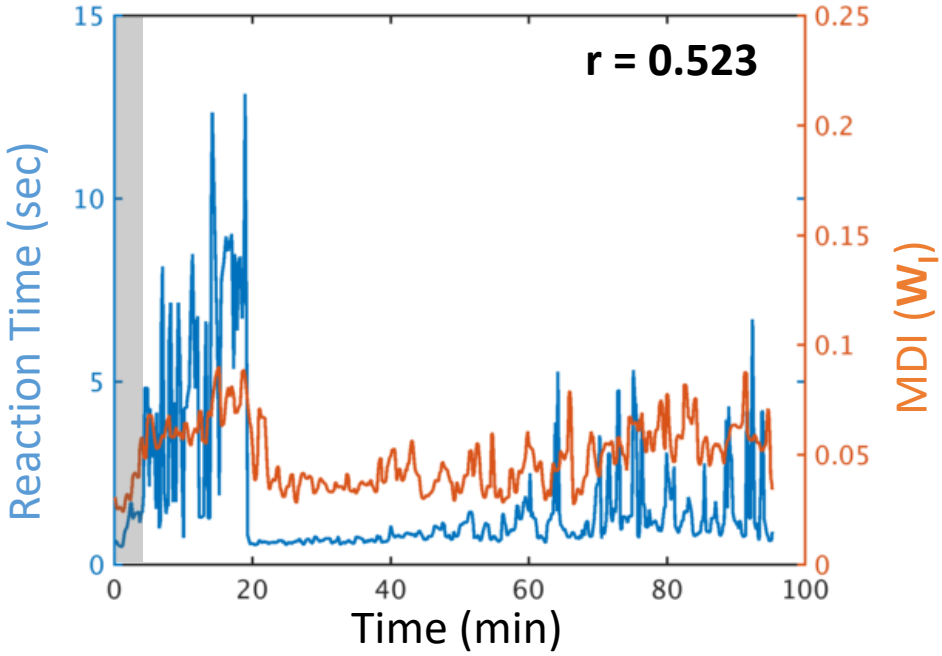


MDI feature space for tracking levels of alertness

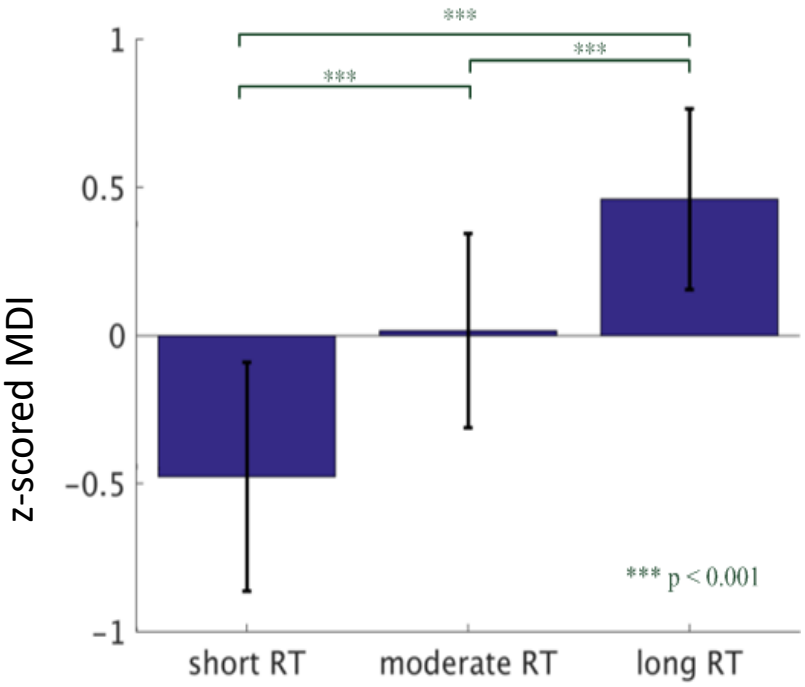


Online tracking using initial models

Initial Model



Across 8 subjects



Conclusion

- Propose a framework to quantitatively assess EEG nonstationarity as an index of the levels of alertness.
- Study results show alert and drowsy states involved different EEG source composition and activity using ICA.
- Study results also show the model-deviation index can quantitatively track the levels of alertness.
- Demonstrate the feasibility of online tracking using the initial ICA models.

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