COMPARING THE EFFECTS OF FATIGUE AND ALCOHOL CONSUMPTION ON LOCOMOTIVE ENGINEERS’ PERFORMANCE IN A RAIL SIMULATOR

Gregory D. ROACH, Jill DORRIAN, Adam FLETCHER and Drew DAWSON
Centre for Sleep Research, University of South Australia, Adelaide, Australia

Laboratory studies have established that the performance impairments due to fatigue and alcohol consumption are quantitatively similar. However, the generalisability of this phenomenon is not clear because comparisons have not been made in realistic work settings with experienced shiftworkers. The aim of the current study was to quantify the effects of fatigue on performance in a simulated work environment (i.e. rail simulator) and compare them with the effects of alcohol consumption. It was hypothesised that fatigue would significantly impair driving performance, and that this impairment would be quantitatively similar to that associated with moderate levels of alcohol consumption. Twenty locomotive engineers participated in the study with a randomised cross-over design and three conditions: baseline, fatigue, and alcohol. During each 8-hour condition, participants completed four driving sessions in the rail simulator. The results indicate that fatigue caused participants to disengage from operating the simulator such that safety was traded off, not necessarily deliberately, against efficiency. The impairment in safety due to fatigue was in a range similar to the impairment associated with moderate levels of alcohol consumption. In summary, the study demonstrated that the effects of fatigue in a simulated work environment can be quantified and may be considerable.

Introduction

The effects of fatigue, induced by sleep deprivation and/or circadian disruption, have been extensively examined. The research indicates that fatigue significantly impairs alertness and performance in the laboratory and in simulated and real work environments (SUGERMAN and WALSH, 1989; BABKOFF et al., 1991; LINDE and BERGSTROM, 1992; DINGES et al., 1997; MCCARTHY and WATERS, 1997; REYNER and HORNE, 1998). Furthermore, several reviews indicate that fatigue greatly increases the likelihood of being seriously injured or even killed in an accident at or away from work (LAUBER and KAYTEN, 1988; MITTLE et al., 1988; DINGES, 1995).

A separate line of research has clearly demonstrated the considerable performance impairment and safety risk associated with alcohol consumption. As blood alcohol concentration (BAC) increases, performance declines on a range of tasks in the laboratory, and in driving and flight simulators (e.g. HENRY et al., 1974; FINNIGAN et al., 1995; TAYLOR et al., 1996). In addition, the risks of being involved and/or injured or killed in a motor vehicle crash increase significantly with increasing BAC (e.g. HOLUBOWYCH et al., 1994; ZADOR et al., 2000).

Over the last two decades in Australia, media campaigns have raised community awareness such that the performance impairment associated with alcohol consumption is now well understood and widely accepted. It is almost unanimously acknowledged that it is unacceptable to drive a motor vehicle, operate complex or dangerous machinery, or work whilst under the influence of alcohol (HOMEL et al., 1988; LOXLEY et al., 1990). This acknowledgement is reflected in laws governing both road safety and occupational health and safety. In contrast, although some industries in Australia have hours of service regulations that specify maximum shift lengths and
minimum break durations, knowledge and acceptance of the impairment associated with fatigue is limited. Indeed, many still erroneously believe that they can either become accustomed to, or push through, the effects of fatigue (for an example, see REYNER and HORNE, 1998). This is obviously a serious misconception that must be addressed.

Dawson and colleagues (DAWSON and REID, 1997; LAMOND and DAWSON, 1999) have formulated an approach to this problem that harnesses existing community understanding by directly comparing the effects of fatigue and alcohol consumption. Others have compared the effects of fatigue and alcohol consumption on measures of sleepiness (ROEHRS et al., 1994), reaction time (PEEKE et al., 1980; KRULL et al., 1993), and simulated driving performance (FAIRCLOUGH and GRAHAM, 1999; ARNEDT et al., 2000), but DAWSON and REID (1997) introduced a novel approach whereby they expressed fatigue-related impairment as a BAC equivalent. Three similar studies considering the effects of total sleep deprivation on various measures of neurobehavioural performance indicate that the impairment in cognitive ability after 17–25 hours of sustained wakefulness beginning in the morning is similar to that associated with a BAC of 0.05–0.10% (DAWSON and REID, 1997; LAMOND and DAWSON, 1999; WILLIAMSON and FEYER, 2000).

Two limitations of these comparison studies are that they have not necessarily been conducted with shiftworkers, and that they have employed computer-based measures of performance in laboratory settings. Both issues raise questions regarding the generalisability of the results to shiftworkers' performance in real workplaces. The current study was designed to overcome these limitations by considering the performance of experienced locomotive engineers driving a realistic train simulator as part of their rostered schedule of work. The aim of the study was to quantify the effects of fatigue and compare them with the effects of alcohol consumption. The results of previous studies examining the effects of sleep deprivation and alcohol consumption led to the hypothesis of a general impairment in performance under the influence of both fatigue and alcohol consumption.

Methods

Twenty locomotive engineers (all male employees of Queensland Rail, QR) volunteered to participate in the study. Potential participants were screened during an interview and using a health questionnaire for health problems, sleep disorders, and medications known to impact on sleep. Participants had a mean (± s.d.) age of 39.4 (± 9.4) years.

The study employed a randomised cross-over design with three conditions: baseline, fatigue, and alcohol. Each condition consisted of four 2-hour sessions. In each session, participants operated the rail simulator for 100 minutes, performed a psychomotor vigilance task, and completed self-assessments of alertness and performance; but only the simulator data are reported here. Participants were instructed to operate the simulator as they would an actual locomotive.

All test sessions were conducted in one of two identical simulators located at QR's driver training centre in Rockhampton, Queensland. Both simulators consisted of a mock locomotive cabin with an interior that resembled an actual locomotive in form and function. The simulated train consisted of a single 2,000 hp General Motors 2100-class diesel locomotive with twenty-six freight-laden wagons. The entire train was 432m long and weighed 1,002 tonnes. A short, heavy train of this type is difficult to manage, particularly on downhill sections of track, because it gathers speed quickly once it has crested an incline.

During each test session, the train was driven along a 62km section of track that had twenty-one bridges, three level crossings, and eight stations. The general track speed limit was 80km/h, with localised speed restrictions of 15, 40, 50, 60, and 70km/h. This piece of track was chosen because it had technically demanding sections that required a high degree of skill to negotiate safely and efficiently (e.g. steep declines leading to speed restricted corners), and it had less demanding sections for which it was difficult to maintain concentration (e.g. steep, straight inclines).
Participants performed the baseline and alcohol conditions during the daytime (approximately 10:00–18:00h) following a night of sleep. The fatigue condition was performed during the night-time (approximately 23:00–07:00h) after two or three consecutive night shifts. During the alcohol condition, participants were breath-tested and given an alcoholic beverage (vodka with mixer) every thirty minutes from 10:00h until they reached a BAC of 0.10% during the final session.

**Measures and Data Analysis**

The effects of fatigue and alcohol consumption on three main measures of driving performance were considered. The measures were:
- duration of extreme speed violations – amount of time during which the train travelled at greater than 25% over the local speed limit. In a real train, violations of this magnitude are likely to cause derailment. Greater values indicate lower safety.
- air brake use – amount of time during which the air brakes were engaged. Greater values indicate lower efficiency.
- fuel consumption. Greater values indicate lower efficiency.

Using the model by DAWSON and FLETCHER (2001), fatigue scores were calculated for each session of the baseline and fatigue conditions based on each participant’s work history over the previous 7 days. On the basis of these scores, each session was allocated into one of three groups: low, moderate, or high fatigue. Subsequently, the effects of fatigue level on the three measures of driving performance were determined using factorial analyses of variance (ANOVA). For the alcohol condition, each session was allocated into one of four groups based on BAC: 0.00–0.025%, 0.025–0.05%, 0.05–0.075%, or 0.075–0.10%. The effects of alcohol consumption on the three measures of driving performance were determined using factorial ANOVA. In all ANOVA analyses, missing values were replaced by the group mean. Post hoc analyses were conducted with Fisher’s protected least significant difference (PLSD) where required.

For measures that were significantly affected by both fatigue level and alcohol consumption, the relationship between BAC and the measure was determined by simple linear regression. The resultant regression equation was used to estimate the value of the measure at the 0.05% and 0.10% BAC levels.

**Results**

The duration of extreme speed violations was significantly affected by fatigue level ($F_{1,16}=5.53$, $p<0.01$). Generally, extreme speed violations increased as fatigue level increased (Fig. 1A). Post-hoc analysis indicated that violations were significantly greater at the high fatigue level than at the low fatigue level ($p<0.01$). The duration of extreme speed violations was also significantly affected by alcohol consumption ($F_{3,16}=2.63$, $p<0.05$). Generally, extreme speed violations increased as BAC increased (Fig. 1A). Post-hoc analysis indicated that violations were significantly greater at the 0.00–0.025% level than at the 0.075–0.10% level ($p<0.01$).

Air brake use was significantly affected by fatigue level ($F_{2,15}=3.76$, $p<0.05$). Post-hoc analyses indicated that brake use was significantly greater at the moderate fatigue level than at the low fatigue level, but was significantly lower at the high fatigue level than at the moderate fatigue level (both $p<0.05$) (Fig. 1B). Air brake use was not significantly affected by BAC ($F_{3,76}=0.02$).

Fuel consumption was significantly affected by fatigue level ($F_{2,15}=6.31$, $p<0.01$). Post-hoc analyses indicated that fuel consumption was significantly lower at the high fatigue level than at both the low and moderate fatigue levels (both $p<0.01$) (Fig. 1C). Fuel consumption was not significantly affected by BAC ($F_{3,76}=0.02$).
Fig. 1. Mean (± s.e.m.) duration of extreme speed violations (A), duration of air brake use (B), and fuel consumption (C) as a function of fatigue level (low, moderate, high). Duration of extreme speed violations at the 0.05% and 0.10% BAC levels is also represented in panel A. BAC did not significantly affect air brake use (B) or fuel consumption (C).

Discussion
Based on the results of previous laboratory- and simulator-based studies, and on anecdotal evidence from experienced locomotive engineer trainers, it was hypothesised that there would be a general decline in performance as both fatigue and alcohol consumption increased (HENRY et al., 1974; SUGERMAN and WALSH, 1989; LINDE and BERGSTROM, 1992; FINNIGAN et al., 1995; TAYLOR et al., 1996; DINGES et al., 1997; REYNER and HORNE, 1998). Specifically, it was hypothesised that fatigue and alcohol consumption would both lead to greater duration of
extreme speed violations (i.e. reduced safety) and greater use of air brakes and fuel (i.e. reduced efficiency).

For the safety measure (i.e. extreme speed violations), performance did decline as both fatigue level and alcohol consumption increased (Fig. 1A). Indeed, the duration of extreme speed violations at the high level of fatigue was in the range associated with moderate levels of alcohol consumption (i.e. BAC=0.05-0.10%). Surprisingly though, neither of the efficiency measures progressively declined as fatigue level or BAC increased (Fig. 1B and 1C). In fact, both air brake use and fuel consumption were lower at the high fatigue level than at the moderate fatigue level, suggesting an increase in efficiency as fatigue increased. This counter-intuitive finding was actually a pseudo-efficiency that can be explained by the safety-efficiency trade-off. At high levels of fatigue, participants disengaged from operating the simulator such that brake use and fuel consumption fell, but extreme speed violations increased, thus greatly increasing the risk of derailment.

This safety-efficiency trade-off became more evident upon consideration of raw simulator outputs. For example, qualitative analysis highlighted the difference in driving behaviour of a particular participant at low and high levels of fatigue as they negotiated the transition from a downhill to uphill section of track through a speed-restricted corner. At the low fatigue level, the participant reduced the throttle and applied the air brake as they travelled downhill and approached the corner in order to comply with the speed restriction. Once through the corner, they released the air brake and increased the throttle to ascend the incline. In contrast, at the high fatigue level, the participant reduced the throttle and applied the air brake too late due to poor planning, and consequently violated the speed limit on the corner. As a result though, less fuel was used to ascend the incline at the high fatigue level compared to the low fatigue level because the train had more momentum at the start of the climb. However, there was a greater risk of derailment at the high fatigue level because the corner was negotiated too fast. In this example then, participants’ fatigue-related disengagement from operation of the simulator lead to safety being traded-off (i.e. the speed limit was violated), albeit not deliberately, against efficiency (i.e. less fuel was used).

It is impractical, and obviously dangerous, to implement an experimental manipulation to deliberately impair performance in a real work setting. Consequently, a simulated work environment (i.e. rail simulator) was used in the current study to approximate a real work environment (i.e. an actual train). However, TORNROS (1998) demonstrated that people might be willing to take greater risks in simulated work environments because the consequences of errors are negligible or non-existent. Thus, it may be that participants in the current study were more willing to compromise safety when fatigued in the simulator than they would in a real locomotive. In a real train then, performance impairment due to fatigue may be manifest more in efficiency measures, and less in safety measures, than was observed in the current study.

**Conclusions**

The current study indicates that the results of laboratory-based research showing that the neurobehavioural performance impairment due to fatigue is similar to that associated with moderate levels of alcohol consumption, may be generalised to some performance measures, particularly those regarding safety, in a simulated work environment. Rather than causing a general decline in performance though, fatigue resulted in a safety-efficiency trade-off due to participants’ disengagement from the operating environment.

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References


