NORMATIVE BASELINE OCULOMOTOR PERFORMANCE

Leland S. Stone[1,†], Jesus A. Garcia Arango[1,2], Terence L. Tyson[1], Rahul Goel[1,2], Mark R. Anderson[1,3], Greg Costedoat[1,2], Nathan H. Feick[1,2], and Erin E. Flynn-Evans[1]

[1]Human Systems Integration Division, NASA Ames Research Center, Moffett Field, CA, [2]San José State University, Moffett Field, CA, and [3]ASRC Federal Data Solutions, Moffett Field, CA

[†]Presenter

Supported by the NASA Human Research Program and the Force Health Protection Program of the Office of Naval Research (SAA2 402925-1).

Introduction

- NASA Ames has developed an eye-movement-based, or “oculometric”, methodology that generates a set of 19 largely **independent functional metrics** of human performance (Stone et al., 2019).
- Multidimensional oculometrics allow for the **simultaneous examination of multiple neural subsystems** of visual, visuomotor and ocular function (i.e., pursuit, saccades, visual motion processing, eccentric gaze holding, pupillary light reflex) and thus the neural processing along multiple brain pathways. It has been used to detect mild traumatic brain injury (Liston et al., 2017), sleep and circadian disruption (Stone et al., 2019), ultra-low-dose alcohol (Tyson et al., 2021), and retinal thickness changes (IWS2022 abstract #1133-000114).
- Here we perform a meta-analysis of control data across four prior studies:
  - ➢ to establish a normal baseline,
  - ➢ to determine reliability and sensitivity for detecting valid changes, and
  - ➢ to perform a preliminary examination of effects of time awake and sex.

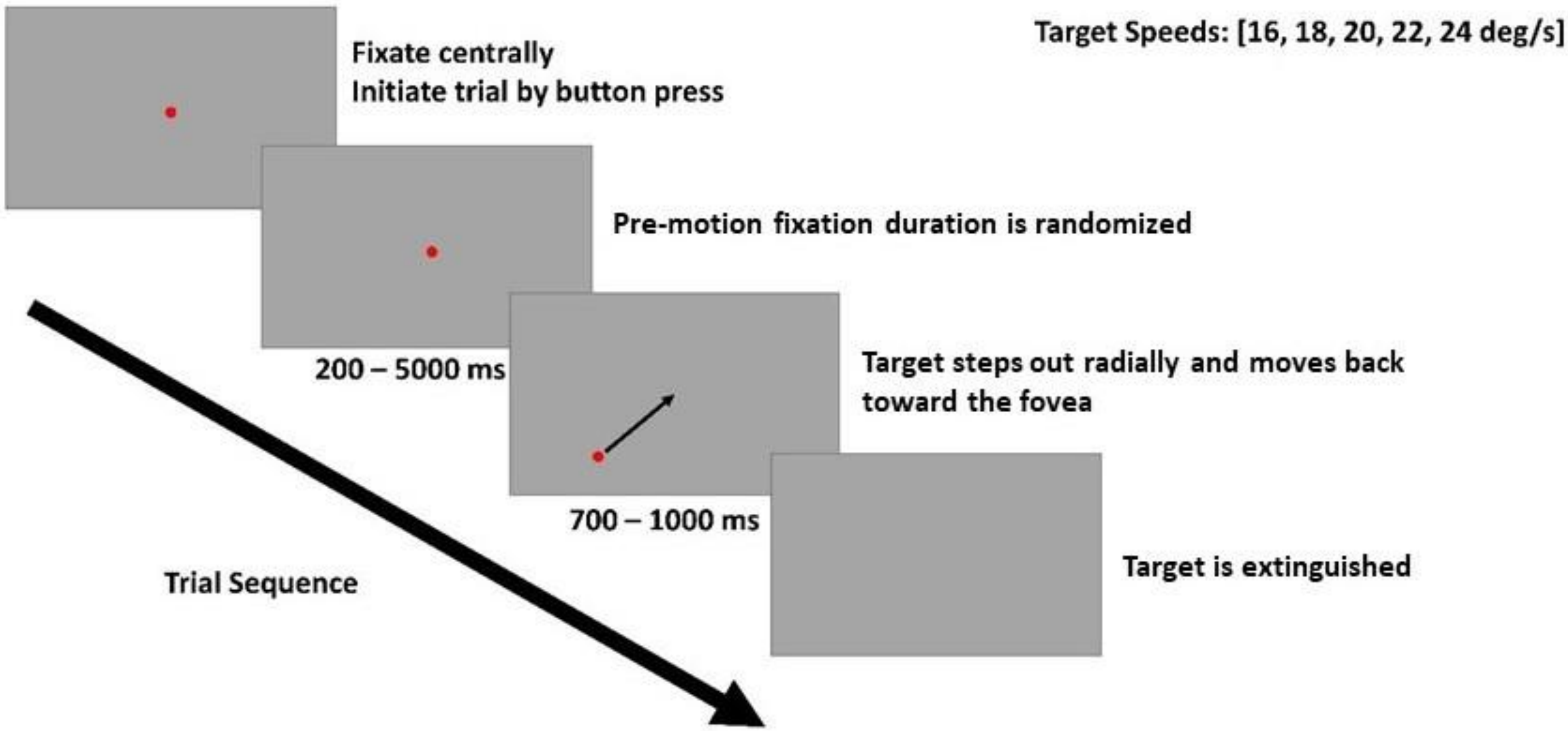
Stone et al., Journal of Physiology, 597(17): 4643–4660 (2019); doi:10.1113/JP277779
Tyson et al., Journal of Physiology, 599(4): 1225–1242 (2021); doi:10.1113/JP280395
Liston, et al., Optometry and Vision Science, 94(1), 51-59 (2017); doi: 10.1097/OPX.0000000000000918

Methods

- Combine 270 daytime control data runs from 43 healthy, well-rested, subjects (20 ♀; 19 - 38 yro) for a set of 19 oculometrics:
  - four for the initiation and maintenance of pursuit,
  - five for saccades,
  - five for visual motion processing,
  - three for the pupillary light reflex (PLR), and
  - two for eccentric gaze holding.
- Quantify reliability using Intra-Class Correlation (ICC) analysis and learning effects by performing simple linear regression using a balanced subset of data (with 6 repeated runs) from 16 subjects (8 female) collected around same time of day (Tyson et al., 2021).
- Determine the effects of time awake, sex, and their interaction using a Linear Mixed-effects Model (LMM) with AR1 structure for repeated runs, subject as a grouping variable, and random intercepts (controlling for learning by subtracting the estimated linear learning trend, if present for that metric).

Tyson et al., Journal of Physiology, 599(4): 1225–1242 (2021), doi:10.1113/JP280395

Oculometric Task



- Five-minute ocular tracking task (after a one-minute calibration process)
- 90 two-second trials capture the coordinated pursuit and saccadic responses to a range of target speeds and directions to yield 19 largely independent oculometrics.

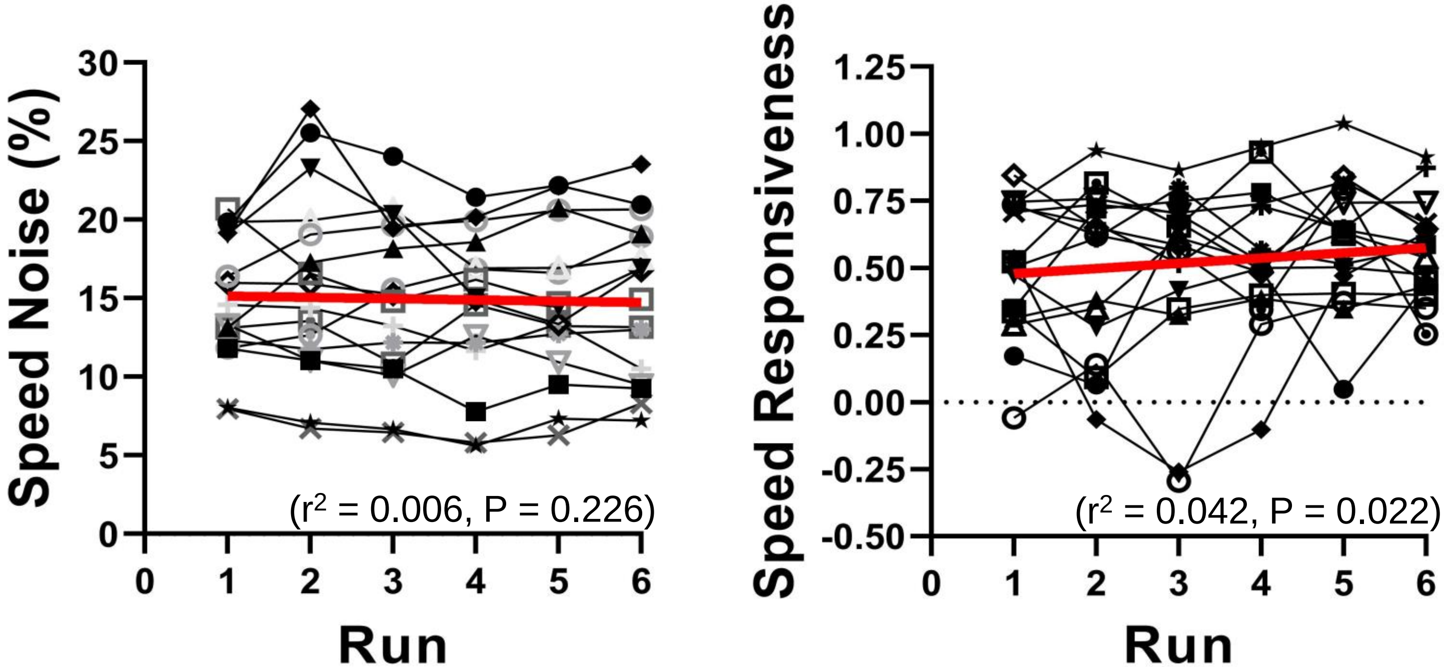
Stone et al., Journal of Physiology, 597(17): 4643–4660 (2019); doi:10.1113/JP277779

Reliability Analysis

Oculometric	Single Measure	Average of 3 Runs
Latency	0.85	0.97
Acceleration	0.85	0.97
Pursuit Gain	0.89	0.98
Saccadic Amplitude	0.88	0.98
Saccadic Rate	0.72	0.94
Propotion Smooth	0.77	0.95
Direction Noise	0.73	0.94
Direction Asymetry	0.73	0.94
Speed Noise	0.85	0.97
Saccadic Vel v. Amp Intercept	0.71	0.94
Pupil Size	0.77	0.95
PLR Constriction Tau	0.70	0.93

- The mean ICC scores for 15 of our 19 metrics indicate stringent test-retest reliability of moderate to excellent:
  - For single measures, 12 metrics have good (> 0.7) mean ICC reliability scores, increasing to excellent (> 0.9) when averaging 3 runs.

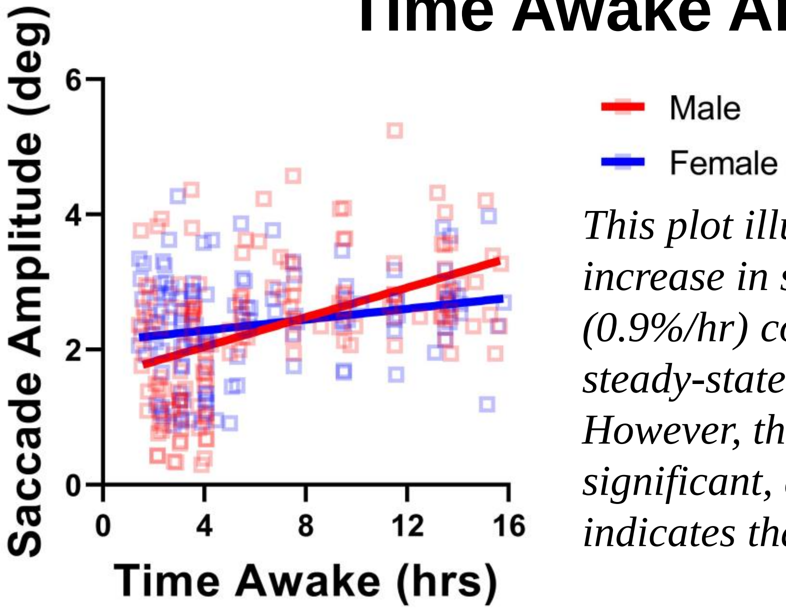
Learning and Sensitivity Analysis



- We found that individual oculometric performance baselines are generally stable with 11 of 19 showing no significant learning effect (e.g., speed noise).
  - ➢ When present, learning was relatively small, averaging less than 2% (0.9 to 3.7%) improvement per run (speed responsiveness had largest effect)

- For 12 oculometrics, a 50% reduction in performance is 80% detectable as significant ($P < 0.05$) with only a single pre/post comparison, with $\sqrt{N}$ improvement with increased number of measurements, of subjects, or of combined metrics.

Time Awake Analysis



This plot illustrates the highly significant overall increase in saccadic amplitude with time awake (0.9%/hr) compensatory for the significant decrease in steady-state gain (0.7%/hr), independent of sex. However, the interaction of time awake and sex is significant, and an analysis of each sex separately indicates that the slope is only significant for males.

- Many oculometrics show highly significant ($P \leq 0.001$) main effects of time awake:
  - ➢ initial pursuit acceleration decreases
  - ➢ steady-state pursuit gain decreases
  - ➢ saccadic amplitude shows compensatory increases
  - ➢ slope of the peak saccadic velocity versus amplitude plot decreases
  - ➢ pupil size increases

- Some metrics exhibited subtle, but significant, effects of sex worthy of further study:
  - ➢ main effect on saccadic dispersion ($P = 0.032$)
  - ➢ interaction with time awake on saccadic amplitude ($P = 0.004$)
  - ➢ interaction with time awake on intercept of saccadic velocity versus amplitude ($P = 0.013$).

Conclusions

- Oculometrics provide a **rapid ready-to-perform assessment tool** to characterize mild neural impairment with:
  - ➢ High reliability (single-measure mean ICC > 0.7 for 12 metrics),
  - ➢ Little or no learning effects (insignificant for 11 metrics), and
  - ➢ High sensitivity – enough to detect subtle effects of time awake.

Furthermore,

- Efforts are ongoing to develop an operationally ready system for collecting oculometric data pre/post/in-flight (under TRISH "OCTAVE" project) and to extend our baseline to include crew-like demographics.

- Oculometrics are a set of validated standard measures of perceptual and sensorimotor performance that could allow NASA to efficiently and reliably:
  - <u>Detect</u> mild sub-clinical visual/visuomotor deficits during/after spaceflight,
  - <u>Gain insight</u> into the nature of potential operational risks,
  - <u>Assess</u> the extent and time-course of progression or functional recovery in longitudinal studies, and the effectiveness of countermeasures.