FATIGUE
and the
EVALUATION OF FATIGUE

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Definitions of Fatigue

- **“Weariness from labor or exertion.” from Webster’s New Collegiate Dictionary, 1980**
- **“An overwhelming sustained sense of exhaustion and decreased capacity for physical and mental work at the usual level.” from Taber’s Cyclopedic Medical Dictionary, 2005.**

It is generally accepted that fatigue can lead to reduced performance, poor judgment, and accidents

Although numerous studies from aviation, aerospace, military, medicine, and other industries indicate an association between fatigue and human error and reduced performance, few work places are properly equipped to monitor fatigue.

WHY ?

One reason for this lack of monitoring of fatigue among workers is the absence of a valid, reliable, quick, easy-to-use, and relevant method for evaluating the state-of-fatigue of workers.

Two Types of Fatigue

- **Peripheral [Muscle] fatigue caused by strenuous physical work.**
- **Central [Mental] fatigue caused by:**
  - **Prolonged , strenuous mental or physical work,**
  - **Prolonged, monotonous, strenuous, mental or physical work,**
  - **Sleep Deprivation.**

Central Fatigue Characteristics:

- **Slower information processing.**
- **Deterioration of thought processes.**
- **Deterioration of decision processes.**
- **Impaired sensory perceptions.**
- **Impaired sensory-motor functions.**

Central Fatigue Performance Variables

- **Individual Differences.**
- **Time of Day.**
- **Type of Work Demands.**

Physiological Causes of Fatigue

1. **Peripheral [Muscular] Fatigue**
   - **a.) reduced energy substrate availability**
   - **b.) reduced oxygen availability**
   - **c.) increased local acidity [lactic acid]**
2. **Central [Mental] Fatigue**
   - **a.) Reticular Activating System (RAS)**

Reticular Activating System Functions

1. **Sleep/Wake Cycles**
2. **General Level of Arousal**
3. **General Level of Alertness**
4. **Responsiveness of the Nervous and Muscular Systems**

Measurements of Fatigue

A. **Subjective**

B. **Objective**

C. **Not Statistically Significantly Correlated**

PMI FIT 2000-3

A biomedical instrument that purports to "track changes in the person's alertness levels and levels of impairment."

It purports to detect, quantify, and monitor fatigue and sleep deprivation.

Purpose of this Evaluation

1) **Determine the validity of the PMI FIT 2000-3 to detect fatigue and sleep deprivation.**

Specific Definition of Fatigue for this Study

"A decrease or impairment in performance capacity produced by continuous 48-hours of sleep deprivation."

The FIT system

By PMI, Inc.

Objective Measurements by PMI FIT 2000-3

1) **Pupil Diameter [Reflex]**
2) **Change in Pupil Amplitude [Reflex]**
3) **Pupil Latency of Change [Reflex]**
4) **Saccadic Velocity [Voluntary Response]**

TEST CONDITIONS

- **Pre-Test:**

Baseline Data – 12 sets of daily measurements per subject at 8:00 am following a typical restful night's sleep.

- **Test Protocol:**

48 hours continuous sleep deprivation with 3 iterations of eye-responses tested every 4 hours.

DATA ANALYZED

1) **Fatigue Classification**
2) **Fatigue Index**
3) **Eye Response Indices:**
    - **a.) Pupil Diameter (PD)**
    - **b.) Constriction Amplitude (CA)**
    - **c.) Constriction Latency (CL)**
    - **d.) Saccadic Velocity (SV)**

Descriptive Characteristics of Fatigue Subjects

Number of Subjects	Gender		Mean Age (yrs)
	Male	Female	
12	4	8	19.7 ± 1.0

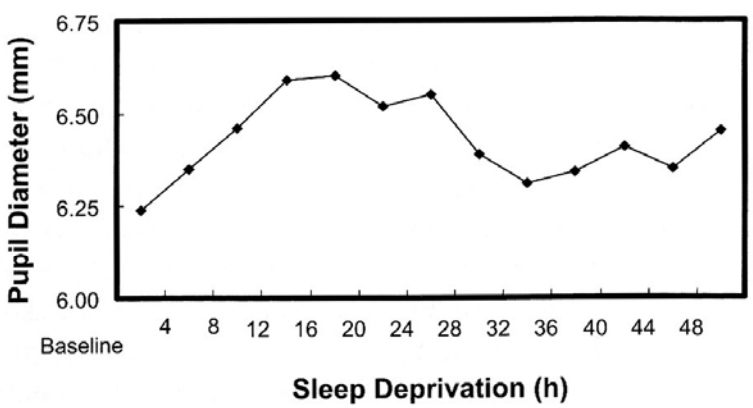
Fatigue Risk: Low (High)

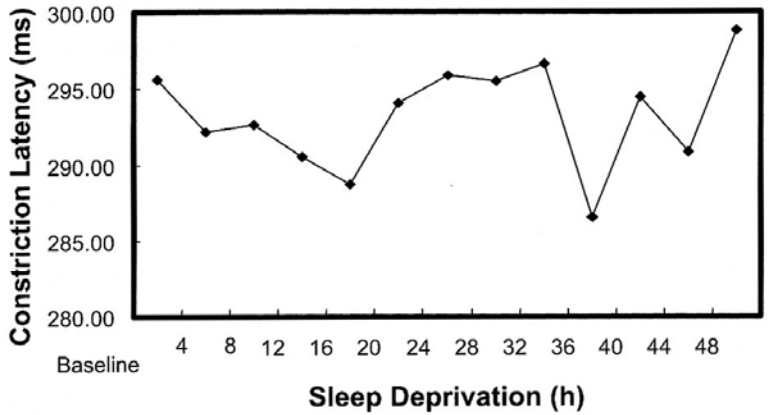
Sleep Deprivation Hours	Baseline	4	8	12	16	20	24	28	32	36	40	44	48
Subject Number													
121	Baseline	1(0)	3(0)	3(0)	3(0)	3(0)	3(0)	3(0)	3(0)	1(2)	2(1)	2(1)	3(0)
122	Baseline	1(0)	3(0)	3(0)	3(0)	3(0)	3(0)	1(0)	2(0)	3(0)	3(0)	3(0)	3(0)
123	Baseline	1(0)	4(0)	3(0)	2(1)	3(0)	3(0)	2(1)	2(1)	3(0)	3(0)	3(0)	3(0)
124	Baseline	1(0)	3(0)	3(0)	3(0)	3(0)	4(0)	3(0)	3(0)	3(0)	4(0)	3(0)	3(0)
151	Baseline	1(2)	3(0)	3(0)	2(1)	2(1)	3(0)	3(0)	3(0)	3(0)	1(2)	3(0)	3(0)
152	Baseline	3(0)	3(0)	3(0)	3(0)	3(0)	3(0)	3(0)	3(0)	3(0)	3(0)	3(0)	3(0)
154	Baseline	3(0)	3(0)	3(0)	3(0)	3(0)	3(0)	3(0)	3(0)	3(0)	3(0)	3(0)	3(0)
155	Baseline	3(0)	3(0)	3(0)	3(0)	3(0)	3(0)	3(0)	3(0)	3(0)	4(0)	3(0)	3(0)
181	Baseline	3(0)	3(0)	3(0)	3(0)	2(1)	1(2)	3(0)	4(0)	3(0)	3(0)	3(0)	3(0)
182	Baseline	3(0)	3(0)	2(1)	3(0)	3(0)	3(0)	3(0)	2(1)	3(0)	3(0)	3(0)	3(0)
183	Baseline	3(0)	3(0)	2(1)	2(1)	3(0)	2(1)	3(0)	2(0)	2(1)	3(0)	3(0)	3(0)
184	Baseline	2(1)	3(0)	3(0)	2(1)	3(0)	3(0)	3(0)	3(0)	3(0)	3(0)	3(0)	3(0)

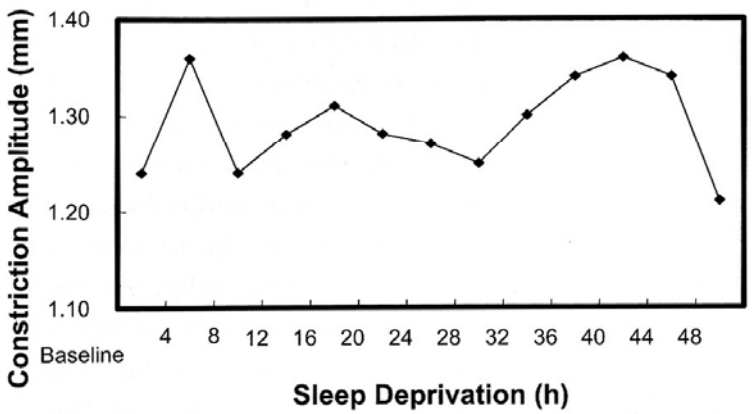
Typically each subject was tested three times. Low risk tests are shown outside of the parentheses and high risk tests are shown inside the parentheses for each time period. For example: At 40 hours subject 121 took three total tests. Two of the tests were low risk while one test was high risk.

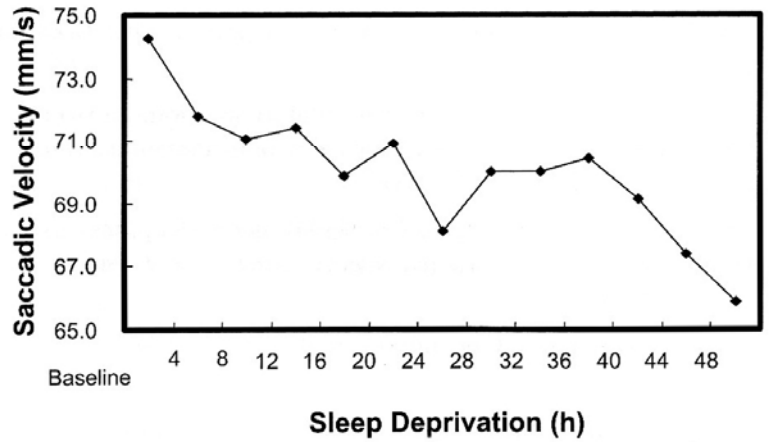
Correlation between Fatigue Index and hours of sleep deprivation

SUBJECT	"r"
121	0.58* (p<0.05)
122	-0.46
123	0.24
124	-0.48
151	-0.44
152	-0.28 [Mean = -0.13]
154	0.29
155	-0.10
181	0.05
182	0.11
183	-0.45
184	-0.65*(p<0.05)

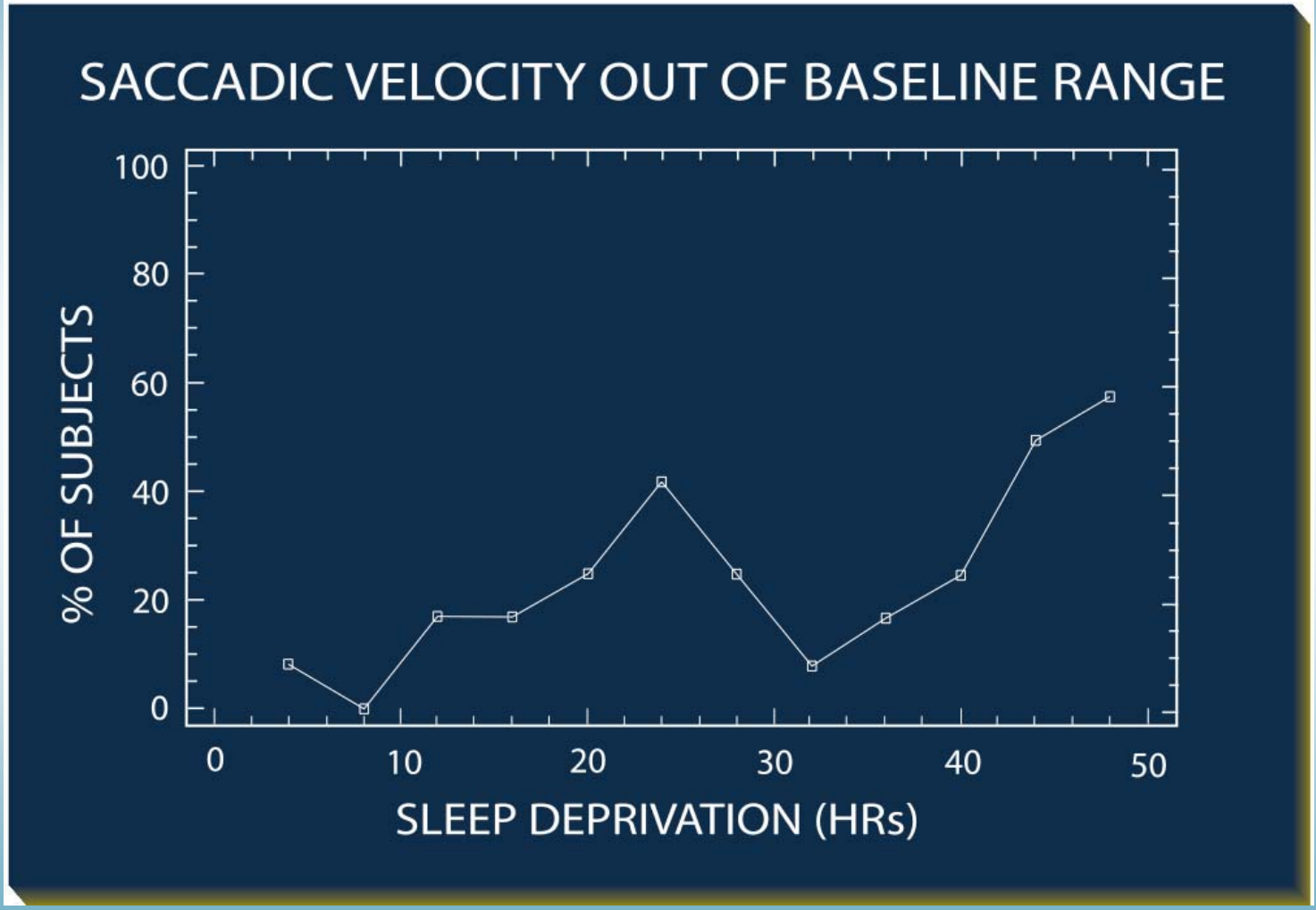

Pupil Diameter (mm)
6.75
6.50
6.25
6.00
Baseline
4 8 12 16 20 24 28 32 36 40 44 48
Sleep Deprivation (h)


Constriction Latency (ms)
300.00
295.00
290.00
285.00
280.00
Baseline
4 8 12 16 20 24 28 32 36 40 44 48
Sleep Deprivation (h)


Constriction Amplitude (mm)
1.40
1.30
1.20
1.10
Baseline
4 8 12 16 20 24 28 32 36 40 44 48
Sleep Deprivation (h)


Saccadic Velocity (mm/s)
75.0
73.0
71.0
69.0
67.0
65.0
Baseline
4 8 12 16 20 24 28 32 36 40 44 48
Sleep Deprivation (h)

Correlation Coefficients (r)



SUMMARY OF RESULTS: 1

1. **No subjects were classified as high risk for fatigue based on the manufacturer's criterion at any point during the 48 hours of sleep deprivation.**

SUMMARY OF RESULTS: 2

2. If the Fatigue Index was indicative of fatigue, it should exhibit a positive correlation coefficient {r} with the hours of sleep deprivation. The mean correlation coefficient was –0.01.

Only one subject exhibited a statistically significant (p=0.05) positive r (0.58) and one exhibited a significantly negative r (-0.65).

SUMMARY OF RESULTS: 3

3(a). Of the 4 eye responses measured, only the saccadic velocity exhibited a statistically significant (p=0.01) correlation coefficient (-0.55) with hours of sleep deprivation.

3(b). However, by the end of the 48 hours of sleep deprivation, only about 60% of subjects' responses were outside of their rested baseline range of responses.

CONCLUSIONS: 1(A)

A.) At the conclusion of the 48 hours of sleep deprivation, the PMI FIT 2000-3 failed to classify a single subject as high risk for fatigue.

CONCLUSIONS: 1(B)

B.) At no time during the 48 hour test period was a subject determined to be at high risk without also being classified as low risk during the 3 iterations every 4 hours.

CONCLUSIONS: 1(C)

C.) Therefore, the PMI FIT 2000-3 is not a valid indicator of fatigue.

CONCLUSIONS: 2

Of the four (4) eye-responses measured, only the saccadic velocity appeared to have a potential to successfully reflect changes with the onset of fatigue.

Specific Work Performance Capacity

Since fatigue is the decrease in work performance capacity, it can be viewed as a condition that is specific to each type of work.

Specific work performance is measured and compared to a baseline measurement of the same individual under typical, non-fatigued conditions.

General RAS Activity

Since central fatigue is a function of the RAS, a measurement of general RAS activity could be used to measure fatigue.

A single or simple set of general RAS activities could be measured that would be applicable and generalizable to any decrease in specific work performance.

The measure would need to be correlated to various levels of work performance capacities.

Work Performance Capacity Advantages & Disadvantages

A.) Advantages:

Very work or Task Specific

B.) Disadvantages:

1. **Length of time required**
2. **Lack of generalizability**
3. **Requires variety of facilities**

General RAS Activity Advantages and Disadvantages

A. Advantages:

1. Fast

2. Ease-of-use

3. Single set of measures for all tasks.

B. Disadvantages:

1. Need to correlate activity with each specific task.

2. Establish “Fatigue Threshold” for each task.