Heart rate variability as an indicator for driver fatigue, different effects of time of day and time-on-task

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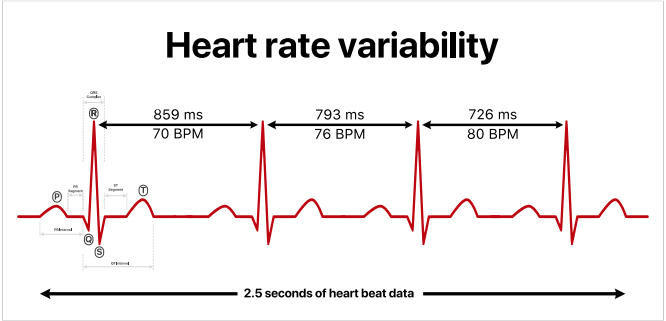
Background

- Heart rate variability (HRV) is the fluctuation of time between adjacent heart beats.
- Generated by heart-brain interaction through the sympathetic and parasympathetic branches of the autonomic nervous system.
- HRV can reflect the response to central autonomic commands associated with stress, physical activity, arousal, sleep, etc. (Silvani et al., 2016).
- HRV has the potential to be a valuable marker for driver fatigue.



Silvani, A., Calandra-Buonaura, G., Dampney, R. A., & Cortelli, P. (2016). Brain–heart interactions: physiology and clinical implications. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 374(2067), 20150181.
Figure: https://commons.wikimedia.org/wiki/File:Heart_rate_variability_(HRV).svg (CC BY-SA 4.0)

Review: HRV-fatigue relation

- Findings about the relationship between HRV and fatigue are inconsistent
- Different experiment implementations may cause the inconsistency in results

Feature	Feature	Increase under fatigue	Decrease under fatigue	No significant change
NN mean	Mean values of NN intervals	(Zeng et al., 2020) (Buendia et al., 2019) (Lenis et al., 2016) (Khamis et al., 2016) (Jung et al., 2014)		(Egelund, 1982)
SDNN	Standard deviation of NN intervals	(Persson et al., 2020) (Buendia et al., 2019) (Lenis et al., 2016)	(Jung et al., 2014)	(Egelund, 1982)
RMSSD	Root mean square of successive differences	(Persson et al., 2020) (Buendia et al., 2019) (Lenis et al., 2016)	(Jung et al., 2014)	
VLF	Very low frequency spectral power	(Zeng et al., 2020)		(Persson et al., 2020)
LF	Low frequency spectral power	(Persson et al., 2020) (Zeng et al., 2020) (Buendia et al., 2019) (Egelund, 1982)	(Jung et al., 2014)	
LFnu	Normalized power in LF band	(Persson et al., 2020) (Buendia et al., 2019)		(Zeng et al., 2020)
HF	High frequency spectral power	(Zeng et al., 2020) (Buendia et al., 2019)	(Jung et al., 2014)	(Persson et al., 2020)
HFnu	Normalized power in HF band		(Persson et al., 2020)	(Buendia et al., 2019) (Zeng et al., 2020)
LF/HF	Ratio between LF and HF	(Persson et al., 2020) (Buendia et al., 2019) (Jung et al., 2014) (Li and Chung, 2013)	(Vicente et al., 2016) (Rahim et al., 2015) (Patel et al., 2011)	(Zeng et al., 2020)

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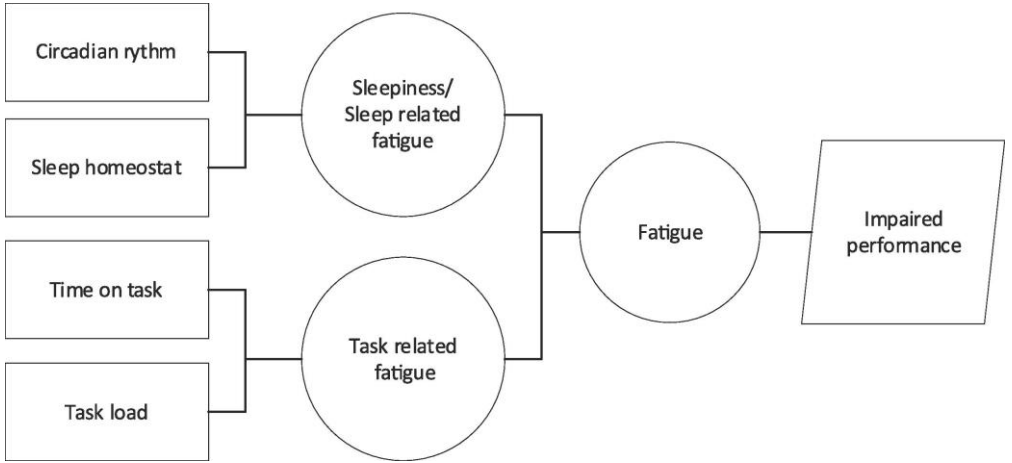
Potential causes for inconsistency

- Number of participants
- Driving condition
- Reference fatigue measure
- Fatigue causing factor



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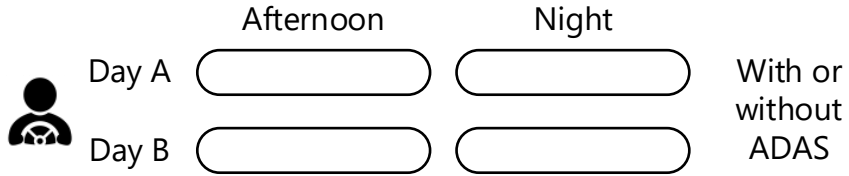
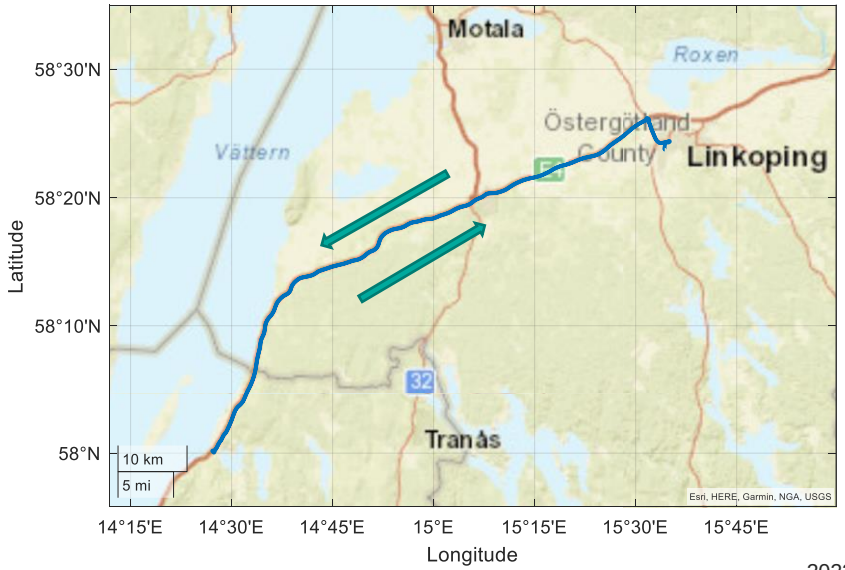
Aim

- The purpose of this study is to investigate relationships between HRV parameters and two fatigue factors, i.e., time of day and time-on-task

Method-dataset

- 89 drivers (36 F, 53 M), 20-59 years old
- 2 days, 4 drives per participant
  - Daytime and nighttime
  - With and without ADAS
- 180km motorway (90km round trip)
- Measurements
  - ECG, EOG, respiration, Eye-tracking
  - Subjective sleepiness rating



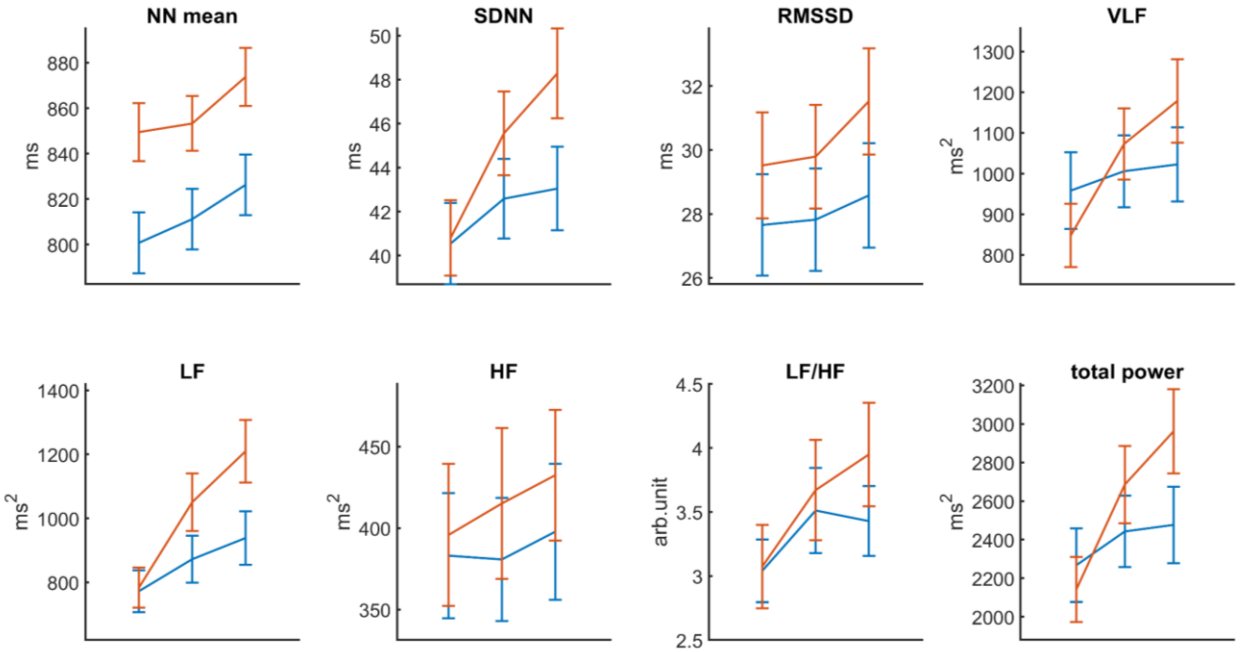


Ahlström, C., Zemblys, R., Jansson, H., Forsberg, C., Karlsson, J., & Anund, A. (2021). Effects of partially automated driving on the development of driver sleepiness. Accident Analysis & Prevention, 153, 106058.

Method-processing

- HRV features extracted with 5-min wide sliding window with 1-min step size.
- Time domain features including NN mean, SDNN, RMSSD, and frequency domain features including VLF, LF, HF, LF/HF
- Each drive divided into four 20-min long segments, two with outward and two with return driving.
- The first 20 min segment was excluded for the analysis to eliminate the influences at the start of the driving caused by being attached with sensors, talking to the test leader and getting familiar with the task, etc.

Results



Mean value of HRV features in three different time-on-task segments (x axis) and separated by afternoon (blue) and night (red) driving. Error bars represent standard error of mean.

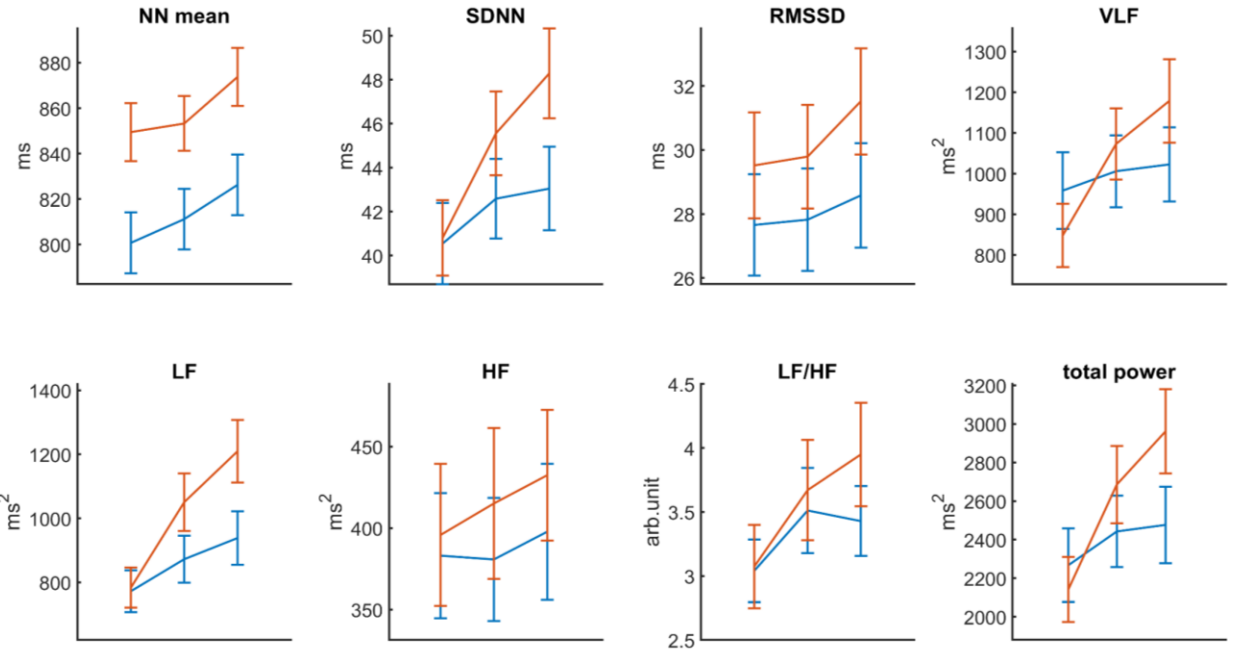
Results

ANOVA test

HRV features	Time of day (df=1)		Time-on-task (df=2)		Interaction, time of day * time-on-task	
	F	p	F	p	F	p
NN mean	**298.96**	**<0.0001**	**29.39**	**<0.0001**	0.46	0.6300
SDNN	**40.10**	**<0.0001**	**46.69**	**<0.0001**	**7.19**	**0.0008**
RMSSD	**48.13**	**<0.0001**	**7.65**	**0.0005**	0.44	0.6443
VLF	2.36	0.1249	**47.70**	**<0.0001**	**10.37**	**<0.0001**
LF	**41.15**	**<0.0001**	**66.11**	**<0.0001**	**8.02**	**0.0003**
HF	**11.24**	**0.0008**	**4.32**	**0.0134**	0.50	0.6069
LF/HF	**9.89**	**0.0017**	**59.88**	**<0.0001**	**6.83**	**0.0011**
Total power	**14.87**	**0.0001**	**46.41**	**<0.0001**	**8.79**	**0.0002**

Results

- No significant difference in mean values between afternoon and night for the first time-on-task segment for SDNN, LF, HF, and LF/HF.
- No significant difference in mean values between first and last time-on-task segments for HF in afternoon driving.



Mean value of HRV features in three different time-on-task segments (x axis) and separated by afternoon (blue) and night (red) driving. Error bars represent standard error of mean.

Conclusions

- Different response patterns to time of day and time-on-task were found for different HRV parameters.
- Fatigue caused by different factors has different influence on driver performance and countermeasures may vary accordingly (Williamson et al., 2011). This difference may indicate a physiological difference in sleep related and task related fatigue.
- It emphasizes the importance of considering the fatigue causing factors when interpreting results from related studies and designing future studies with physiological measurements.

Williamson, A., Lombardi, D. A., Folkard, S., Stutts, J., Courtney, T. K., & Connor, J. L. (2011). The link between fatigue and safety. Accident Analysis and Prevention, 43(2), 498–515.

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