Sleep Medicine Reviews 18 (2014) 141–152

Contents lists available at SciVerse ScienceDirect

Sleep Medicine Reviews

journal homepage: www.elsevier.com/locate/smrv

CLINICAL REVIEW

Look before you (s)leep: Evaluating the use of fatigue detection technologies within a fatigue risk management system for the road transport industry

Drew Dawson [a,*], Amelia K. Searle [b,d], Jessica L. Paterson [a,c]

[a] Central Queensland University, Appleton Institute, PO Box 42, Goodwood, SA 5034, Australia
[b] University of Adelaide, School of Population Health, Centre for Traumatic Stress Studies, 122 Frome St, Adelaide, SA 5001, Australia

ARTICLE INFO

Article history:
Received 7 December 2012
Received in revised form
1 March 2013
Accepted 18 March 2013
Available online 21 June 2013

Keywords:
Fatigue
Fatigue detection
Fatigue risk management systems
FRMS

SUMMARY

Fatigue is a significant risk factor in workplace accidents and fatalities. Several technologies have been developed for organisations seeking to identify and reduce fatigue-related risk. These devices purportedly monitor behavioural correlates of fatigue and/or task performance and are understandably appealing as a visible risk control. This paper critically reviews evidence supporting fatigue detection technologies and identifies criteria for assessing evidence supporting these technologies.

Fatigue detection devices, and relevant reliability and validation data, were identified by systematically searching the scientific, grey and marketing literature. Identified devices typically assessed correlates of fatigue using either psychophysiological measures or embedded performance measures drawn from the equipment being operated. Critically, the majority of the 'validation' data were not found within the scientific peer-reviewed literature, but within the quasi-scientific, grey or marketing literature.

Based on the validation evidence available, none of the current technologies met *all* the proposed regulatory criteria for a legally and scientifically defensible device. Further, none were sufficiently well validated to provide a comprehensive solution to managing fatigue-related risk at the individual level in real time. Nevertheless, several of the technologies may be considered a potentially useful element of a broader fatigue risk management system. To aid organisations and regulators contemplating their use, we propose a set of evaluative and operational criteria that would likely meet the legal requirements for exercising due diligence in the selection and use of these technologies in workplace settings.

Introduction

Fatigue and driving impairment

Fatigue is a major safety issue in transport.[1] In recent decades, various studies have documented a significant association between fatigue and increased risk of accident and injury.[2] In road transport, estimates of the contribution of fatigue range from 10% to as high as 60% of heavy vehicle crashes.[3] Given the high risk posed by fatigue in the transport sector, and the relatively sedentary nature of driving, fatigue detection devices have typically been designed for and marketed to transport organisations.

For the purposes of this paper, fatigue is defined as 'sleepiness resulting from the neurobiological processes regulating sleep and circadian rhythms' – that is, 'the drive to sleep'.[4–6] According to this view, fatigue is influenced by three main factors: 1) prior sleep, 2) prior wake, and 3) time of day.[2] First, numerous laboratory studies have demonstrated that restricting sleep by small amounts (below threshold values of around five hours for one night or six hours over multiple nights) results in cumulative daytime performance deficits on neuro-behavioural measures, including tracking, vigilance and reaction time.[2,7,8] Second, fatigue increases monotonically from the moment of awakening. Research has shown that 17 h of sustained wakefulness following a good night's sleep produces performance deficits (measured in the early morning hours) that are comparable to those seen at a level of 0.05% blood alcohol concentration.[9] Third, fatigue and alertness follow a circadian (24-h) rhythm, with the highest levels of fatigue generally seen in the early hours of the morning (e.g., 02:00 h–06:00 h), and with a second smaller dip in the early afternoon (e.g., 13:00 h–16:00 h).[10] Prior sleep, prior wake and time of day interact to influence fatigue.[2] Within the waking period fatigue due to 'time-on-task' may also influence performance, however, this issue is beyond the scope of this paper.

* Corresponding author. Tel.: +61 8 8378 4517; fax: +61 8 8378 4532.
E-mail addresses: drew.dawson@cqu.edu.au (D. Dawson), amelia.searle@adelaide.edu.au (A.K. Searle), jessica.paterson@cqu.edu.au (J.L. Paterson).
[c] Tel.: +61 8 8378 4517; fax: +61 8 8378 4532.
[d] Tel.: +61 8 8313 0870; fax: +61 8 8313 5368.

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http://dx.doi.org/10.1016/j.smrv.2013.03.003

Abbreviations

ANU	Australian National University
ASTiD	advisory system for tired drivers
DSS	driver state sensor
EDVTCS	engine driver vigilance telematic control system
EEG	electroencephalography
FIT	fitness impairment tester
FRMS	fatigue risk management system
GPS	global positioning system
GSR	galvanic skin resistance
MWT	maintenance of wakefulness test
NHTSA	National Highway Traffic Safety Administration
OCPT	online continuous performance test
OSLER	Oxford sleep resistance test
OSPAT	occupational safety performance assessment test
PERCLOS	percentage of time that eyes are 80–100% closed across a given time period
PVT	psychomotor vigilance test
SMS	safety management system
UK	United Kingdom
US	United States

Fatigue risk management controls

Quantifying and controlling fatigue-related risk requires a multi-faceted approach. One of the most common multi-factorial approaches, the 'defences-in-depth' model,[11] outlines a five level model of hazard control. According to this approach, a fatigue-related incident (level 5) is the consequence of a fatigue related error (level 4), which is typically preceded by the signs and symptoms of fatigue (level 3). An individual exhibiting the signs and symptoms of fatigue has typically had insufficient sleep (level 2), which may be due to an insufficient sleep opportunity (level 1). Because a fatigue-related accident is a relatively low frequency/high consequence event, an effective fatigue risk management system (FRMS) needs to focus on identifying lead indicators that are high frequency/low consequence events. By focussing on high frequency lead indicators, risk may be identified more effectively and controls implemented at all four levels of this risk trajectory. This may prevent fatigue-related incidents more effectively.[11]

Most organisations implement controls at the first and/or second levels of the defences-in-depth hierarchy.[12] Specifically, organisations may employ 'hours-of-service' and 'rules-of-rostering' to ensure an adequate sleep opportunity between shifts. Some companies also employ mathematical fatigue modelling tools[13] to assist rostering, for the same purpose. Organisations may also monitor driving hours through the use of highway surveillance cameras and actual sleep obtained using sleep diaries or wrist actigraphy monitors. However, first and/or second level controls may not be sufficient to prevent fatigue-related incidents. Organisations cannot always guarantee that employee working time arrangements are compliant with policy or that self-report sleep–wake data supporting 'fitness-for-duty' policies are reliable.

Thus, there is a potential benefit for fatigue-detection technologies that identify fatigued workers and/or notify an organisation, or the workers themselves, when fatigue-related risk has reached an unacceptable level. These technologies are typically designed to detect behavioural indicators of fatigue (i.e., a level 3 control). Several technologies are already in use in the transport, health and mining industries. Devices may be based on neurobehavioural and physiological correlates of fatigue (e.g., reaction time or frequency, duration and rate of eye closures), or embedded performance measures (e.g., vehicle dynamics such as variability in velocity or steering lane position). While fatigue detection devices may often be marketed as effective solutions for managing fatigue-related risk, there is currently little systematic evidence regarding their scientific reliability or validity or legal defensibility. There are no current regulatory guidelines regarding the appropriate use of these technologies and how they contribute to the effectiveness of an FRMS.

Scope of review

This report aims to critically review currently available and emerging fatigue technologies (level 3 controls). There are several existing reviews on fatigue detection devices, which vary in scope.[14–20] We update this literature, to include new devices and emerging research, and to exclude devices that are no longer commercially available. Our scope is purposely broader than most pre-existing reviews. That is, to address issues regarding the legal and scientific defensibility of fatigue detection technologies and their role within the broader context of a multi-faceted FRMS.

Method

Literature was obtained by searching 1) academic search engines (e.g., ISI, PsycInfo, Google scholar), 2) government/industry websites (e.g., AustRoads, Australian Transport Safety Bureau, Transport Research International Documentation, Australian Road Research Board, US and European websites including USDOT, Federal Railroad Administration FMCSA), and 3) a substantial online 'grey literature', using the search terms *fatigue*, *sleepiness*, *drowsiness*, *alertness*, *detection*, *monitor*, *management*, *technology*, and *countermeasure* (and variations thereof).

Key academic peer-reviewed journals (e.g., *Transportation Research Part F*, *Accident Analysis and Prevention*, *and Safety Science*) were also searched. References within relevant articles were subsequently obtained. Finally, companies that developed fatigue detection devices were contacted directly and asked to provide technical specifications, reliability and/or validation data.

Ideally, a legally and scientifically defensible fatigue detection device would be capable of measuring fatigue and performance in an individual in real time, as well as predicting future fatigue levels.[21] It must be valid (by measuring a fatigue sensitive behaviour such as blink velocity), reliable (doing this consistently, as employees and managers may come to depend on it), sensitive (predicting unacceptable fatigue levels, and minimising missed events), specific (minimising false alarms, as drivers may then distrust the device) and generalisable (to all users, by accounting for individual differences).[22] Sensitivity is especially important, as the device must be able to detect signs of fatigue that *precede* the occurrence of fatigue-related incident, so that appropriate countermeasures can be put in place. Devices must also demonstrate "operational validity",[23] in that it is desirable that they are suitably robust and reliable for use in industrial settings; they must collect high quality data with minimal interference (sweat, sunlight etc.), be portable, minimally intrusive and accepted by users.

Evidence of the devices' capabilities should be demonstrated in laboratory and field studies, using large samples and undertaken in a sample of the population of interest (e.g., heavy vehicle drivers). Devices should discriminate between normal alertness and fatigue, resulting from either partial or total sleep restriction, long shifts, time of day, or a combination of these factors. Ideally, performance of the technology should be compared to several other fatigue-detection devices, including the current gold standard, the psychomotor vigilance test (PVT),[24] as well as to real or simulated task performance. Devices must be validated by independent third