Fatigue Management for the 21st Century

10TH INTERNATIONAL CONFERENCE ON MANAGING FATIGUE

23 MARCH 2017

THOMAS J. BALKIN, PHD, D,ABSM

WRAIR
Walter Reed Army Institute of Research
Soldier Health • World Health

Outline

1. Background
   - Definition of ‘fatigue’
   - Brief history of ‘hours of service” (HOS) rules in the US

2. Sleep and Performance: State of the Relevant Science
   - The interactive effects of Sleep, ‘Time on Task’, and Circadian Rhythm
   - Sleep Banking: Implications for the operational environment
   - Administration of caffeine across multiple days of sleep restriction

3. The Walter Reed Alertness Management System
   - Hardware
   - Software
   - Interventions

4. 2B-Alert Mathematical Performance Prediction Model
   - Recent Improvements
   - Illustration of capabilities (website version)

Fatigue

- ***Physical fatigue***
  - *Muscle weakness; lack of strength.*
  - *Some causes: Illness, medication, heavy physical exercise.*
- ***Mental fatigue***
  - *Decreased wakefulness; sleepiness; drowsiness.*
  - *Decreased state of attention.*
  - *Some causes: Illness, medication, lack of mental stimulation, lack of adequate sleep (many possible reasons), time of day (Circadian rhythm), physical fatigue.*

From FMSCA Presentation by Tom Yager in 2007: "Commercial Motor Vehicle Drivers' Hours of Service: Background Information"

What is the Purpose of HOS rules?

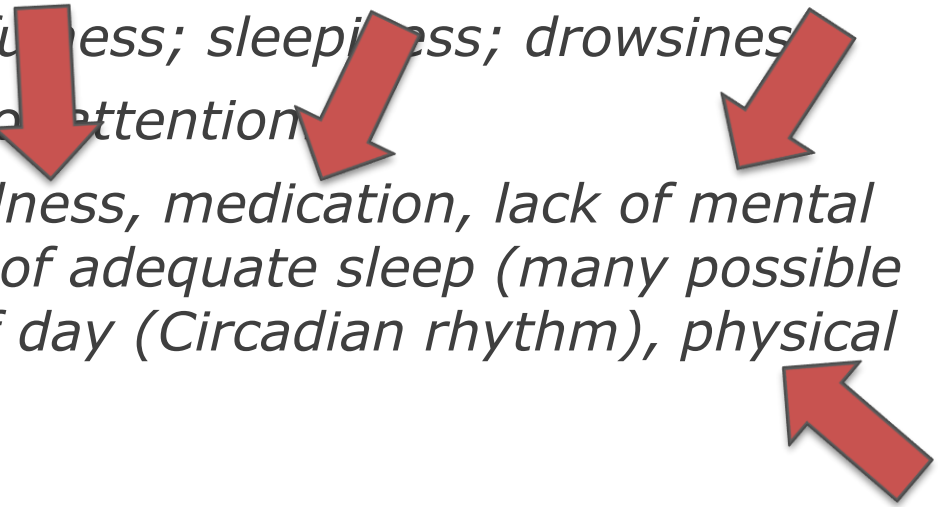
Hours of Service (HOS) Rule Purpose

- *Reduce truck and bus crashes by preventing driving of a commercial motor vehicle (CMV) while fatigued. Do so by providing adequate opportunities for sleep by a healthy CMV driver.*

From FMSCA Presentation by Tom Yager in 2007: "Commercial Motor Vehicle Drivers' Hours of Service: Background Information"

Fatigue

- ***Physical fatigue***
  - *Muscle weakness; lack of strength.*
  - *Some causes: Illness, medication, heavy physical exercise.*
- ***Mental fatigue***
  - *Decreased wakefulness; sleepiness; drowsiness*
  - *Decreased state of attention*
  - *Some causes: Illness, medication, lack of mental stimulation, lack of adequate sleep (many possible reasons), time of day (Circadian rhythm), physical fatigue.*



From FMSCA Presentation by Tom Yager in 2007: "Commercial Motor Vehicle Drivers' Hours of Service: Background Information"

Working Definition of Fatigue

Classically, ***fatigue*** is a hypothetical construct invoked to account for subjective tiredness and associated performance deficits resulting from the application of physical and/or mental effort over time – i.e., "time on task" effects.

Sleepiness is a hypothetical construct invoked to account for deficits in alertness and performance resulting from (a) extended wakefulness/sleep loss and/or (b) wakefulness during the descending phase of the circadian rhythm of alertness (from approximately 2300 to 0800 hrs).

In the operational environment, ***extended 'time on task' often results in extended wakefulness/sleep loss*** (stretching into the early morning hours) – and the rate at which operational performance declines during a military operation is function of the *combined* effects of both factors.

Fatigue = Sleepiness + Time on Task

80-Year Anniversary of HOS Rules

In 1937, the (now-abolished) Interstate Commerce Commission (ICC) established the first HOS rules for commercial drivers.

These rules limited commercial drivers to 12 hours of work within a 15-hour on-duty period. Work was defined as "*loading, unloading, driving (10 hrs limit), handling freight, preparing reports, preparing vehicles for service, or performing any other duty pertaining to the transportation of passengers or property."*

The ICC intended that the 3-hour difference between "on-duty" and "hours of work" would be used for meals and rest breaks. The weekly maximum was limited to 60 hours over 7 days (non-daily drivers), or 70 hours over 8 days (daily drivers). Thus, within the 24-hour day, drivers would be allowed 12 hours of actual work within a 15-hour period (i.e., with three hours of breaks), and would have 9 hours off-duty to sleep and engage in other activities of daily living.

Hours of Service Over the Years

	1937	1962	2003	2005, 2007, 2008
Driving	10 hours	10 hours	11 hours	11 hours
Duty Period	24 consecutive hours from duty start time	15-hour driving window, extendable by breaks	14-hour driving window, not extendable by breaks	14-hour driving window, not extendable by breaks
Off-duty	8 hours	8 hours	10 hours	10 hours
7/8 Day Limits	60/70 hours in 7/8 days	60/70 hours in 7/8 days	60/70 hours in 7/8 days	60/70 hours in 7/8 days
Restart of 60/70 Hr Period	None	None	34-hour restart	34-hour restart
Sleeper Berth	2 undefined periods totaling 8 hours	2 periods totaling 8 or more hours; each a minimum of 2 hours	2 periods totaling 10 or more hours; each a minimum of 2 hours.	2 periods totaling 10 or more hours; one at least 8 consec. Hours; other at least 2 off duty or sleeper
Time period reference	24 hour period from duty start time	Hours accumulated following 8 hours off duty	Hours accumulated following 10 hours off duty	Hours accumulated following 10 hours off duty

From FMSCA Presentation by Tom Yager in 2007: "Commercial Motor Vehicle Drivers' Hours of Service: Background Information"

Current Hours of Service Rules

PROPERTY-CARRYING DRIVERS

11-Hour Driving Limit: May drive a maximum of 11 hours after 10 consecutive hours off duty.

14-Hour Limit: May not drive beyond the 14th consecutive hour after coming on duty, following 10 consecutive hours off duty. Off-duty time does not extend the 14-hour period.

Rest Breaks: May drive only if 8 hours or less have passed since end of driver's last off-duty or sleeper berth period of at least 30 minutes. Does not apply to drivers using either of the short-haul exceptions in 395.1(e). [49 CFR 397.5 mandatory "in attendance" time may be included in break if no other duties performed]

60/70-Hour Limit: May not drive after 60/70 hours on duty in 7/8 consecutive days. A driver may restart a 7/8 consecutive day period after taking 34 or more consecutive hours off duty.

Must include two periods from 1 a.m. to 5 a.m. home terminal time, and may only be used once per week [illegible] hours, measured from the beginning of the previous restart.

Suspended

NOTICE: The Consolidated and Further Continuing Appropriations Act of 2015 was enacted on December 16, 2014, suspending enforcement of new requirements for use of the 34-hour restart, pending a study. Based on the findings from the study, the 34-hour restart rule in operational effect on June 30, 2013, is restored to full force and effect. The requirement for two off-duty periods of 1:00 a.m. to 5:00 a.m. in section 395.3(c) of the Agency's hours-of-service rules will not be enforced, nor will the once-per-week limit on use of the restart in 395.3(d).

Sleeper Berth Provision: Drivers using the sleeper berth provision must take at least 8 consecutive hours in the sleeper berth, plus a separate 2 consecutive hours either in the sleeper berth, off duty, or any combination of the two.

PASSENGER-CARRYING DRIVERS

10-Hour Driving Limit: May drive a maximum of 10 hours after 8 consecutive hours off duty.

15-Hour Limit: May not drive after having been on duty for 15 hours, following 8 consecutive hours off duty. Off-duty time is not included in the 15-hour period.

60/70-Hour Limit: May not drive after 60/70 hours on duty in 7/8 consecutive days.

Sleeper Berth Provision: Drivers using a sleeper berth must take at least 8 hours in the sleeper berth, and may split the sleeper berth time into two periods provided neither is less than 2 hours.

From FMCSA website:
https://www.fmcsa.dot.gov/regulations/hours-service/summary-hours-service-regulations
Updated: Thursday, March 9, 2017

Can we do better?

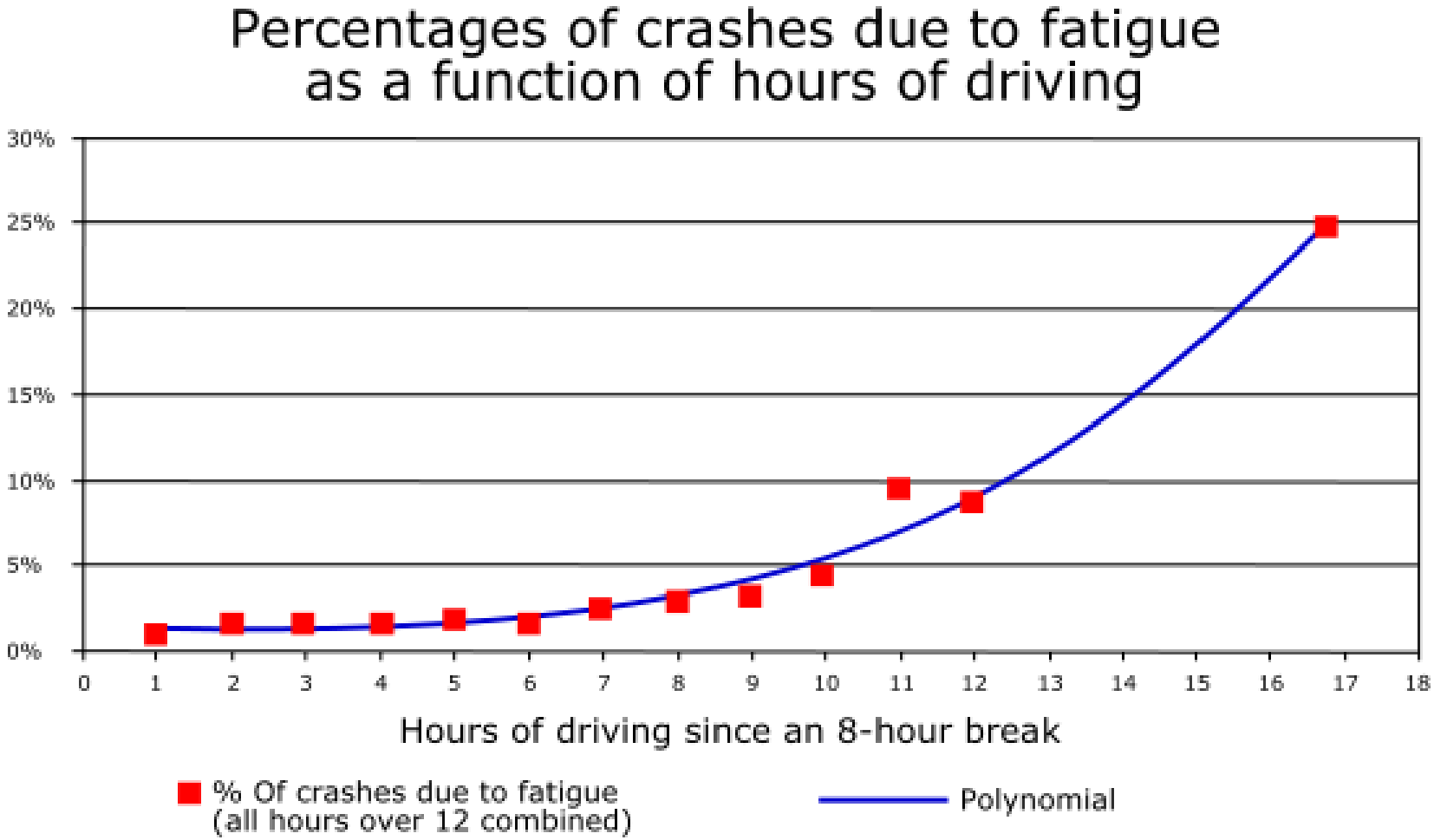
State of the Relevant Science I

The “Big Three” Factors that Interactively Determine Military Operational Performance:

A. Sleep Debt

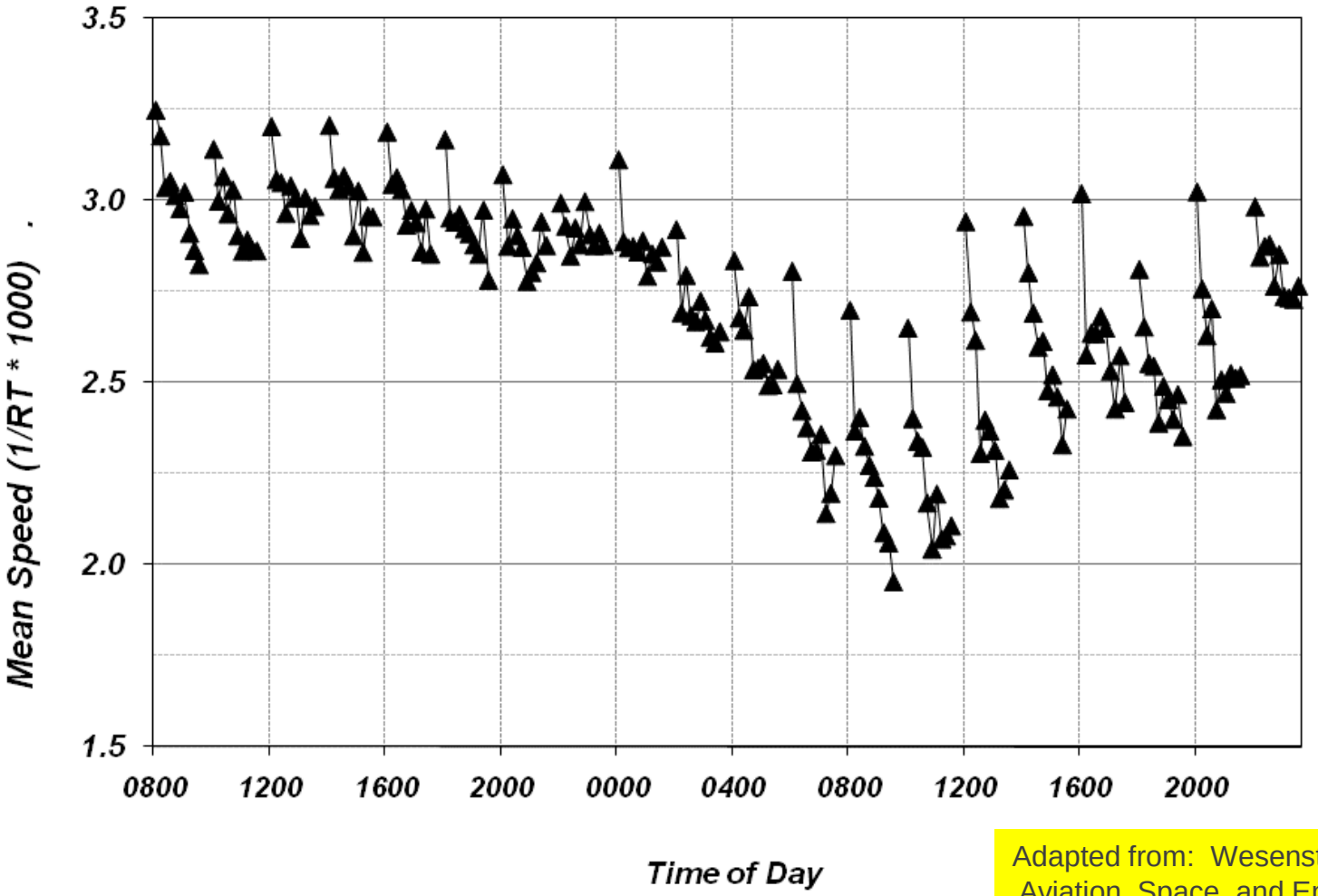
B. Circadian Rhythm of Alertness

C. Time on Task



Source: [Federal Motor Carrier Safety Administration]

Circadian Rhythm, Sleep Deprivation, and Time on Task Interactions



Adapted from: Wesensten et al. (2004). Aviation, Space, and Environmental Medicine, 75, 520- 525.

State of the Relevant Science II

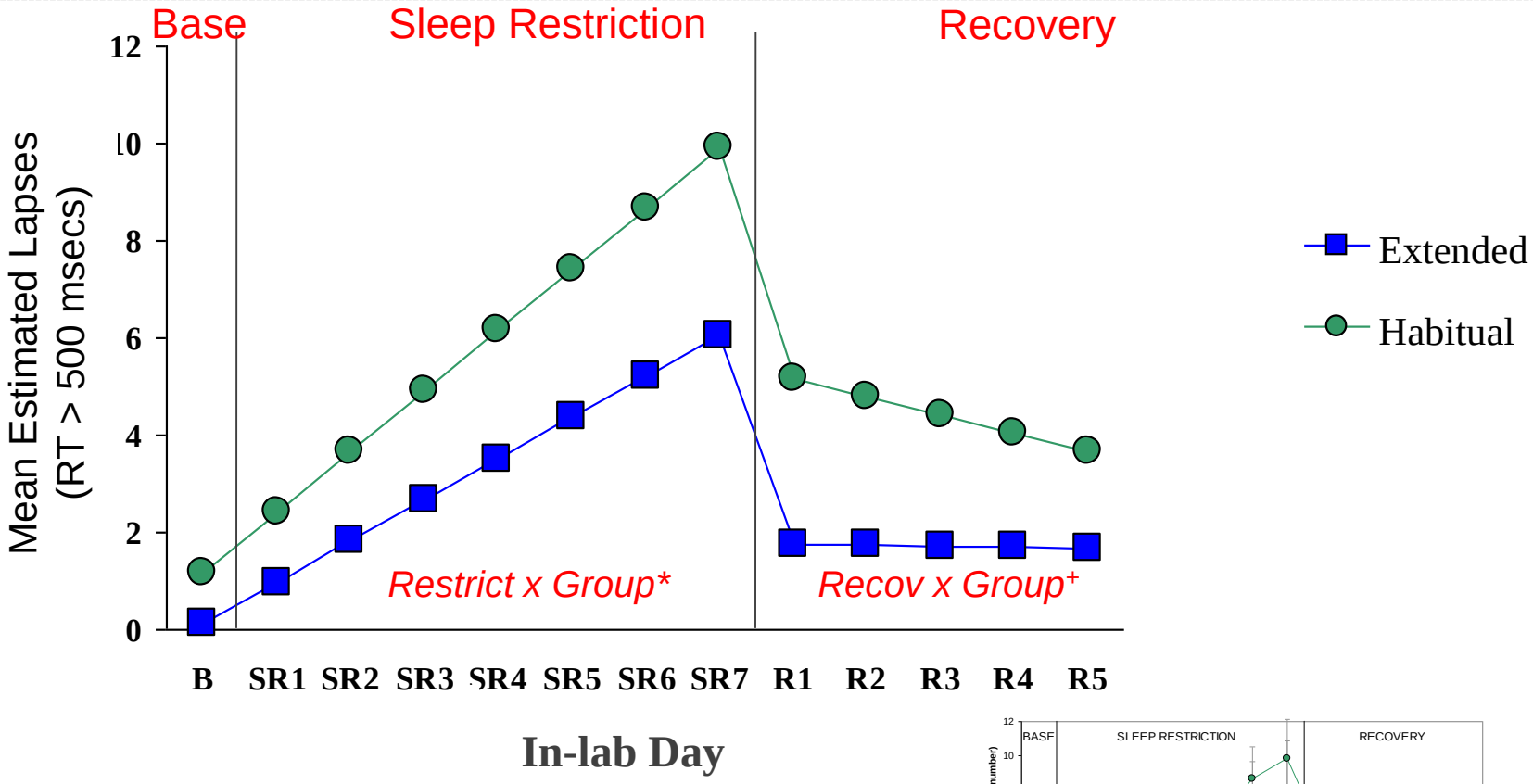
Individual Sleep History:

"Sleep Banking". The more sleep that an individual obtains *prior to* an operation involving sleep loss (either acute total sleep deprivation or multiple days of sleep restriction) the better the performance

Rupp et al. (2009) Study Design

1. 14-day AT-HOME "sleep schedule assessment"
   a. Reported usual TIB ~7 hrs.
   b. Used to determine "Habitual" sleep schedule

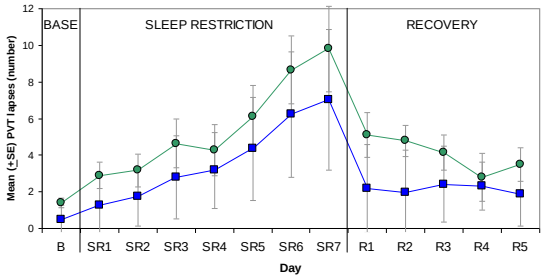
Recovery of PVT Lapses



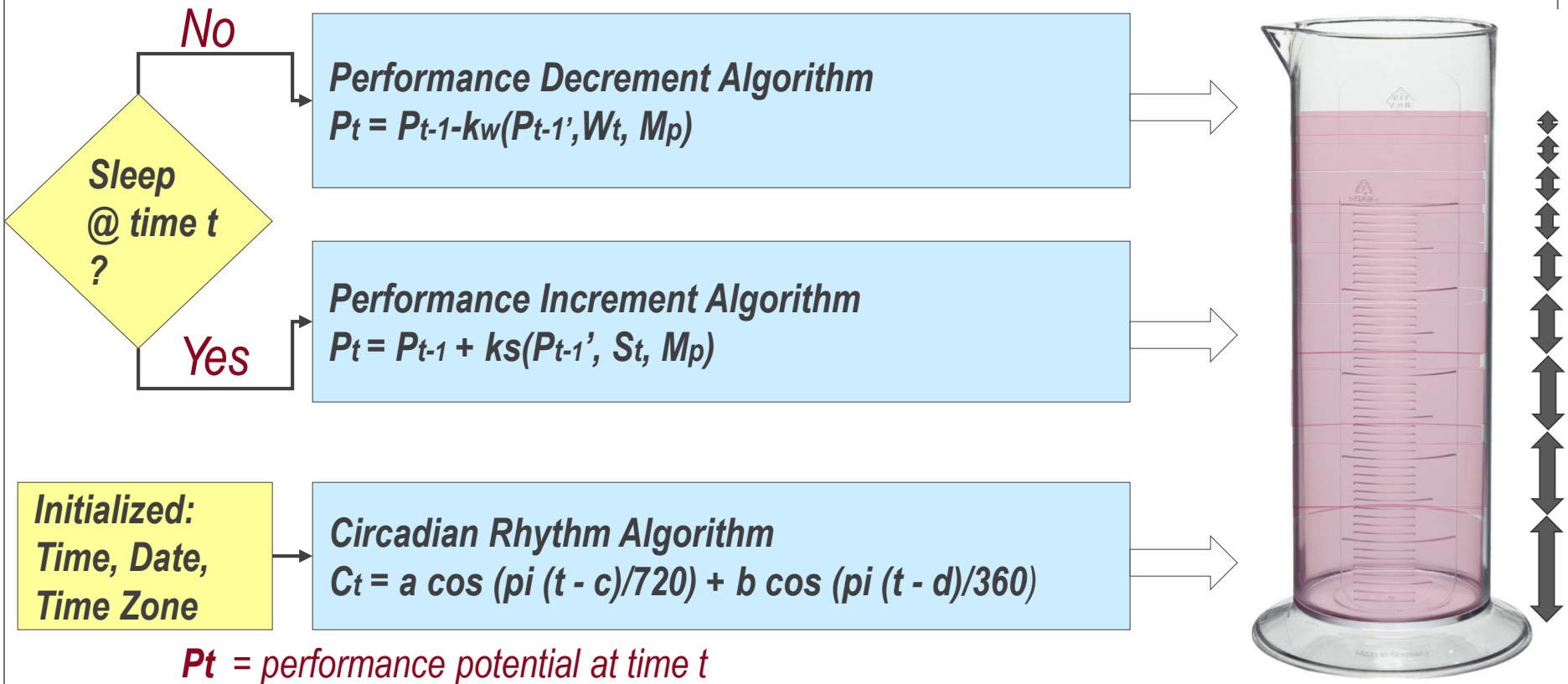
*Restrict x Group, p = .01

+Recov x Group, p = .03

Estimated means, controlling for age.



The Sleep Reservoir: (what we used to think)



Pt = performance potential at time t

kw = rate of decline during wake

ks = rate of recuperation during sleep

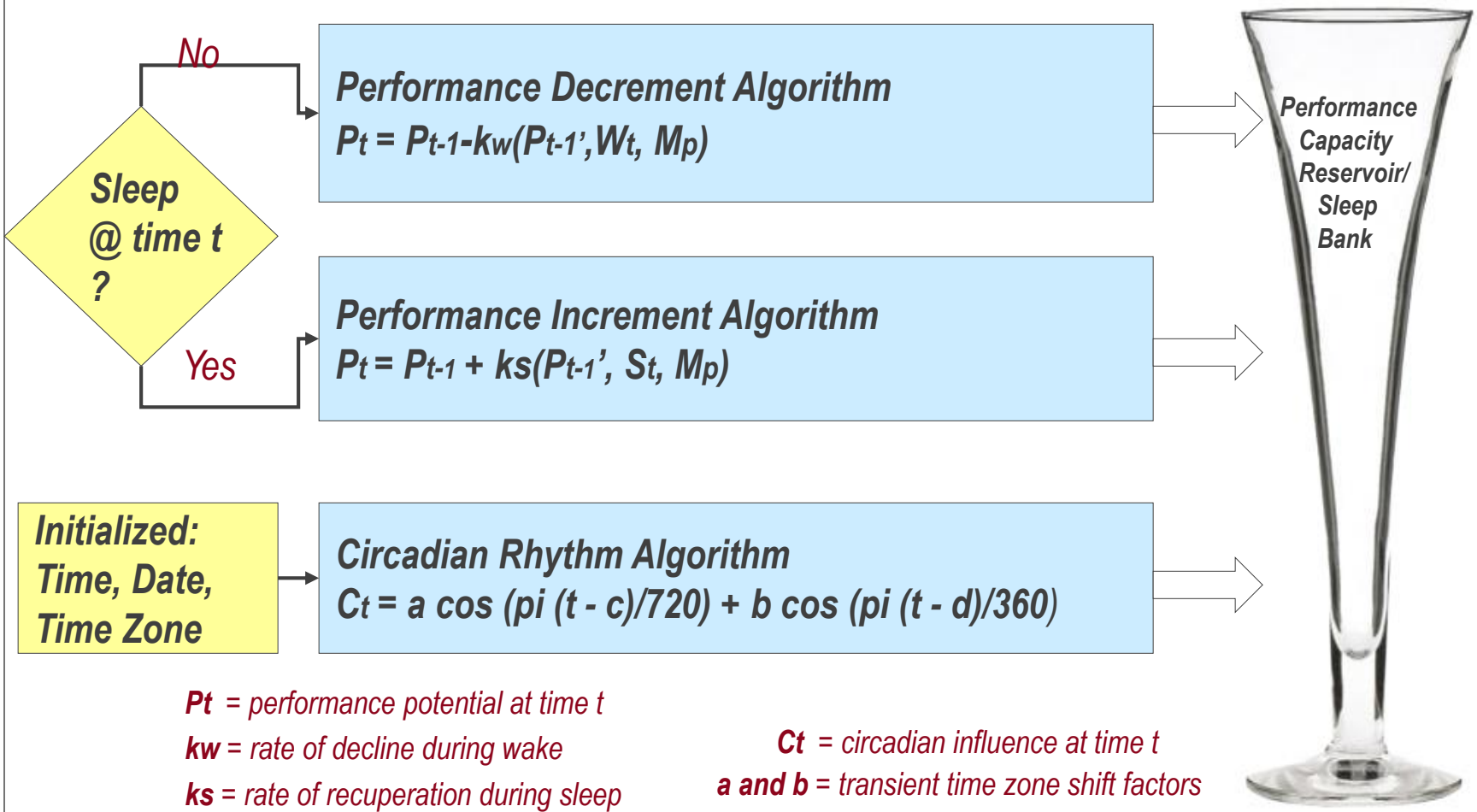
Mp = specific measure of performance

Ct = circadian influence at time t

a and b = transient time zone shift factors

c and d = acrophase of 24- and 12-hour rhythms

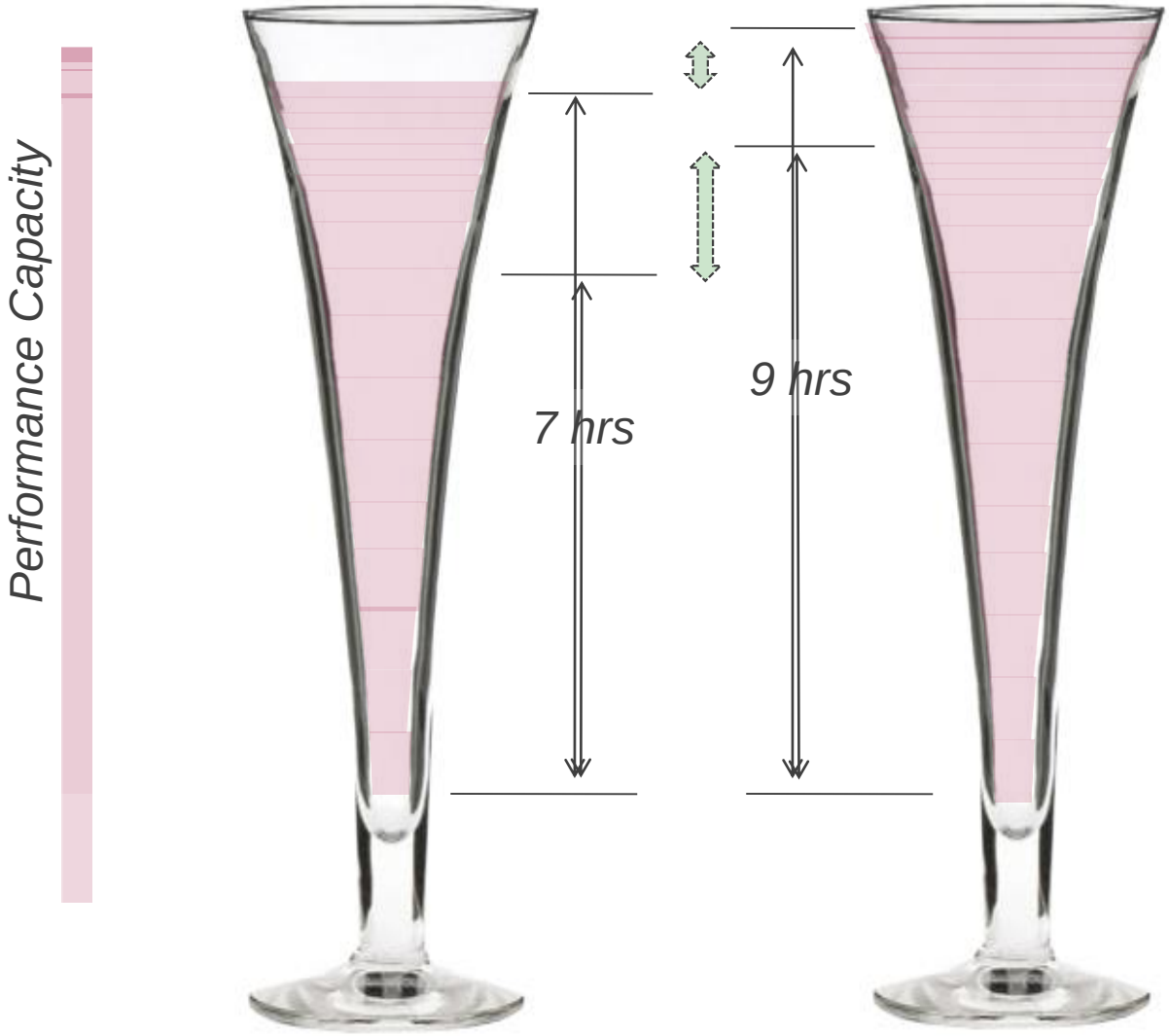
The Sleep Reservoir: (what we now think)



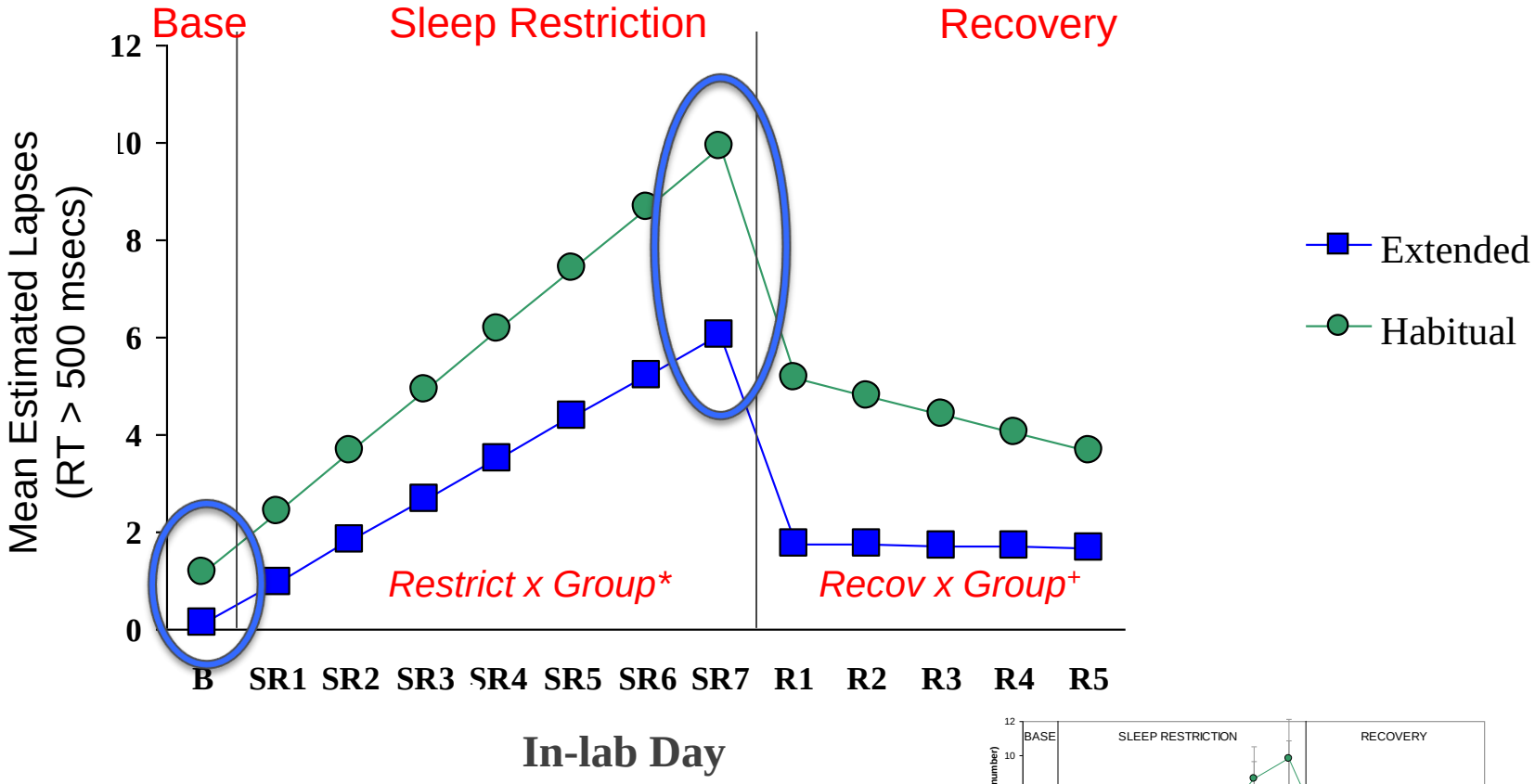
Pt = performance potential at time t
kw = rate of decline during wake
ks = rate of recuperation during sleep
Mp = specific measure of performance

Ct = circadian influence at time t
a and b = transient time zone shift factors
c and d = acrophase of 24- and 12- hour rhythms


Performance Capacity
7 hrs
9 hrs


Performance Capacity
7 hrs
9 hrs

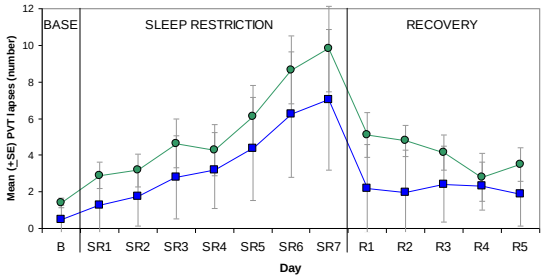
Recovery of PVT Lapses



*Restrict x Group, p = .01

+Recov x Group, p = .03

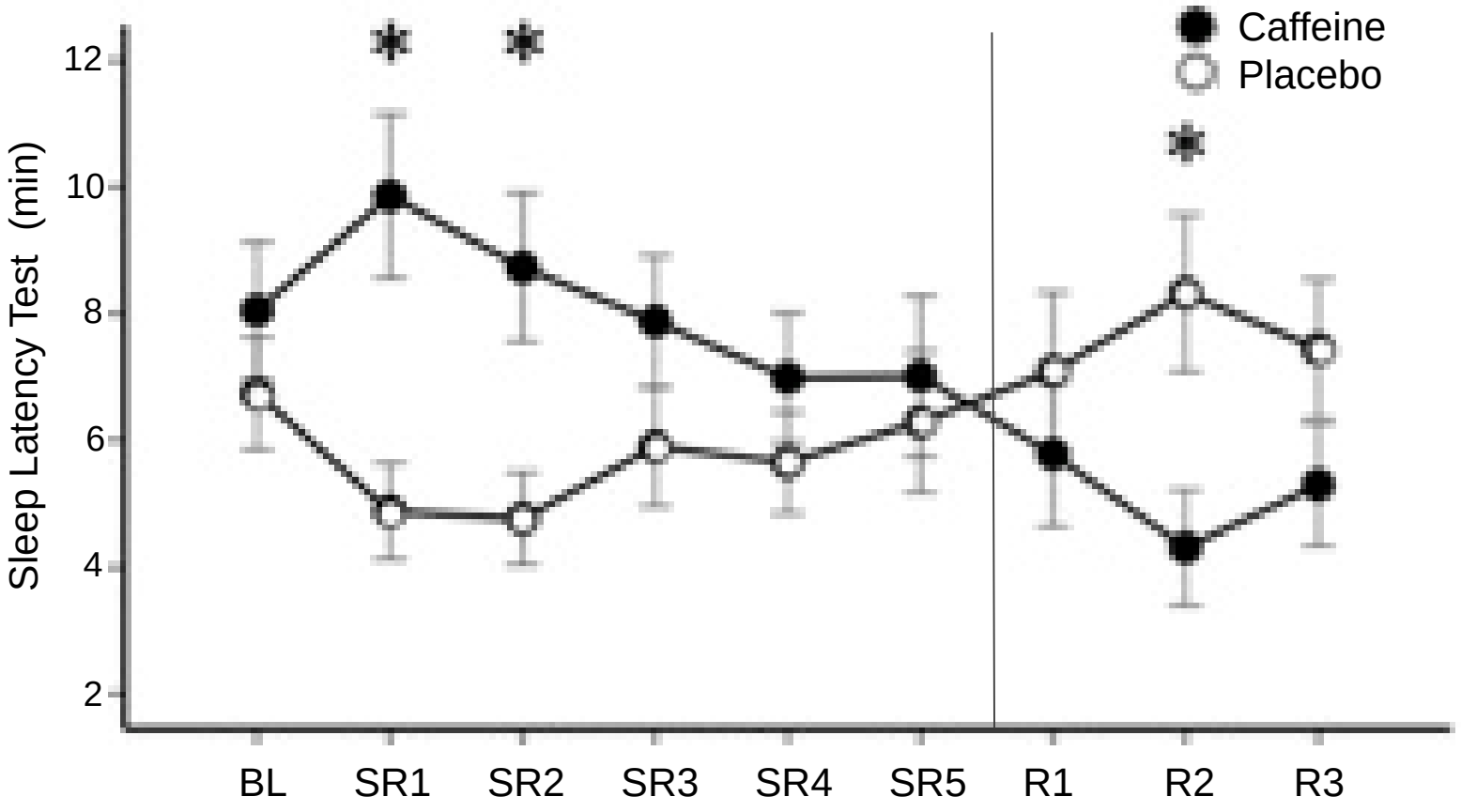
Estimated means, controlling for age.



State of the Relevant Science III

Effects of daily use of caffeine across multiple days of sleep restriction

Effectiveness of Caffeine Across 5 Days of Sleep Restriction and Effects on Subsequent Recovery



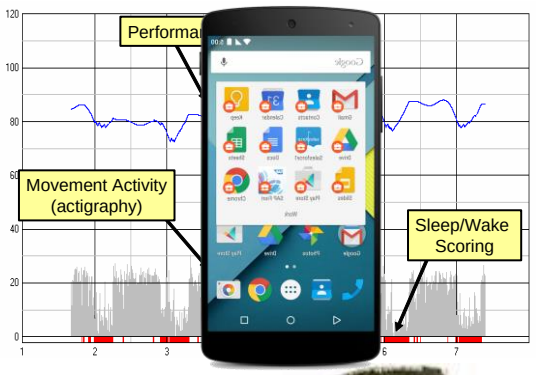
The WRAIR Alertness Management System

Wrist Actigraphy

- Because that which cannot be measured in the field cannot be managed in the field

Performance Prediction (2B-Alert) Model

- So that operational performance degradation can be anticipated and planned for, and informed decisions regarding dosage and timing of countermeasures can be made.



Armamentarium of Countermeasures

- Stimulants to restore/maintain performance during sustained/continuous operations when there is little or no opportunity to sleep
- Sleep inducers to enhance recuperative sleep when needed

2B-Alert Model: Recent Improvements

1. Smartphone version has the ability to "learn" the individual when he/she intermittently performs a PVT on the smartphone over a 2-week period - including individual differences in (a) sensitivity / resilience to sleep loss and (b) responsiveness to caffeine

2. Improved prediction of the effects of caffeine during acute sleep loss and chronic sleep restriction – effects on both performance and subsequent recuperation rate during recovery sleep.

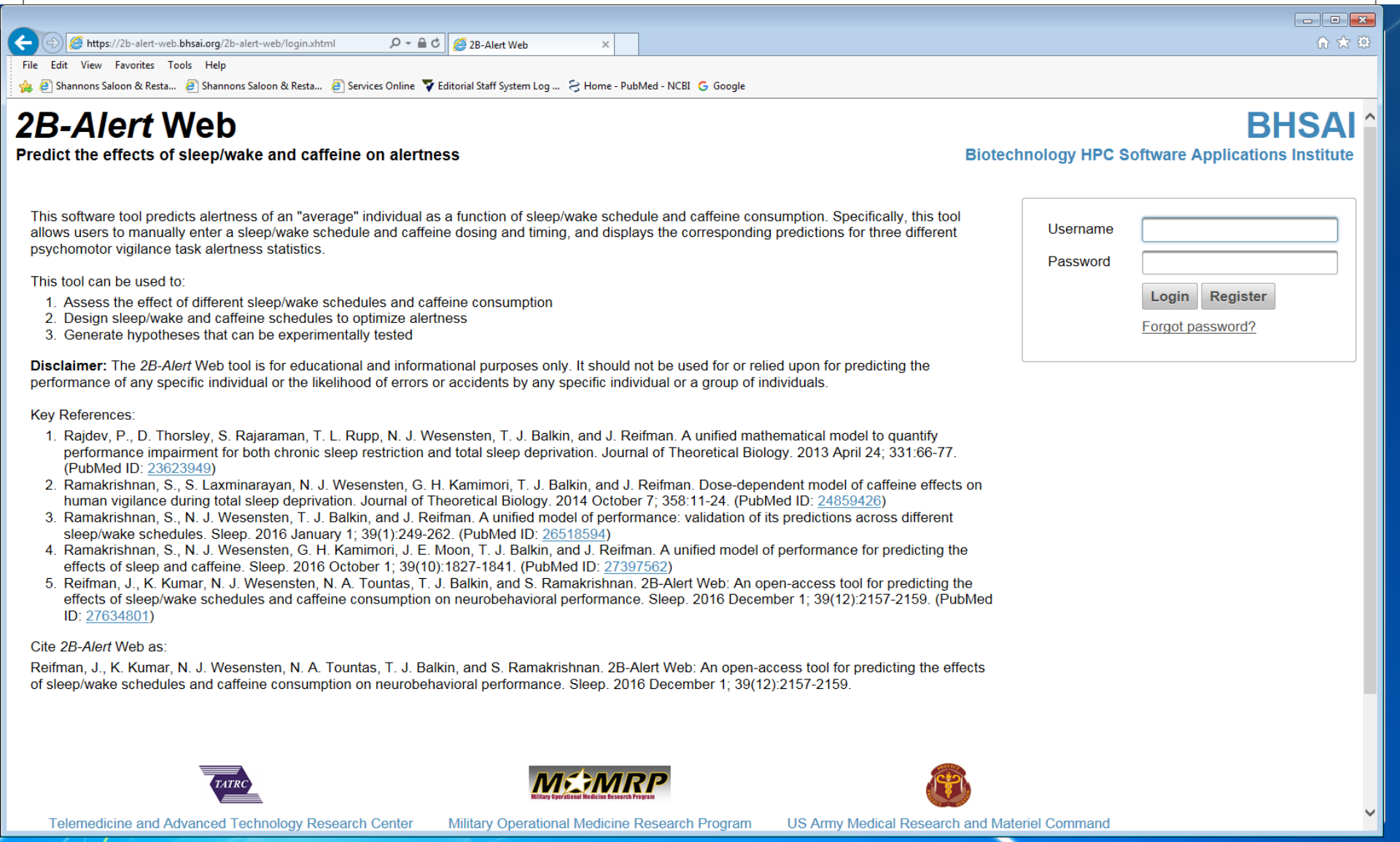
3. Next iteration will include a function that provides specific guidance re: timing and dose level of caffeine to optimize performance for any operational scenario.

2B-Alert Web

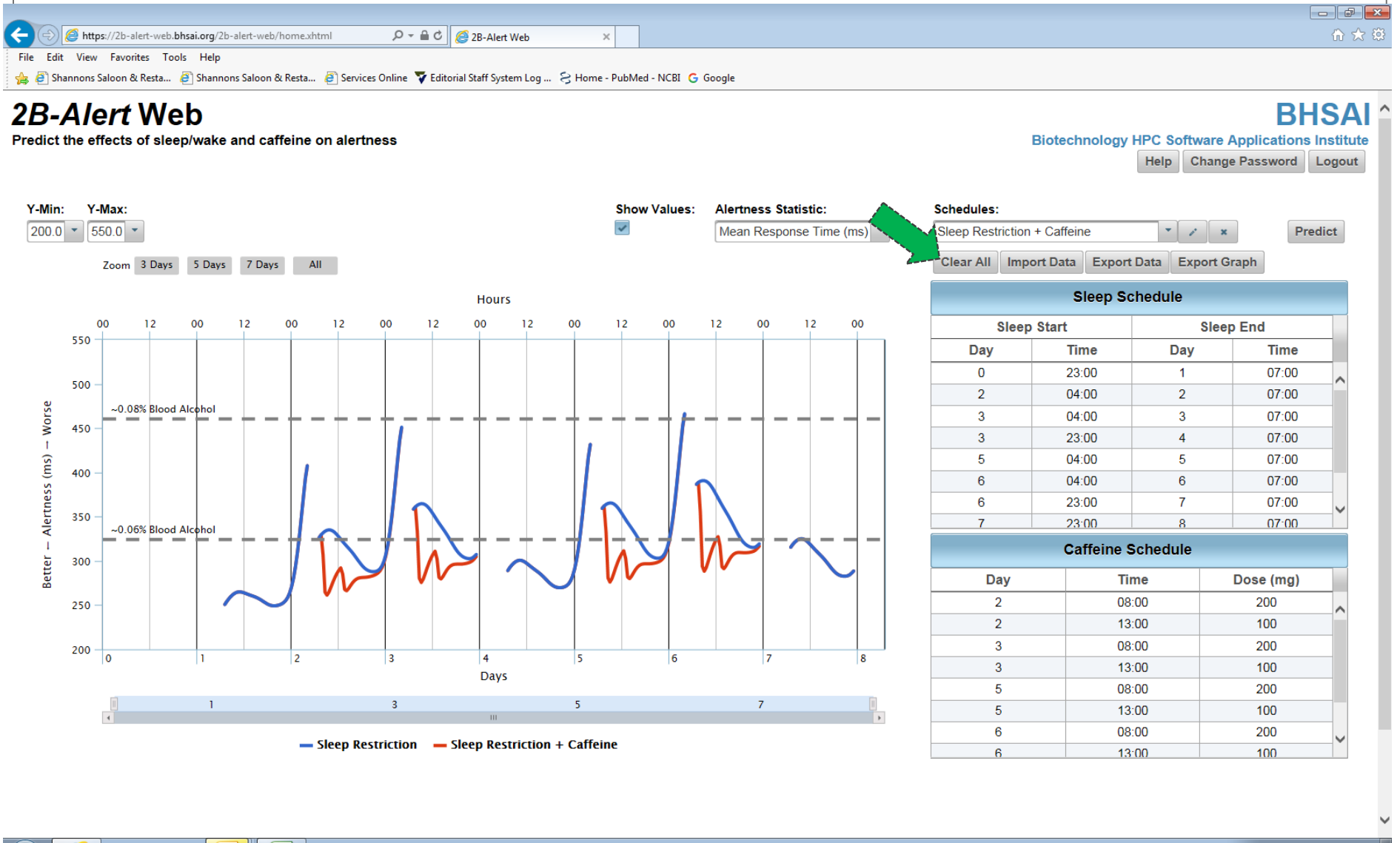
https://2b-alert-web.bhsai.org/2b-alert-web/login.xhtml

NOTE: Currently, this website only works if accessed with a PC. The website fails to recognize some commands from Apple computers.

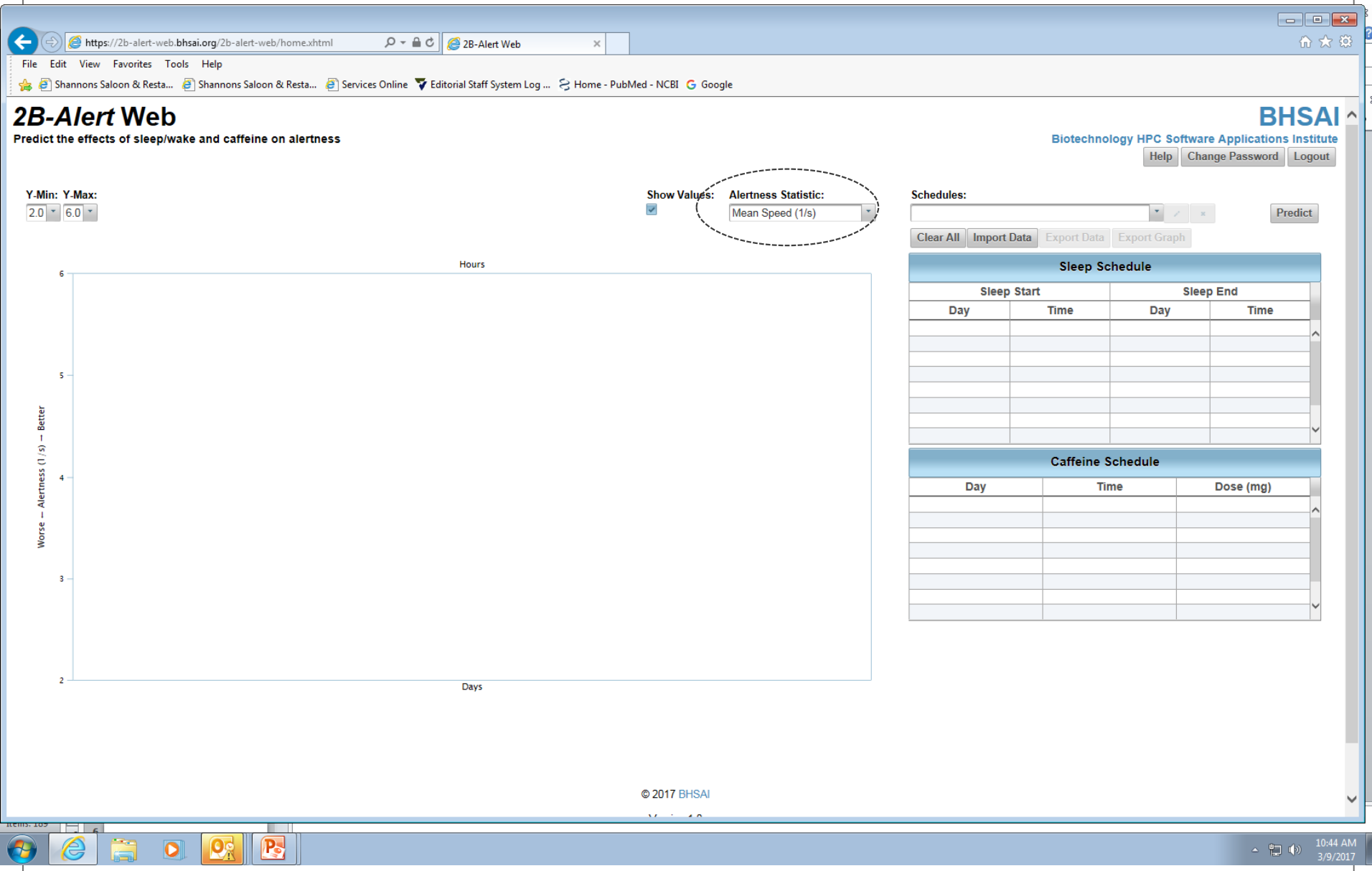
Log-in Page


https://2b-alert-web.bhsai.org/2b-alert-web/login.xhtml
2B-Alert Web
File Edit View Favorites Tools Help
Shannons Saloon & Resta... Shannons Saloon & Resta... Services Online Editorial Staff System Log ... Home - PubMed - NCBI Google
2B-Alert Web
Predict the effects of sleep/wake and caffeine on alertness
BHSAI
Biotechnology HPC Software Applications Institute
This software tool predicts alertness of an "average" individual as a function of sleep/wake schedule and caffeine consumption. Specifically, this tool allows users to manually enter a sleep/wake schedule and caffeine dosing and timing, and displays the corresponding predictions for three different psychomotor vigilance task alertness statistics.
This tool can be used to:
1. Assess the effect of different sleep/wake schedules and caffeine consumption
2. Design sleep/wake and caffeine schedules to optimize alertness
3. Generate hypotheses that can be experimentally tested
Disclaimer: 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.
Key References:
1. Rajdev, P., D. Thorsley, S. Rajaraman, T. L. Rupp, N. J. Wesensten, T. J. Balkin, and J. Reifman. A unified mathematical model to quantify performance impairment for both chronic sleep restriction and total sleep deprivation. Journal of Theoretical Biology. 2013 April 24; 331:66-77. (PubMed ID: 23623949)
2. Ramakrishnan, S., S. Laxminarayan, N. J. Wesensten, G. H. Kamimori, T. J. Balkin, and J. Reifman. Dose-dependent model of caffeine effects on human vigilance during total sleep deprivation. Journal of Theoretical Biology. 2014 October 7; 358:11-24. (PubMed ID: 24859426)
3. Ramakrishnan, S., N. J. Wesensten, T. J. Balkin, and J. Reifman. A unified model of performance: validation of its predictions across different sleep/wake schedules. Sleep. 2016 January 1; 39(1):249-262. (PubMed ID: 26518594)
4. Ramakrishnan, S., N. J. Wesensten, G. H. Kamimori, J. E. Moon, T. J. Balkin, and J. Reifman. A unified model of performance for predicting the effects of sleep and caffeine. Sleep. 2016 October 1; 39(10):1827-1841. (PubMed ID: 27397562)
5. Reifman, J., K. Kumar, N. J. Wesensten, N. A. Tountas, T. J. Balkin, and S. Ramakrishnan. 2B-Alert Web: An open-access tool for predicting the effects of sleep/wake schedules and caffeine consumption on neurobehavioral performance. Sleep. 2016 December 1; 39(12):2157-2159. (PubMed ID: 27634801)
Cite 2B-Alert Web as:
Reifman, J., K. Kumar, N. J. Wesensten, N. A. Tountas, T. J. Balkin, and S. Ramakrishnan. 2B-Alert Web: An open-access tool for predicting the effects of sleep/wake schedules and caffeine consumption on neurobehavioral performance. Sleep. 2016 December 1; 39(12):2157-2159.
Username
Password
Login
Register
Forgot password?
TATRC
Telemedicine and Advanced Technology Research Center
MOMRP
Military Operational Medicine Research Program
US Army Medical Research and Materiel Command
12:49 PM
3/9/2017

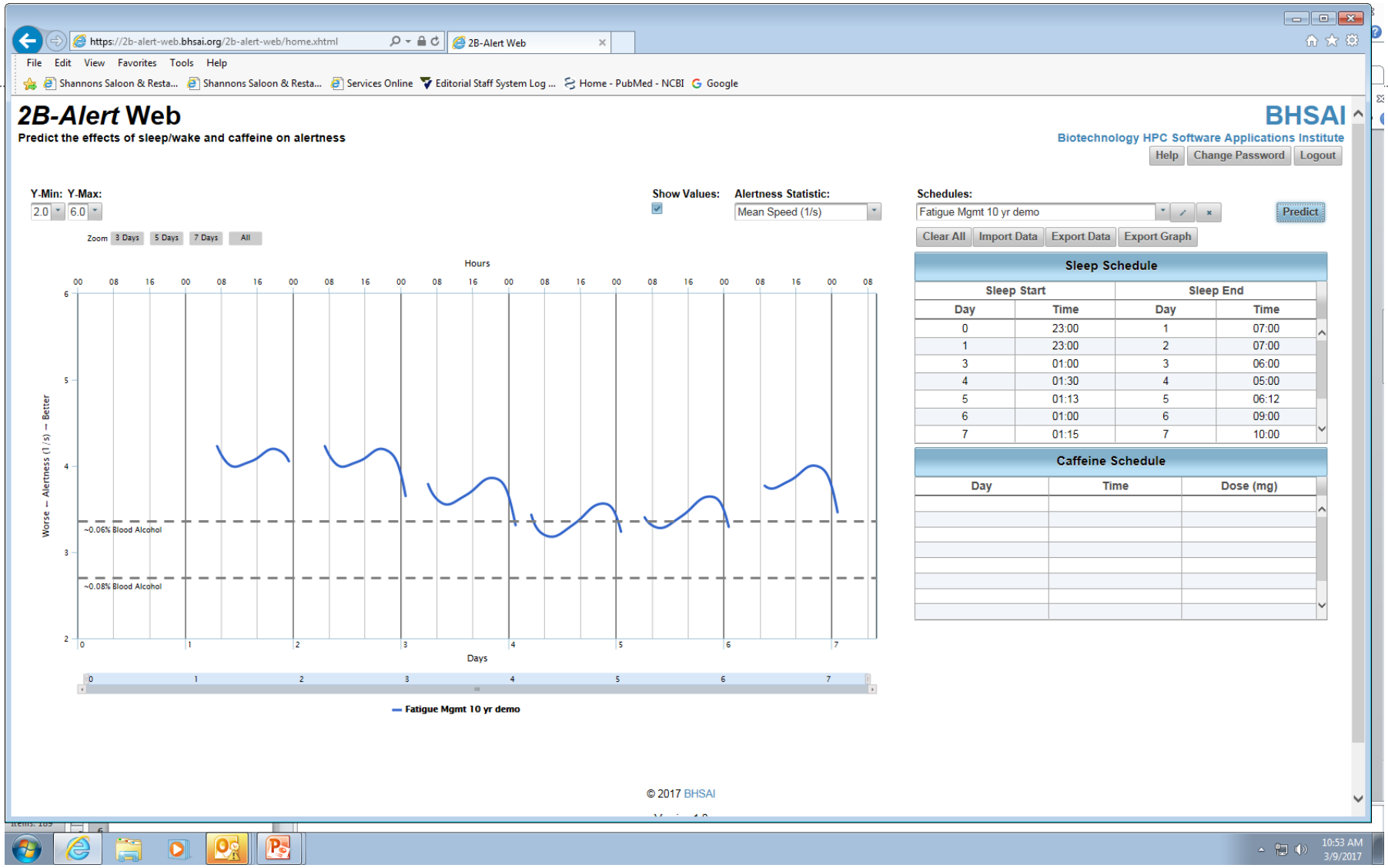
Initial 2B-Alert Screen



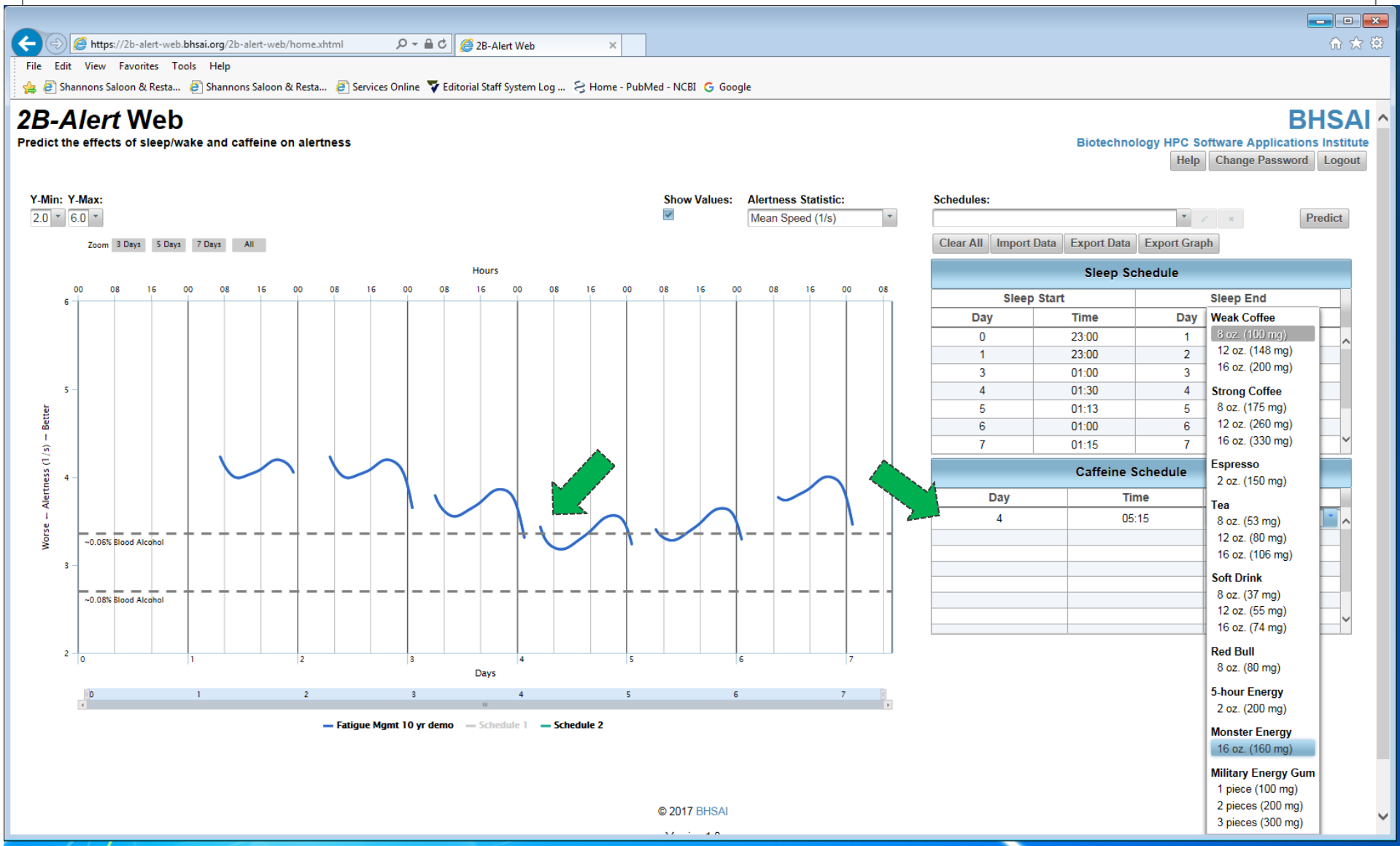
Cleared of Data



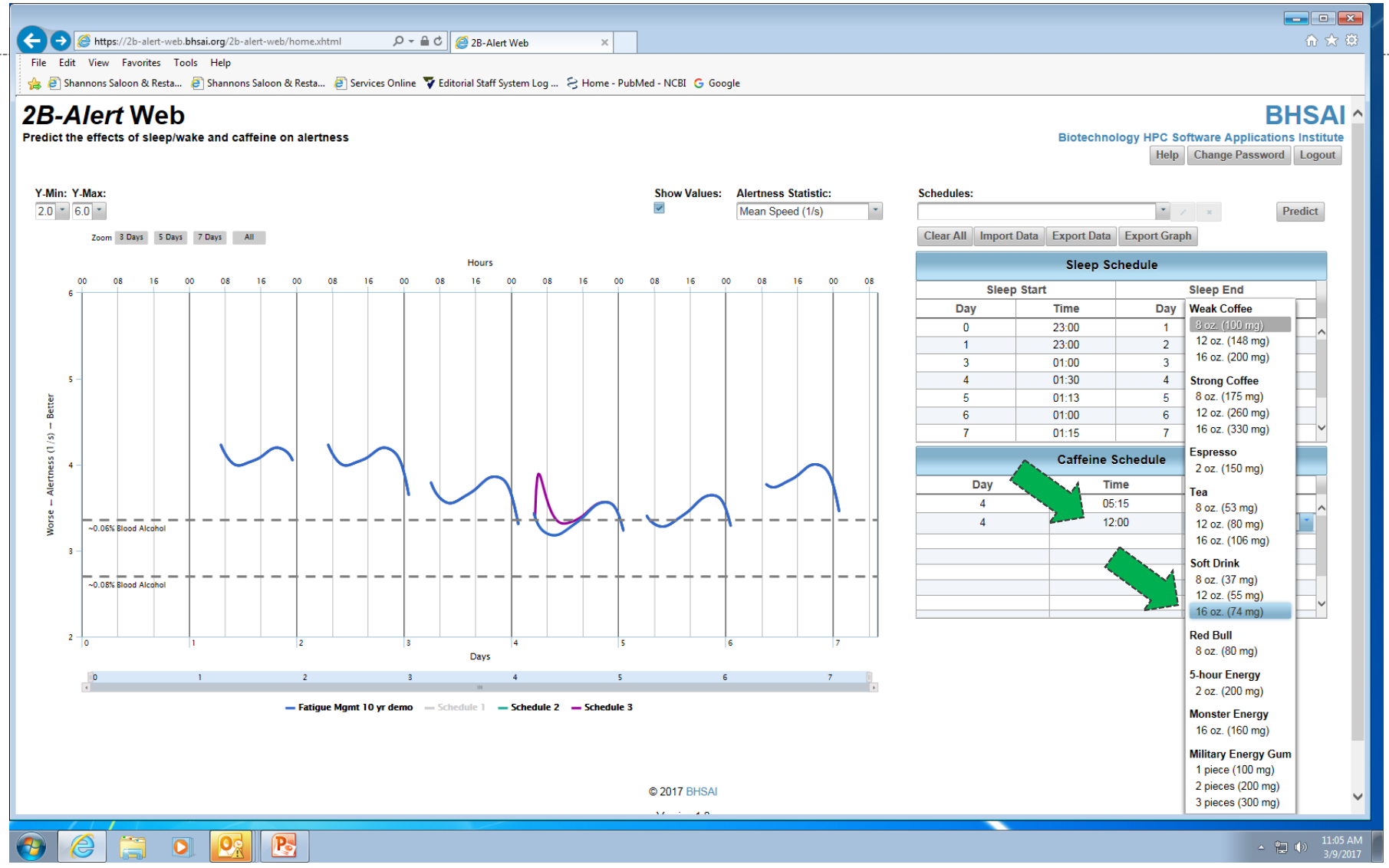
Schedule: 8, 8, 5, 3.5, 5, 8, 8.75 Hrs of Sleep per Night



Goal: Maintain Performance Above 0.06 BAC Equivalency Level



2nd Dose of Caffeine Added



2nd Dose of Caffeine Added

https://2b-alert-web.bhsai.org/2b-alert-web/home.xhtml — 2B-Alert Web

File Edit View Favorites Tools Help

Shannons Saloon & Resta... | Shannons Saloon & Resta... | Services Online | Editorial Staff System Log ... | Home - PubMed - NCBI | Google

2B-Alert Web

Predict the effects of sleep/wake and caffeine on alertness

BHSAI

Biotechnology HPC Software Applications Institute

Help | Change Password | Logout

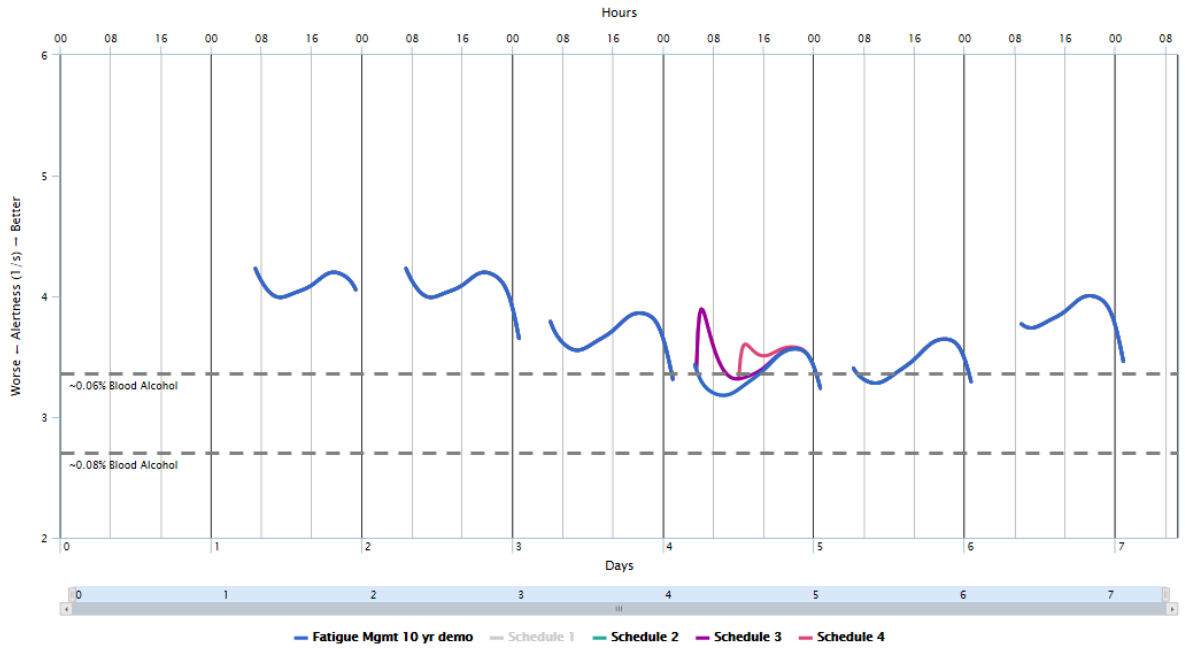
Y-Min: 2.0 Y-Max: 6.0

Show Values: ☑ Alertness Statistic: Mean Speed (1/s)

Schedules: Schedule 4 Predict

Clear All | Import Data | Export Data | Export Graph

Zoom: 3 Days | 5 Days | 7 Days | All



Sleep Schedule

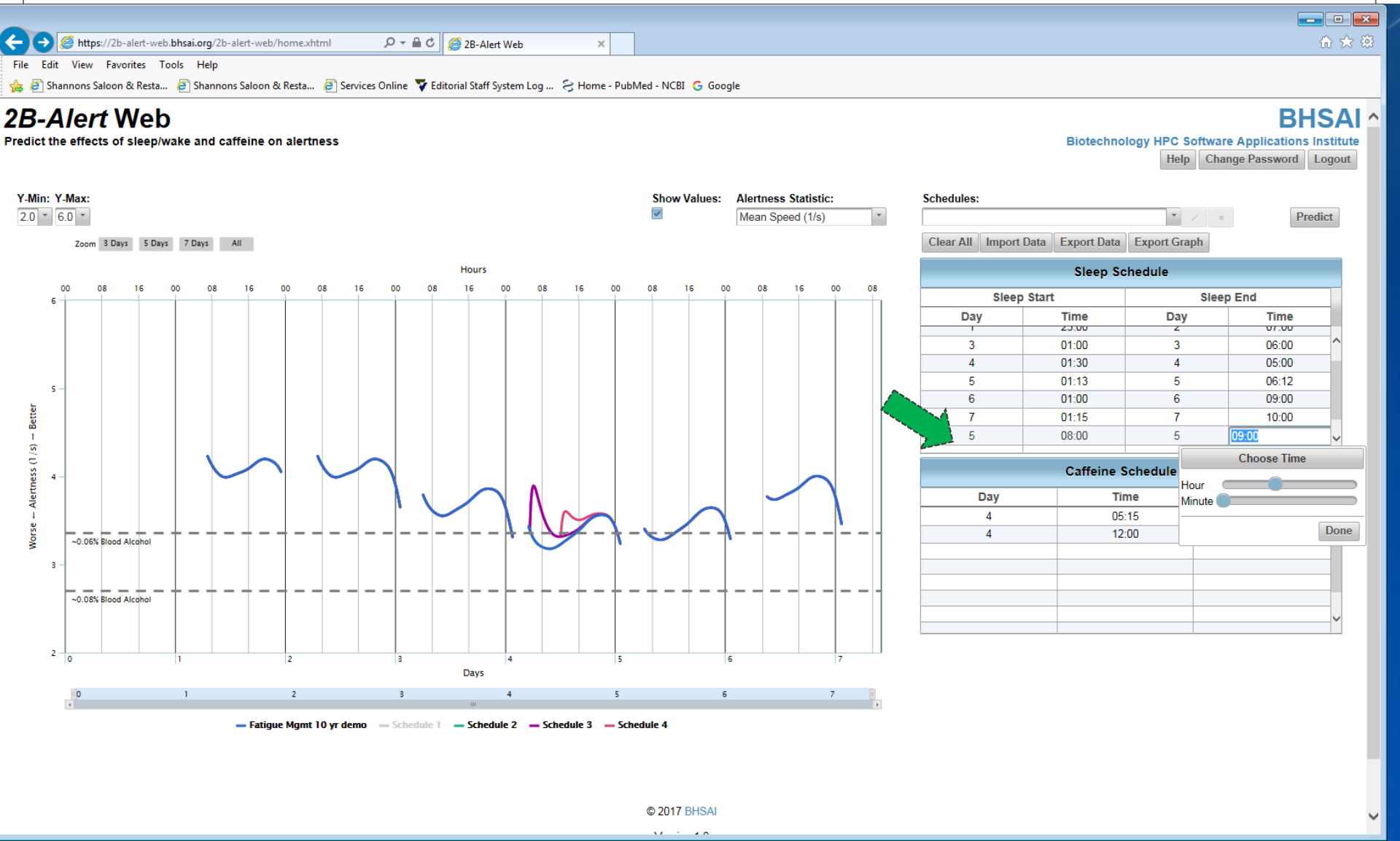
Sleep Start		Sleep End	
Day	Time	Day	Time
0	23:00	1	07:00
1	23:00	2	07:00
3	01:00	3	06:00
4	01:30	4	05:00
5	01:13	5	06:12
6	01:00	6	09:00
7	01:15	7	10:00

Caffeine Schedule

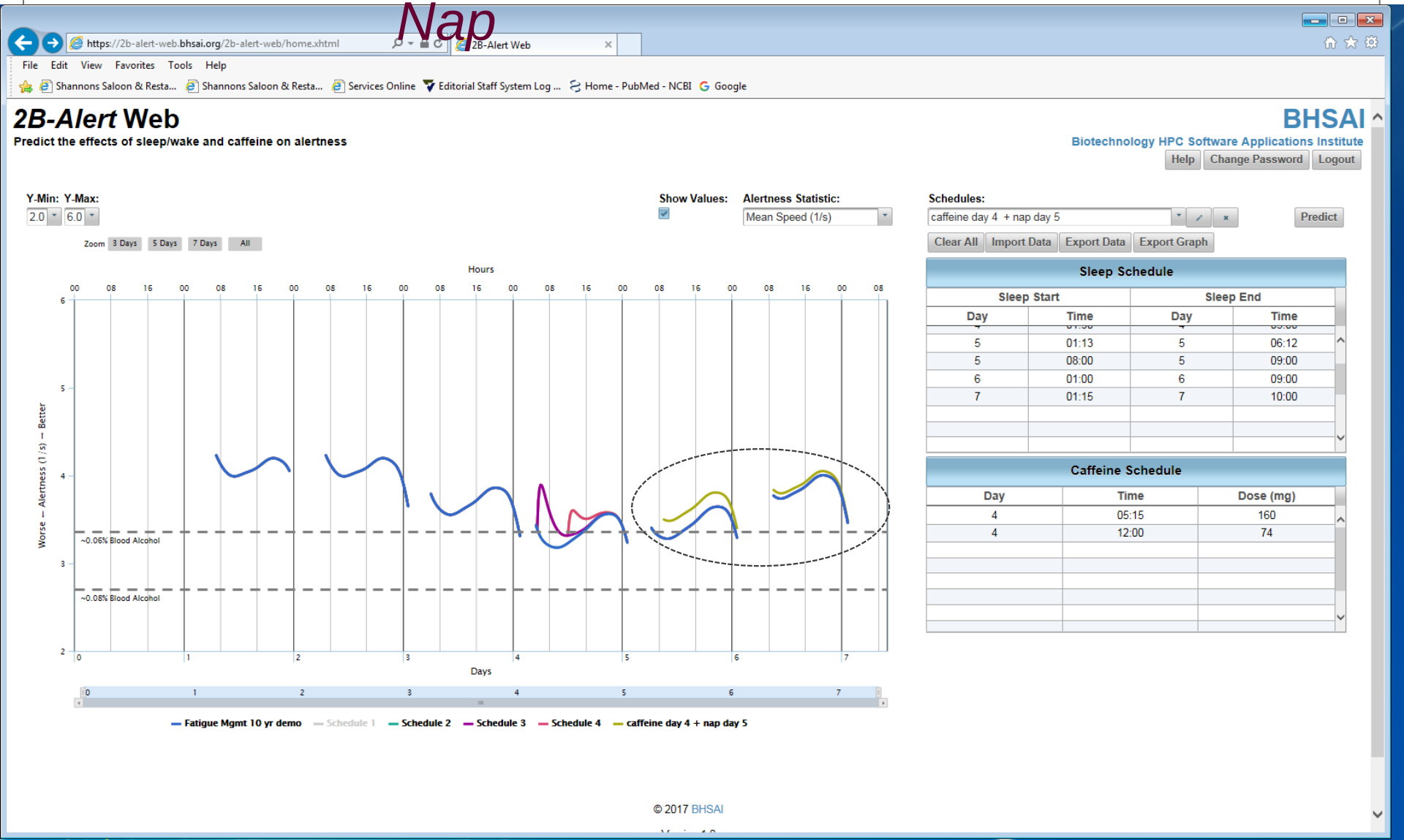
Day	Time	Dose (mg)
4	05:15	160
4	12:00	74

11:08 AM 3/9/2017

Add 1 Hour Nap on Morning of Day 5

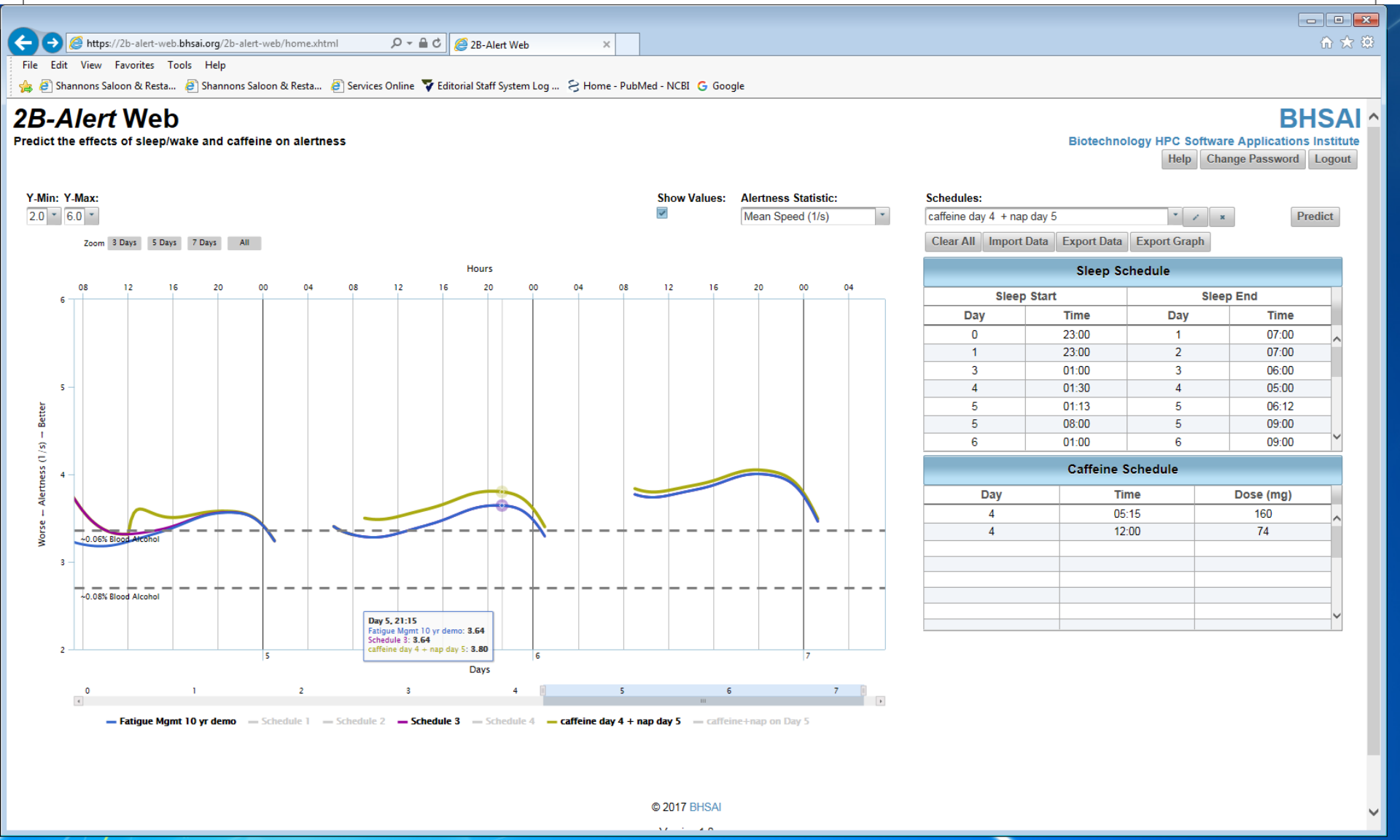


Long-Lasting Effect Nap



Note the relatively long-lasting beneficial effect of a nap

Zoom and Cursor Scroll Functions



Demo 2

Schedule: 8, 8, 5, 3.5, 5, 8 Hours of Sleep per Night

https://2b-alert-web.bhsai.org/2b-alert-web/home.xhtml — 2B-Alert Web

File Edit View Favorites Tools Help

Shannons Saloon & Resta... | Shannons Saloon & Resta... | Services Online | Editorial Staff System Log ... | Home - PubMed - NCBI | Google

2B-Alert Web

Predict the effects of sleep/wake and caffeine on alertness

BHSAI

Biotechnology HPC Software Applications Institute

Help | Change Password | Logout

Y-Min: 2.0 **Y-Max:** 6.0

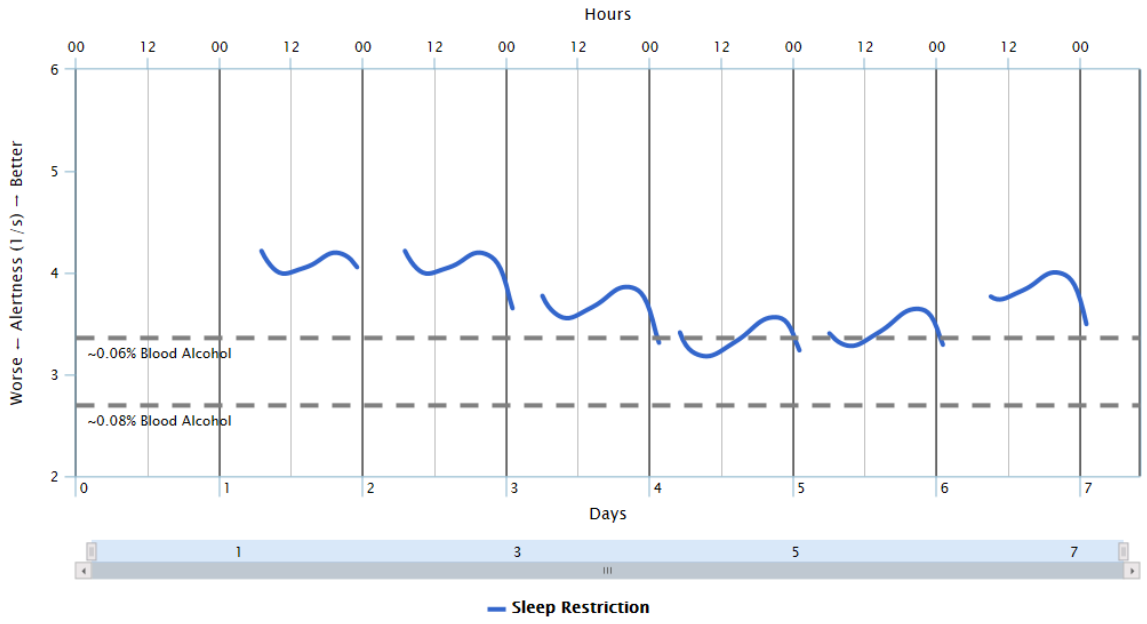
Show Values: ☑

Alertness Statistic: Mean Speed (1/s)

Schedules: Sleep Restriction — Predict

Clear All | Import Data | Export Data | Export Graph

Zoom: 3 Days | 5 Days | 7 Days | All



Sleep Schedule

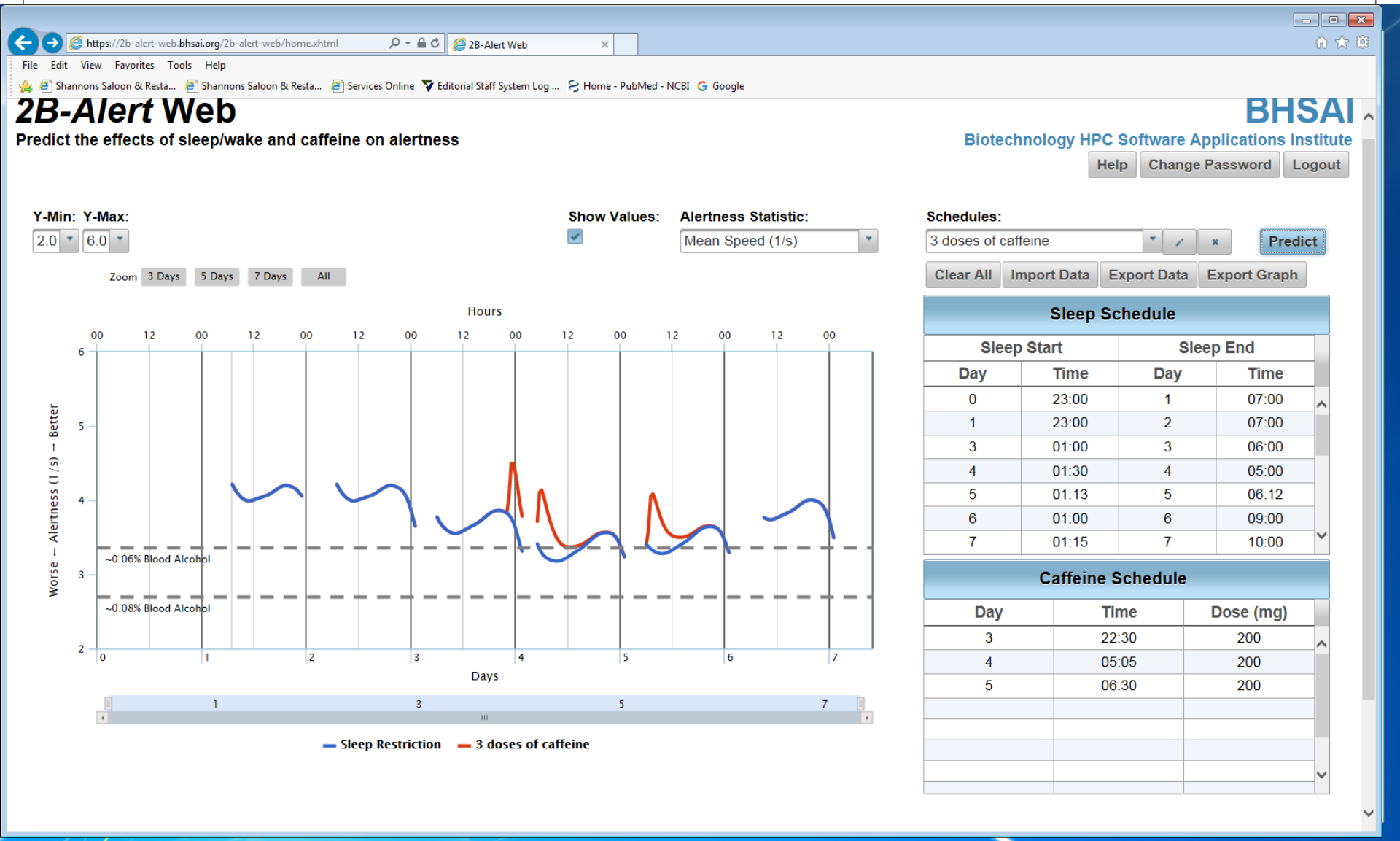
Sleep Start		Sleep End	
Day	Time	Day	Time
0	23:00	1	07:00
1	23:00	2	07:00
3	01:00	3	06:00
4	01:30	4	05:00
5	01:13	5	06:12
6	01:00	6	09:00
7	01:15	7	10:00

Caffeine Schedule

Day	Time	Dose (mg)

2:38 PM 3/9/2017

Three Strategically Timed 200 mg Doses of Caffeine



…combined with three 30-minute noontime naps

https://2b-alert-web.bhsai.org/2b-alert-web/home.xhtml — 2B-Alert Web

File Edit View Favorites Tools Help

Shannons Saloon & Resta... | Shannons Saloon & Resta... | Services Online | Editorial Staff System Log ... | Home - PubMed - NCBI | Google

2B-Alert Web

Predict the effects of sleep/wake and caffeine on alertness

BHSAI

Biotechnology HPC Software Applications Institute

Help | Change Password | Logout

Y-Min: 2.0 **Y-Max:** 6.0

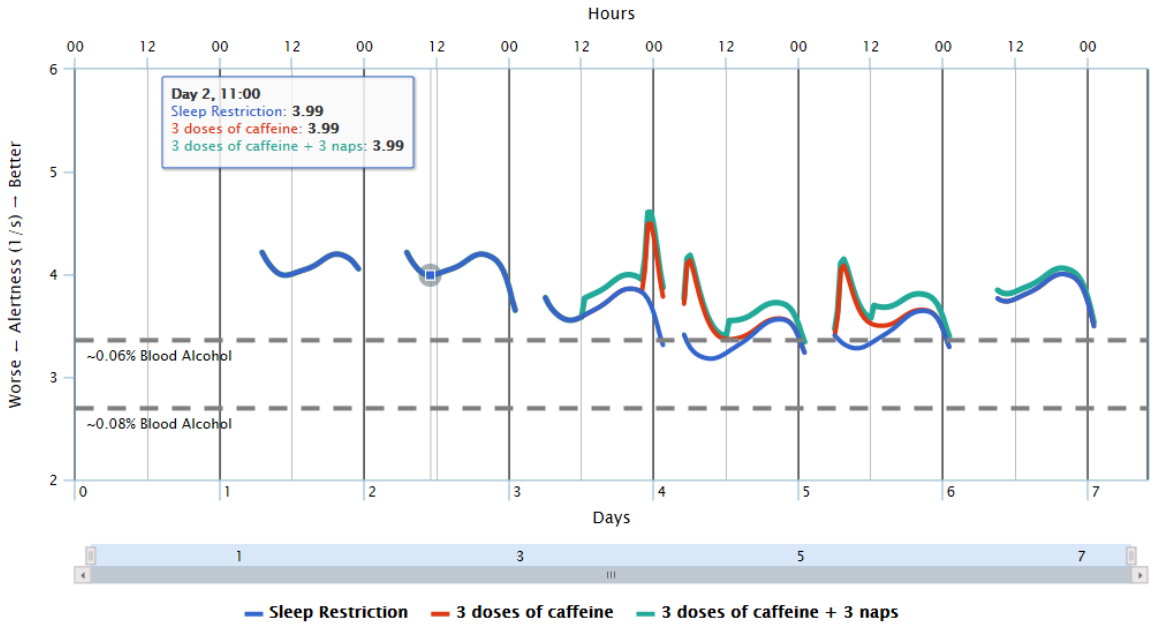
Show Values: ☑

Alertness Statistic: Mean Speed (1/s)

Schedules: 3 doses of caffeine + 3 naps — Predict

Clear All | Import Data | Export Data | Export Graph

Zoom: 3 Days | 5 Days | 7 Days | All



Sleep Schedule

Sleep Start		Sleep End	
Day	Time	Day	Time
0	23:00	1	07:00
1	23:00	2	07:00
3	01:00	3	06:00
3	12:00	3	12:30
4	01:30	4	05:00
4	12:00	4	12:30
5	01:13	5	06:12

Caffeine Schedule

Day	Time	Dose (mg)
3	22:30	200
4	05:05	200
5	06:30	200

2:49 PM 3/9/2017

Thank You

This material has been reviewed by the Walter Reed Army Institute of Research, and there is no objection to its presentation. However, the opinions or assertions contained herein are the private views of the author and are not to be construed as official or as reflecting the position of the Department of the Army or the Department of Defense.

Thomas J. Balkin, Ph.D.
Walter Reed Army Institute of Research
Phone +1 (301) 319-9350
FAX: +1 (301) 319-9979
Email: thomas.j.balkin.ctr@mail.mil