Low-dose Caffeine Administration During Acute Sleep Deprivation Eliminates Visual Motion Processing Impairment, but Does Not Improve Saccadic Rate

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INTRODUCTION

- Oculomotor behavior and Visual Motion Processing vary with time awake:
  - Pursuit initiation and steady-state gain reduced,
  - Saccadic rate increased to compensate, and
  - Precision in direction/speed processing reduced.
- Low-dose caffeine (~0.3 mg/kg) is associated with increased alertness and performance on visual reaction time tasks (Wyatt et al. 2004)
- We hypothesized that the impairment of oculomotor and visual metrics associated with time awake would be mitigated by low-dose caffeine administration.

METHODS

- Healthy participants (mean age = 25.0, ±5.6) completed an overnight laboratory sleep-deprivation constant routine study (Mills *et al*. 1978) with (N = 9) or without (N = 12) caffeine administration.
- Two-week at-home pre-study schedule with 8.5 hours in bed with regular timing, verified by actigraphy, call-ins, and sleep logs
- Comprehensive Oculomotor Behavioral Response Assessment (Liston & Stone, 2014; Figure 1)
  - Participant required to track constant velocity target motion across the screen for ~1 second (radial Rashbass step-ramps)
  - Motion onset at unpredictable time and location with unpredictable direction and speed.
  - All directions covered in 2° steps
  - Speeds of 16, 18, 20, 22, or 24 deg/s
  - Data-collection runs administered 2-5 times during the day and hourly from habitual bedtime until morning
  - High-speed eye-tracking system used to measure and compute 12 metrics per trial with 180 trials per run.

A

B

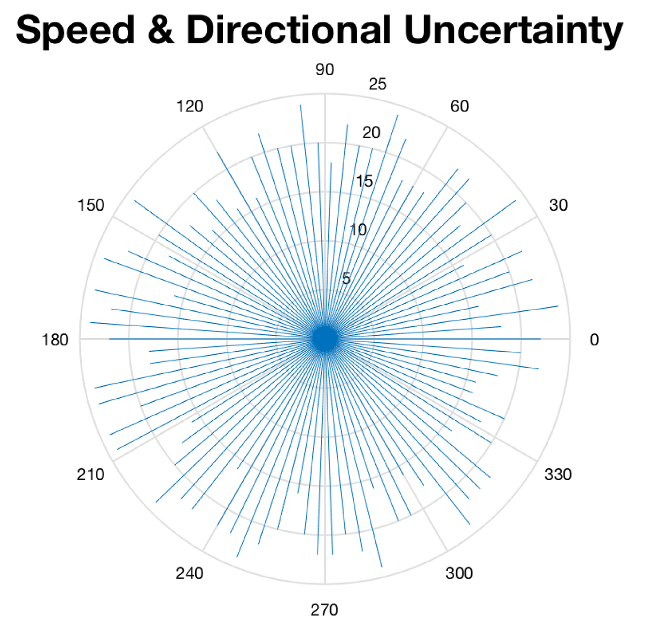

Figure 1. A. Eye-tracking and display system. B. Example of randomized trial speeds and directions.

RESULTS

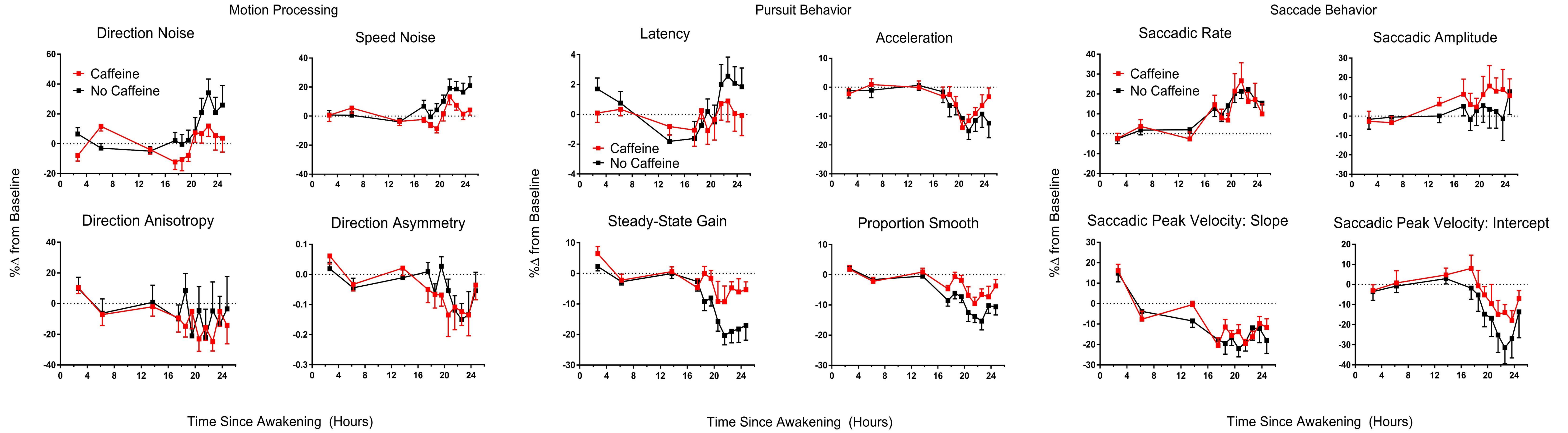

Figure 2. *Each panel plots the percentage deviation (%Δ) from baseline (dashed black line, average of daytime measurements) with each measurement binned by run (± SEM across participants). The black curves show runs without caffeine administration and the red curves with caffeine administration.*

- Acceleration and gain of pursuit, saccadic rate, proportion smooth, peak velocity (slope & intercept), as well as direction and speed noise, all showed significant linear trends as a function of time awake across a 24-hr period, without caffeine administration (Stone *et al*. 2019).
- ANCOVA comparison of the caffeine and no-caffeine trends showed that the linear trend was eliminated for direction ($p < 0.05$) and speed ($p < 0.005$) noise, and approximately halved for pursuit gain ($p < 0.006$) and proportion smooth ($p < 0.005$).
- Caffeine administration was associated with a linear increase in saccadic amplitude with time awake ($p < 0.003$).

CONCLUSIONS

- Caffeine was protective of visual motion processing during sleep-deprivation and circadian misalignment with precision remaining at baseline levels overnight under low-dose caffeine.
- Caffeine was only partially protective of pursuit gain and proportion smooth, but enabled a compensatory increase in saccadic amplitude with time awake not seen without caffeine.
- While the amplitude of catch-up saccades increased only with low-dose caffeine, the increase in saccadic rate with time awake remained the same with or without caffeine.
- We conclude that the systematic impairment of the precision of visual motion processing with time awake was largely a homeostatic effect, while time-awake trends on tracking gain may have reflected a mixture of homeostatic and circadian effects thus are only partially mitigated by caffeine.

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