

Cardiac-Activity Measures for Assessing Airport Ramp-Tower Controller's Workload

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Human Factors and Ergonomics Society (HFES) Annual Meeting
September 19-23, 2016, Washington, DC

Background

- Subjective measures of workload have known shortcomings.
 - “Subjective”
 - Low sensitivity

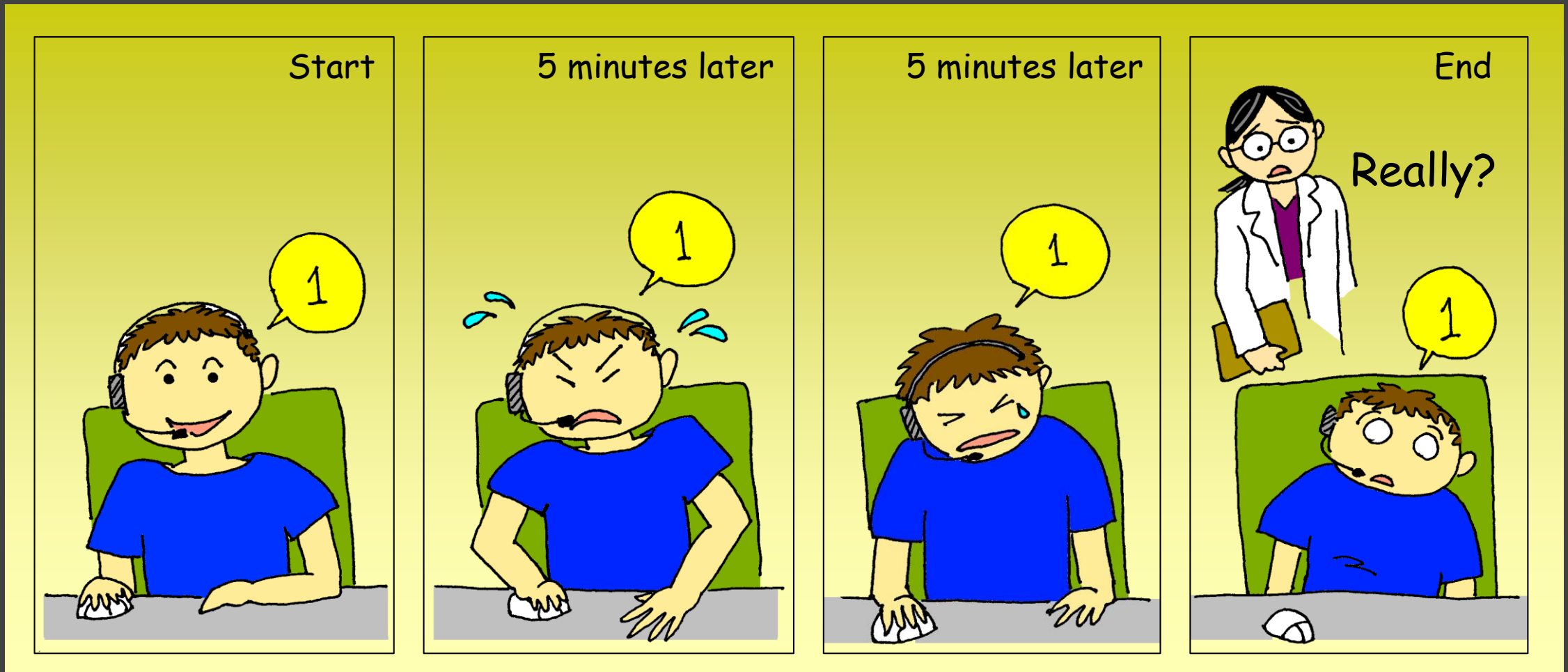
Low Sensitivity

"Please rate your workload level on the scale of 1 to 7, where 1 is the lowest workload and 7 is the highest."

This scenario should cause high workload...



Another case of low sensitivity



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Background

- Subjective measures of workload have known shortcomings.
 - “Subjective” “Objective”
 - Low sensitivity “??”
 - Sparse data, likely missing the important event “Continuous”
 - Potentially distracting, if measured in real time “Non-intrusive”
- **Physiological measures** may potentially address these weaknesses.

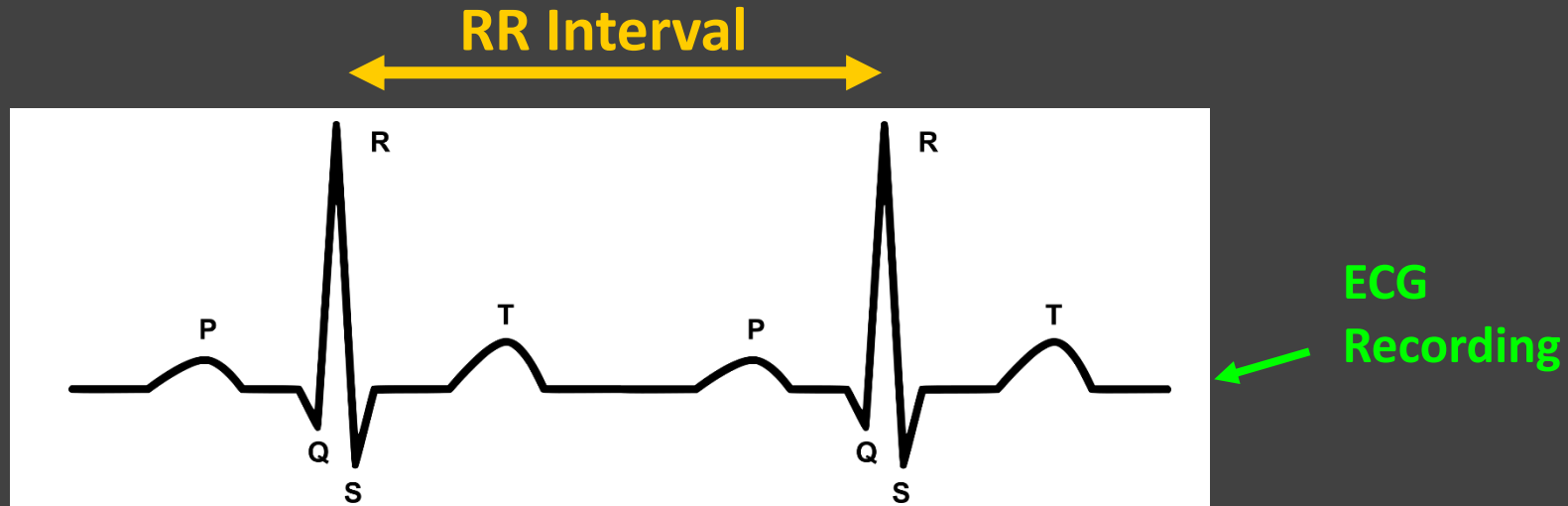
Goal

To examine if **mean heart rate (HR)** and **heart rate variability (HRV)** can be used to measure the controller workload in our air-traffic-control simulation evaluation studies.

- Compared **mean HR** and **HRV** with the real-time self-reported subjective workload rating results.
- Assessed if **mean HR** and **HRV** could replace the subjective measures (e.g., in field tests).

Mean Heart Rate (HR)

- The average number of beats/minute.
 - Derived from the “RR intervals.”

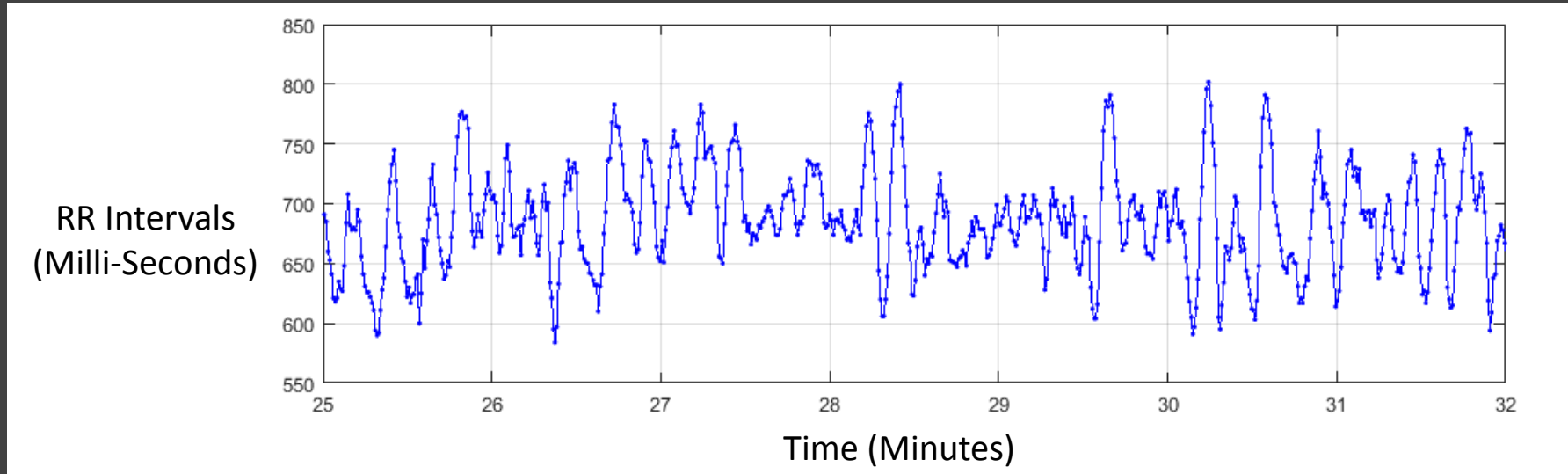


Credit: Agateller (Anthony Atkielski) via Wikimedia Commons

- Considered to reflect an overall level of general arousal, physical work, task demands, and emotional response. (Wierwille & Eggemeier, 1993)

Heart Rate Variability (HRV)

- Measure of variability in the RR intervals.



- Thought to reflect the balance of autonomic nervous system:
 - HF power (0.15 – 0.4 Hz): Parasympathetic activity
 - LF power (0.04 – 0.15 Hz): Parasympathetic and sympathetic activities
 - MF power suppression (0.08 – 0.15 Hz): Increased cognitive effort

Past Studies

- HRV MF suppression used to measure workload:

Authors (Year)	Studied Task
Vicente, Thornton, & Moray (1987)	Low-fidelity hovercraft course-tracking simulation
Rowe, Sibert, & Irwin (1998)	Air-traffic-control game
Tattersall & Hockey (1995)	Military long-haul flight simulation

- Skeptics:
 - Inconsistent MF results for AGARD-STRESS battery task workload (Nickel & Nachreiner, 2003)
 - Large individual differences in stress reactions of autonomic nervous system (Berntson & Cacioppo, 2004)

Methods

Airport Ramp Tower Simulation

- Simulation evaluation of a NASA's departure-metering decision-support tool, Spot and Runway Departure Advisor (SARDA).



- 6 Charlotte airport ramp-tower controllers
- 16 runs per controller
- 65-70 minutes departure “push”
- Self-reported subjective workload rating at every 5 minute
- Resulted in 10-12% taxi fuel saving
- No increase in the controller workload

ECG Recording

- RR intervals were recorded with Firstbeat Bodyguard 2 (BG2).
 - Attached to the body via 2 electrodes.
 - Sampling rate = 1000 Hz
- No activity constraint
 - Free to sit, stand, and walk around.
 - OK to smoke or drink tea/coffee during a break.

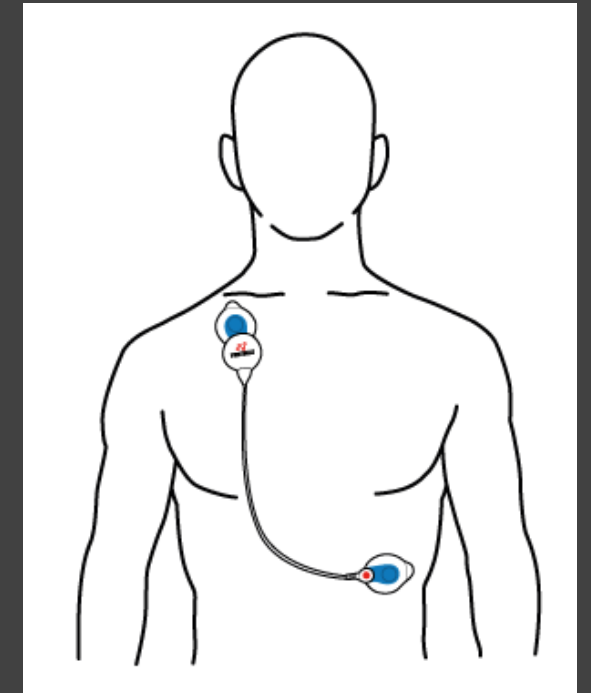
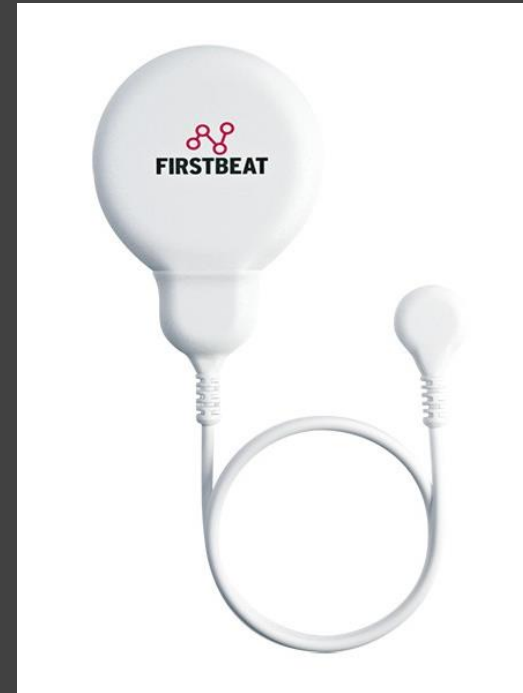


Photo & illustration credit: Firstbeat

Computation of Mean HR and HRV

1. Artifacts in the RR interval data were removed. (No replacement.)
2. Mean HR were computed within the 2-minute windows around the sampling times of the real-time workload ratings.
3. Within the same 2-minute windows, MF, HF, and the total power (0.04 – 0.15 Hz) HRV were computed.
 - Lomb-Scargle Periodogram algorithm was used to estimate the power spectral density.
4. MF and HF were normalized with the total power.

Statistical Tests

Linear Mixed Model (LMM) regression was applied.

$$Y = WL + P + WL * P + \varepsilon$$

Mean HR,
HRV MF (normalized),
or HRV HF (normalized)

Workload rating
■ Fixed, continuous effect

Participant
■ Random, categorical effect

Interaction

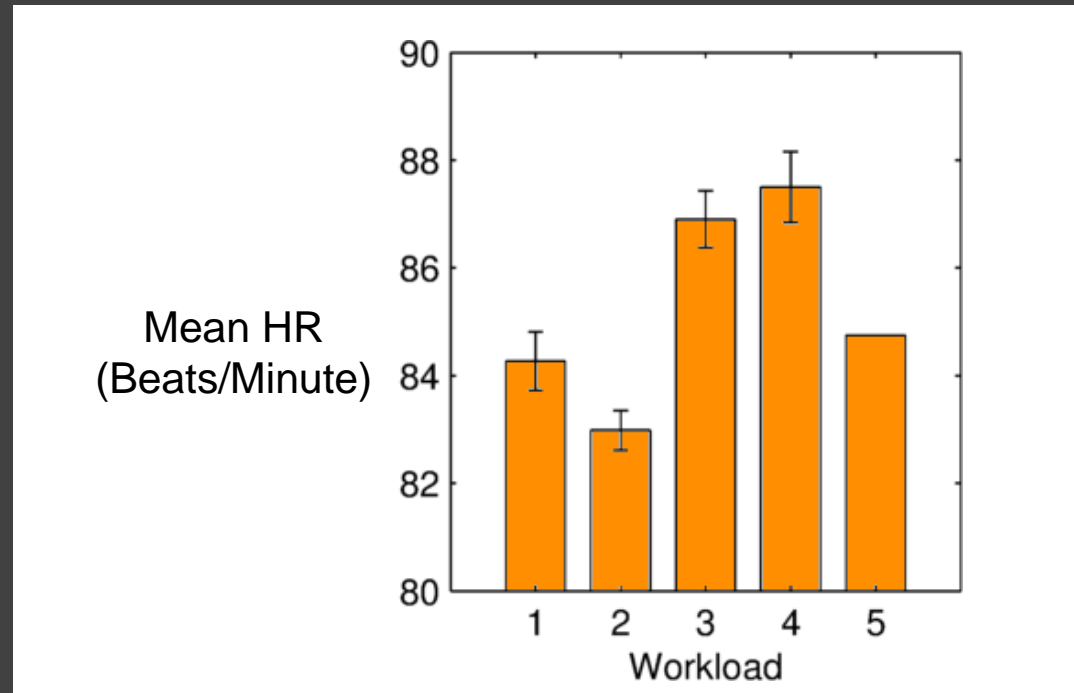
Error

The diagram shows the equation $Y = WL + P + WL * P + \varepsilon$ with five yellow arrows pointing to its components. The first arrow points from the text 'Mean HR, HRV MF (normalized), or HRV HF (normalized)' to the variable Y . The second arrow points from the text 'Workload rating' and '■ Fixed, continuous effect' to the variable WL . The third arrow points from the text 'Participant' and '■ Random, categorical effect' to the variable P . The fourth arrow points from the text 'Interaction' to the interaction term $WL * P$. The fifth arrow points from the text 'Error' to the error term ε .

Results & Discussion

Mean HR Results

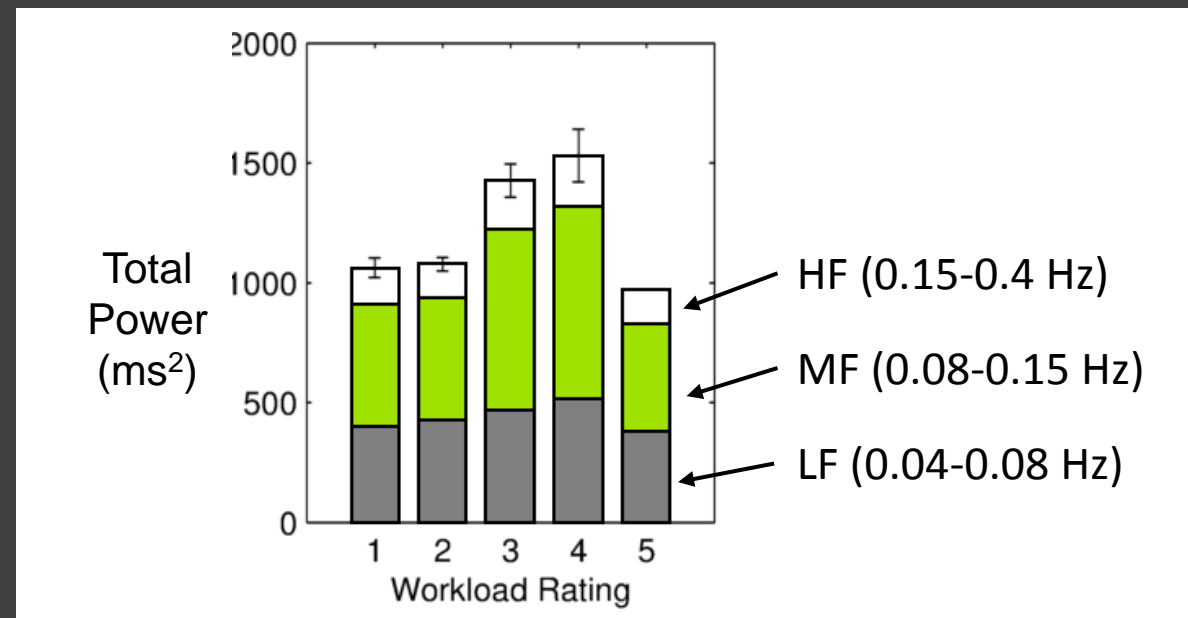
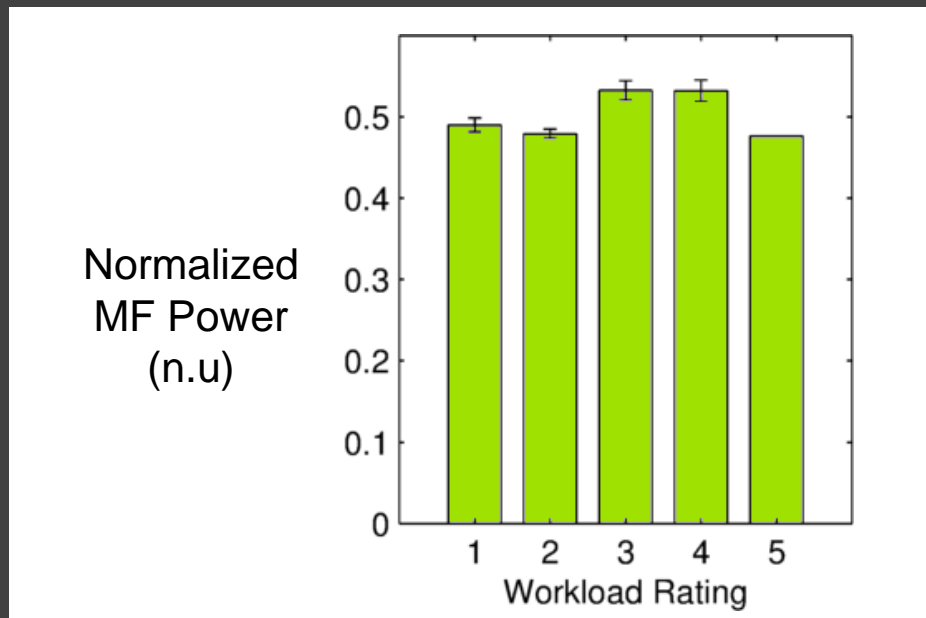
- The LMM did not find statistical significance in workload (WL) effect.



- The graph shows only a weak trend.

HRV Results

- For the normalized MF, WL effect was statistically significant ($p < 0.01$).
 - However, the estimated coefficient was in the wrong direction (0.015; $SE = 0.006$).



- The total power also increased when WL = 3 or 4 (again, the wrong direction).

Discussion

- **Mean HR:** only weak correlation with the workload ratings
 - Subjective measures are not necessarily the true state of workload.
- **HRV-MF and HRV-Total power:** contradictory trend directions
 - Were they more “relaxed” when they reported WL = 3 or 4? (Unlikely.)
 - More plausible explanation: HRV must have sensed something else.
 - Increased speech when traffic volume was high.
 - Posture change, walking around, sipping water, etc.

Summary

- In our airport ramp-tower simulation, we found that mean HR was only weakly correlated with the controller's self-reported workload levels.
- HRV results were contradictory and inconclusive.
- Until further research is conducted to understand the effects of speech, posture changes, etc., using HR or HRV measures as a sole mean of workload assessment in field tests is not recommended.
- It is recommended to measure HR and HRV along with subjective measures.