SLEEP COGNITION AND BEHAVIOR

2B-Alert Web: An Open-Access Tool for Predicting the Effects of Sleep/Wake Schedules and Caffeine Consumption on Neurobehavioral Performance

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Study Objectives: Computational tools that predict the effects of daily sleep/wake amounts on neurobehavioral performance are critical components of fatigue management systems, allowing for the identification of periods during which individuals are at increased risk for performance errors. However, none of the existing computational tools is publicly available, and the commercially available tools do not account for the beneficial effects of caffeine on performance, limiting their practical utility. Here, we introduce *2B-Alert* Web, an open-access tool for predicting neurobehavioral performance, which accounts for the effects of sleep/wake schedules, time of day, and caffeine consumption, while incorporating the latest scientific findings in sleep restriction, sleep extension, and recovery sleep.

Methods: We combined our validated Unified Model of Performance and our validated caffeine model to form a single, integrated modeling framework instantiated as a Web-enabled tool. *2B-Alert* Web allows users to input daily sleep/wake schedules and caffeine consumption (dosage and time) to obtain group-average predictions of neurobehavioral performance based on psychomotor vigilance tasks. *2B-Alert* Web is accessible at: https://2b-alert-web.bhsai.org.

Results: The *2B-Alert* Web tool allows users to obtain predictions for mean response time, mean reciprocal response time, and number of lapses. The graphing tool allows for simultaneous display of up to seven different sleep/wake and caffeine schedules. The schedules and corresponding predicted outputs can be saved as a Microsoft Excel file; the corresponding plots can be saved as an image file. The schedules and predictions are erased when the user logs off, thereby maintaining privacy and confidentiality.

Conclusions: The publicly accessible *2B-Alert* Web tool is available for operators, schedulers, and neurobehavioral scientists as well as the general public to determine the impact of any given sleep/wake schedule, caffeine consumption, and time of day on performance of a group of individuals. This evidence-based tool can be used as a decision aid to design effective work schedules, guide the design of future sleep restriction and caffeine studies, and increase public awareness of the effects of sleep amounts, time of day, and caffeine on alertness.

Keywords: biomathematical model, sleep schedule, caffeine model, prediction tool, PVT

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INTRODUCTION

Over the past decade, computational tools have been increasingly used across a range of public and commercial sectors (e.g., aviation, mining, and nuclear power plant operations) as components of fatigue risk management systems aimed at optimizing duty-time alertness and thereby minimizing fatigue-related errors and accidents.[1,2] These tools are based on biomathematical models that predict daily variations in neurobehavioral performance as a function of sleep/wake amounts and time of day. Such tools are particularly beneficial in industries that are engaged in 24-h operations and require shift-work schedules. However, to date, there are no open-access tools available, and none of the commercially available tools contain biomathematical models that also predict the performance-improving effects of caffeine. In addition, most available tools are based on biomathematical models that have not been updated to account for the latest scientific findings on sleep restriction, sleep extension, and recovery sleep.

Here, we describe *2B-Alert* Web, an open-access tool developed by the United States Army Medical Research and Materiel Command (Ft. Detrick, MD), which predicts the effects of any given sleep/wake schedule, caffeine consumption, and time of day on neurobehavioral performance. *2B-Alert* Web combines our validated Unified Model of Performance (UMP)[3] with our validated caffeine model[4,5] to form a single, integrated modeling framework (henceforth termed UMP). Both models have been shown to produce accurate predictions of group-average performance, and both are based on psychomotor vigilance task (PVT) data obtained from a variety of laboratory and field studies. The experimental conditions in these studies ranged from sleep extension to chronic sleep restriction to total sleep deprivation, with several performed to determine the performance effects of caffeine administered on various schedules and at varying dosages (from repeated 50-mg doses to a single dose of 600 mg).[3–5] *2B-Alert* Web is publicly accessible through a secure Web browser via a user-defined username and password.

METHODS

Figure 1 shows a screen capture of the *2B-Alert* Web interface input menus and output plots that appear upon login.

Inputs and Outputs

User inputs to *2B-Alert* Web include (1) sleep schedule (day and time of sleep start and sleep end) and (2) caffeine schedule (day, time, and dose of caffeine, which may be selected from a drop-down menu of popular commercially available caffeine-containing products), all for the same time zone. For each schedule, users may input up to 100 separate sleep periods and up to 400 separate caffeine consumption events (one event = timing + dosage entry). Each sleep/caffeine schedule can be saved using a unique schedule name (e.g., "Sleep Restriction + Caffeine," in Figure 1). Sleep and caffeine inputs are entered manually via the Web-browser interface or imported from a Microsoft Excel file using a predefined format.

For each sleep/caffeine schedule, *2B-Alert* Web generates performance predictions for three 10-min PVT statistics: number of lapses (lapse = response time ≥ 500 ms), mean response time,

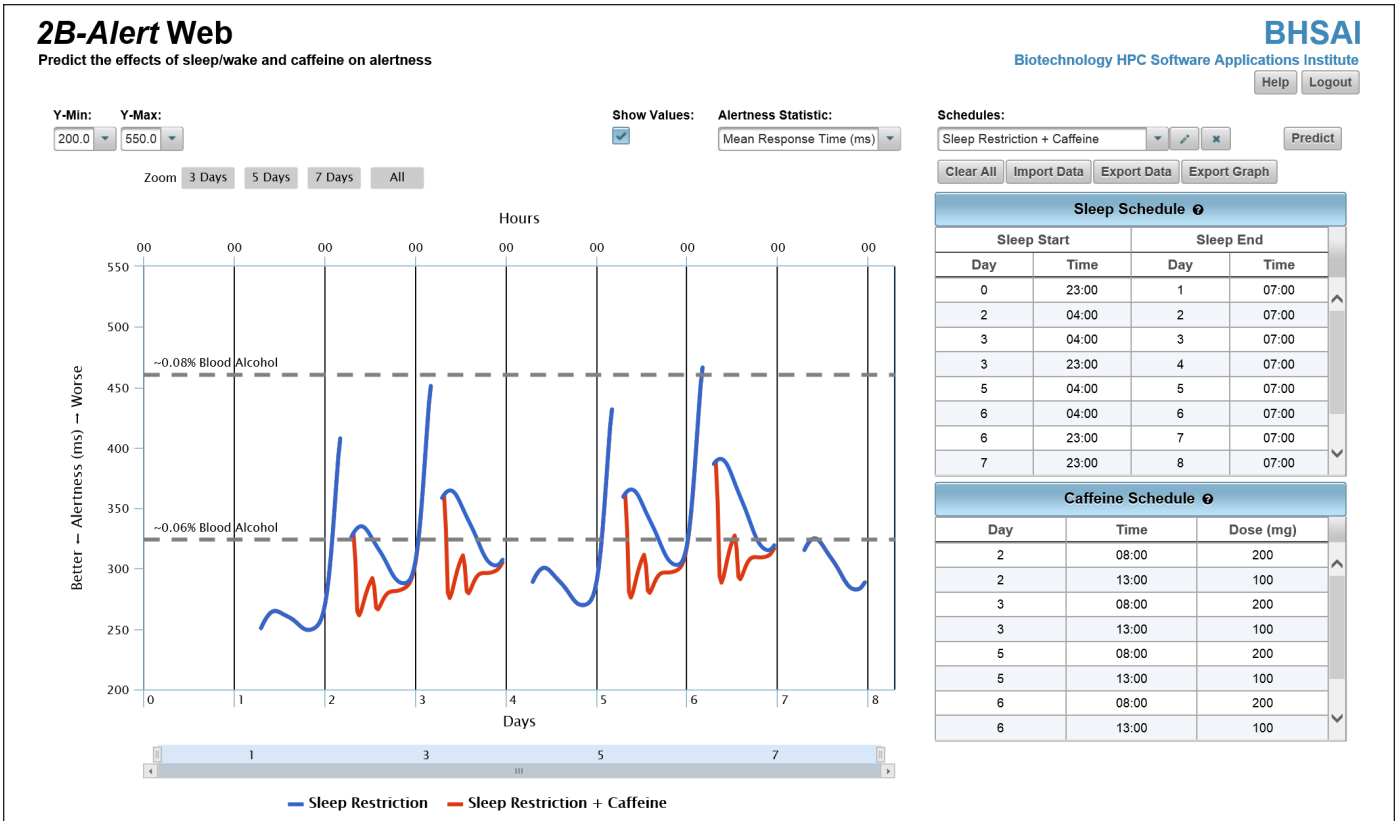

Figure 1—The *2B-Alert* Web opening screen after login. *2B-Alert* Web is pre-loaded with two sleep/wake and caffeine schedules. Predicted mean response time for the schedule named "Sleep Restriction" is plotted as a blue line, and predicted mean response time for the schedule named "Sleep Restriction + Caffeine" is plotted as a red line. For each plot line, discontinuities represent sleep periods. Up to seven plots can be simultaneously displayed, but only one sleep/wake and caffeine schedule can be displayed at a time (right panels). The figure shows the Sleep Restriction + Caffeine schedule.

and mean speed (i.e., mean reciprocal response time). Users choose which statistic to plot via the "Alertness Statistic" drop-down menu (Figure 1). The sleep/caffeine input schedules and corresponding predicted outputs can be saved as an Excel file via the "Export Data" function button; the displayed plots can be saved as an image file via the "Export Graph" function button.

Initial Conditions and Model Assumptions

The UMP neurobehavioral performance predictions are initialized to 8 h of sleep per night (23:00–07:00), and the tool assumes that there is no sleep debt before day "0." From that point, user entries of 8 h of sleep per day add no sleep debt (i.e., maintains daily performance at its initial level, plus/minus circadian variation). User entries of sleep durations < 8 h per day degrade performance, and sleep durations > 8 h per day improve performance. Consistent with our previously published "fading memory" concept,[6] the more recent the sleep/wake period, the greater its influence on predicted performance.

Caffeine effects on performance are multiplicative,[4,5] where the magnitude of change in performance due to caffeine is a function of the (1) size of the caffeine dose (in mg), (2) duration of time since the last caffeine event, and (3) time of day of the caffeine event.

Model Limitations

First, sleep requirement, caffeine sensitivity, and neurobehavioral performance due to sleep deprivation can vary significantly among individuals.[7,8] However, the *2B-Alert* Web tool only provides (average) performance predictions for a group of individuals. Second, because the UMP was developed using primarily PVT data under laboratory conditions, the extent to which its predictions are applicable to different operational settings or to other neurobehavioral performance measures or for predicting occurrence of accidents is not known. Finally, because the UMP does not consider the effects of sleep inertia, PVT performance for the first hour after awakening from sleep episodes may be worse than predicted by the tool.

System Architecture

2B-Alert Web is hosted on an Apache Tomcat Web server that is accessible via a secure service over Hypertext Transfer Protocol Secure (https). It was developed based on a three-tier architecture, composed of a backend database, a controller, and presentation tiers. The first tier consists of an Oracle database server that stores user account information to provide secure access to the *2B-Alert* Web application. The second (controller) tier provides access to the prediction engine and implements the functionality required to create and manage multiple predictions. The third (presentation) tier provides interactive plotting capabilities for multiple predictions with the ability to dynamically zoom on the x-axis of the plots. The controller and presentation tiers were developed using Java Platform, Enterprise Edition 7, JavaServer Faces 2.2, and PrimeFaces 5.2

technologies. The graphical user interface in the presentation tier uses Web standards supported by modern Web browsers, including Internet Explorer version 11, Chrome version 49, and Firefox version 38, without any need for plugins.

Access and Privacy

2B-Alert Web is publicly accessible at https://2b-alert-web.bhsai.org. Upon registration, users receive a confirmation Email containing username and password information, which can be changed. Neither user-entered schedules nor prediction outputs are saved online; both are erased when the user logs off, thereby maintaining privacy and data confidentiality.

RESULTS

Figure 1 shows *2B-Alert* Web plots for two schedules named "Sleep Restriction" and "Sleep Restriction + Caffeine." The mean response time (in ms) statistic is displayed. Discontinuities in the plot lines represent sleep periods. In the Sleep Restriction schedule example, 2 cycles of 8, 3, and 3 h of sleep per night are followed by 2 nights of 8-h sleep. The Sleep Restriction + Caffeine schedule example (shown in Figure 1) consists of the same sleep restriction schedule but with the addition of 2 caffeine doses per day (200 mg at 08:00 and 100 mg at 13:00) on those days preceded by 3 h of nighttime sleep. The user can display one schedule at a time by selecting the desired schedule name in the "Schedules" drop-down menu.

The graph shows plots for the 2 schedules, in which the number of days displayed (x-axis) and the range of PVT-statistics values (y-axis) are modifiable. When "Show Values" is selected, values for individual prediction points are displayed when hovering the computer mouse pointer over the plots. Predictions for up to 7 sleep/caffeine schedules can be displayed simultaneously. For reference, the graph includes dashed lines representing PVT predictions for 2 blood alcohol concentration (BAC) thresholds. [Using results from Dawson and Reid[9] and Williamson et al.,[10] we determined that performance at 19 h of continued wakefulness corresponds to a 0.06% BAC performance equivalent, and that performance at 24 h of continued wakefulness corresponds to 0.08% BAC (the legal driving limit in the United States).]

Contextual help for a given functionality is available by hovering the computer mouse over a particular function button or portion of the plot or by clicking the "Help" function button, which takes the user to a four-page guide. We recommend that users review this four-page user guide before using the *2B-Alert* Web tool.

DISCUSSION

2B-Alert Web is the first open-access, Web-enabled computational tool for predicting the effects of sleep/wake schedule, caffeine consumption, and time of day on neurobehavioral performance using a biomathematical model whose predictions have been validated against results from a variety of laboratory and field studies. The tool allows users to simultaneously compare predictions from multiple sleep/wake and caffeine schedules, and affords the means to optimize work schedules and generate predictions that can be experimentally tested. The *2B-Alert* Web tool bridges the gap between scientific findings and implementable tools and thus should be of value to operational and research communities.

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DISCLOSURE STATEMENT

This was not an industry supported study. This work was sponsored by the Military Operational Medicine Research Area Directorate of the U.S. Army Medical Research and Materiel Command, Ft. Detrick, MD. The authors have indicated no financial conflicts of interest. The opinions and assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the U.S. Army or of the U.S. Department of Defense. The *2B-Alert* Web tool is for educational and informational purposes only. It should not be used for or relied upon for predicting the performance of any specific individual or the likelihood of errors or accidents by any specific individual or a group of individuals. This paper has been approved for public release with unlimited distribution.