Sleepiness on Task can be Detected Using Heart Rate Fluctuations

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Introduction

Complex regulatory and biofeedback systems rule human function and behavior. Sleep is vital, ruled by homeostatic balance and circadian oscillations. Sleepiness represents an important causal factor for accidents and daytime malfunction. Analysis of instantaneous fluctuations in heart rate allows to estimate the cardiac autonomic regulation at the sinus node level[1] and represents a window to other complex physiological functions such as sleep and wakefulness.[2] Our goal is to find a non-invasive method to predict involuntary falling asleep on task, mainly while driving.

Methods

- The present study was performed on 10 healthy volunteers.
- The study involved a 34-hour sleep deprivation protocol including two alternating tasks:
  - A standard, passive, 45 minute Maintenance of Wakefulness Test (MWT).
  - A 90 kilometer Driving Simulation (DS).
- During the entire protocol electroencephalogram (EEG), electromyogram (EMG), eye movements (EOG), electrocardiogram (ECG) as well as audio-video were continuously monitored, recorded, and later analyzed off-line.
- Microsleeps (MS) lasting for 3-15 seconds and falling asleep (FA) events lasting 15-120 seconds were detected from EEG and EOG analysis.
- The ECG was analyzed using R-R interval (RRI)
  - Behavior in the time domain,
  - Time-frequency decomposition
  - Entropy
  - Poincare plots (n+1).

Results

✓ The sleep deprivation setting created a large number of MS and FA events during both active DS test and passive MWT tasks.

✓ Time domain analysis was applied to RRI as a function of time awake, and was normalized to the personal average before first MS (B4MS). The values of some parameters after the first MS (AFMS) differed significantly for most calculated parameters, both for MWT and for DS.

A. MWT B. DS

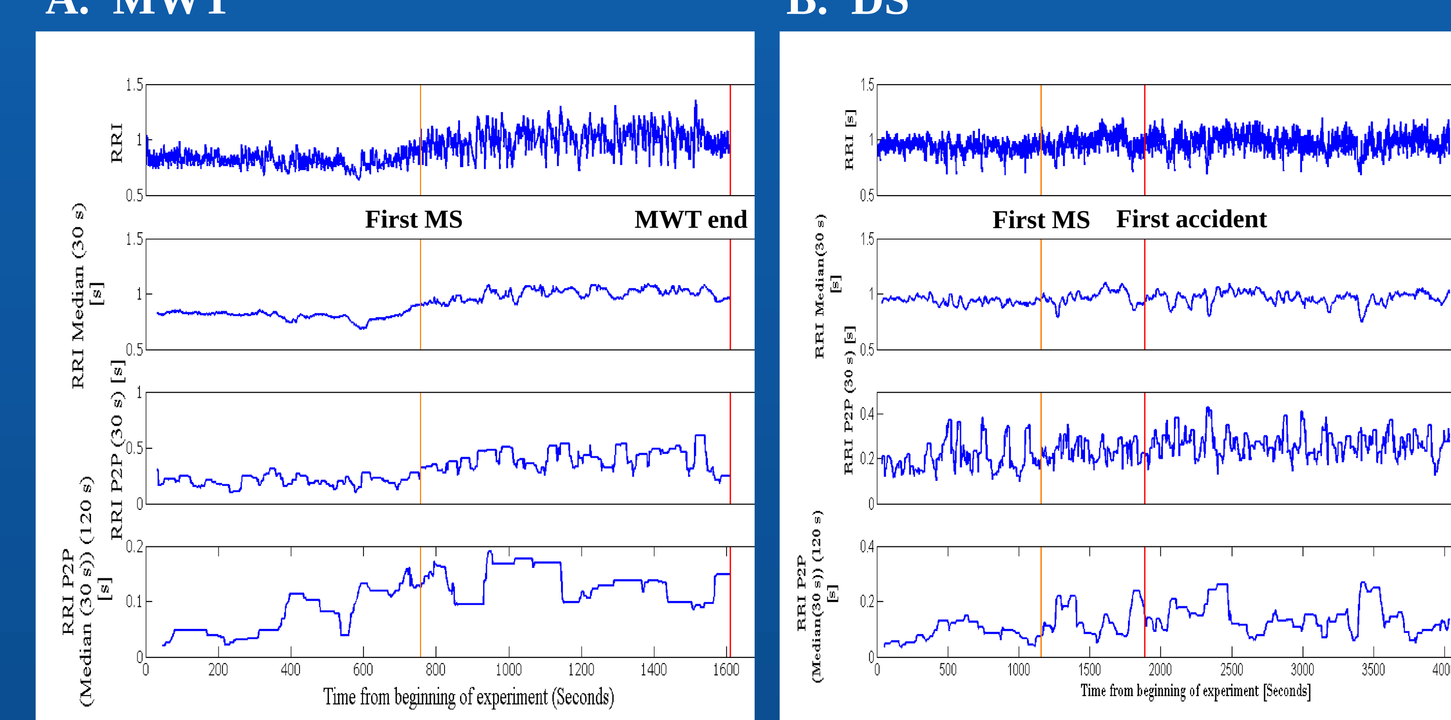

Fig 1: From top to bottom graphs of RRI; RRI median (representing the RRI mean-line); RRI peak to peak (representing the RRI variability), and peak to peak of the median; during A. MWT and in B. DS. Orange line shows time of first MS, red line shows in A. end of MWT, in B. time of first accident.

A. MWT B. DS

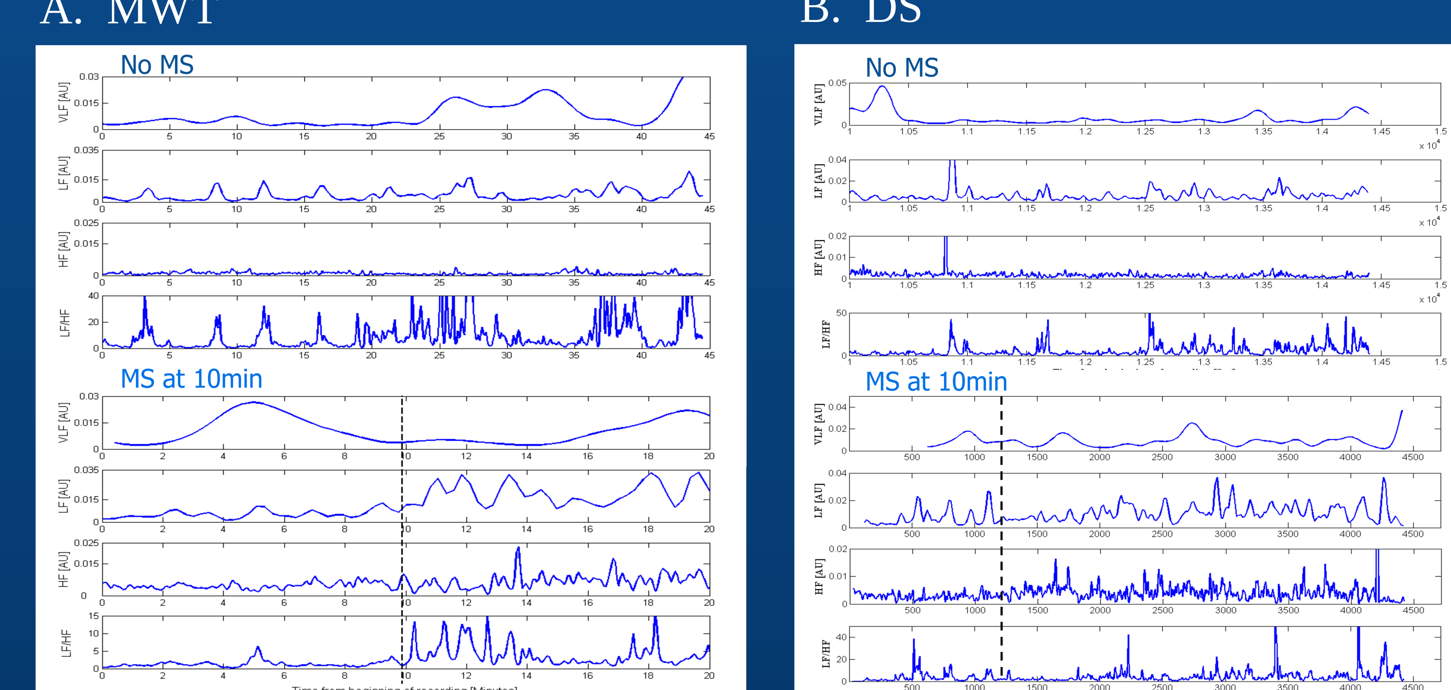

Fig 2: Sample readings for a subject during A. MWT or B. DS. The graphs show spectral variables as a function of time, the top four in the absence of MS, the bottom four in the presence of a micro-sleep event. Dashed line marks the first MS.

✓ Similar results were obtained for Time-Frequency Domain (TFD) variables such as LF, HF and LF/HF ratio.

✓ Significant differences were also observed for Non linear parameters, such as those derived from Poincare Plots and Entropy.

✓ On average the first accident on the simulator task occurred 2-7 minutes after the first MS.

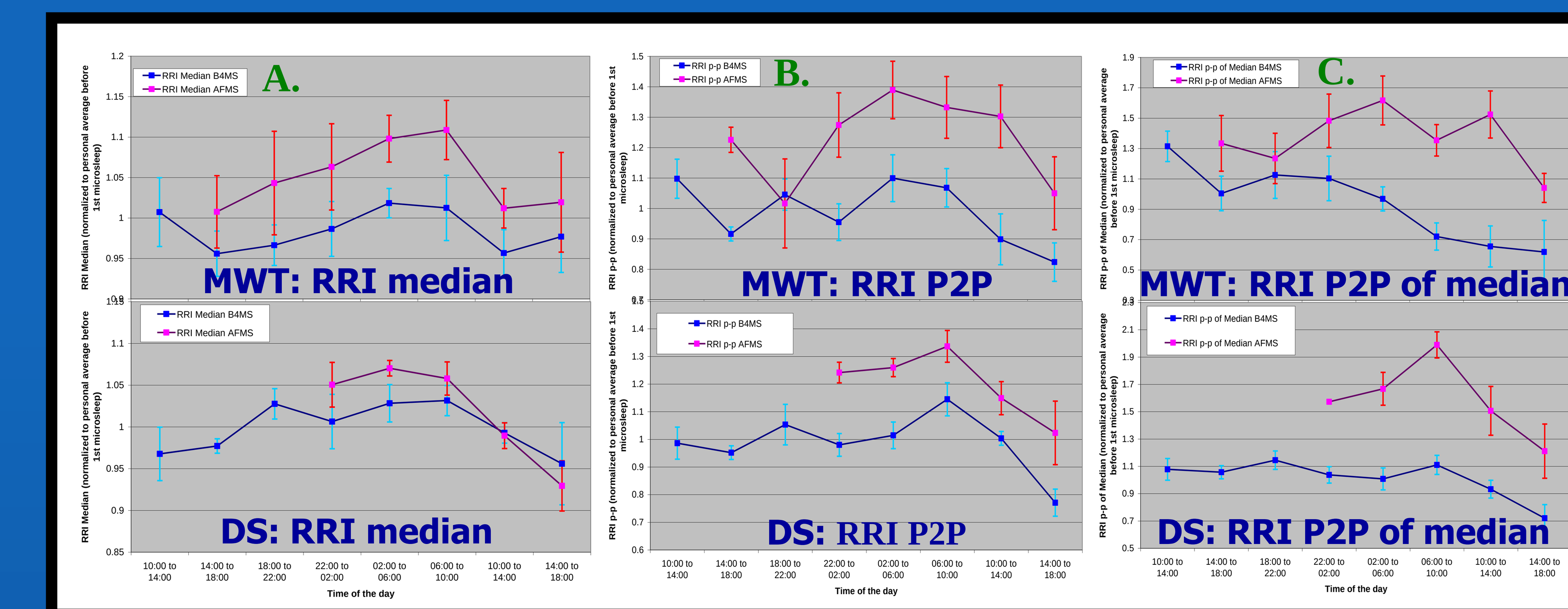

Fig 3: A. Averaged RRI median. B. Averaged RRI Entropy. C. Averaged RRI peak to peak of median. All normalized to personal average before first microsleep.

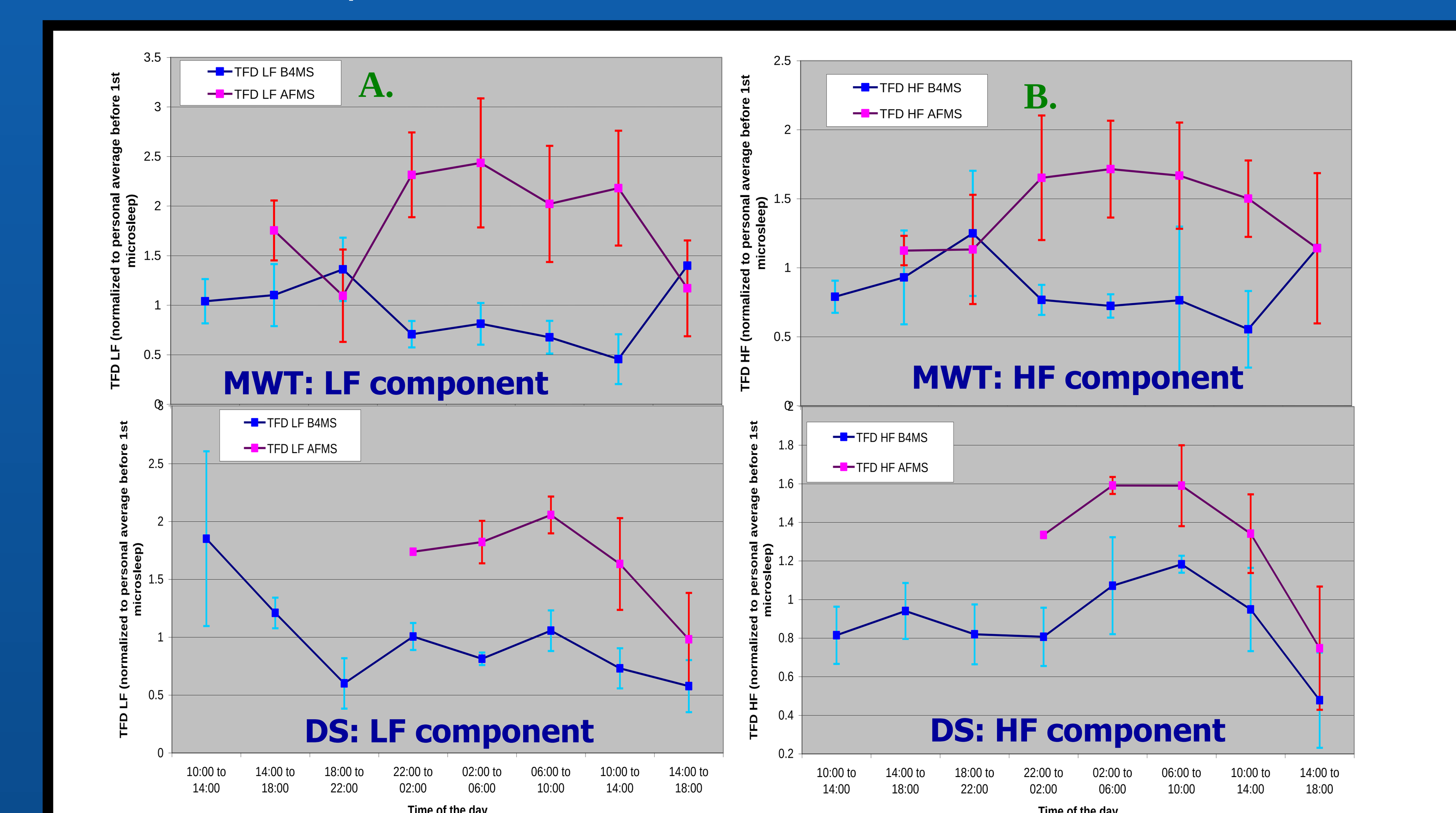

Fig 4: TFD of RRI; A. LF component. B. HF component. All normalized to personal average before first microsleep.

Conclusions

➤ We can thus conclude that the first MS represents a cutoff point in the behavior of HRV based on a number of calculated parameters in the time and time frequency domains.

➤ There are clear HRV markers that indicate sleepiness in sleep deprived subjects. It remains to find if these markers are relevant in non-sleep deprived subjects while performing the same tasks. Provided some of these variables show the same trends, a threshold should be defined as to imminent danger while driving and when a subject should be stopped from continuing a task.

References

1. Baharav, A., S. Kotagal, V. Gibbons, B.K. Rubin, G. Pratt, J. Karin, and S. Akselrod, *Fluctuations in autonomic nervous activity during sleep displayed by power spectrum analysis of heart rate variability.* Neurology, 1995. 45(6): p. 1183-7.
2. Decker, M.J., S. Eyal, Z. Shinar, Y. Fuxman, C. Cahan, W.C. Reeves, and A. Baharav, *Validation of ECG-derived sleep architecture and ventilation in sleep apnea and chronic fatigue syndrome.* Sleep Breath, 2009.