Effects of Time-Based Metering on Heart-Rate Variability and Ocular Indices of Mental Workload

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Time-Based Flow Management (TBFM)

- Purpose
  - The increase in the number of TBFM-adapted airports may require an En Route sector to participate in the simultaneous metering of a higher number of destinations.
  - To ensure the ongoing success of TBFM, the FAA TBFM Program Office, TBFM National Ops Team, the National Air Traffic Controllers Association (NATCA), the NextGen Integration and Evaluation Capability (NIEC) at the FAA Tech Center, and the FAA Human Factors Branch partnered to examine the impact of multiple metering lists.
- Participants
  - Twelve male Certified Professional Controllers (CPCs) from seven En Route facilities with an average of 10 years of En Route Experience.
- Design and apparatus
  - Three adjacent En Route sectors with Radar (R)- and Data (D)-sides.
  - Simulation pilots controlling aircraft.
  - Main IV: Number of metered airports.
    - 1,3,5,7, and mixed (3 metered and 2 miles-in-trail flows).
    - R vs. D Side for some analyses.
  - Thirty 50-minute runs.

Physiological Measures

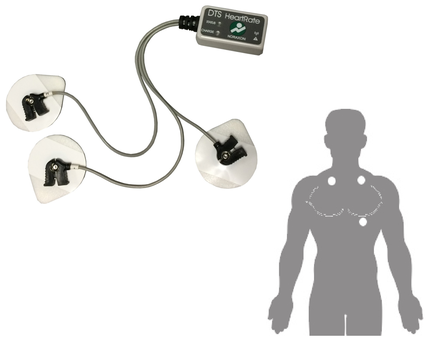
- Heart Rate Variability (HRV) and eye tracking have been studied to some extent in the ATC domain (Backs, 1995; Conte et al., 2012; Mulder, 1992; Mulder & Mulder-Hajonides van der Meulen, 1973).
- However, their utility has not, to date, been fully validated in this particular domain (Murphy & Smith, 2001).
- Purpose
  - Provide further validation of heart rate variability and eye tracking measures in high-fidelity ATC simulations.
  - Use results to corroborate performance and workload findings with Masalonis et al. (2015).

Heart Rate Variability

- Measure of nervous system activity that's shown to be an index of mental workload.
- It reflects, among other factors, the slowing of the sympathetic nervous system by the parasympathetic nervous system using the vagal nerve (Aasman, G. Mulder, & L. Mulder, 1987; Mulder & Mulder-Hajonides van der Meulen, 1973; Porges, 2000; Porges, 2003; Rowe, Sibert, & Irwin, 1998).
- Rather than raw heart rate, HRV is a measure of the time between each beat.

Wireless Electrocardiogram (ECG)

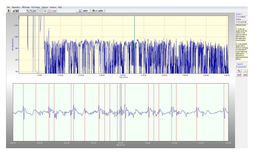
- Noraxon DTS HeartRate application
  - Shave hair (if any) from upper chest and below left breast.
  - Apply electrodes.
  - Test for clean signal. If signal is distorted, reshave chest, clean with alcohol swab, and apply new electrodes.
- For the present study:
  - Electrodes attached at start of day and remained on throughout the day.
  - Collected data at 1,500 Hz.



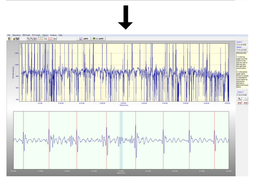
HRV Data Cleanup

- Imported data into Nevrokard aHRV module.
- Processed to remove erroneous beats and add missing beats.
- Applied low-pass and high-pass filters to help remove motion artifacts.
- Manually inspected each file for erroneous beats (shown as troughs) and missing beats (shown as peaks). Added and removed beats as necessary.
- Applied a MATLAB smoothing script that resolved additional erroneous and missing beats. It filled in gaps with an average beat based on 30 seconds of data preceding the missing beat.

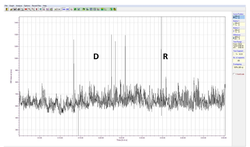
Dirty data with default detection rate and suboptimal filtering.



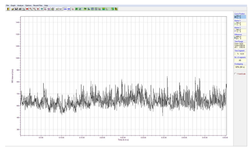
Dirty data with improved filtering.



After manual correction, before final smoothing script.



After manual correction, after final smoothing script (peaks and troughs removed).

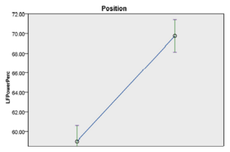


HRV Analysis

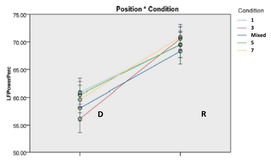
- Used CZF (Conte, Zbilut, Federici) method (Conte et al. 2012).
- Instead of a transformation, e.g., fast Fourier, CZF calculates the total variability between each R-R interval and presents them in measures of low-, mid-, and high-frequency.

HRV Results

- R-side workload is higher than D-side
- LF PowerPerc is a measure of the power of the low-frequency band of the HRV signal



- R vs. D effect holds for all conditions
- Small but significant workload effect of metering 7 airports



Eye Tracker

- Applied Science Laboratories eye tracker.
  - Uses a combination of headgear and eye gear to determine point and duration of gaze, as well as pupil diameter.
- Scene planes:
  - R-side monitor.
  - D-side monitor.
  - Keyboard.
  - ERIDS-like display.
  - Workload Assessment Keypad.

Gaze and Pupil Diameter

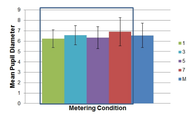
- Tracking point of gaze and fixation provides information about areas of interest.
- Pupil diameter provides information about cognitive workload (Pomplun & Sunkara, 2003).

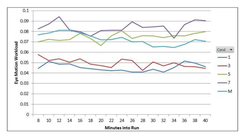
Eye tracker calibration

Protecting our participants against NIEC Plague of 2014

Eye Tracking Results

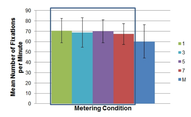
- Pupil diameter shows effect of R-side vs. D-side but not of metering condition.

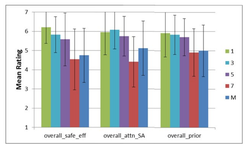




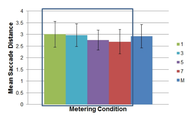
- Eye motion workload shows 5, 7, and Mixed higher than 1, 3 for R-side.

- Fixation count suggests workload shift away from R-side and toward D-side in 7 and M conditions.





- Saccade distance goes down when metering more airports, suggesting "tunneling."



- Other measures examined include fixation duration and blink rate. These generally did not provide meaningful or easily interpreted results.

Conclusions

- HRV and Eye Tracking are sensitive measures for workload assessment in high-fidelity ATC simulations.
- Data cleanup, validation, and reduction are workload intensive.

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