Tenth International Conference on Managing Fatigue: Abstract for Review

Sleep loss and change detection: a driving simulator study

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Problem

Driver sleepiness contributes to an estimated 15-30% of road crashes. Whereas the most typical sleep-related crashes (i.e., where a single vehicle runs off a monotonous road) are relatively well researched, atypical sleep-related crashes are poorly understood. The current work focused on understanding subtle impairments associated with sleepiness and visual attention which may impair driving ability prior to extreme out-of-lane events. For example, it is well established that sleepiness impairs sustained attention, as measured using the psychomotor vigilance task (PVT). However, sustained attention is not the only attentional component vital for safe driving; the ability to detect changes is also influential. This study investigates whether sleep loss impairs change detection ability.

Method

Twenty-one participants (12 female) aged 18-33 years (M = 23.1, SD = 3.9) participated in a driving simulator study. All participants completed a familiarisation drive and two experimental sessions (in counterbalanced order); one following a normal night of sleep (7-8h) and one after sleep restriction to five hours. Study sessions were conducted at either: 10.30am (8 participants), 12.00 noon (4 participants), 1.30pm (6 participants) or 3.00pm (6 participants). Participants completed both experimental sessions at the same time of day at least 3 days apart. Prior sleep was recorded by sleep diary and actigraphy.

The driving simulator comprised a complete automatic vehicle, SCANeR™ studio software v1.4, 180° forward field of view and a 6 degrees-of-freedom motion base. During each study session participants continuously drove 5 laps of an 11.3km circuit (total ~45 minutes), 50% of the driving time was in an urban environment (60km/h) and 50% in a rural environment (100km/h).

Twenty change detection events were experienced per drive; 12 change-present trials (6 urban, 6 rural) and 8 change-absent trials (4 urban, 4 rural). During a change detection event the simulator screens went black for 500ms, returning to either an identical scene or a scene with one change (e.g. altered speed zone or road position of a vehicle). The same change events were used during both study sessions but the timing, location and change target characteristics (e.g. vehicle colour) were varied. All change detection objects appeared multiple times throughout the drive ensuring that the specific objects where not associated with change detection events. Change-present trials were only considered “correct” if participants correctly identified the object which had changed.

Subjective sleepiness was rated using the Karalinska Sleepiness Score (KSS). Sleep related eye symptoms (5 point scale), effort to stay awake (7 point scale) and subjective workload (NASA-Task Load index (TLX)) were recorded post-drive.

Results

Total sleep time (calculated from sleep diary) was significantly reduced between the normal sleep (*M* = 473 min, *SD* = 57) and the sleep restriction condition (M = 300 min, *SD* = 19), *t(23)* = 14.38, *p* < .001. This was associated with a significant increase in subjective sleepiness (Normal sleep: *M* = 3.7, *SD* = 1.6; Sleep restriction: *M* = 5.1, *SD* = 1.6) prior to entering the simulator, *t*(23) = 4.43, *p* <.001. Similarly, all post-drive subjective measures indicated participants were impaired by sleep loss: eyelids were rated as significantly heavier (Normal sleep: *M* = 1.9, *SD* =0.9; Sleep restriction: *M* = 3.4, *SD* = 1.1), *t*(23) = 6.67, *p* <.001, eye strain increased (Normal sleep: *M* = 2.0, *SD* =1.0; Sleep restriction: *M* = 3.1, *SD* = 1.2), *t*(23) = 3.22, *p* = .004, as did difficulty focusing (Normal sleep: *M* = 1.0, *SD* =1.1; Sleep restriction: *M* = 3.0, *SD* = 1.0), *t*(23) = 4.03, *p* = .001. Participants also reported requiring increased effort to stay awake (Normal sleep: *M* = 2.2, *SD* =1.2; Sleep restriction: *M* = 4.4, *SD* = 1.5), *t*(21) = 5.90, *p* < .001 and experiencing higher workload (NASA-TLX; Normal sleep: *M* = 199.5, *SD* =84.2; Sleep restriction: *M* = 96.9, *SD* = 19.8), *t*(23) = 2.09, *p* =.048, following sleep loss.

Participants demonstrated high accuracy for change-absent trials, regardless of sleep condition (Normal sleep: *M* = 93.3%, *SD* = 13.0%; Sleep restriction: *M* = 94.1%, *SD* = 9.9%), *t*(23) = 1.15, *p* =.262. Accuracy was lower for change-present trials than change-absent, but also did not significantly differ between sleep condition (Normal sleep: urban *M* = 41.3%, *SD* = 18.0%, rural *M* = 65.3%, *SD* = 16.8%; Sleep restriction: urban *M* = 36.8%, *SD* = 20.1%, rural *M* = 68.4%, *SD* = 15.5%), *F*(1,23) = 0.05, *p* =0.833. There was a significant main effect of environment, participants were more accurate at identifying changes in rural than urban environments *F*(1,23) = 121.85, *p* < .001. The interaction between sleep condition and environment was not significant, *F*(1,23) = 1.38, *p* =2.52.

Discussion

Despite feeling sleepier, requiring greater effort to stay awake, and experiencing an increase in sleep-related eye symptoms participants accuracy for change detection was not impaired following a single night of restricted sleep (5 hours).The driving environment in which changes occur is a better predictor of whether observers will experience change blindness (i.e., failure to detect changes), with drivers being more efficient at detecting changes in rural environments.

To our knowledge no other studies have specifically considered the impact of sleep loss on driving-related change detection. Previous research examining the effects of sleep loss on attention has predominantly operationalised attention by measuring reaction time to the PVT. Using the PVT it has consistently been shown that sleep loss impairs attention. One explanation for this discrepancy is that there are fundamental differences in way that performance is measured. The impaired outcome of the PVT is reaction time, whereas change blindness is measured as accuracy. Future research should consider whether sleepiness impacts the time taken to change detection even though accuracy is maintained, as a delay in change detection could result in a collision if the driver has insufficient braking time.

Participants were better at detecting changes in rural compared with urban environments, even though the characteristics of the change (e.g., type of object that changed) were matched. The reduced accuracy for detecting changes in urban environments is most likely attributable to the fact that urban scenes involve greater visual clutter and complexity, making it more difficult to identify specific objects of interest.

Summary

In summary, the current research demonstrates that drivers often experience change blindness, and are more susceptible in urban environments. This is attentional failure occurs both when alert and sleepy.