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The Comparison of Ergonomic Workload Stress Index(EWSI) Among the Different Workload Assessment Techniques

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ABSTRACT

The Ergonomic Workload Stress Index(EWSI) was developed to predict the existence and level of the ergonomic workload stress in the workplace. To determine the validity of model, the values of the EWSI and two other similar techniques, Job Severity Index(JSI) and Physical Work Stress Index(PWSI) were evaluated in two actual industrial environments. The results from the validation study provide further substantial evidence that two techniques, JSI and PWSI, which have similar objective considerations, are significantly associated with the value of the EWSI among the employees participating in the experimentation.

1. Introduction

Numerous studies have been performed to verify and estimate the existence and level of perceived workload stress imposed on the human operator by the external workload in man-machine systems [2, 4, 16]. The influences of workload stress on human performance and behavior have also been studied by Gomer et al. [7] and Melamed et al. [12].

Traditionally, the emphasis has been made on estimating either physical or mental workload only, without taking into account both types of workload elements. Since the workload stress has either physical or mental origin, there is a critical need to develop a workload standard estimation technique which takes into account both mental and physical elements of a man-machine system.

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In order to develop such workload estimation standards, one must consider all types of internal and external stressors and their corressponding stresses. The stressors may be physical or psychological and their responses may be qualitative or quantitative. All stressors and their responses must be considered if the effectiveness of a man-machine system is to be optimized. In an industrial environment, the performance and productivity of an individual is affected, whether the imposed stressor is physical or mental.

For all these reasons, the development of a better analytical workload stress prediction model which is a comprehensive, accurate, and easy to use measurement technique is highly desired. In modeling EWSI, the task and workplace variables that have the most influence on workload stress are considered because the determination of workload plays an important role in designing and evaluating an existing man-machine system. Two theories were applied in developing the EWSI model. The fuzzy logic and set theory was introduced to capture the subject's stress perception. The Analytic Hierarchy Process(AHP) was introduced to estimate the importance of the task and workplace variables.

Often, ergonomic practitioners and system desigers are confronted by a lack of agreement or instances of dissociation between different measures of workload stress. This dissociation is, for example, between measures of workload stress and performance. The correlation between workload stress measures is either not significant or is negative. For example, people(or systems) that appear to have a higher workload stress by one measure are shown to have a lower workload stress by another.

Therefore, an interesting part of the analysis is to perform an analysis of the relationship among other workload stress measurement techniques and hence to ensure that the EWSI model is valid and reliable. The EWSI was implemented in two actual industrial environments using several diffenent jobs and workplaces and compared to other workload estimation techniques, such as Job Severity Index(JSI [1]) and Physical Work Stress Index(PWSI [4]) to determine how well the model predicts the existence and the intensity of stress.

The following two validation methods were designed and conducted as :

1. Field Validation Method I – EWSI vs. JSI : Calculate the Job Severity Index(JSI), the ratio of the demands of the job and the capacities of the operator, to compare to the implemented results of the EWSI.
2. Field Validation Method II – EWSI vs. PWSI : Calculate the Physical Work Stress Index (PWSI), which is assessed by sampling the status and changes of key postural elements of the operator's task, to compare to the implemented results of the EWSI.

During the field validation procedure, a considerable number of industrial workers from a drilling tools manufacturing industry(n=19 ; male=15, female=4) and linen and uniform rental service industry(n=52 ; male=29, female=23) are involved in this validation procedure. The study population for these industries is the non-managerial work force employed in Houston, Texas area, and has an age range from 19 to 57 years.

2. An Overview of Three Different Workload Measurement Techniques

A. The Analysis of Ergonomic Workload Stress Index(EWSI)

This study was performed to develop a unique and integrated index for determining the occupational ergonomic workload stress. Thus, the objectives of this stydy were to predict the existence and level of the ergonomic workload stress in the workplace and to determine the degree of stress that will affect the worker in terms of physiological health, accident and injury rate, and productivity.

The procedure for modeling EWSI involved the following steps :

Step 1. Select and define the stressors that exist in a man-machine system(i.e., tasks and workplace variables which have most influential factors on stress).

Step 2. Intorduce fuzzy set parameters for the selected variables.

Step 3. Utilize the principle of "maximum meaningfulness" [6, 15] in determining the level of workload stress.

Step 4. Determine the weighting factors(which are used as coefficients) by applying Analytic Hierarchy Process(AHP [13]).

Step 5. Calculate the composite value of workload stress which is the EWSI.

Some of the job risk factors which are the most influential to occupational workload stress in a man-machine system are selected to form a strong basis for modeling the EWSI－Physical Job Demand Stressors(S_1), Environmental Stressors(S_2), Body Motion and Postural Stressors(S_3), Mental Job Demand Stressors(S_4).

In modeling EWSI, the linguistic values(e.g., "heavy," "high," "moderate") of the task and the workplace variables(e.g., physical job demand, environmental, postural, and mental demand stressors) which can capture the operator's perception on stress are introduced as a value of variables.

The construction of the membership function starts with identifying and acquiring the properties of the numerical assignments of the membership values within the confines of the theory of measurement(e.g., most people perceived heaviness of load with over 25kg).

The physical job demand basically implies Manual Materials Handling(MMH) which includes lifting, lowering, carrying, pushing, and pulling tasks. Thus, the job risk factors due to MMH are defined and five fuzzy sets of membership functions for these variables are collected from several sources [3, 14, 1, 5, 11]. The linguistic values of these variables are determined as follows :

s_1 = Weight of load : "very light," "light," "medium," "heavy," "very heavy,"

s_2 = Frequency of load : "very low," "low," "medium," "high," "very high,"

s_3 = Duration of load : "very short," "short," "medium," "long," "very long," and

s_4 = Moving distance of load : "very close," "close," "medium," "far," "very far."

The membership function is used to give expression to a fuzzy set. Assuming that we have a finite support set for subjective heaviness, which is sometimes called a base variable or universe of discourse, the following expression can be established :

$$s_1 = \{x_1, x_2, \cdots, x_n\}.$$

The fuzzy subset A(e.g., "heavy") of s_1(i.e., weight of load) is then expressed by

$$A = \sum_{i=1}^{n} \frac{\mu_A(x_i)}{x_i} = \left[\frac{0}{1}, \frac{0}{15}, \frac{0.1}{20}, \frac{0.5}{25}, \frac{0.9}{30}, \frac{1.0}{32}, \frac{0.95}{34}, \frac{0.7}{40}, \frac{0.1}{50}, \frac{0}{60} \right].$$

The numerator indicates the grade of membership and the denominator denotes the elements of the suport set in kilograms. The terms may be discarded for which either the grade of membership function is 0 or the base variable is 0 because they are meaningless. The equation given above can be used to express the degree of membership functions of stress from each stressor.

The sigma symbol used in the subset A (i.e., "heavy") expression means the union in fuzzy operation in which the grade is a maximum when the corresponding elements of the support set have the same value. It should be noted that either the plus symbols or the commas can be used for the representation of the membership function in fuzzy subset.

The next step is to collect the value for the level of stress from each linguistic variable. When the term must designate a precise object of universe of discourse, the principle of "maximum meaningfulness" [6] states that the "meaning" of the term is the object that has the maximum membership value in the fuzzy set named by the term. Since we define the universe of discourse over the normalized region, {0, 1}, the level of stress could be the support set corresponding to the highest grade of membership function. For example, if we select the linguistic value "heavy" for the weight of load, the level of stress for this variable will be 0.6.

By applying all the concepts discussed, the fuzzy set S_1, stress induced by physical job demand, can be expressed as

$$S_1 = \left[\frac{\max u'_{A_1}(x_j)}{x_j}, \frac{\max u'_{A_2}(x_j)}{x_j}, \frac{\max u'_{A_3}(x_j)}{x_j}, \frac{\max u'_{A_4}(x_j)}{x_j} \right],$$

where

$\dfrac{\max u'_{A_k}(x_j)}{x_j}$ is the collection of normal fuzzy sets for k=1, 2, 3, and 4.

A fuzzy set with a membership function that has a grade of 1 is colled "normal". In other words, A is called "normal" when

$$\max_{x \in X} u_A(x) = 1.$$

The grade in a fuzzy set can be anything from 0 to 1, and this range is different from the crisp set that has only two grades(0 and 1). Thus, the environmental stressors and the postural workload stresses can be assessed by the crisp set which is defined as either 1 or 0.

Along with the above variables, EWSI also includes the Mental Job Demand. The objective is to find how much mental and perceptual activity is required in performing a job(e.g., calculating, thinking, deciding, communicating, remembering, looking, and searching).

To get each workload stressor level, respective weighting factors for each contributing factors are multiplied by their corresponding workload stress levels and summed. Thus the equation becomes

$$\hat{S}_1 = \sum_{i=1}^{3} \sum_{j=1}^{n} w_{ij} \cdot \tilde{x}_{ij}, \qquad \text{for } \tilde{x}_{ij} > 0,$$

where

$\hat{S}_1$ indicates the stress level of total contributing factors for each stressor(S_1, S_2, S_3),

w_{ij} indicates respective priority weighting factors associated with n contributing factors, and

$\tilde{x}_{ij}$ denotes the element of the support set corresponding to the $u(x_{ij}) = 1$.

The pairwise comparison needs to be performed again for the physical job demand(S_1), environmental condition(S_2), body motion and posture(S_3), and mental job demand(S_4) to get the overall workload stress level for the specific job. The results will show the relative importance of these variables regarding the impact on stress. The overall workload stress level will then be calculated by using an equation which can be expressed as

$$EWSI = \sum_{i=1}^{3} W_i \cdot \hat{S}_i + W_4 \cdot \hat{S}_4,$$

where

W_i denotes weighting factors for physical, environmental, and postural stressor,

$\hat{S}_i$ indicates the workload stress level of total contributing factors for S_1, S_2, and S_3,

W_4 denotes weighting factor for mental job demand stressor, and

$\hat{S}_4$ indicates the support set of the normal fuzzy set in S_4.

To calculate the value of EWSI, the data collection should be administered in advance. The sequence of the data collection procedures for the EWSI analysis is as follows :

1. The subject's demographic data(e.g., age and gender) along with the job title are recorded into the EWSI data collection sheet.
2. The linguistic variables were used to collect the data for each stressor. The selection of the answers are basically based on the memory and experience of the subject's perception to

stressors. The subjects were asked to choose one of the fuzzy sets for physical and mental job demand variables based on their perception of workload stress. For example, the subjective heaviness was expressed in five fuzzy sets : "very light," "light," "medium," "heavy," and "very heavy." The data collection for other variables consist of two selections, either "comfortable" or "uncomfortable" for the environmental stressors and either "no" or "yes" for the postural discomforts.

3. The weighting factors are collected using the AHP weighting data collection sheet. The subjects are asked to perform pairwise comparisons between the streessors based on the scale provided in the data collection sheet.

The interpretation of the "meaning" of the workload stress index is an essential procedure in determining usefulness to the end users. Therefore, a regression analysis was conducted between the valus of EWSI and the heart rate as an indication of workload. From this regression analysis, the classification of EWSI is set and presented in Table 1.

Table 1. Classification of EWSI as an Indication of Workload

Assessment of Workload	EWSI
Very Low(resting)	0.00 – 0.31
Low	0.31 – 0.51
Moderate	0.51 – 0.67
High	0.67 – 0.83
Very High	0.83 – 1.00
Extremely High	1.00 ≤

B. The Analysis of Job Severity Index(JSI)

In this section, the JSI method was applied to the previously mentioned industries. Given the same task and working condition, this analysis can ensure the validity of the EWSI model if there exists similar results between the JSI and the EWSI in terms of the severity of injuries and illness rate.

Ayoub et al. [1] developed and validated the Job Severity Index(JSI) as a means whereby job design and employee placement can be based on an acceptable measure of injury potential. The JSI is defined as the time-weighted and frequency-weighted average of the maximum weight required by each task divided by the selected lifting capacity given the lifting task conditions. Therefore, this method can be classified as an objective workload assessment technique. The resules of this study illustrate that the relationship between the JSI and the frequency, severity, and cost of manual materials handling injuries is very close.

Two factors, the demands of the job and the capacities of the operator, determine whether a MMH job is injurious to the operator. Often, job demands are expressed as the weight lifted with certain frequencies, over a given range, with containers of certain sizes, and other such factors. The related capacity of the operator can be expressed by his or her lifting ability, as based on physiological, biomechanical, or psychophysical criteria.

Conceptually, JSI can be represented by the equation

$$JSI = \left\{ \frac{\text{Job Demand}}{\text{Operator Capacity}} \right\}, \text{ for the given job conditions.}$$

In order to quantify JSI, job demands and operator capacity must be specified for given job conditions including container size and level and frequency of lift. There are several methods available for determining the lifting capacity of an employee such as biomechanical, physiological, and psychophysical methods. In the development of JSI, the psychophysical method was used for determining employee capacity. Ayoub et al. [1] developed a set of mathematical models to estimate the maximum acceptable weight of lift based on various conditions of lifting frequency, container size, and range of lift, coupled with a few strength and anthropometric measurements. The coefficients for the linear regression models are presented in Table 2. These equations estimate the sum of the maximum acceptable weight of lift plus body weight.

As noted, JSI is a function of the ratio of job demands to worker capacity. However, since a job consists of several tasks, the JSI calculation should consider the time-weighted and frequency-weighted average of the maximum weight required by each task divided by the capacity associated with lifting ranges required by each task.

Table 2. Prediction Models for Maximum Acceptable Weight of Lift Plus Body Weight for Both Male and Female

Lifting Range	Constant Term	Sex Code*	Weight Code**	Arm Strength	Age	Shoulder Height	Back Strength	Abdominal Depth	Dynamic Endurance
(F-K)	-32.73	-12.85	11.020	0.143	-0.251	0.556	0.056	2.23	0.797
(F-S)	-65.96	-7.33	5.422	0.185	-0.271	0.652	0.077	2.94	1.830
(F-R)	-18.72	-8.82	73.53	0.210	-0.405	0.344	0.068	2.82	0.647
(K-S)	-25.02	-8.41	5.318	0.265	-0.275	0.348	0.105	2.85	0.642
(K-R)	-35.92	-8.58	7.851	0.297	-0.226	0.042	0.018	2.34	0.962
(S-R)	-16.98	-8.88	9.251	0.096	-0.268	0.402	0.099	2.14	0.494

* Sex code is "0" for male and "1" for female.

** Weight code is "0" if body weight is below the median and "1" if above the median(median body weight : female=62.3kg, male=77.1kg).

The time-weighted and frequency-weighted JSI is stated algebraically as

$$JSI = \sum_{i=1}^{n} \left(\frac{Hours_i}{Hours_t} \times \frac{Days_i}{Days_t} \sum_{j=1}^{m_i} \frac{F_j}{F_i} \times \frac{WT_j}{CAP_j} \right),$$

where

n = number of subtask groups,

m_i = number of task in Group i,

$Hours_i$ = exposure hours per day for Group i,

$Hours_t$ = number of hours per day that a job is performed,

$Days_i$ = exposue days per week for Group i,

$Days_t$ = total days per week for job,

F_j = lifting frequency for Task j,

F_i = total lifting frequency for Group i,

WT_j = maximum weight of lift required by Task j, and

CAP_j = the selected applicable weight of lift adjusted for frequency of lift and box size.

To calculate the JSI, physical dimensions of the workplace and subject characteristics were taken with an anthropometric kit comprised of calipers, extension rods, tape and skin markers. The isometric strength equipment was used to measure the various lifting strengths such as back, arm, and leg strength, as well as pulling and pushing strengths.

The anthropometric and strength data has been collected from 19 workers in the drilling tools manufacturing industry and is shown in Table 3.

Table 3. Subject's Demographic and Anthropometric Measurements-Drilling Tools Manufacturing Industry

Characteristic	Male (N=15)		Female (N=4)	
	Mean	S. D.	Mean	S. D.
Age(years)	39.53	8.16	44.00	6.06
Height(cm)	173.76	8.00	162.70	9.50
Weight(kg)	76.18	15.42	63.60	5.70
Shoulder Height(cm)	145.87	7.93	135.85	7.98
Abdominal Depth(cm)	22.38	4.34	26.73	4.57
Hand Length(cm)	18.67	1.36	18.03	0.83
Arm Strength(kg)	53.18	26.73	22.03	6.65
Leg Strength(kg)	82.08	21.57	39.43	17.28
Back Strength(kg)	106.91	12.82	53.43	18.47
Pulling Strength(kg)	77.23	23.83	37.30	15.09
Pushing Strength(kg)	74.10	10.85	21.13	6.79

The same measurements for 52 workers from the linen and uniform rental service industry were taken and these are presented in Table 4.

The mean and standard deviation for all anthropometric data were compared to 1985 projected body sizes from NASA Anthropometric Data(1978). The isometric strengths measured on the male and female workers were compared to the reference population(NIOSH [14]). Detailed results of these comparisons can be found in Jung et al. [8, 9].

Table 4. Subject's Demographic and Anthropometric Measurements-Linen and Uniform Rental Service Industry

Characteristic	Male (N=29)		Female (N=23)	
	Mean	S. D.	Mean	S. D.
Age(years)	31.00	10.26	32.83	7.91
Height(cm)	175.04	7.51	158.56	7.99
Weight(kg)	79.92	13.49	73.30	16.63
Shoulder Height(cm)	147.06	7.08	132.00	7.09
Abdominal Depth(cm)	23.67	4.35	23.43	4.64
Hand Length(cm)	18.66	2.17	16.87	2.13
Arm Strength(kg)	46.16	12.30	25.92	6.51
Leg Strength(kg)	68.62	31.51	41.42	15.55
Back Strength(kg)	104.73	28.25	56.23	19.14
Pulling Strength(kg)	61.49	21.15	35.41	10.60
Pushing Strength(kg)	61.83	20.56	29.38	10.94

C. The Analysis of Physical Work Stress Index(PWSI)

As in the previous section, the PWSI technique was also reviewed and applied to the same two idustries. Given the same task and working conditions, this analysis can also ensure the validity of the EWSI model if there exist similar results between this analysis and EWSI in terms of the severity of injuries and illness rate. The comparisons among the three techniques, EWSI, JSI, and PWSI, can identify whether the model developed here is reliable and applicable.

The PWSI, developed by Chen et al. [4], is an observation method of physical work stress analysis, which possesses the ease of application of traditional work study techniques, but also provides better accounting of human and task variables. The logic behind the model and the computational procedures of PWSI is that physical work stress can be assessed by sampling the status and changes of key postural elements of the operator's task. The results of this study indicated that the higher the PWSI value, the higher the dynamic work stress, and the lower the PWSI value, the higher the static work stress might be.

The PWSI method involves the following components : (1) movement required to accomplish a job, (2) orientation with regard to the primary work place, (3) posture base, (4) hand position, (5) acceleration(vibration), (6) thermal load, and (7) external load.

The technique includes the process of activity sampling of the above physical work components. The static/dynamic load factor describes the change, or lack of change, in each of the components of physical work stress. The instantaneous load factor describes the physical work stress averaged over a series of snapshots of the task. The static/dynamic load, instantaneous load, and PWSI values are derived from these data.

The summarized data collection sheet is in Table 5 and mathematical basis of the computation for PWSI is as follows :

Basic Component : K, K=1 to 8.

Sample : I, I = 1 to NI(NI = number of samples).

Observation(rank score) : X(K, I), K = 1 to 8, I=1 to NI.

Absolute difference : $D(K, I) = ABS(X(K, I) - X(K, I-1))$, I = 2 to NI.

Sum of differences : $SUM(K) = \sum_{I=2}^{NI} D(K, I)$.

Average differences : $AV(K) = \frac{SUM(K)}{(NI-1)}$

Table 5. PWSI Data Collection Sheet with Variable Definition

Component	Component Ordinal Values			
Movement (K=1)	Primary workplace 1	Paces 5-10m 2	Primary 10-50m 3	Workplace > 50m 4
Orientation (K=2)	Forward 1	Right 2	Left 3	Backward 4
Posture Base (K=3)	In box 1	Edge of box 2	Outside of box 3	Outside two planes 4
Left Hand Position (K=4)	In box 1	Edge of box 2	Outside of box 3	Outside two planes 4
Right Hand Position (K=5)	Lying 1	Sitting 2	Leaning 3	Standing 4
Acceleration (K=6)	Zero 1	Slight 2	Moderate 3	Heavy 4
Thermal Load (K=7)	20-25℃ 1	25-30℃ 15-20℃ 2	30-35℃ 0-15℃ 3	> 35℃ < 0℃ 4
External Load (K=8)	0-0.5kg 1	0.5-5kg 2	5-10kg 3	10-20kg 4

Component weight : $W(K)$, $K = 1$ to 7.

Component Static /Dynamic load : $CSDL(K) = W(K) \times AV(K) \times AV(8)$, $K = 1$ to 7.

Component Instantaneous load : $CINSL(K) = W(K) \times X(K, I) \times \frac{X(8, 1)}{NI}$, $I = 1$ to NI, $K = 1$ to 7.

Static /Dynamic load : $SDL = \sum_{K=1}^{7} CSDL(K)$.

Instantaneous load : $INSL = \sum_{K=1}^{7} CINSL(K)$.

Overall PWSI value : $PWSL = 0.571 \times SDl + 0.429 \times INSL$.

On the basis of analysis through video recording and observation, the data was collected from two different industries and analyses were performed by using the Ergonomic Analysis SYstem (EASY). EASY was developed by the same authors to evaluate the PWSI and other ergonomic related problems for problem solving.

3. Results of Comparison-EWSI vs. JSI, PWSI, and Epideniological Measurements

The values of rthe EWSI, JSI, and PWSI that were calculated from the drilling tools manufacturing industry are shown in Table 6. This industry is the leading supplier of rotary drilling tools for mining, construction, and workover drilling throughout the world. Its product lines cover every type of drilling operation, including blast holes, exploration, water well workover, shaft drilling and raise boring.

95 occupational injury and illness records were also reviewed over a 4-year and 3-month period, from January 1, 1988 to March 31, 1992. The number of recordable cases and total lost workdays for various types of operations are given in Table 6.

The calculated EWSI, JSI, and PWSI value with other analysis results for various jobs in linen and uniform rental service industry is shown in Table 7. A major portion of activities in this industry is composed of various types of manual materials handling(e.g., loading /unloading of garments from /to route trucks ; soil separation ; loading /unloading of garments from /to washers, dryers, and extractors ; hanging of shirts and pants ; sorting garments ; folding of shop towels ; and moving materials in the stockroom). An enormous amount of physical labor is used in this industry. As we see from Table 7, the least value for all three measurements occurred for the checker and the greatest for the route salesmen.

Table 6. Incidence and Severity of Different Jobs with PWSI, JSI, and EWSI-Drilling Tools Manufacturing Industry

Job Title	No. Cases	Lost Workdays	PWSI	JSI	EWSI
Chamfer Operator	2	25	3.27	1.87	0.35
Equipment Operator	1	5	N/A	N/A	N/A
Furnace Operator	3	22	3.38	3.30	0.56
Grind Operator	15	295	5.39	4.90	0.83
Heat Treat Operator	3	283	3.66	3.68	0.55
Hip Technician	1	0	1.00	0.20	0.22
Inspector	5	65	2.88	2.07	0.49
Machinist	0	0	1.00	0.10	0.24
Maintenance Tech.	6	10	3.64	3.99	0.50
Material Handler	2	16	4.22	1.34	0.53
Office Personnel	1	0	N/A	N/A	N/A
P.B. Operator	16	316	6.70	6.12	0.86
P.G. Operator	2	29	3.34	2.45	0.42
Press Operator	14	159	6.70	5.57	0.81
Q.C. Lab Technician	1	32	1.32	0.20	0.27
Service Shop	8	29	5.25	4.32	0.73
Supervisor	3	6	N/A	N/A	N/A
Tipset Technician	1	5	1.54	0.90	0.30
Tool Maker	2	0	3.82	2.61	0.43
Tool Room Inspector	5	45	2.18	3.20	0.49
Tumble Operator	1	19	3.00	1.40	0.31
Utility Operator	3	26	N/A	N/A	N/A
Total	**95**	**1387**	–	–	–

1. The number of lost workdays includes compensable injuries and illness for days away from work and days of restricted work activity due to injury.
2. N/A means that data were not available for those jobs.

A review of the injury and illness record in the linen service industry was conducted covering a 4 year period(1988-1992). Data from over 246 compensable work-related accidents and injury data from a total of 353 workers was collected and reviewed based on total injury cases and total lost workdays for different operations.

Figure 1 shows the plot of EWSI versus JSI and PWSI for the drilling tools manufacturing industry. Very close linear relationship between EWSI and JSI as well as between EWSI and PWSI were found with, R^2 = 0.877 and 0.861, respectively.

Table 7. Incidence and Severity of Different Jobs with PWSI, JSI, with EWSI-Linen and Uniform Rental Service Industry

Job Title	No. Cases	Lost Workdays	PWSI	JSI	EWSI
Checker	1	0	0.06	0.27	0.21
Counter Sales	1	0	0.46	0.36	0.31
Dry Cleaning	1	0	1.45	0.83	0.32
Engineer	6	77	2.11	0.91	0.58
Extractor	5	28	3.79	2.67	0.59
Flatwork	21	652	3.56	2.40	0.78
Hot Shot Driver	2	34	1.89	1.67	0.45
Maintenance	22	347	3.62	2.41	0.82
Marker	1	0	0.78	0.54	0.29
Mat Roller	3	4	2.01	0.85	0.51
Material Handler	2	1	2.99	1.71	0.49
Mending	1	0	0.96	0.65	0.30
Packout	8	74	2.14	1.18	0.58
Presser	16	99	3.09	1.16	0.59
Route Sales	65	938	5.08	3.01	0.98
Serv. Superv.	13	6	1.89	1.20	0.59
Silk Finisher	1	1	0.87	0.47	0.32
Soilroom	30	184	4.71	2.80	0.96
Supervisor	2	0	N/A	N/A	N/A
Tumble Dry	1	1	0.98	1.11	0.39
Warehouse	19	88	3.18	1.32	0.60
Washroom	20	164	3.25	2.70	0.60
Total	**246**	**2698**	—	—	—

1. The number of lost workdays includes compensable injuries and illness for days away from work and days of restricted work activity due to injury.
2. N/A means that data were not available for those jobs.

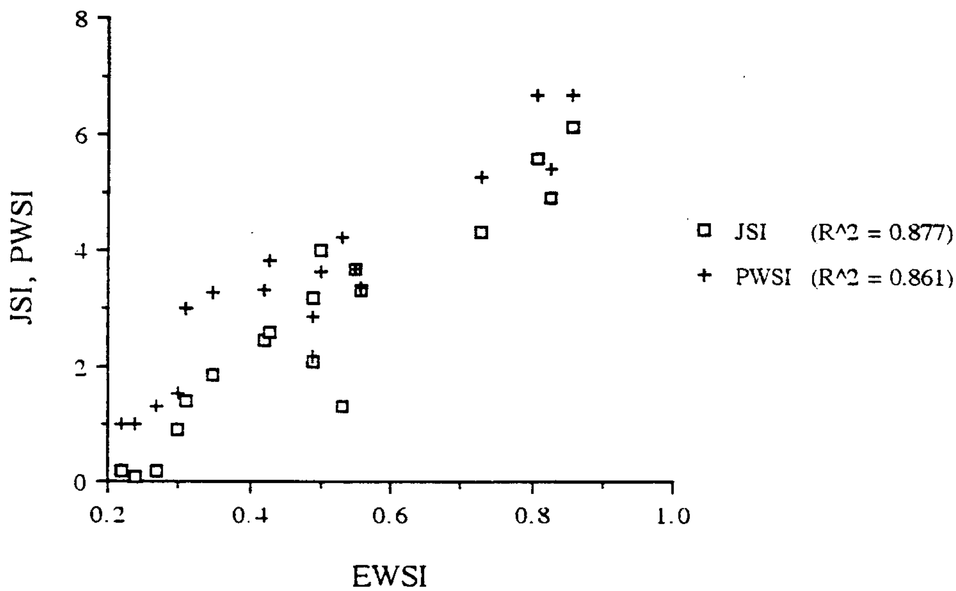

Figure 1. A Scattered Plot of EWSI vs. JSI and EWSI vs. PWSI for Drilling Tool Manufacturing Industry

Table 7 shows the statistical results for JSI versus EWSI, JSI versus PWSI, and JSI versus frequency of injuries and illness. The results from this analysis indicate that there seems to be a close relationship between the different measurements.

Table 7. The Statistical Results for JSI(Dependent Variable) vs. EWSI, PWSI, and Epidemiological Measurements for Drilling Tool Manufacturing Industry

Statistical Criteria	Drilling Tool Manufacturing Co.			Linen and Uniform Service Co.		
	EWSI	PWSI	Injury	EWSI	PWSI	Injury
R^2	0.877	0.799	0.778	0.701	0.823	0.509
R	0.937	0.894	0.882	0.837	0.907	0.713
S. E.	0.666	0.852	0.897	0.486	0.373	0.623

Figure 2 shows the plot of the EWSI versus JSI and the EWSI versus PWSI for the linen and uniform rental service industry. Very close linear relationships between EWSI and JSI and between EWSI and PWSI were found with, R^2 = 0.701 and 0.857, respectively.

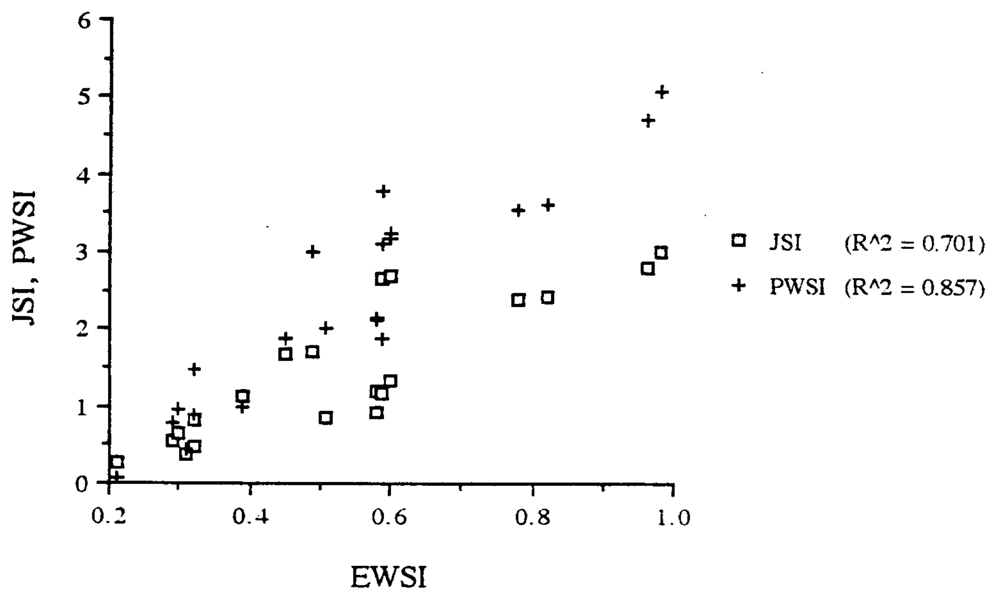

Figure 2. A Scattered Plot of EWSI vs. JSI and EWSI vs. PWSI for Linen and Uniform Rental Service Industry

Table 8 shows the statistical results for PWSI versus EWSI, PWSI versus JSI, and PWSI versus frequency of injuries and illness. The results from this analysis indicate that there is a close relationship between the different measurements.

Table 8. The Statistical Results for PWSI(Dependent Variable) vs. EWSI, JSI, and Epidemiological Measurements for Linen and Uniform Rental Service Industry

Statistical Criteria	Drilling Tool Manufacturing Co.			Linen and Uniform Service Co.		
	EWSI	PWSI	Injury	EWSI	PWSI	Injury
R^2	0.861	0.799	0.709	0.857	0.823	0.640
R	0.928	0.894	0.842	0.926	0.907	0.800
S. E.	0.669	0.802	0.966	0.520	0.577	0.824

The following results were drawn from the analysis of different workload measurements techniques :

1. Significant relationships were found among three different techniques.
2. Significant relationship between epidemiological measurements and PWSI was found.
3. No significant relationship was found between lost workdays and any of the three techniques.

High workload, in these techniques, can certainly be considered to result in a stress state, and give rise to either strain(from the high levels of effort required to maintain task goals under increasingly difficult task conditions) or to accident and illness rate. If the recorded rating is above the safety threshold,(i.e., rating EWSI value of 0.67), investigation or attention is necessary. Conversely, it can be argued that a low workload is not stressful(at least in the sense meant here, in which stress only occurs in response to perceived demands). Rather, low workload is associated with a passive or constrained response to the environment, involving boredom, lack of challenge, and low job satisfaction.

4. Discussions and Conclusion

Workload is an important, integrative concept that determines the abilities of human operators of complex systems to accomplish mission requirements, given the equipment and training that are provided and the organizational and environmental constraints that are placed on them. Workload stress can be measured with reasonable accuracy. However, there are considerable problems in separating job-related workload stress from other sources. There are also problems associated with particular task events as a source of acute workload stress.

Even though much research has been conducted on predicting and estimating to what extend individuals can safely handle workload stress, there are discrepancies in the results reported by several researchers. These discrepancies could be due to differences in the subject population used in the studies in terms of age, jobs, experimental conditions, or methodologies employed to determine the workload stress. Because each measure is especially sensitive to different workload causes and consequences, the results obtained with different measures may not covary. However, recent research in the field is focused on clarifying the underlying causes of such dissociations and on formulating a model of workload/performance trade-offs.

In principle, it should be possible to develop predictive models that are sufficiently accurate, so as to eliminate the need for empirical assessments. In practice, however, predictive models neither can, nor should, be used alone without empirical assessments to verify their accuracy, given the capabilities of existing techniques. The predictions provided by these models should not be treated as established facts, but, rather, as suggested guidance. In particular, the value of predictive models is that they can make rough predictions of figures of merit, which, if not 100 percent reliable, are at least considerably better than chance. Furthermore, these models can also often objectively identify points of potentially high workload and diagnose their cause.

The experience from this study suggests that such research will be challenging to design and analyze, but that it also has great potential for increasing our understanding of the etiology of occupational health and illness. It is presented that the results of validation studies show EWSI is very helpful to aid in interpreting the results of workload analysis, identifying workload criteria, and improving the accuracy of workload prediction. Of course, the model implmented here is not perfect. The source of the residual error, whether it lies in the basic logic or in the validation procedure, remains to be determined by further analysis and additional experimentation.

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