# THE STRAIN INDEX: USING TASK LEVEL OUTPUTS TO EVALUATE JOB RISK

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## ABSTRACT

Upper extremity cumulative trauma disorders are prevalent in the workplace. These problems have both economic and quality of life repercussions. Existing ergonomic analysis tools are primarily intended to estimate the ergonomic risk associated with single-task jobs, however, in today's workplace many jobs contain more than one task and some may include job rotation, which further complicates analysis. This paper explores one method of modifying an existing tool, The Strain Index, to assess the ergonomic risk of multi-task jobs in a case control setting. This method is based upon the same philosophical approach developed by the 1994 Revised NIOSH Lifting Equation Cumulative Lifting Index. Using this approach and modifying the final score by the "busy ratio", and a cut point of 0.8 the sensitivity is 0.9, the specificity is 0.5, the odds ratio is 19.2 (CI = 1.8 to 200), and the p-value from Fisher's Exact Test is 0.01. If dual cut points are used with a lower cut point of 0.8 and an upper cut point of 2.4 an odds ratio of 54 (confidence interval 2.8-1040) is achieved, indicating that a person is 54 times more likely to become injured on a job that has a score greater than 2.4 than a person working on a job with a score less than 0.8.

## INTRODUCTION

Today's workplace is increasingly dynamic and demanding. As time constraints tighten and medical costs increase, job descriptions get larger. This increase in variation is a reflection of more effective production design and the belief that increased variation in activities may reduce ergonomic injuries.

As the complexity of jobs increases ergonomic analysis tools need to be developed that reflect this complexity. A preliminary step may be to determine if existing ergonomic analysis tools, originally developed for single-task jobs, can be modified to estimate the risk of multi-task jobs. This paper explores one method of aggregating the risk of multi-task jobs from task level Strain Index (SI) outputs.

## STUDY BACKGROUND

Two automotive plants were selected from the six plants originally included in a larger study sponsored by UAW-Ford. The original study collected data for 677 jobs. Job analysis included collection of weights, forces, distances and other data including worker feedback, speed of work and other qualitative and quantitative data. Each job was videotaped.

Two workers from each job were asked to fill out symptom surveys. Occupational health nurses (OCHNS) administered these surveys. Occupational health doctors (OCMDs) administered physical exams on two workers from each job. (This study does not incorporate the physical exam results.) First time office visits (FTOV's) and injuries associated with each job were also collected from each plant's medical data base. FTOV's were limited to reports for the twelve months previous to the site visit. This time frame was used because jobs and job descriptions may change with every model year.

The two plants used in this study were selected for two primary reasons: 1) the job cycle times were consistent within these plants; 2) there was little job rotation at these plants. That is, while each job was multi-task in nature, the workers did not rotate between jobs. This lack of rotation helps to minimize confounders that exist when an employee performs different jobs during the workday.

## STRAIN INDEX

The Strain Index (SI) was developed by Drs. Moore and Garg and presented in their 1995 paper "The Strain Index: a proposed method to analyze jobs for risk of distal upper extremity disorders" (Moore and Garge, 1995). A visceral overview is appropriate but it is not intended to replace the original paper.

There are six variable used to determine the SI score. These variables are both qualitative and quantitative.

1. Intensity of Exertion is a qualitative measure of the percent maximum voluntary contraction that a task requires to perform one time. This is a function of the force required and upper extremity posture.
2. Duration of effort is determined by timing the duration of the exertion and is a measure of the physiological and biomechanical stress related to how long an exertion is maintained.
3. Efforts per minute is synonymous with frequency of exertions per minute.
4. Hand/wrist posture relates the anatomical posture of the hand.
5. Speed of work estimates "the perceived pace of the task and accounts for the additional stresses associated with dynamic work (i.e., maximal voluntary strength decreases and EMG amplitude increases as contraction speed increases.") (Moore and Garg 1995).
6. Duration of task per day is a measure of how much of the workday is allocated to performing that task.

Each of these variables attempts to quantify the amount of the physical and physiological strain experienced by the muscle-tendon units of the distal upper extremity due to physical activity or the stress associated with the task.

These muscle-tendon units not only experience tensile loading but also compressive loading from adjacent articular structures when the tendon changes direction (i.e., at a joint). That is, the loading that a tendon experiences is a function not only of the intensity of the exertion but also the DUE posture during the exertion. The more severe (non-neutral) the posture, the greater the compressive force experienced by the muscle-tendon unit. Therefore, it may be useful to recognize that the intensity of effort and hand/hand postures are variables associated with biomechanical stress while the other four variables are associated with endurance, rest and other physiological aspects. In this sense, these four variables can be described as fatigue, or physiological variables.

**SI Calculation Step 1: Data Collection**

Each task is observed. Six aspects of each task are recorded and compared with quantitative and qualitative measures provided by the SI authors. Ratings correspond with each measure. These metrics and their corresponding ratings are presented in Tables 1-6, and summarized in Table 7. Tables 1-6, combine the metrics/descriptions and the rating of each level for each SI variable. This combines steps 1 and 2 of the SI process.

Intensity of Exertion is an estimate of the strength required to perform the task one time. There are five rating criterion used for this variable: “Light”, “Somewhat Hard”, “Hard”, “Very Hard” and, “Near Maximal”. These criteria can be linked to percent maximal strength, the ten-point Borg Scale, and Perceived Effort. Table 1 illustrates these relationships.

It has been proposed that if a 10-point Borg scale is used then, the Borg score can be divided by two to determine the SI intensity of effort rating.

Table1: Intensity rating for Strain Index.

| Rating Criterion | % Maximum Strength | Borg Scale | Perceived Effort | Rating |
|---|---|---|---|---|
| Light | <10% | < 2 | Barely noticeable or relaxed effort | 1 |
| Somewhat Hard | 10-29% | 4 | Noticeable or definite effort | 2 |
| Hard | 30-49% | 6 | Obvious effort; unchanged facial expression | 3 |
| Very Hard | 50-79% | 8 | Substantial effort; changes facial expression | 4 |
| Near Maximal | >79% | 10 | Uses shoulder or trunk to generate force | 5 |

Duration of Exertion is calculated by measuring the duration of all exertions during an observation period, then dividing the measured effort duration by the total observation time and multiplying by 100. For the purpose of this study the total observation time is the cycle time.

$$\%Duration\ of\ Exertion = \frac{Effort\ Duration}{Cycle\ Time} * 100$$

Table 2: Percent Duration of Effort Ratings for the Strain Index

| % Duration of Effort | Rating |
|---|---|
| <10 | 1 |
| 10-29 | 2 |
| 30-49 | 3 |
| 50-79 | 4 |
| >=80 | 5 |

Efforts per Minute are determined by counting the number of exertions that occur during an observation period, then dividing the number of exertions per cycle by the duration of the observation period, measured in minutes.

$$Efforts\ per\ Minute = \frac{Number\ of\ Exertions\ per\ Cycle}{Cycle\ Time\ (\mathrm{min})}$$

Table 3: Efforts per Minute Ratings for the Strain Index

| Efforts/Minute | Rating |
|---|---|
| <4 | 1 |
| 4-8 | 2 |
| 9-14 | 3 |
| 15-19 | 4 |
| $\geq$20 | 5 |

Hand/Wrist Posture is an estimate of the hand or wrist position relative to neutral. The quantitative and qualitative markers are presented in Table 4.

Table 4: Hand/Wrist rating for Strain Index.

| Rating Criterion | Wrist Extension (degrees) | Wrist Flexion (degrees) | Ulnar Deviation (degrees) | Perceived Posture | Rating |
|---|---|---|---|---|---|
| Very Good | 0-10 | 0-5 | 0-10 | Perfectly neutral | 1 |
| Good | 11-25 | 6-15 | 11-15 | Near neutral | 2 |
| Fair | 26-40 | 16-30 | 16-20 | Non-neutral | 3 |
| Bad | 41-55 | 31-50 | 21-25 | Marked deviation | 4 |
| Very Bad | >55 | >50 | >25 | Near extreme | 5 |

Speed of Work is an estimate of how fast the worker is working. The rating criterion guidelines are presented in Table 5.

Table 5: Speed of work rating for Strain Index.

| Rating Criterion | Perceived Speed | Rating |
|---|---|---|
| Very Slow | Extremely relaxed pace | 1 |
| Slow | "Taking one's own time" | 2 |
| Fair | "Normal" speed of motion | 3 |
| Fast | Rushed, but able to keep up | 4 |
| Very Fast | Rushed and barely or unable to keep up | 5 |

Duration of Task per Day is a measure of the total time that a task is performed per day. It is either measured or obtained from plant personnel. Duration of Task per Day is divided into five categories: <1hr, 1-2 hrs, 2-4 hrs, 4-8 hrs and, ≥8 hrs per day and the ratings are presented in Table 6.

Table 6: Duration of Task per Day ratings for Strain Index.

| Duration of Task Per Day (hours) | Rating |
|---|---|
| <1 | 1 |
| 1-2 | 2 |
| 2-4 | 3 |
| 4-8 | 4 |
| >=8 | 5 |

**SI Calculation Step 2: Determine the Ratings**

After each variable is observed and described using the metrics provided by the SI authors, determine the ratings for each variable described above. Table 7 is an overview of the variables and their ratings.

Table 7: Combined rating values for Strain Index.

| Rating Values | Intensity of Exertion | Duration of Exertion | Efforts per Minute | Hand/Wrist Posture | Speed of Work | Duration per day (hrs) |
|---|---|---|---|---|---|---|
| **1** | Light | <10 | <4 | Very Good | Very Slow | 0-1 |
| **2** | Somewhat Hard | 10-29 | 4-8 | Good | Slow | 1-2 |
| **3** | Hard | 30-49 | 9-14 | Fair | Fair | 2-4 |
| **4** | Very Hard | 50-79 | 15-19 | Bad | Fast | 4-8 |
| **5** | Near Maximal | ≥80 | ≥20 | Very Bad | Very Fast | >8 |

**SI Calculation Step 3: Determine the Multipliers**

Each variable's multiplier is determined by its rating. The relationship between the SI rating scores and the SI multipliers are illustrated in Table 8.

Table 8: Multipliers for Strain Index.

| Rating Values | Intensity of Exertion Multiplier (IEM) | Duration of Exertion Multiplier (DEM) | Efforts per Minute Multiplier (EMM) | Hand/Wrist Posture Multiplier (HPM) | Speed of Work Multiplier (SWM) | Duration per Day Multiplier (DDM) |
|---|---|---|---|---|---|---|
| 1 | 1 | 0.5 | 0.5 | 1.0 | 1.0 | 0.25 |
| 2 | 3 | 1.0 | 1.0 | 1.0 | 1.0 | 0.50 |
| 3 | 6 | 1.5 | 1.5 | 1.5 | 1.0 | 0.75 |
| 4 | 9 | 2.0 | 2.0 | 2.0 | 1.5 | 1.00 |
| 5 | 13 | 3.0 | 3.0 | 3.0 | 2.0 | 1.50 |

**SI Calculation Step 4: Determine the SI Score**

The SI score is the product of the six multipliers:

SI score = IEM X DEM X EMM X HPM X SWM X DDM

## METHODS

### Data collection

Case and control jobs were identified. A job was considered to be a case when every person interviewed by the nurses reported a symptom from that job and there had been at least one FTOV that attributed the reported injury to that job during the past 12 months. A control job was defined as a job on which no participants reported symptoms and there had been no FTOV associating that job as a source of injury for the past 12 months. A total of 17 case and 11 control jobs were identified and used in this study.

Video data from each plant were collected from the UAW-Ford archives for a case/control study. These jobs were randomly mixed so that the observers would not know if a particular job was considered a case or a control.

Videos of each job were observed. Each job was divided into work elements or tasks. Tasks are contiguous activities of a job that could be removed from the job and transferred to another workstation. Usually they have they involve the sames motion and intensity of efforts.

Cycle time was calculated by the average daily production. Two task attributes were timed with a stopwatch. The first attribute was ‘time busy.’ Time busy was defined as time during which the operator was occupied performing that task and would be unable to perform another task at that time with that hand. This metric is useful in many ways. The ratio of busy time to cycle time provides insight into how much ‘non-busy’ time is available to the worker. This ‘non-busy’ time may be used for rest or it may provide time if an error occurs. Such a ratio may give insight into the psychophysical and psychosocial demands of a job. For the purpose of this study, busy time was used to determine the ‘allocated time’ for each task. Allocated time for a task is the amount of time a person is busy plus the amount of rest associated with that task.

The second timed attribute was effort duration. This is the time during which the operator is exerting a significant force for that task. This time of exertion is used to determine the 'Duration of Effort' SI variable. The cycle time was determined by average daily production and shift length. Effort duration is the time element required to determine the percent duration of effort for the Strain Index.

## COMPOSITE LIFTING INDEX

Because the Composite Strain Index emulates the methodology of the Composite Lifting Index (CLI) a brief review of the CLI may be helpful (DHHS, 1994).

For each lifting task, a Recommended Weight Limit (RWL) is calculated for both the Frequency Independent Lifting Index (FILI) and Single Task Lifting Index (STLI) by multiplying a Load Constant (LC) of 51 lbs. (which represents the load that most people can safely lift one time in an optimum posture and good grip) by factors which represent, for that task, the horizontal location of the load (HM), vertical location of the load (VM), vertical distance that the load travels (DM), torso rotation or asymmetry (AM), type of grip or coupling (CM), and, in the case of the STLI, the frequency of the lift/lower (FM). These relationships are described in the equations below.

The RWL to calculate FILI is:

FIRWL = 51 lbs. * HM * VM * DM * AM * CM  (Note the absence of FM.)

The RWL to calculate STLI is:

STRWL = 51 lbs. * HM * VM * DM * AM * FM * CM = FIRWL * FM

For each task the FILI and STLI are calculated by dividing the load weight by the FIRWL and STRWL:

$$FILI = \frac{Load\ Weight}{FIRWL}$$

$$STLI = \frac{Load\ Weight}{STRWL}$$

Using these terms the CLI is calculated using:

$$CLI = STLI_1 + \sum \Delta LI$$

Where:

$$\sum \Delta LI = (FILI_2 X (\frac{1}{FM_{1,2}} - \frac{1}{FM_1}) + FILI_3 X (\frac{1}{FM_{1,2,3}} - \frac{1}{FM_{1,2}}) + FILI_4 X (\frac{1}{FM_{1,2,3,4}} - \frac{1}{FM_{1,2,3}}) + ...FILI_n X (\frac{1}{FM_{1,2,3,4,...n}} - \frac{1}{FM_{1,2,3,..(n-1)}})$$

## COMPOSITE SI SCORE

Composite SI Score uses the frequency and duration of effort multipliers for the current and previous tasks and subtracts from it the product of the multipliers for the previous tasks. The following equation illustrates this process for a 5-task job.

Composite SI Score = $STSI_{max}$ + FEDISI2*[(DEM1*EM1*DEM2*EM2)-(DEM1*EM1)]+
FEDISI3*[(DEM1*EM1*DEM2*EM2* DEM3*EM3)-(DEM1*EM1*DEM2*EM2)]+
FEDISI4*[(DEM1*EM1*DEM2*EM2* DEM3*EM3* DEM4*EM4)-
(DEM1*EM1*DEM2*EM2 DEM3*EM3)]+
FEDISI5*[(DEM1*EM1*DEM2*EM2* DEM3*EM3* DEM4*EM4* DEM5*EM5)-
(DEM1*EM1*DEM2*EM2 DEM3*EM3* DEM4*EM4)]

Where:

$STSI_{max}$ = Maximum Single Task Strain Index Score for the job.
$FEDISI_i$= Frequency and Effort Duration Independent Strain Index Score for the i ranked task as described below.

$$FEDISI_i = IEM_i * HPM_i * SWM_i * DDM_i$$

$DEM_i$=Duration of Effort Multiplier for the i ranked task.
$EM_i$=Efforts per Minute Multiplier for the i ranked task.

Note: it is possible to have negative numbers using this algorithm. This occurs when the product of the EM and DEM of the current task is less than 1. This implies that by introducing a greater variety of tasks with less frequency and duration there may be a protective effect. This case was investigated as well as an algorithm that set all negative additions to zero. Setting negative additions to zero seems reasonable because in the NIOSH CLI, as frequency decreases the additional term goes to zero; it does not become negative.

### Busy Ratio

Each task CSI score was modified by the busy ratio. The busy ratio is the total amount of busy time during each cycle divided by the total cycle time.

$$\text{Busy Ratio} = \frac{\sum_{i=1}^{j} \text{Time Busy}_i}{\text{Cycle Time}} = \frac{\textit{Total}\ \text{Time Busy}}{\text{Cycle Time}}$$

This ratio is useful because it give insight into what proportion of time during the task the worker is unable to perform other tasks. To determine the proportion of rest time during each job cycle subtract the busy ratio from 1. This ratio may provide insight into how much recovery time is available to the worker. This may also indicate the level of psychosocial demands are associated with the job. This ratio also helps to account for relatively infrequent tasks or tasks with short durations yet still reduce recovery time.

# RESULTS

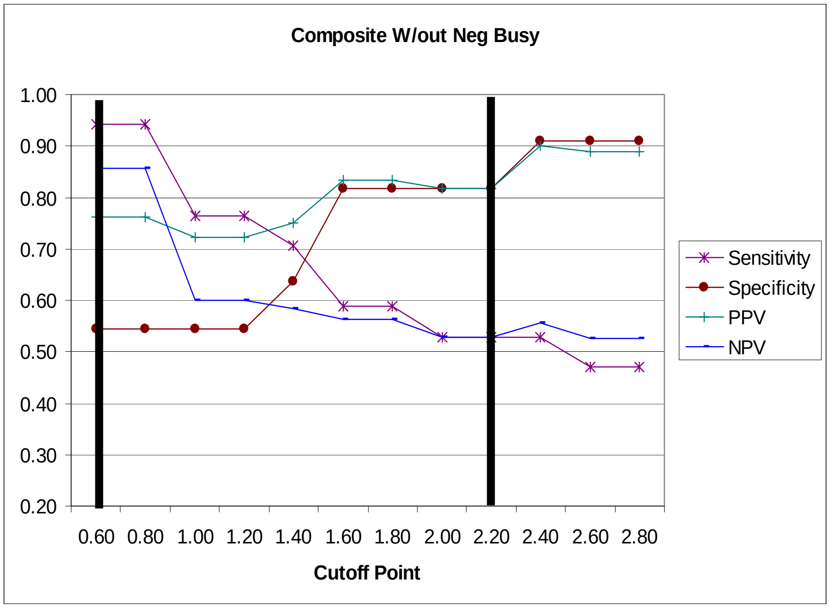


Figure 5: Composite W/out Negatives Busy:
Sensitivity, Specificity, PPV, NPV

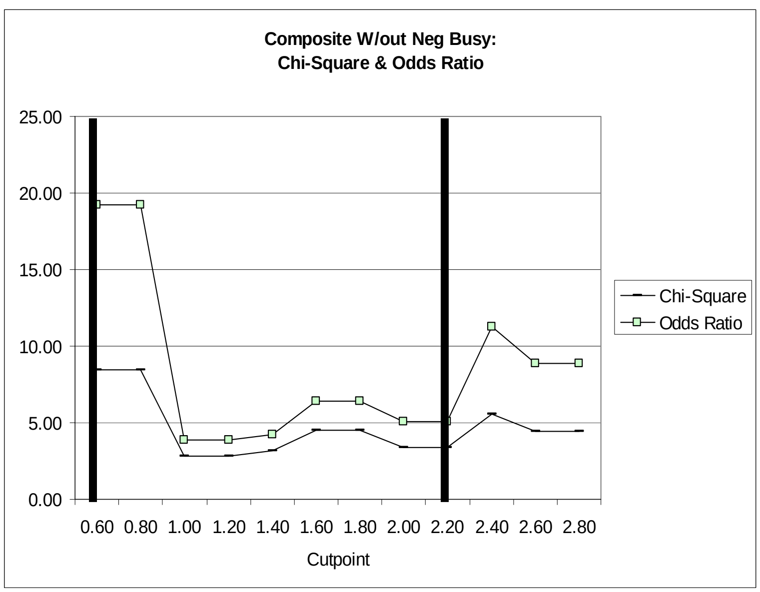


Figure 6: Composite W/Out Negative:
Busy: Chi-Square & Odds Ratio

Table 9: 2X2 for Low cut point
Composite w/out Negatives Busy

| Cut Point: 0.8 | | Actual | |
|---|---|---|---|
| | | Case | Control |
| Test | High | 16 | 5 |
| | Low | 1 | 6 |

At a cut point of 0.8, the sensitivity is 0.9, the specificity is 0.5, the odds ratio is 19.2 (CI = 1.8 to 200), and the p-value from Fisher's Exact Test is 0.01.

Table 10: 2X2 for High cut point Composite
w/out Negatives Busy

| Cut Point: 2.4 | | Actual | |
|---|---|---|---|
| | | Case | Control |
| Test | High | 9 | 1 |
| | Low | 8 | 10 |

At a cut point of 2.4, the sensitivity is 0.5, the specificity is 0.9, the odds ratio is 11.2 (CI from 1.1 to 108), and the p-value from Fisher's Exact Test is 0.04.

Table 11: 2X2 matrix for the dual cut point Composite
w/out Negatives Busy

| Dual Cut Points | | Actual | |
|---|---|---|---|
| | | Case | Control |
| Test | >2.4 | 9 | 1 |
| | <0.8 | 1 | 6 |

This accounts for 17 of the 27 subjects and has an odds ratio of 54 (confidence interval 2.8-1040), indicating that a person is 54 times more likely to become injured on a job that has a score greater than 2.4 than a person working on a job with a score less than 0.8

## CONCLUSION

These results indicate that the Strain Index may be modified to estimate the risk to distal upper extremity ergonomic risk injury. Certainly, additional research with a larger population is necessary to validate and improve these results. Also, if continuous SI multipliers could be used instead of discrete multipliers, the error introduced by the discrete categories may be reduced.


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