Refining Sleep Predictions Using Actigraphy in Operational Environments: Studies with Pilots

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Problem

While sleep is a critical input for most biomathematical modeling applications, data on actual sleep times may not be readily available from the operational environment. The development of sleep estimators has been a useful step in reducing the uncertainty around model-based estimates. However, the extent to which sleep estimates are representative of actual behaviors is central to the value of predictive modeling analyses. In this paper, we describe an iterative harmonizer approach for refining sleep estimates in pilots.

Method

When explicit sleep inputs are unavailable, the SAFTE-FAST modeler can estimate likely sleep times for a given duty schedule. With this AutoSleep function, sleep periods are added to the schedule based on a number of adjustable parameters including the relationship to each of: typical sleep times, time of work start/end, length of wake and time zones crossed. A first step to the harmonizer sleep estimation approach involves modeling duty schedules using gradual iterations of AutoSleep settings. Minute-by-minute estimates of sleep times are then be compared with minute by minute recordings of actual sleep durations to determine which AutoSleep settings result in sleep estimates that most closely resemble actual sleep times.

For the present analysis, we obtained a data set that included actigraphy (1-minute epoch) and sleep diary data collected from commercial airline pilots during 10-14 day periods that included normal operations. We report here the results of the most recent harmonizer study based on 22 distinct actigraph records from airline pilots working for a single airline. Pilot duty schedules were then analyzed with the SAFTE-FAST modeler using iterative variations in the AutoSleep settings, such that each pilot duty schedule was analyzed using all possible combinations of AutoSleep settings.

Minute-by-minute estimations of sleep times as generated by AutoSleep were compared with minute-by-minute actigraphy data scored for sleep/wake. Signal detection analyses were used to compare AutoSleep estimations against actual sleep and identify the single set of AutoSleep settings that most accurately characterized the sleep of the group of pilots. Two criteria were used: 1) the minute-by-minute percent correct identification of sleep/wake, and 2) the overall estimate of sleep per 24 hrs compared to actual sleep records for the group. We selected the best set of parameters based on the average of these two criteria.

Results

The analysis required over 9,700 iterations of the sleep estimation settings and yielded best-fit values for eight parameters of the sleep estimator. The process improved the percent correct categorization of sleep/wake from 85.6% with default settings to 88.2%, and improved total sleep per day from 88.2% to 99.97% correct. In general, the default settings over-estimated the amount of sleep per day for this study group and that error was corrected by harmonization.

Discussion

Predictive modeling of the effects of fatigue requires estimation of sleep timing and duration that accurately represents behavior for industry workers of interest. We present a method for refining sleep estimates that can be customized for the operational environment. Future work will consider the possibility of clustering of sleep patterns within a group that require distinctly different sleep estimation parameters for each cluster.