Saccade-Pursuit Coordination During Ocular Tracking Across Different Impairment Sources

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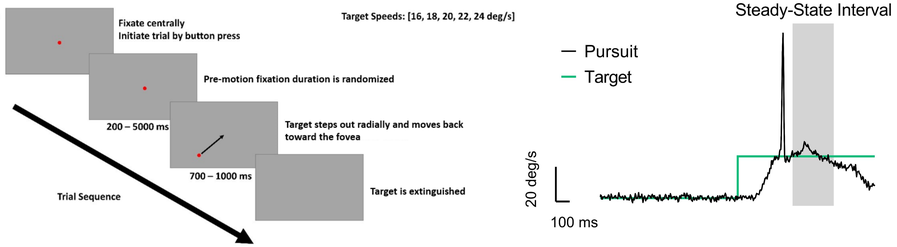
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Introduction

Sleep loss[1] and alcohol[2] have been shown to impair smooth pursuit and its underlying visual motion processing in humans. This study examines the saccadic compensation for this poor pursuit. We also investigate the mitigating effects of caffeine on acute sleep loss.

Methods



Ocular Tracking Task:

- Step-ramp Rashbass-like ocular tracking task[3].
- 90-trial session (90 directions, 5 speeds).
- Tracking target is randomized in direction, speed, and motion onset.

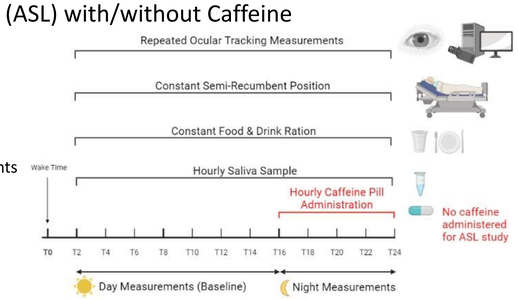
Acute Sleep Loss (ASL) with/without Caffeine

At-Home Preparation (14 days):

- Fixed nightly sleep schedule
- No caffeine or alcohol

Constant Routine[4,5] (1 day):

- Repeated day/night oculometric measurements
- Constant dim room illumination (< 15 lux)
- Constant isocaloric food rations
- Constant semi-recumbent posture
- No time cues



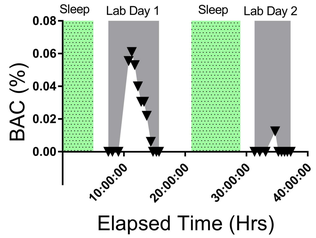
Low-Dose Alcohol

At-Home Preparation (3 days):

- Fixed sleep schedule
- No caffeine or alcohol

Lab Study (2 days):

- Two sequential lab days
- Repeated oculometric & BAC measurements
- Single EtOH dose administration per lab day
- Dose targeted either 0.06% or 0.02% peak BAC



Chronic Sleep Restriction (CSR)

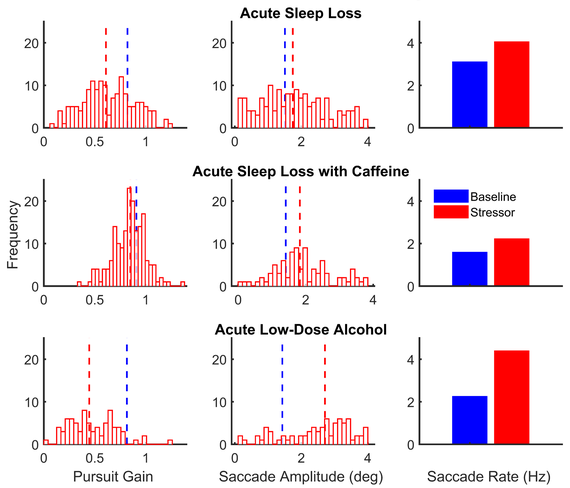
At-Home Preparation (2x14 days):

- Fixed sleep schedule (5 hrs or 9 hrs sleep)
- CSR condition: 5-hr sleep/day for 1 week prior to lab visit
- No caffeine or alcohol

Lab Study (2 days):

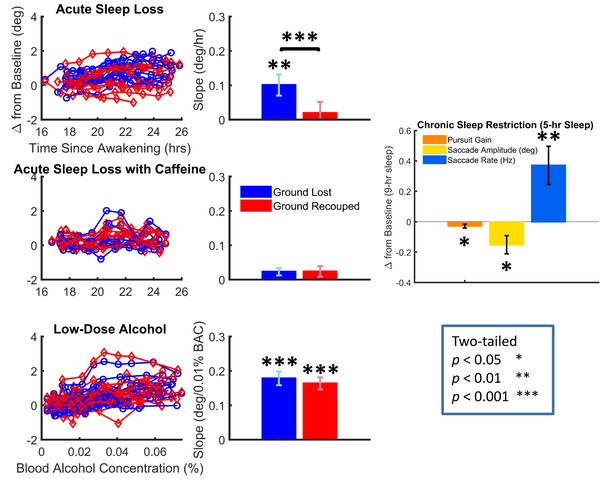
- Lab day at the end of each 14-day at-home prep
- Lab day assesses impact of a 5-hr or 9-hr sleep schedule
- Same constant routine constraints as the ASL conditions

Individual Case Study



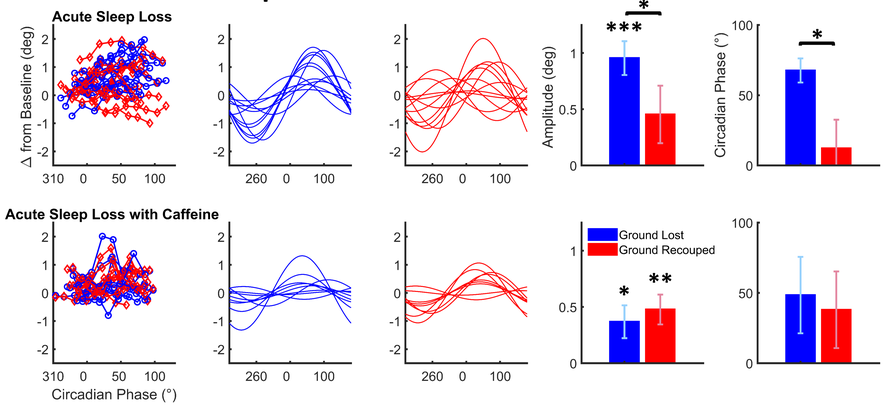
- Pursuit gain decreased for both ASL and EtOH relative to baseline.
- Saccadic rate increases for both ASL and EtOH relative to baseline.
- However, saccadic amplitude only increased for EtOH.

Dose-Dependent Saccadic Compensation



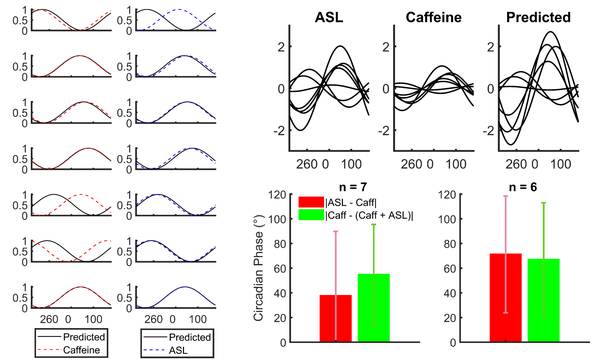
- ASL: Significant ground lost, which is significantly higher than ground recouped, consistent with partial compensation. Impairment is eliminated with caffeine.
- EtOH: Significant ground lost and ground recouped, consistent with full compensation.
- CSR: Pursuit gain and saccade amplitude significantly decreased, but saccade rate increased. Note: * indicates one-tailed, not two-tailed for CSR analysis.

Circadian-Dependence of Saccade-Pursuit Coordination



- Significant circadian modulation in ground lost with ASL is reduced by caffeine ($p < 0.01$, independent-measures t-test, one-tailed).
- Significant difference in modulation between ground lost and ground recouped with ASL.
- Significant difference in phase between ground lost and ground recouped is eliminated by caffeine.
- Large variance in phase of ground gained is induced by ASL.

Circadian Phase Variability of Saccadic Compensation



- Adding an estimate of the homeostatic effect during ASL to the circadian modulation under ASL and caffeine predicts the phase variance of ASL circadian modulation in ground recouped for 6 of the 7 subjects who were tested under both conditions.
- Across all 7 subjects, an estimate of the homeostatic effect of ASL predicts phase of the circadian modulation well.
- Across the subset of 6 subjects, the prediction is nearly perfect (mean Δ = -4.2˚, p = 0.30, paired t-test).

Conclusion

- We have previously shown that ASL and EtOH impair pursuit tracking albeit differently.
- We show here that saccadic compensation is different under these conditions, appearing complete with EtOH, but not with ASL (or CSR).
- We also show that caffeine largely eliminates the ASL pursuit deficit, obviating the need for compensation.

References: [1] Stone et al. Distinct pattern of oculomotor impairment associated with acute sleep loss and circadian misalignment. J Physiol. 2019 Sep;597(17):4643-4660. doi: 10.1113/JP277779. [2] Tyson et al. Dose-dependent sensorimotor impairment in human ocular tracking after acute low-dose alcohol administration. J Physiol. 2021 Feb;599(4):1225-1242. doi: 10.1113/JP280395. [3] Liston DB, Stone LS. Oculometric assessment of dynamic visual processing. J Vis. 2014 Dec 19;14(14):12. doi: 10.1167/14.14.12. [4] Duffy JF, Dijk DJ. Getting through to circadian oscillators: why use constant routines? J Biol Rhythms. 2002 Feb;17(1):4-13. doi: 10.1177/074873002129002294.[5] Figure created with BioRender.com