

## Driver fatigue during extended rail operations

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Received 31 October 2007; accepted 25 January 2008

### Abstract

**Objectives:** Relay is an effective mode of freight transportation within Australia. Relay requires two crews to drive the train continuously from one specified destination to another and return with crews working in alternating shifts. The aim of the current investigation was to assess fatigue levels during extended relay operations.

**Methods:** Nine drivers participated and data were collected from 16 four-day trips. Fatigue was assessed objectively and subjectively prior to and following each trip and before and after each 8 h shift.

**Results:** Analyses revealed a trend for elevated fatigue at the end of each shift. Designated 8 h rest periods appeared sufficient to reduce fatigue to levels recorded prior to departure and prevent accumulation of fatigue across the trip.

**Conclusions:** Drivers seemed to cope well with the 8 h rotating sleep/wake regime. While fatigue did not observably accumulate, it is possible that operational measures may better reflect fatigue experienced over the course of each trip.

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**Keywords:** Train drivers; Fatigue; Rail

### 1. Introduction

Increased sleepiness and high levels of fatigue are commonplace in many shift-work settings and field data have consistently shown that these feelings are particularly prevalent during the night (Härmä et al., 2002; Ingre et al., 2004; Torsvall and Åkerstedt, 1987; Paley and Tepas, 1994). Moreover, severe sleepiness and difficulties in staying awake are typically accompanied by behavioural impairment. Tilley et al. (1982), for example, assessed train drivers' reaction time before the end of each shift and found that not only were the workers impaired during the night but also their performance deteriorated as a function of the number of days into a roster. With data such as these in mind, it is not surprising that errors and accidents are most prevalent at night (de Vries-Griever and Meijman, 1987). As such, there is concern for the productivity and efficiency at work and also for the safety and well-being of the workers both during work and non-work hours.

The rail industry has been the focus of numerous investigations around the world. More specifically, research within the rail industry has assessed the impact of night shifts (Hak and Kampman, 1981; Torsvall and Åkerstedt, 1987; Härmä et al., 2002), early morning shifts (Hak and Kampman, 1981; Härmä et al., 2002; Ingre et al., 2004), afternoon/evening shifts (Hak and Kampman, 1981; Härmä et al., 2002), irregular shift systems (Sallinen et al., 2003), varying break lengths (Roach et al., 2003) and extended leave (Kandelaars et al., 2005). All of these studies have identified concerns with regard to shift-work in terms of both sleep and sleepiness. Within the Australian rail industry there is a unique type of shift-work rostering called relay. Despite the prevalence of relay work in Australia, there has been very little research specifically devoted to the impact of this type of work on the train drivers themselves.

Relay operations require multiple crews to work the train continuously during a round trip from one specified destination to another. The crews work in alternating shifts (usually 6–10 h in duration), where their sleep/duty times are opposite. There are both short (<2 days) and extended relay (>2 days) operations. Both involve irregular work

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hours that generally include day, night, morning and evening shifts. Workplace research has identified that the highest levels of sleepiness and fatigue are generally associated with early morning shifts and night shifts (Härmä et al., 2002; Ingre et al., 2004). As such, relay drivers may experience increased levels of sleepiness and fatigue when working at these times, which may put them at an increased risk of accident and error (de Vries-Griever and Meijman, 1987).

Also of concern is the impact that relay operations have on drivers' sleep. Previous research investigating relay operations has shown that on an 8 h-on/8 h-off roster (which would involve the continued shifting of the circadian system, unlike a 6- or 12-hourly rotation), drivers' sleep can be restricted to 5.3 h per 24 h during an extended trip (Jay et al., 2006). In light of laboratory-based research, this sleep restriction is of concern. It has been shown that waking functions may become impaired in a dose-dependant manner when time in bed (TIB) is reduced to 7 h (i.e. under 6.5 h total sleep time (TST)) or less, and maintained for several days (Belenky et al., 2003; van Dongen et al., 2003). Further to this is the fact that relay drivers' sleep is obtained in split sleep periods, which may not be as restorative as a single 5–6 h sleep period. This may have further implications for waking functions. Notably, Lamond et al. (2005) illustrated that for short relay operations (<2 days) reduced sleep did not significantly impact on the drivers' waking functions. However, it might be reasonable to suggest that over a longer trip, such as the return trip from Port Augusta to Darwin (an approximately 5930 km round trip), the cumulative effects of the sleep restriction and the split sleep periods on both sleepiness and waking functions will be more pronounced.

Further to the concern regarding increased fatigue and impaired performance during relay operations is the length of time required for drivers to recover following each trip. The relay investigation by Lamond et al. (2005) did not measure alertness or performance beyond the trip itself, and as such the aftereffects of this specific type of work have not been explored. Drivers working from Port

Augusta to Darwin operation could be departing on another trip <48 h after returning from the previous one (regulations at the time of data collection). In circumstances such as these, due to the departure and arrival times of the trains, drivers may only have one full night's sleep prior to their next trip. It seems reasonable to assume that workers are performing at or near to their optimum at the beginning of each rostering shift cycle. Therefore, it is important to understand whether the allocated time off is sufficient for recovery.

Research specifically investigating the impact of relay work is limited. The research that does exist suggests that the shorter relay operations do not significantly affect drivers' sleepiness levels and waking functions. It is not known, however, what the consequences will be for sleepiness and waking functions when these operations are extended beyond 2 days. The main aim of this study was to investigate the impact of this unique rostering system on relay drivers' perception of fatigue and their waking functions both before and after each 8 h shift whilst working the extended relay operation from Port Augusta to Darwin and to examine their recovery in the 3 days following each trip.

## 2. Methods

### 2.1. Study design

This study investigated the impact of extended relay operations on train drivers' waking functions and fatigue levels. A typical relay trip spanned across 5 days and consisted of a trip from Port Augusta to Darwin followed by an overnight stay in Darwin (between 8–14 h) before returning to Port Augusta (Fig. 1). Two crews, each consisting of two drivers, rotated every 8 h, giving each crew an 8 h rest prior to each 8 h working shift. There were two rosters: Roster 1—where the first shift out of Port Augusta was a working shift and Roster 2—where the first shift out of Port Augusta was a resting shift (see Fig. 1). Those drivers working Roster 1 had three 8 h working

Depart Port Augusta

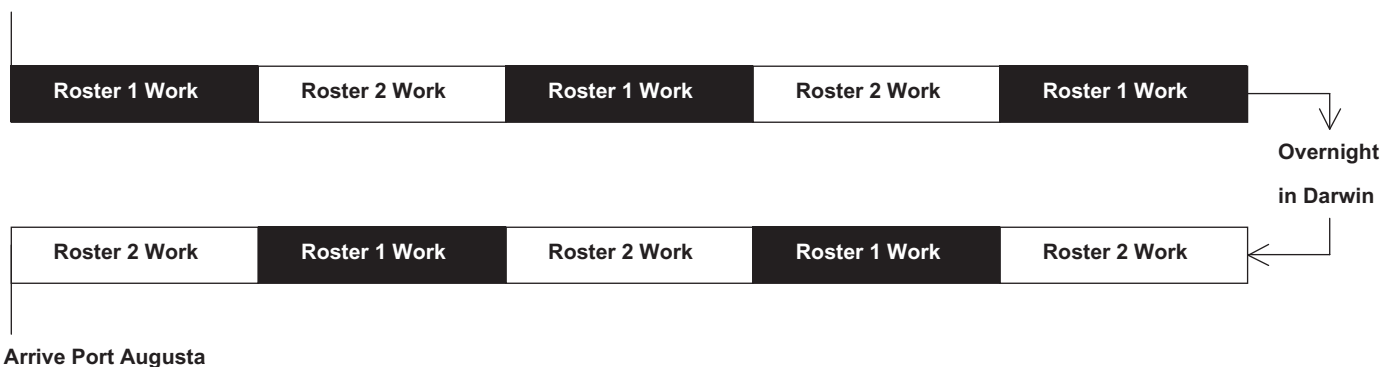


Fig. 1. Schematic representation of each Port-Augusta to Darwin return trip. Each black or white box represents an 8 h work-shift. When the Roster 1 crew is working, the Roster 2 crew is using the on-board rest-facilities for sleeping/resting and vice versa. On some of the trips there was another, short work/rest period before arriving back to Port Augusta. If at all this shift was required, it was only for a couple of hours in duration.

shifts prior to arrival in Darwin and two on the return trip. Those drivers working Roster 2 out of Port Augusta had two 8 h working shifts on the first leg of the trip and three on the return trip. When returning from Darwin to Port Augusta, drivers had two resting and three working shifts. Ethics approval was granted by the University of South Australia Human Research Ethics committee and as such meets ethical standards (Touitou et al., 2004).

## 2.2. Participants

Nine drivers (out of 27 eligible drivers) volunteered to participate. All participants were male and their demographic data are presented in Table 1. Six of the nine participants were married or living with a partner and three of the drivers were smokers. All drivers regularly drank tea/coffee and consumed alcohol. No drivers had ever suffered any serious head injuries, accidents or concussion, nor did they have a personal or family history of asthma, stroke or allergies. Two drivers had a family history of heart attack and high blood pressure and one driver reported that he had high blood pressure. Eight of the nine drivers regularly participated in mild forms of exercise (e.g. walking) that largely took place on days off.

## 2.3. Assessment of waking functions

### 2.3.1. Psychomotor vigilance task

A 5 min response time (RT) task was used to assess performance before, during, and in the 3 days following each trip. During the trip, drivers would typically complete the task 10–15 min before and after each shift. The RT task was completed on a Palm Pilot using the PalmPVT (PVT-Psychomotor Vigilance Task) program, developed by The Walter Reed Army Institute of Research (Thorne et al., 2005). The PalmPilot device has been validated (Thorne et al., 2005) against the commercially available PVT-192 device (Dinges and Powell, 1985).

Table 1  
Participant demographics taken from responses in the General Health Questionnaire

	Mean $\pm$ St. dev.	Range
Age	51.3 $\pm$ 6.4	42–63
Body mass index <sup>a</sup>	30.4 $\pm$ 4.4	24.7–37.5
Years working irregular hours	31.2 $\pm$ 6.2	22–40
Years as a train driver	27.0 $\pm$ 7.5	15–39
Years working relay	22.3 $\pm$ 11.7	0.7–35
Sleep quality at home <sup>b</sup>	2.5 $\pm$ 0.6	2–3.5
Sleep quality in the relay vans <sup>b</sup>	3.3 $\pm$ 0.9	2–5
Sleep quality in Darwin <sup>b</sup>	2.7 $\pm$ 0.8	2–4

<sup>a</sup>Calculated from self-reported weight and height measurements in General Health Questionnaire.

<sup>b</sup>Values obtained from 5-point sleep quality index (1 = “very well”–5 = “very poorly”) prior to data collection.

### 2.3.2. Samn–Perelli Fatigue Checklist

The scale used to assess fatigue was the 7-point Samn–Perelli Fatigue Checklist (Samn and Perelli, 1982). This scale was administered before, during and after each trip. Participants were instructed to circle the number (1–7) corresponding to the statement that best described how they were feeling at that point in time. Circling a ‘1’ indicated that the participant was feeling “fully alert, wide awake” and circling a ‘7’ indicated that the participant was feeling “completely exhausted, unable to function effectively”.

## 3. Procedure

On the day prior to each trip, baseline (‘pre-trip’) data were collected for the PalmPVT and fatigue ratings. In all cases this was a rostered day off. Data were collected at three time points (typically in the morning, early afternoon and late afternoon/evening). Prior to each trip participants had spent at least three nights at home, at least one of which was a full night (i.e. not preceded by a late/evening shift or followed by an early morning shift). For seven of the 11 trips, drivers had two full nights at home prior to the trip. During each trip, PalmPVT and fatigue ratings were recorded before and after each working shift. Drivers were encouraged to do the PalmPVT and complete their fatigue ratings as soon as possible prior to and following each shift without causing disruption to their work duties. In most cases it was within approximately 15–30 min. Finally, data collection continued in the 3 (recovery) days following each trip with drivers completing the PalmPVT and fatigue ratings twice daily, typically once in the morning and once in the afternoon/evening.

## 4. Data sets

For seven drivers, data were collected on two trips: one when they were working Rosters 1 and one when they were working Roster 2. For two drivers data were collected for one trip, when working Roster 1. There were no missing data on the pre-trip baseline day or during the trip itself. Therefore, there were  $n = 45$  (Roster 1) and  $n = 35$  (Roster 2) values each for pre-shift PalmPVT, post-shift PalmPVT, pre-shift fatigue and post-shift fatigue.

The test scores and rating values were averaged to obtain one value and one fatigue rating per driver per recovery day. There was no missing data on recovery day 1 and as such the sample sizes for Rosters 1 and 2 were  $n = 9$  and  $n = 7$ , respectively. On recovery days 2 and 3, there were data missing from two drivers for Roster 1 and one driver for Roster 2, making the sample size for both PalmPVT and fatigue for recovery days 2 and 3,  $n = 7$  and  $n = 6$ , respectively.

## 5. Data analysis

The variables extracted were: mean response time, lapses (response times  $> 500$  ms), fastest 10% of response times

and mean fatigue ratings. A reciprocal transformation ( $1/RT \times 1000$ ) was applied to the raw response time data (mean and fastest 10%) before analysis to correct for proportionality between the mean and the standard deviation. Given that the timing of the shifts (in relation to the beginning of each trip) differed for each roster, the two rosters were analysed separately. Repeated measures ANOVA using the mixed-model procedure was performed for each variable. This was done to determine significant deviations from the pre-trip baseline across the trip and recovery. Where a significant main effect of time was obtained, planned comparisons were used to compare trip and recovery values back to the pre-trip value. Data were analysed using SPSS v12.0 for Windows. Original, uncorrected degrees of freedom are reported.

## 6. Results

### 6.1. Changes in PVT and subjective fatigue across the trip

Results from separate mixed-model ANOVA are presented in Table 2.

In terms of the PalmPVT variables, significant changes across the trip and recovery were found in Roster 1 for mean RRT. Changes in other PVT variables for Roster 1 and all PVT variables for Roster 2 did not yield statistically significant results. Subjective fatigue ratings varied significantly across the trip in both rosters. Results for mean RRT and subjective fatigue ratings are displayed graphically in Figs. 2 and 3, respectively.

For Roster 1, mean RRT following shift 5 was slower compared to baseline, though this was not statistically significant ( $P=0.06$ ). Similarly, mean RRT prior to shift 4, immediately following the overnight stay in Darwin, was faster, again, however, not significantly so ( $P=0.06$ ). In terms of subjective fatigue ratings, results from planned comparisons (Roster 1) indicated significant increases in fatigue compared to the pre-trip baseline for all five shifts' post-shift ratings. Ratings on the three recovery days did not differ significantly from the pre-trip value. For Roster 2, planned comparisons revealed that ratings following shifts 2 and 4 were significantly greater than the pre-trip baseline. Ratings on recovery day 3 were significantly less.

Table 2  
Mixed-model results for each Roster comparing changes in PVT and fatigue variable across pre-trip, trip and recovery

	Mean RRT		Lapses		Fastest 10% RRT		Fatigue <sup>a</sup>	
Roster 1	$F_{13,78} = 3.7$	$P < 0.05$	$F_{13,78} = 1.1$	NS	$F_{13,78} = 1.9$	NS	$F_{13,78} = 12.2$	$P < 0.001$
Roster 2	$F_{13,65} = 1.3$	NS	$F_{13,65} = 1.3$	NS	$F_{13,65} = 1.0$	NS	$F_{13,65} = 8.8$	$P < 0.01$

<sup>a</sup>Fatigue ratings taken from the Samn–Perelli fatigue checklist.

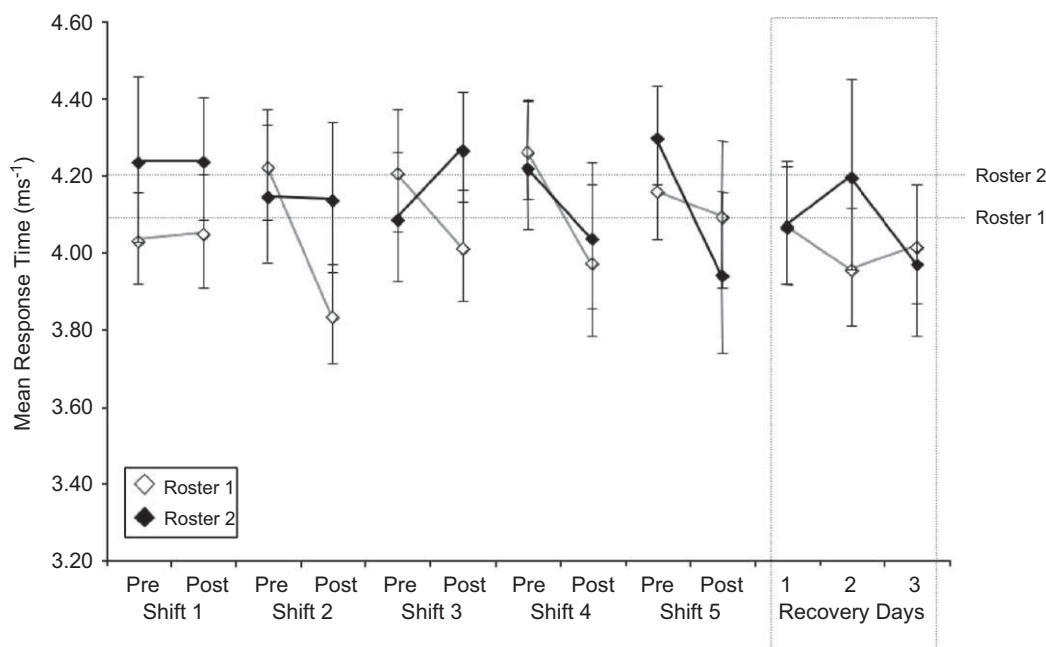


Fig. 2. Response times across each trip and recovery. Data are mean  $\pm$  SEM. Lower values indicate slower response times. When working, Roster 1 drivers worked three 8 h shifts (Shifts 1–3) and Roster 2 drivers worked two 8 h shifts (Shifts 1–2) prior to the overnight stay in Darwin.

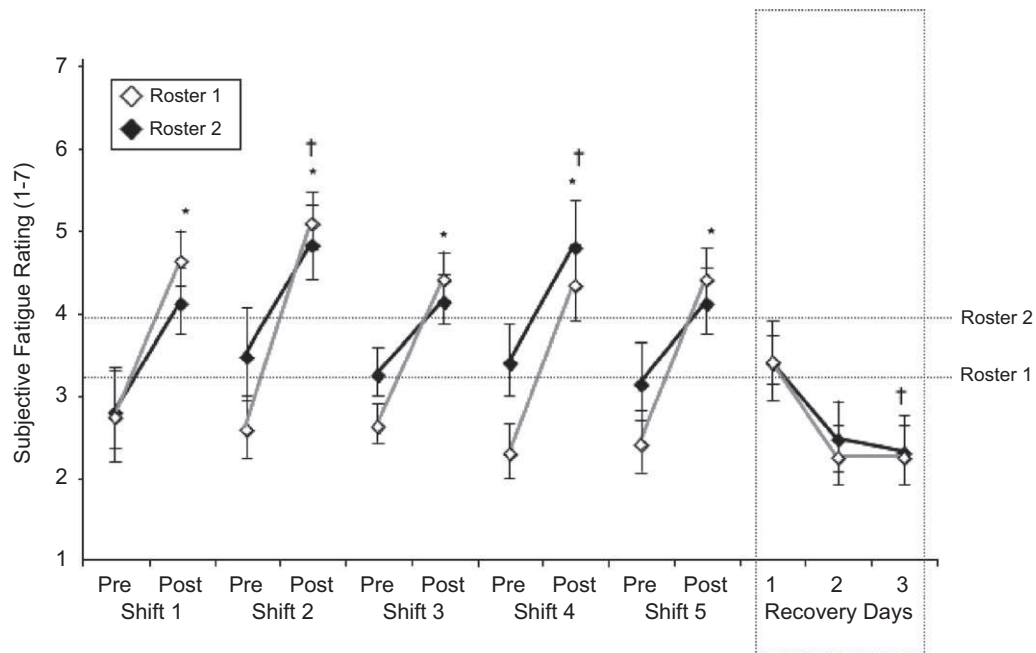


Fig. 3. Subjective fatigue ratings across each trip and recovery. Data are mean  $\pm$  SEM. When working, Roster 1 drivers worked three 8 h shifts (Shifts 1–3) and Roster 2 drivers worked two 8 h shifts (Shifts 1–2) prior to the overnight stay in Darwin. \* denotes a significant difference from pre-trip baseline for Roster 1; † denotes a significant difference from pre-trip baseline for Roster 2.

## 7. Discussion

The current study sought to determine the impact of the Port Augusta to Darwin extended relay operation on drivers' fatigue. Past research focusing on the short relay operations (<2-day) has found that drivers are able to maintain alertness for the duration of these shorter trips (Lamond et al., 2005). It was not known, however, whether the longer trips would result in accumulation of fatigue across the trip, thereby making drivers more susceptible to error and accident. Furthermore, recovery following relay trips (whether long or short) has not previously been investigated. Both objective and subjective measurements were examined to determine the impact of the Port Augusta to Darwin operations and the nature of 'recovery' following such extended relay trips.

When drivers worked Roster 1, the general trend was for performance to be poorer at the end of each shift. Impairment, however, was relatively short-lived, with the 8 h rest periods generally able to reverse the impact of the prior shift and return response times to the pre-trip baseline level. This seemed to prevent impairment from accumulating across the trip. For Roster 2, while there was a general trend for response times to be slower following each shift, particularly on the return leg, this was not statistically significant. In terms of subjective fatigue ratings, there were significant changes across the trip in both rosters. Again, the general trend was for fatigue to be greater at the end of each shift, but each rest period was enough to reduce fatigue levels and as such fatigue did not increase as the trip progressed.

These results are of particular interest given the findings from other shift-work research. For example, in a study investigating train driver fatigue, Tilley et al. (1982) found that workers' reaction time performance deteriorated as a function of the number of days into a shift-working roster. Indeed, there have been other studies that also support this finding (Totterdell et al., 1995; Petrilli et al., 2006). As noted, however, in the current study, no such deterioration across the number of days worked was observed. Notably, Totterdell et al. (1995) for example, who reported progressive increases in performance impairment or fatigue throughout a roster, looked at the impact of successive night shifts, which may have a differential impact on performance and fatigue compared to the 8-hourly rotation of the relay drivers' work. Unlike permanent night shifts where all sleep periods occur during the day, some sleep periods for the relay drivers occurred at night, where they obtained more sleep as compared to that during the day.

Additionally, the overnight stay in Darwin may also have played a role in preventing cumulative increases in performance impairment and fatigue. The time in Darwin represents not only the opportunity for a longer, night-time sleep period, but also a break from work and an opportunity to "wind-down" before the return leg of the trip. The increased recovery value of the Darwin sleep period is shown in previously published data (Jay et al., 2006). Not only did the drivers rate this sleep as being of significantly superior quality compared to relay van sleep periods, but it also contained significantly more SWS. It is possible that after 2 days and nights on the train, drivers' performance impairment and fatigue levels are indeed



building, but the rostered time in Darwin may have served to refresh the drivers, thereby making them less vulnerable to continued increases in fatigue during the return journey. In this sense, the 4-day trip is broken into two, short rosters, which may explain why more profound effects were not observed. This hypothesis would complement the conclusions drawn by Lamond et al. (2005), where drivers' alertness was maintained during the short, 2 day operations.

The fact that few significant changes in PVT performance were observed across the trip should not necessarily lead to conclusions that the trip itself is not fatiguing. Without using a simulator or tracking actual operational measures, it is difficult to replicate the vigilance required during an 8 h shift. Fatigue levels increase as a function of time-on-task, and time-on-task effects on fatigue are greater during monotonous tasks (Richter et al., 2005). Notably, some 8 h shifts during the trip involved driving the train across an unchanging landscape, with few speed changes and no train crosses. Therefore, the monotony associated with shifts such as these may potentially exacerbate fatigue levels, particularly towards the end of an 8 h shift. Taking this monotony into consideration, in combination with their restricted sleep patterns and time-of-day, it is doubtful that the drivers are not fatigued at all. It is possible that the extent of their fatigue was not captured in the chosen task.

Another possibility may relate to the time at which the tests were administered. To avoid disruption to the crews whilst working, tests were completed as near to the beginning and end of each shift as possible. However, fatigue levels may have been suppressed somewhat at these times given the heightened levels of activity involved with taking over the train. This was observed by Eriksen et al. (2006) in a simulated 6 h-on/6 h-off sea-watch system. The authors suggested that, in taking over responsibility for the ship, officers' levels of sleepiness at the beginning of each shift masked any expected time-of-day effect. This may have also been the case in the current study.

A further aim of this study was to look at drivers' recovery following each trip. For Roster 1, although drivers did experience significant changes from baseline in performance across the trip and recovery, response times on all three recovery days did not deviate significantly from the baseline. Similar to the sleeps during the trip, the short sleep they obtained immediately after arriving back in Port Augusta was enough to reverse any impairment brought about by the last shift. Subsequent night-time sleeps at home or simply being away from work kept them at that same level for the following two recovery days. For Roster 2, there were no significant changes from baseline in response to the time performance either during the trip or during recovery. In this sense, drivers did not need to recover per se because the trip did not significantly impact on their ability to perform on the task. In terms of the subjective fatigue ratings, both rosters deviated from baseline at points during the trip but reported fatigue on all recovery days did not significantly deviate from base-

line, excluding recovery day 3 for Roster 2, which indicated a lower level of fatigue.

While the data suggest that the drivers' recovery following each trip was rapid, generally occurring after one short sleep period at home, a valid consideration is whether the type of recovery that the drivers needed following each trip was even detectable by a performance task and fatigue rating scale. Totterdell et al. (1995) noted that worldwide work hours regulations are generally based on the assumption that the time at work may have a negative impact on the well-being of the workers themselves. In terms of relay rostering, therefore, factors such as being away from home and "living" with the same other workers for 4 days at a time combined with missing social events and interactions may all take their toll on the drivers. Measures directed at assessing the well-being of the drivers, used by Totterdell et al. (1995), such as level of social satisfaction, cheerfulness, calmness and perceived workload may provide additional information regarding their recovery and the sufficiency of allocated recovery periods.

Finally, analysing the rate of recovery in terms of significant deviations from the pre-trip baseline should be viewed with a degree of caution. While drivers had an average of two full nights' sleep before participating, some had worked during those days. Recovery in this context, therefore, is not back to a baseline that represents their optimal performance, or lowest levels of fatigue. Instead, the extent of their recovery is determined by how they happened to be feeling prior to each particular trip. For future investigations, it would be of theoretical interest to investigate the impact of these trips following a prolonged break from work, after a holiday for example, whereby a 'true' baseline may be more attainable. From a practical perspective, however, how drivers are able to recover and cope from one trip to the next is of most interest given that for most of each year they are completing these 4-day trips with approximately 2 to 3 days recovery in between.

## 8. Conclusions

In terms of response time performance, the relay drivers seemed to cope with the enforced 8 h-on 8 h-off routine for the duration of the trip. While there was a clear trend for fatigue levels to be elevated at the end of each working shift (particularly during Roster 1), each 8 h rest period appeared sufficient to reduce fatigue to levels recorded prior to departure. Field-based studies that are able to quantify fatigue using more operational measures or that are able to track vigilance for the entirety of an 8 h shift may better reflect the impact of this rostering system on driver fatigue.

## Acknowledgements

We would like to thank the nine volunteers for their participation and Frank Hussey for his help throughout all phases of the project. This research was supported by

*Australian Railroad Group, FreightLink and Pacific National.*

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