Tenth International Conference on Managing Fatigue: Abstract for Review

How much is left in your "sleep tank"? A simple model for sleep history feedback

Jillian Dorrian, University of South Australia, jill.dorrian@unisa.edu.au [corresponding author]
Steven Hursh, Institutes for Behavior Resources Inc., shursh@ibrinc.org
Lauren Waggoner, Institutes for Behavior Resources Inc., lwaggoner@ibrinc.org
Charlotte Gupta, University of South Australia, charlotte.gupta@mymail.unisa.edu.au
Crystal Grant, University of South Australia, crystal.grant@mymail.unisa.edu.au
Maja Pajcin, University of South Australia, maja.pajcin@mymail.unisa.edu.au
Alison Coates, University of South Australia, alison.coates@unisa.edu.au
David Kennaway, Adelaide University, david.kennaway@adelaide.edu.au
Leonie Heilbronn, Adelaide University, leonie.heilbronn@adelaide.edu.au
Chris Della Vedova, University of South Australia, Chris.DellaVedova@unisa.edu.au
Siobhan Banks, University of South Australia, siobhan.banks@unisa.edu.au

Problem [100 words]

Sleep loss results in increased likelihood of error and accident, in the workplace and on the roads. Alongside more widespread understanding of sleep loss related risks, come increasingly affordable, technology-supported methods for sleep recording. Sleep history feedback may help with fatigue-related decision making – Should I drive? Am I fit for work? In particular, it is often useful to project fatigue assessments into the future – Towards the end of my shift, will I still be fit for work, or for my commute? This study examines a model that uses sleep history to provide useful feedback to aid in fatigue-related decision-making.

Method [250 words]

The "Sleep Tank," analogous to the fuel tank in a car, is refilled by sleep, and depletes during wake. Required inputs are sleep period time and efficiency. Maximum tank size represents the sleep-fuel required to remain awake for four days. The model focuses on the sleep process of the two-process model. It does not include a circadian factor (i.e. it will have a known residual error due to this rhythmic component). This "simplification" is deliberate to enable immediate and continuous feedback from basic sleep inputs.

Initial validation was conducted using data from a simulated nightshift study. Ten, healthy males (18-35y) stayed in the laboratory for 7 days, which included a 10h baseline sleep opportunity and daytime performance testing (BL), followed by four simulated nightshifts (2000h-0600h), with daytime sleep opportunities (1000h-1600h), then a 10h nighttime sleep opportunity to return to daytime schedule (RTDS), before a final period of daytime performance testing. Psychomotor Vigilance Task (PVT) and Karolinska Sleepiness Scale (KSS, 1=extremely alert to 9=extremely sleepy-fighting sleep) were performed at 1200h on BL and RTDS, and at 1830h, 2130h 0000h and 0400h each simulated nightshift. A 40-minute York Driving Simulation was performed at 1730h, 2030h and 0300h on each simulated nightshift (Figure 1). On BL, Day4 and RTDS, sleep was monitored using polysomnography. Model outputs were calculated using sleep period timing and sleep efficiency (for BL, day sleeps and RTDS using polysomnographic recordings) for each participant. These were then compared to study metrics of performance and sleepiness.

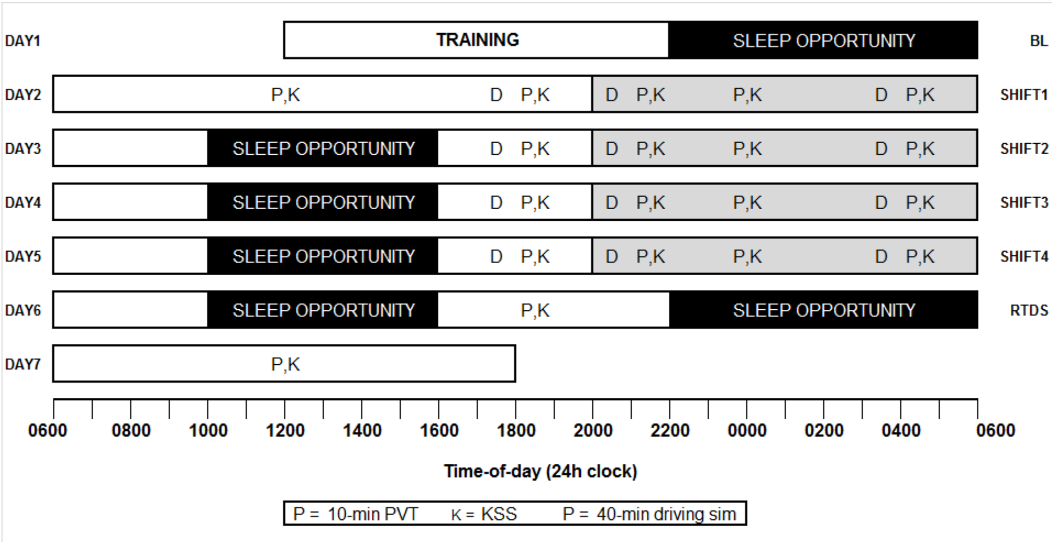

Figure 1. ***Protocol Diagram –*** Time-of-day (24h clock) is on the x-axis, with day of study on the y-axis. Black bars indicate sleep opportunities and grey bars indicate simulated night shifts. BL=Baseline, Shift1-4=simulated night shifts, RTDS=return to daytime schedule. PVT=Psychomotor Vigilance Task, KSS=Karolinska Sleepiness Scale.

Results [250 words]

Performance and sleepiness were significantly worse during the last test session of the shift compared to earlier trials, and sleepiness was significantly worse during the first shift compared to shifts 2-4 (*p*<0.01, Table 1).

Table 1. ***Performance Changes During Simulated Night Work –*** Mixed effects ANOVA for PVT Lapses (response times>500msec), KSS (1=extremely alert to 9=extremely sleepy-fighting sleep) and driving simulator %time in safe zone (%time within 10km/h of the speed limit and within 0.8m of the centre of the lane) with fixed effects of shift (1-4), trial (PVT,KSS = 1830h/ 2130h /0000h /0400h; %safe zone = 1730h/ 2030h/ 0300h) and shift* trial with a random effect of subjectID.

	Shift			**Trial**			**Shift*Trial**			***Post-hoc***
	F	**df**	***p***	***F***	**df**	***p***	***F***	**df**	***p***	***p*<0.01**
PVT	0.09	3,134.0	0.966	23.96	3,134.0	<0.001	0.25	9,134.0	0.985	1830h, 2130h, 0000h < 0300h
KSS	6.63	3,134.0	<0.001	62.02	3,134.0	<0.001	1.42	9,134.0	0.183	1830h < 0000h, 0300h Shift1 > Shifts2-4
%Safe Zone	2.04	3,99.0	0.113	10.24	2,99	<0.001	0.87	6,99.0	0.518	1730h, 2030h > 0300h

Figure 2 illustrates the suggested hours left to “get sleep.” On waking at BL, there is >20h “in the tank,” with a latest advisable bedtime of 5:45am. After waking from subsequent daytime sleep periods, the starting value “in the tank” is lower, with latest advisable bedtimes moving earlier in the shift across multiple nights.

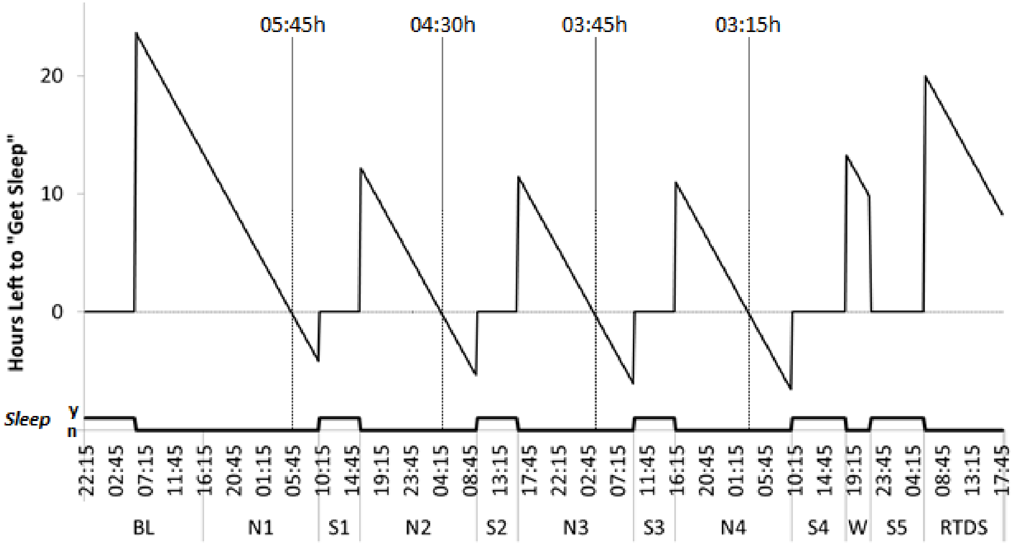

Figure 2. ***Model Hours Left to "Get Sleep" Metric –*** Time-of-day (24h clock) is on the x-axis, hours left to "get sleep" (an estimate of the latest advisable bedtime given what remains in the "Sleep Tank") on the y-axis. Sleep opportunities are shown along the x-axis. BL=Baseline, N1-4=nightshifts, S1-4=Sleep opportunities, RTDS=return to daytime schedule. Times for y=0 (latest advisable bedtimes) are indicated.

Figure 3 displays the percentage remaining in the tank (Tank%), which is highest on waking, with longer, more efficient sleep periods filling the tank to a greater level. Mixed effects regression (with a random effect of subjectID) indicated that Tank% was a significant predictor of PVT lapses (β=-0.44, sterr=0.06, t=-6.87, p<0.001), and KSS (β=-0.20, sterr=0.03, t=-7.68, p<0.001), such that every 5% reduction resulted in an increase of one lapse, or one point on the KSS. Tank% was also a significant predictor of %time in the Safe Zone (β=0.75, sterr=0.22, t=3.40, p=0.001), such that every 1% increase in the tank resulted in a 0.75% increase in time spent in the Safe Zone.

Time series correlations between Tank% and performance and sleepiness metrics were calculated for each person, then *r-z* transformed. Average (and sterr) across participants was calculated and then reverse-transformed for *r*. On average, correlations were moderate (PVT lapses r_{Lag0}=-0.50, sterr=0.08, R^2=0.25; KSS r_{Lag0}=-0.54, sterr=0.08, R^2=0.30; %Time in Safe Zone r_{Lag0}=0.45, sterr=0.17, R^2=0.20).

Discussion [250 words]

Initial examination of the correspondence between model predictions and performance and sleepiness measures from a four-night simulated nightshift protocol indicated relatively good predictive value, with percentage left in the "Sleep Tank" significantly predicting performance lapses, subjective sleepiness and safe driving during a 40-minute driving simulation. The model explained an average of 20-30% of the variance across participants. Performance and sleepiness were worst at the trials closest to model-indicated latest advisable bedtimes. Not only did this simple model map onto the performance and sleepiness low points during the night shifts, but also onto the recovery points after the final daytime sleep and return to daytime schedule.

Next steps include examining the model with different shift schedules in the laboratory and the field, and using polysomnographic sleep recording to estimate sleep period time and sleep efficiency (as in the current study) as well as actigraphic estimates of these measures. Results provide tentative evidence that this "Sleep Tank" model may be an informative tool to aid in individual decision-making based on sleep history.

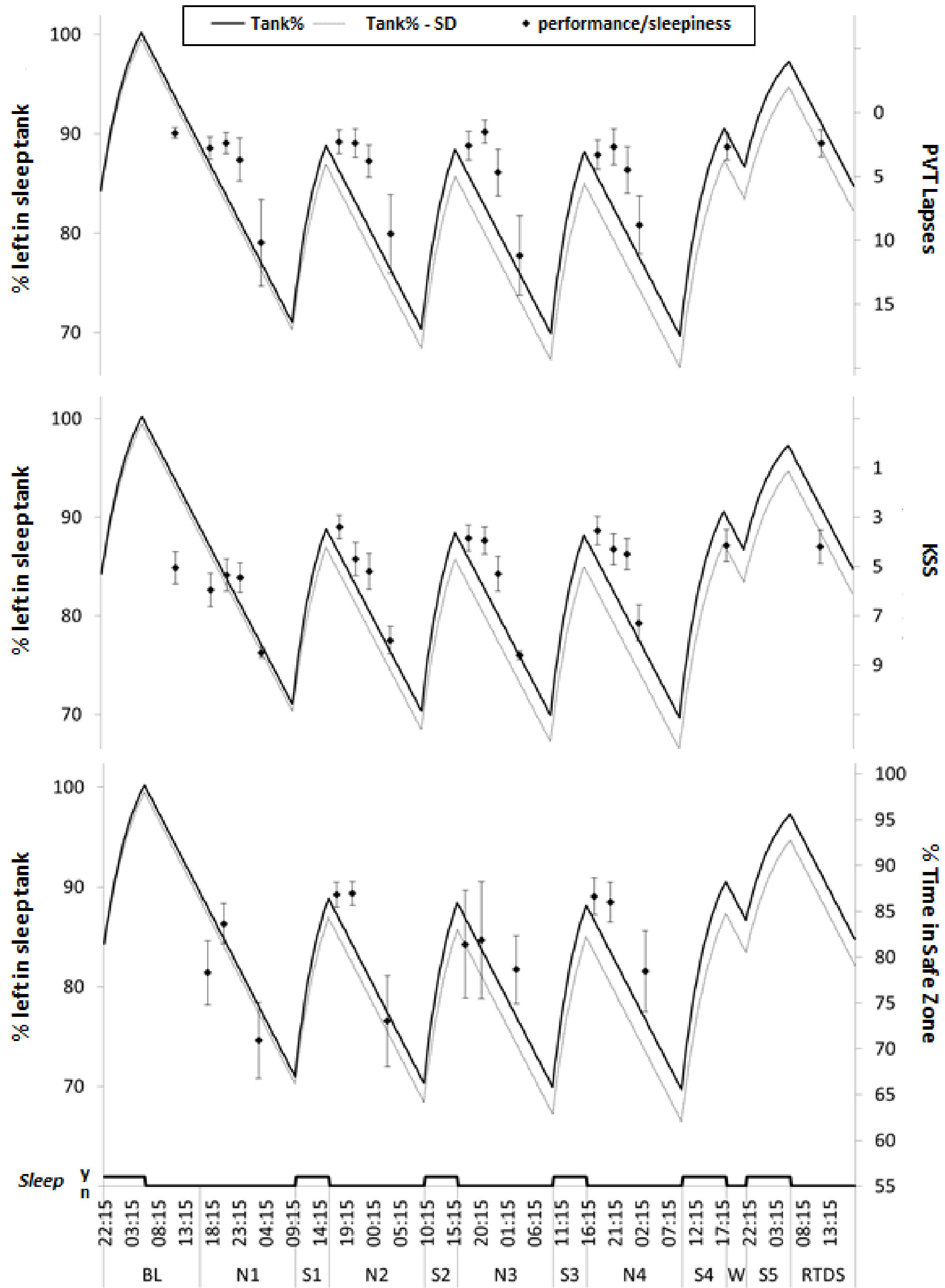

Figure 3. ***"Sleep Tank", Performance and Sleepiness –*** Time-of-day (24h clock) is on the x-axis, with % left in the sleep tank on the y-axis. Sleep opportunities are shown along the x-axis. BL=Baseline, N1-4=nightshifts, S1-4=Sleep opportunities, RTDS=return to daytime schedule. PVT Lapses (upper), KSS (middle) and %Time in the Safe Zone (%time within 10km/h of the speed limit and within 0.8m of the centre of the lane) from the driving simulator (lower) are superimposed over model output.

Summary [150 words]

Increasingly, people are gaining access to information about their sleep. Using this information to make evidence-based decisions relating to fatigue safety is not always straightforward. Arithmetic transformation of sleep duration and quality into an intuitive "Sleep Tank," which includes suggestions such as the number of hours until more sleep is critical, may assist individual deliberation about fitness for work at that moment, and across a coming shift. Further validation is necessary, however initial findings are promising. Following validation of the model (and the devices) "Sleep Tank" calculations could be added to consumer-grade actigraphs and/or sleep monitoring apps to help people to map the performance and safety implications of their recent sleep history.