A model of shiftworker sleep/wake behaviour

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A B S T R A C T
Software-based biomathematical models of alertness provide a means to estimate fatigue-related risk in advance of a schedule being worked. Obtaining a good estimate of employees’ sleep/wake behaviour during non-work periods is critical in obtaining accurate estimates of alertness. This is because estimates of alertness are generated based on estimated sleep and wake times, not rest and work times per se. The purpose of the current analysis was to evaluate the predictive validity of a novel version of a previously published sleep predictor model. This model was originally designed to predict sleep probability for aviation pilots in connection with long-haul flight operations. It has since been modified to predict sleep periods for industrial shiftwork rosters in non-transmeridian environments. The algorithm uses two procedures to predict sleep timing and duration: (1) estimate the total amount of sleep likely to be obtained in a given rest period; and then (2) estimate the timing and duration of sleep periods within that rest period. The sleep periods predicted in the second procedure are generated such that their combined sum is a priori equivalent to the total amount of sleep predicted in the first procedure. The model was parameterized and validated based on a sample of 225 train drivers who collected work/rest and sleep/wake data for two weeks during normal commercial operations. Agreement between observed and predicted sleep periods was robust (percent agreement ~85%) and compared favourably with agreement levels between sleep behaviours exhibited by the same individual on distinct occasions but where shift sequences were repeated. These results are discussed within the context of ongoing efforts to develop individualized biomathematical models of alertness.

1. Introduction

Biomathematical models of alertness continue to play an important role in the management of fatigue-related risk in industrial settings (Dawson et al., 2011). In recent years, validation of existing models (Van Dongen, 2004) and the development of new models (Akerstedt et al., 2008; McCauley et al., 2009) has focused extensively on performance outputs, and in particular the potential for individualized alertness predictions (Rajaraman et al., 2009; Van Dongen et al., 2007). Only a relatively limited number of analyses have focused on predicting the timing and duration of sleep in shiftwork settings (Darwent et al., 2010; Kandelaars et al., 2006). Sleep is a major determinant of the biological processes that regulate alertness. Obtaining accurate estimates of sleep is therefore critical to the validity of all biomathematical models of alertness.

Models of sleep have traditionally been based solely on the biological processes of sleep homeostasis and circadian rhythmicity (e.g. Daan et al., 1984). Variation in sleep between individuals has likewise been viewed as the product of trait-like, interindividual differences in these biological processes (Archer et al., 2008; Mongrain et al., 2006; Van Dongen et al., 2007; Van Dongen and Belenky, 2009). While this paradigm has proven sufficient to explain sleep phenomena observed in laboratory settings (Achermann et al., 1993; Akerstedt et al., 2008; Daan et al., 1984; Jewett and Kronauer, 1999), the emphasis on biology has overshadowed the role of non-biological factors that influence sleep timing and duration in everyday settings.

The biological processes that regulate the sleep/wake cycle can be mediated by voluntary decisions that preference social imperatives over sleep (Basnér et al., 2007; Basnér and Dingés, 2009; Geiger-Brown et al., 2011; Mistlberger and Skene, 2004; Monk and Wagner, 1989). The contribution of these decisions is not always obvious because individuals normally choose to be asleep when the biological drive for sleep is strong (i.e., at night) and when social imperatives to be awake are weak (i.e., also at night). This is not the case for shiftworkers who are routinely required to sleep at times of the day when the social imperatives to be awake are comparatively strong. To manage conflicting demands, shiftworkers develop a range of behavioural strategies (e.g. anticipatory napping, split sleeps) (Menna-Barreto et al., 1993; Tepas and Carvalhais, 1990), often accompanied by pharmacological