Use of Meta-Analysis to derive PSF multipliers for Human Reliability Analysis

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PSAM 9

Outline for Today

- Introduction
- Method
  - Meta-Analysis
  - PSF Multipliers
- Results
- Conclusions
- Next Steps

What is a PSF?

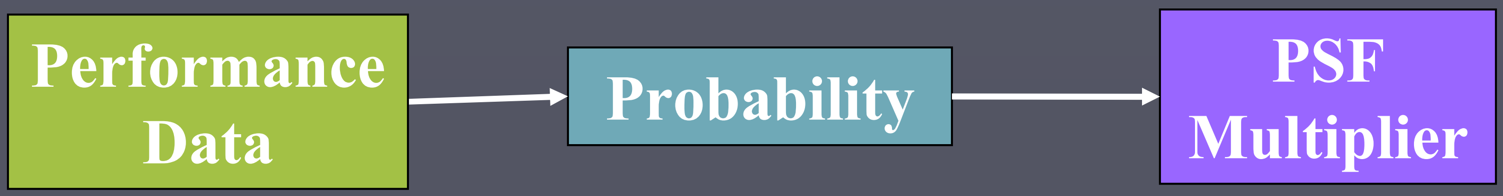
- PSF – Performance Shaping Factor
- Factors which influence human error rates
- Typically in Human Reliability Analysis (HRA) are used to modify normal error rates
  - e.g. SPAR-H

$$HEP = P_0 \prod_{i-1}^{n} PSF_i$$

(Gertman et al., 2005)

Goals of this research:

- Use available data on studies looking at sleep deprivation effect on performance for the purpose of developing a framework to aid in the quantification of PSF multiplier for use in HRA



What is Meta-analysis?

- What it is:
  - Synthesis of results from available literature about a topic
  - Structured format to extract information from selected studies
  - Compiles data to quantify an overall effect
  - Weighted by both
    - Sample size
    - Size of change in variable of interest
- Background:
  - Statistical concepts introduced by Pearson
  - 1st done by Smith and Glass in 1977

Smith, M., and Glass, G. (1977). "Meta-Analysis of Psychotherapy Outcome Studies." American Psychologist **32**: 752–760

5 Steps of Meta-analysis

- Formulate the problem
- Collect the data
- Evaluate the data (coding)
- Analyze the data (calculate Effect Size)
- Report the findings

What is an Effect Size?

- Term often used in psychological and biological studies
- Describes the amount of change in output variable due to changes in the input variable
  - Nominal or control performance vs. test condition performance
- Many statistical definitions of Effect Size

Common Effect Size Calculations for Cohen's d

$$ES = \frac{(X_1 - X_2)}{s_{pooled}}$$

$$ES = \sqrt{\frac{F(n_1 + n_2)}{n_1 n_2}}$$

$$ES = t\sqrt{\frac{(n_1 + n_2)}{n_1 n_2}}$$

$$s_{pooled} = \sqrt{\frac{(n_1 - 1)s_1^{\ 2} + (n_2 - 1)s_2^{\ 2}}{n_1 + n_2 - 1}}$$

Where,

ES = standardized mean difference effect size

X_1 = mean of control

X_2 = mean of test

S_p = pooled sample deviation

$s_1^{\ 2}$ = variance of sample 1

s_2^2 = variance of sample 2

n_1 = control sample size

n_2 = test sample size

F = F value

t = t-test value

d = Cohen's Effect Size

Probability Measure

- Probability measure defined in terms of the probability of the reaction time being longer under sleep deprivation then with normal sleep
- Data from multiple studies is used to supply data for calculating probabilities

Define Probability Model (Reaction Time)

- Model reaction time as random variable
- Assuming Normal Distributions:

$$P(g<0)=\Phi\left(0-\frac{\mu_C-\mu_T}{\sqrt{\sigma_C^2+\sigma_T^2}}\right)=\Phi\left(0-\frac{\mu_g}{\sigma_g}\right)=\Phi(-\beta)$$

- Where:

  C = control condition reaction time – normal sleep

  T = test condition reaction time – sleep deprived

  $\mu_g = \mu_C - \mu_T$

  $\sigma_g = \sqrt{(\sigma_C^2 + \sigma_T^2)}$

  $\beta = \mu_g / \sigma_g$

Define Error Region (Reaction Time)

- Connect Effect Size to error probability
- Define g = C-T for Reaction Time
  - C – measured value under Control condition
  - T – measured value under Test condition
- Define error as T>C
  - Fatigue degradation -- Test performance takes longer than control
  - i.e. $g<0$
- Assume T and C are normally distributed
- Then, g is also normally distributed
- Probability of Error = $P(g < 0)$

MA Effect Size results and β values

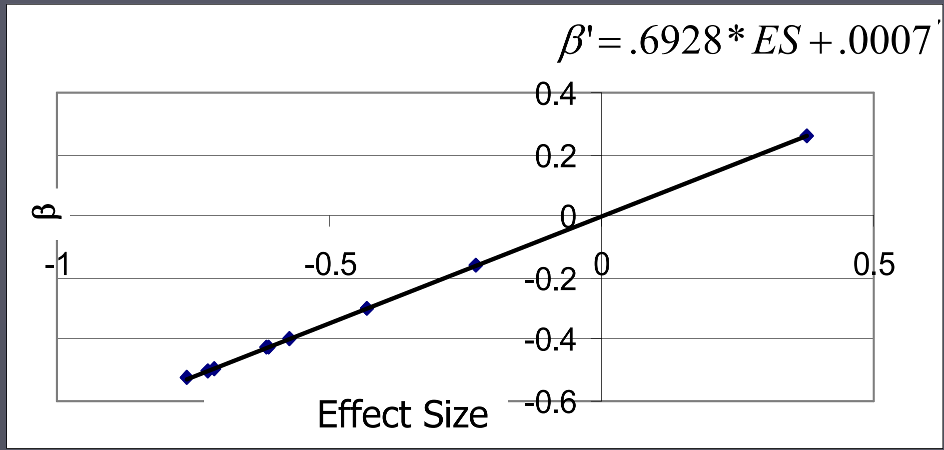
- Calculate ES
- Calculate $\beta = (\mu_g / \sigma_g)$

Study	Sleep Dep (hrs)	Effect Size	Beta
Chee_2004	24	-0.615	-0.426
Chee_2004	24	-0.572	-0.396
Chee_2004	24	-0.230	-0.159
Nilsson_2005	31.5	-0.763	-0.526
Choo_2005	24.4	-0.713	-0.493
Choo_2005	24.4	-0.724	-0.500
Choo_2005	24.4	-0.432	-0.299
Choo_2005	24.4	-0.613	-0.424
Thomas_2000	24	0.376	0.262

- Plot Effect Size and β to find relationship

Method to calculate β′ equation from ES and β

- Estimate a linear relationship between Effect Size and β
- Used to approximate a β when only Effect Size data is present in study



This equation is valid only for this data set

Connecting probabilities from study data to PSF Multipliers

- Proposing a connection between error probability and PSF multipliers
- In this example
  - When C=T the probability of (g<0) = 0.5
  - This is the condition of no change or a PSF =1
  - Divide the probability of β by 0.5

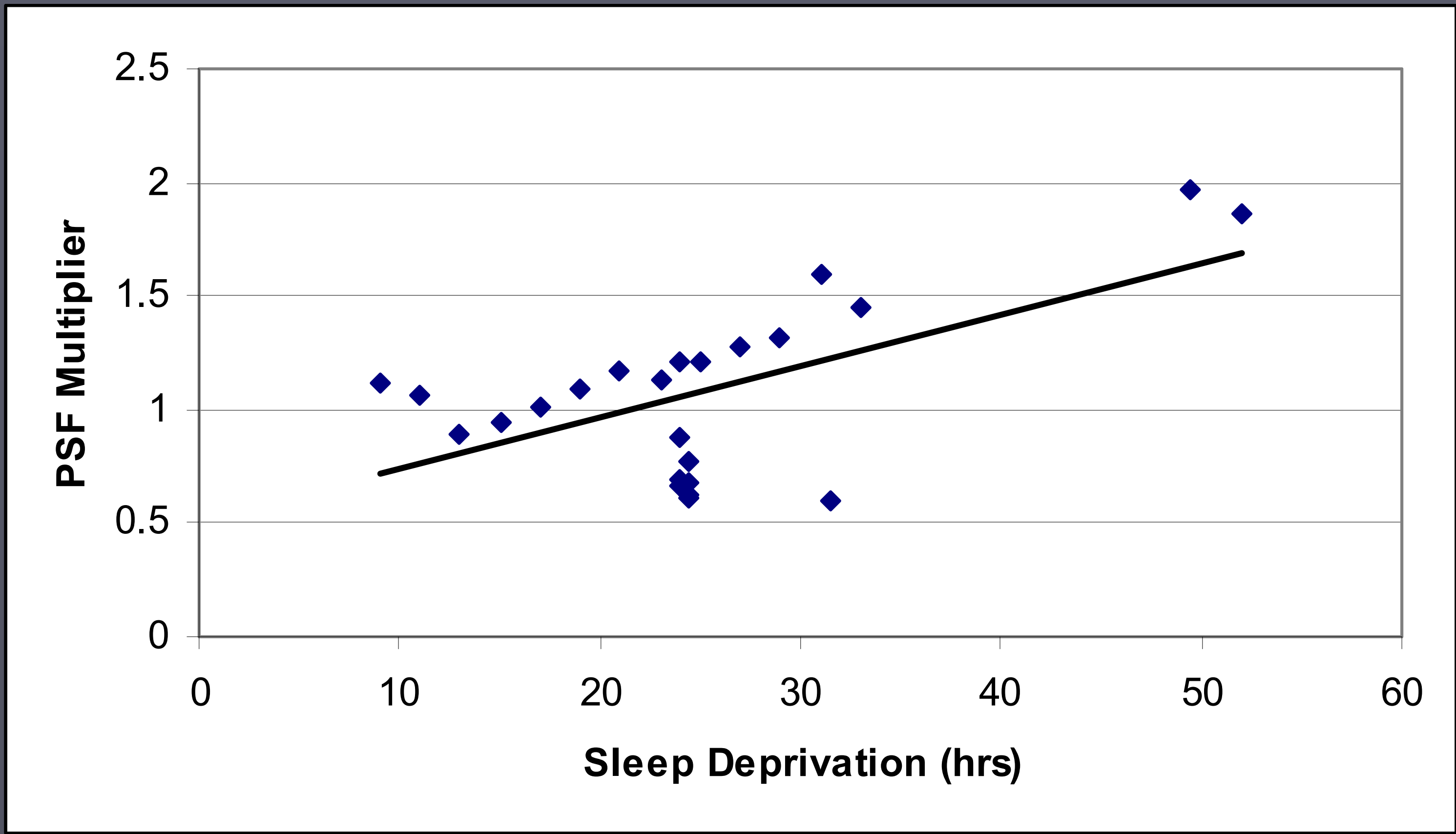
$$\text{Multiplier} = \Phi\,(-\beta)/0.5$$

Calculate β′ then Derive PSF Multipliers

Study	SD (hrs)	ES	β'	Multiplier
Marmuff_2005	9	0.2	0.146	1.116
Marmuff_2005	11	0.1	0.076	1.061
Marmuff_2005	13	-0.2	-0.132	0.895
Marmuff_2005	15	-0.1	-0.062	0.950
Marmuff_2005	17	0	0.007	1.006
Marmuff_2005	19	0.16	0.118	1.094
Marmuff_2005	21	0.29	0.208	1.165
Marmuff_2005	23	0.23	0.166	1.132
Marmuff_2005	25	0.38	0.270	1.213
Marmuff_2005	27	0.49	0.346	1.271
Marmuff_2005	29	0.59	0.416	1.322
Marmuff_2005	31	1.19	0.831	1.594
Marmuff_2005	33	0.85	0.596	1.449
Killgore_2006	49.5	3.216	2.235	1.975
Kobbeltvedt_2005	52	2.102	1.463	1.857

- $\beta' = .693 * ES + .007$
- Multiplier $= \Phi(\beta)/.05$

Hours of SD vs. Derived PSF Multipliers



Procedure Summary

- Use sleep deprivation effect on performance data from various sources
- Find ES from individual studies
- Connect Effect Size to error probability
  - Relate ES to β
  - Calculate β' in absence of β data
- Propose a connection between error probability and PSF multipliers
- Method for basing PSF multipliers on the empirical data used to calculate the ES and probabilities

Next Steps

- Look at other psychomotor performance measures
- Accuracy
  - Different Limit state definition for probability model
  - Define error ($g<0$) as $T<C$
  - Fatigue degradation -- Test accuracy is less than that of Control
- Expand data set to reach a population β' equation