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The Impact of New Technology on Sleep Data Collection and Model Validation

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Problem

In aviation, human errors and improper decision-making are influenced by sleepiness and fatigue. One way of counteracting fatigue in aircrew is through flight and duty time limitations. However, regulatory bodies are currently discussing how to incorporate sleep and performance science directly into their fatigue risk management systems, by means of bio-mathematical sleepiness and fatigue modeling.

Several models have been introduced over the past decades, but in order to see wider use, they need to be validated against operational experience. The present study seeks to leverage the possibilities offered by new technologies in order to validate the inner workings of one such model.

Method

Traditional data collections require an organization for handling logistics of devices, data collection protocols, and training. The resulting data is often inconsistent, and by the time these inconsistencies are noted, the data is too old to be easily corrected. This leads to high costs and poor scalability.
Data collection by means of an application on a smart phone offers some significant advantages:

- All data being collected by the same application reduces the need for distribution, and the proliferation of smart phones almost eliminates the need for distribution altogether.
- You can use e-training to improve scalability, and geographic reach.
- Inconsistencies in the collected data is discovered at time of entry, radically improving the probability that data can be corrected. Showing users a graphical representation of what has been entered helps ensure the quality of that data.
- Other possibilities enabled by the technology includes actively prompting users for data input by notifications, and the ability to automatically load roster data via a feed from the airline scheduling system.

For the present paper we used an application like the one described to collect data in three waves over a two-year time period (in the years 2011-2012) using a crowd-sourcing strategy. Information about the data collection was spread through airlines aircrew unions and similar resources, interested aircrew then signed up for participation in the study at a website. After the completion of data collection, crew submitted the data wirelessly over the Internet. The data was manually inspected and uploads missing data were discarded.

Results

After the manual screening the data set contained data from 136 aircrews. Variables included demographic data (age, gender, position, and circadian type), work shift data (first departure and last arrival for each shift), a sleep/wake log, and sleepiness assessments on the Karolinska Sleepiness Scale.

This data set was then used to validate the sub-components of the Three-Process Model of Alertness (TPM). The results based on multilevel linear and non-linear mixed effects models showed that the TPM predictions correlated with observed ratings of sleepiness, but explorative analyses suggest that the default model can be improved and reduced to include only two-processes (S+C), with adjusted phases of the circadian process based on a single question of circadian type.

The results also suggest that a model based sleep generator is feasible. Even though the analysis suggests an increase in model error, it is still an important addition in many applications where sleep history is missing.

We could see a small deviation during the first hour awake, consistent with sleep inertia. Despite this we were not able to validate the sleep inertia proves of TPM, suggesting that some of the default parameters need to be changed.

Finally, we extended and validated the model with:

- a function to model jetlag acclimatization,
- estimates of individual differences, including reference limits accounting for 50%, 75% and 90% of the population,
- functions for predicting the probability of any level of sleepiness, for ecological assessment of absolute and relative risk of sleepiness in shift systems for safety applications.

Discussion

The present study has validated the Three Process Model of alertness (TPM), including extensions added since its inception in 1990. The result suggests that with an assumed default phase of 16.8 h for process C, an optimal model includes the processes SB+C+U but not W. However, with an improved and circadian type adjusted C, process U is no longer part of the model. We could not validate that the sleep inertia function adds to the model. This is probably because sleep inertia is mainly in effect after forced awakening, with a substantial partial sleep deprivation, and such situations were not common in the present data.

We could also validate that model based generated sleep is feasible if observed sleep is not available. However, this leads to a significantly increased error in predictions. Acclimatization of the circadian process to a different time zone was also possible, but with an optimal rate of 30% instead of the assumed daily rate of 50% of the difference between local time and internal acclimatized time.

The present study also validated the feasibility of smart phone based data collection. After initially setting up the required infrastructure, the collection was completed at a very low cost compared to traditional data collections. The data quality was also of a high quality and with minimal data loss. So far, the main drawback of this method is that the tool still has a steep learning curve and thus can be considered slightly taxing by crew. This will be addressed in future versions of the application.

Summary

The present study has validated the internal processes of TPM on aircrew, and explored potential large improvements to the parameters and sleep generator based on a question of circadian type. We have also extended the model to include individual differences, reference limits accounting for 50%, 75% and 90% of the population, as well as a direct prediction of probabilities of any level of sleepiness for absolute and relative risk assessment of work schedules in safety applications. The explorative findings and extension made to the model need further validations in independent studies, ideally with large representative samples to provide normative data on model parameters.

The study also shows a blueprint for limiting the cost and increasing the data quality of future data collections. Removing important obstacles for data collection will mean that data can be collected continuously by airlines, leading to lots of new large data sets.