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

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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...

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Another case of low sensitivity

Start

5 minutes later

5 minutes later

End

Really?

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Background

- Subjective measures of workload have known shortcomings.
  - “Subjective”
  - Low sensitivity
  - Sparse data, likely missing the important event
  - Potentially distracting, if measured in real time

- 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.”

- 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:

<table>
<thead>
<tr>
<th>Authors (Year)</th>
<th>Studied Task</th>
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<tbody>
<tr>
<td>Vicente, Thornton, &amp; Moray (1987)</td>
<td>Low-fidelity hovercraft course-tracking simulation</td>
</tr>
<tr>
<td>Rowe, Sibert, &amp; Irwin (1998)</td>
<td>Air-traffic-control game</td>
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- 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.
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.
Linear Mixed Model (LMM) regression was applied.

\[ Y = WL + P + WL \ast P + \varepsilon \]

- Mean HR, HRV MF (normalized), or HRV HF (normalized)
- Workload rating
  - Fixed, continuous effect
- Participant
  - Random, categorical effect
- Interaction
- Error
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.
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.