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Managing fatigue: It really is about sleep

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ABSTRACT

Biomathematical models of fatigue can assist organisations to estimate the fatigue consequences of a roster before operations commence. These estimates do not account for the diversity of sleep behaviours exhibited by employees. The purpose of this study was to develop sleep transfer functions describing the likely distributions of sleep around fatigue level estimates produced by a commercial biomathematical model of fatigue. Participants included 347 (18 females, 329 males) train drivers working commercial railway operations in Australia. They provided detailed information about their sleep behaviours using sleep diaries and wrist activity monitors. On average, drivers slept for 7.7 ($\pm$1.7) h in the 24 h before work and 15.1 ($\pm$2.5) h in the 48 h before work. The amount of sleep obtained by drivers before shifts differed only marginally across morning, afternoon and night shifts. Shifts were also classified into one of seven ranked categories using estimated fatigue level scores. Higher fatigue score categories were associated with significant reductions in the amount of sleep obtained before shifts, but there was substantial within-category variation. The study findings demonstrate that biomathematical models of fatigue have utility for designing round-the-clock rosters that provide sufficient sleep opportunities for the average employee. Robust variability in the amount of sleep obtained by drivers indicate that models are relatively poor tools for ensuring that all employees obtain sufficient sleep. These findings demonstrate the importance of developing approaches for managing the sleep behaviour of individual employees.

1. Introduction

In recent decades, the limitations of traditional hours of service regulations for the management of fatigue have been recognized (Jones et al., 2005; Sussman and Coplen, 2000). A consensus view is emerging that effective fatigue risk management systems (FRMS) may be achieved by policies and procedures implemented at the organizational and individual employee levels (Lerman et al., 2012). Proponents argue that a locally-tailored fatigue-risk management system can mitigate fatigue-related risks while concurrently allowing greater flexibility in the hours that employees can work (Cabon et al., 2012; Dawson and Zee, 2005; Gander et al., 2011).

In the FRMS framework, fatigue-related errors can be viewed as the end-point of a causal sequence of events termed, 'the fatigue hazard trajectory' (Dawson and McCulloch, 2005). The trajectory concludes with a fatigue-related error committed by an individual in a fatigued state, exhibiting symptoms or signs of fatigue. The fatigued state arises because insufficient sleep is obtained to maintain alertness at a given time of day after a given length of wake. Insufficient sleep is attributable to either an organisational failure to provide adequate rest opportunities or an individual failure to obtain sufficient sleep in an otherwise adequate rest opportunity.

The incidence of fatigue-related errors may be reduced via screening assessments targeted at sequential steps of the hazard trajectory (Dawson and McCulloch, 2005). Thus, biomathematical models of fatigue use software-based algorithms to assess whether scheduled work/rest periods provide employees with sufficient sleep opportunities (Mallis et al., 2004). The amount of sleep obtained by employees in these opportunities can be evaluated when they report for work, using either sleep monitoring devices or direct self-report. Symptoms and signs of fatigue that otherwise present at work can be detected using one or more fatigue recognition technologies (Balkin et al., 2011).

1.1. Biomathematical models of fatigue

Organisations implement biomathematical models to manage the fatigue-related risks associated with hours of work. The scores

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output by biomathematical fatigue models vary in their specific metrics, but all provide an estimate of the fatigue level associated with rostered shifts (Mallis et al., 2004). The assumption underlying numerical quantification is that higher levels of fatigue yield elevated levels of fatigue-related risk. Outputs are typically represented on a dimensionless numerical scale, i.e. without a unit of measurement, but some models include transfer functions that relate outputs to measurable phenomena, e.g. reaction time (Mallis et al., 2004). The purpose of these is to provide an external frame of reference for calibrating and interpreting model outputs.

The distinction between the fatigue level outputs produced by models and fatigue-related risk is important. On the one hand, 'fatigue level' refers to neurobehavioural deficits caused by disturbances in circadian and sleep homeostatic processes (Dijk and Archer, 2009). On the other, 'fatigue-related risk' refers to the extent of exposure to the potential costs of accidents caused by fatigue. The latter is the product of accident likelihood and the financial, social and human cost of accidents. In the absence of mitigating factors, fatigue level contributes to risk only by increasing the likelihood of fatigue-related accidents. By implication, the association between outputs and risk is unlikely to be constant across industries, nor within them.

Model outputs are typically used to classify shifts into tiered risk categories based on fatigue model outputs, e.g. safe vs. unsafe, low vs. moderate vs. high risk. Stratification of model outputs provides a more convenient method for precluding a given sequence of work or for imposing risk-mitigation strategies than raw scores alone. To account for variable risk profiles across industries, most commercial models permit organisations to modify the fatigue score thresholds for delimiting categories of risk. Despite this, industry reports and expert commentary continue to raise concerns in respect to the potential for over-reliance on fatigue models to evaluate safety risks (Civil Aviation Safety Authority, 2014; Dawson et al., 2011; Fourie et al., 2010; Gander et al., 2011; Independent Transport Safety Regulator, 2010).

One factor contributing to these concerns is the relative paucity of research to establish empirical thresholds for classifying shifts into risk categories (Williamson et al., 2011). To date, empirical research on fatigue models has focused primarily on validation of fatigue level estimates (Van Dongen, 2004). The presumption made by most models of a simple linear relationship between fatigue and the safety risks of work is not borne out by empirical investigation (Williamson et al., 2011). Establishing the nature of this relationship is problematic because of the low frequency of accidents in some industries, poor accident reporting and/or publication standards, and difficulties associated with causal attribution in accident investigation (Armstrong et al., 2013; Radun and Summala, 2004).

Another factor contributing to concerns with biomathematical models is that outputs are applicable only to the average individual. Fatigue model outputs are generated under the implicit assumption that the fatigue consequences of a roster are uniform for all employees. By implication, the amount of sleep obtained by employees in the rest periods of a given roster is presumed to be the same. In reality, some proportion of employees will obtain less sleep than predicted, with the consequence that fatigue score outputs are likely to underestimate the fatigue experienced by these employees. Conversely, another proportion will obtain more sleep than predicted, with the consequence that fatigue score outputs are likely to overestimate the fatigue experienced by these employees.

1.2. Purpose of this manuscript

The purpose of this investigation is to develop sleep transfer functions that permit interpretation of fatigue score outputs for a group of employees, i.e. rather than just the average employee. Like other transfer functions, sleep provides an intuitive metric for the non-expert to interpret fatigue level estimates. Thus, in the presence of doubt about the exact link between fatigue scores and fatigue-related risk, information about sleep could serve as useful supplementary information on which to base decisions. A sleep transfer function is potentially useful because it is one of the two basic factors that contribute to fatigue level estimates. Percentile distributions of sleep therefore provide a proxy for the likely distribution of fatigue level estimates for a group of employees working a given roster.

To quantify sleep, we use the prior sleep model proposed by Dawson and McCulloch (2005), which posits simple heuristics to evaluate whether an employee has obtained sufficient sleep before starting work. According to this model, employees should aim to obtain at least X h of sleep in the 24 h before work and Y h of sleep in the 48 h before work. The authors propose X and Y thresholds of 5 and 12 h, respectively, although subsequent empirical modelling of performance and error suggest that an X threshold of 6 h might better distinguish poor performance (Ferguson et al., 2011; Thomas and Ferguson, 2010). In this manuscript, the empirical relationship between the fatigue level outputs of a model and distributions of the sleep obtained by employees in the 24 and 48 h before work was evaluated. The proposed approach to extending the application of fatigue models is potentially generalizable to other models, but the Fatigue Audit InterDyne (FAID) software developed by our research group was utilised in this instance.

2. Material and methods

2.1. Ethics

The research protocol complied with the Australian National Guidelines on Ethical Conduct in Human Research. Ethical approval for conducting the studies was granted by the Human Research Ethics Committee of Central Queensland University.

2.2. Recruitment

Analyses were based on two data sets: (1) an original investigation conducted in 1995–97 (Roach et al., 2003); and (2) a repeat investigation conducted in 2010–12. The target population in both studies were train drivers working metropolitan and rural passenger and freight rail operations in Australia. Potential recruits in the original 1995–97 study were targeted at seven rail organisations at 1 of 14 depots located across five Australian states. Potential recruits in the 2010–2012 study were sampled from three rail organisations at 1 of 20 depots located across four Australian states. Participation was open to all train drivers employed by the collaborating organisations.

Recruitment sessions were arranged with collaborating rail organisations at local depots. Attendees were informed that the purpose of the investigation was to enhance biomathematical models of fatigue and that participation would involve measurement of sleep behaviour using activity monitors. Potential recruits were also informed that participation was voluntary, that any information collected would be de-identified and confidential, and that non-participation or withdrawal from the study would not influence future employment conditions. At the closure of each recruitment session, attendees were given an Information Sheet, Consent Form, General Demographic Questionnaire and a replied-paid envelope in which to return the signed Consent Form should they agree to participate in the study. Participants did not receive any financial incentive for completing the study.