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Job Level Risk Assessment Using Task Level Strain Index Scores: A Pilot Study

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This paper explores 2 methods of modifying the Strain Index (SI) to assess the ergonomic risk of multi-task jobs. Twenty-eight automotive jobs (15 cases and 13 controls) were studied. The first method is based on the maximum task SI score, and the second method is modeled on the NIOSH Composite Lifting Index (CLI) algorithm, named cumulative assessment of risk to the distal upper extremity (CARD). Significant odds ratios of 11 (CI 1.7–69) and 24 (CI 2.4–240) were obtained using the modified maximum task and CARD, respectively. This indicates that modification of the SI may be useful in determining the risk of distal upper extremity injury associated with a multi-task job.

Strain Index   Distal Upper Extremity (DUE)   multi-task risk assessment

1. INTRODUCTION/BACKGROUND

1.1. Introduction

Work-related upper extremity cumulative trauma disorders (UECTDs) are a problem in terms of both economic and quality of life measures. In 2000, the Bureau of Labor Statistics (BLS) reported 68,323 injuries or illnesses occurred as a result of repetitive motion, including typing or key entry, repetitive use of tools, and repetitive placing, grasping or moving of objects other than tools [1]. Of these repetitive motion injuries, approximately 75% affected the upper extremities. The National Academy of Sciences has estimated that the costs (direct and indirect) of ergonomic injuries to employees, employers, and society as a whole can be conservatively estimated at US $50 billion annually [2]. These costs are a reflection of the fact that injuries and illnesses resulting from repetitive motion have the longest work absences (median 19 days) compared to other workplace events and exposures [1].

The ability to predict which tasks and combination of activities can lead to upper-extremity, work-related musculoskeletal disorders (MSDs) will help to

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determine which existing jobs require modification. The ability to predict which jobs, or which aspects of each job, may be hazardous can also be used proactively, that is, as a job, workstation, or tool is designed, assessments and modifications can be made before the job, workstation or tool is produced or sold. Such a metric can also provide a measurement of the effectiveness of proposed changes, thereby, enhancing the allocation of a company's resources.

There are existing analysis tools that attempt to estimate the ergonomic risk of single-task jobs to the distal upper extremities (DUE). DUE usually refers to the elbow, wrist, hand, and fingers. Single-task jobs are jobs in which there is only one repeated motion, or very similar motions, with the same, or nearly the same, effort level required throughout the job. Existing tools include Rapid Upper Limb Assessment (RULA) [3], ACGIH Hand Activity Level Threshold Value Limit (HALTLV) [4], and the Strain Index (SI) [5].

In today's workplace, there is an increased amount of job rotation and jobs that are not single-task in nature. The increased job rotation and/or expanded job descriptions may be a reflection of increased flexibility within manufacturing plants but they are also likely because of an increased awareness that performing a single task throughout the day may be more hazardous than performing multiple, varied tasks throughout the workday. While this variation of tasks throughout the workday may provide some protection for the worker, it increases the difficulty associated with estimating the ergonomic risk of these multi-task jobs.

The purpose of this paper is to investigate various methods of modifying the SI to estimate the risk of multi-task jobs. The SI analysis tool was chosen because it is often used in industry and, its six multipliers aid in establishing which aspect of the task is most risky. The methods used to combine task level risk assessment into job level risk assessments include maximum SI task score for the job, various weighted averages, and variations of the techniques and concepts used to determine the Composite Lifting Index (CLI) as described in the 1994 Revised NIOSH Lifting Equation [6].

The SI was developed by Drs. Moore and Garg [5]. The SI requires the qualitative and quantitative measures of six variables: intensity of exertion, duration of exertion per cycle, efforts per minute, wrist posture, speed of exertion, and duration of task per day.

1.2. Background

1.2.1. SI

There are four steps to calculating the SI score: data collection, assignment of ratings values, determination of the multipliers, and calculation of the SI score.

There are six variables that need to be collected for each task; each variable is assigned a rating and a multiplier. The abbreviations for the multipliers are in parentheses.

1. Intensity of Exertion (IEM) 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 (DEM) 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 (EMM) is synonymous with frequency of exertions per minute.
4. Hand/wrist posture (HPM) relates the anatomical posture of the hand.
5. Speed of Work (SWM) estimates the perceived pace of the task and accounts for the additional stresses associated with dynamic work.
6. Duration of Task (DDM) per day is a measure of how much of the workday is allocated to performing that task.

Tables 1 and 2 summarize the ratings and the multipliers for each of these six multipliers.

The SI score is the product of these six multipliers. Various cut points for the SI scores have been proposed for assessing the ergonomic risk of a job. In the original paper, any single-task job with an SI score greater than 5 was associated with an increase in morbidity to the DUE [5]. Subsequently, it has been proposed that jobs with an SI score of 3 or less are presumed *safe* or have a lower risk associated

TABLE 1. Strain Index (SI) Ratings

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

TABLE 2. Strain Index (SI) Multipliers

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 of Task (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

with them. Jobs with an SI score between 3 and 7 are a *tough call*, and jobs with scores greater than 7 are *hazardous* [7]. Later, Rucker and Moore proposed that "the use of 5.0 as the criterion Strain Index score for classifying jobs as 'hazardous' versus 'safe' has generally been substantiated, but … suggest that the criterion score might be higher (~9.0) in manufacturing" (p. 72) [8]. The aforementioned research indicates that while the SI is a useful estimator of ergonomic risk, there is still much work to be done to determine the optimal cut points.

The multiplier of each of these six variables attempts to quantify the contribution of each of these six variables to the total amount of 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. It may be useful to recognize that the intensity level and hand postures are variables associated with biomechanical stress.

Endurance, rest, and other physiological aspects are addressed in the four remaining variables (duration of effort, efforts per minute, speed of work, duration of task per day). These can be described as fatigue or physiological variables.

The SI was developed and validated using single-task jobs. It is proposed that the SI would be even more useful, however, if it could be extended to estimate the cumulative risk of a job with more than one task. Two methods of accomplishing this are discussed here:

1. Maximum task
2. An approach similar to the 1994 Revised NIOSH CLI in which new EMM and DEM are calculated based upon cumulative frequencies and duration of effort. The approach will be referred to as CARD (Cumulative Assessment of Risk to the Distal Upper Extremity).

1.2.2. The maximum task approach

The maximum task SI score approach is appealing because it requires simply calculating the SI score for each individual task within a job. The task that has the highest SI score defines the risk of the multi-task job. This approach implies that the only task of concern is the task with the highest SI score and interactions amongst tasks are negligible.

While the task with the highest SI score may be the greatest contributor to ergonomic risk, it is difficult to accept that interactions between tasks do not exist and, more importantly, that adding more tasks (even with lower SI scores) to a job with no increase in cycle time, does not affect the risk associated with a job.

Taken to its extreme, this approach can lead to curious conclusions. For example, consider a job with a cycle time of 1 min and consisting of only one task with an SI score of 3 and 30 s of non-busy time. If an industrial engineer decides to keep this worker busy for the entire 1 min by adding an additional task that takes 30 s and has an SI score of 2, then the maximum task approach would still estimate the risk of this job as 3, despite the decreased amount of rest.

This is particularly true given that the SI is driven by intensity and modified to a much lesser extent by the other five variables; thus, this may underestimate the additional risk associated with a highly repetitive, albeit less intense, task.

The maximum task approach ignores that there may be a great deal of rest time, or that time is spent doing tasks that are significantly less demanding than that described by the maximum task. In this case, the maximum SI score may overestimate the risk associated with that job. Alternatively, it may underestimate the risk of a job when there is little or no time to rest because of the temporal demands of tasks with lower SI scores.

1.2.3. CARD

This method is modeled after the NIOSH CLI. CARD uses the maximum SI task score and then increases the score based upon a combination of biomechanical risk and physiological stress.

The CLI score from the 1994 Revised NIOSH Lifting Equation provides an interesting framework for assessing the cumulative risk of different lifting tasks. This approach separates the biomechanical stresses (usually associated with posture and force) and physiological stresses (usually associated with effort duration, number of efforts, and other metrics of fatigue). The CLI tool accumulates these stresses as more lifts are added to the job description. This method is computationally more involved and will be described later.

Each of these approaches has merits and shortcomings. Simple methods, such as using the maximum task SI score, do not include the interactions of tasks. These interactions may increase or, possibly, decrease the risk associated with a particular job. More complex analysis, similar to that used in the CLI, may have a perceived increase of accuracy. However, because the accuracy of the output is limited by the accuracy of the input, such accuracy may be inflated, if not illusory. Also, these complex methods may not significantly alter the risk assessment for the job.

While other approaches were investigated in this pilot study, only the maximum SI score and CARD are presented here.

1.3. Study Background

Two automotive plants with data from 217 jobs were selected from 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. First-time office visits (FTOVs) and injuries associated with each job were also collected from each plant's medical database. FTOVs were limited to reports for the 12 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: (a) the job cycle times were similar within and between these plants (40–120 s); (b) 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.

2. METHODS

2.1. Data Collection

Case and control jobs were identified. A job was considered to be a case when each of the two people on that job 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 15 case and 13 control jobs from the 217 jobs were identified and used in this 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 were defined as contiguous activities, with similar motions and intensity of exertions that could be removed from the job and transferred to another workstation.

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 a task and would be unable to perform another task at that time with that hand. This metric is useful in several 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 to make a correction if an error or disruption 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 allocated time was determined as follows:

$$\text{Allocated Time}_i = \frac{\text{Time Busy}_i}{\sum_{i=1}^{j} \text{Time Busy}_i} \bullet \text{CT}, \quad (1)$$

where CT—cycle time, i—task number, j—number of tasks in job.

The ratio of busy time to cycle time is also used in this study to modify the job scores:

$$\text{Busy Ratio} = \frac{\sum_{i=1}^{j} \text{Time Busy}_i}{\text{CT}}. \quad (2)$$

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 dividing the shift length by the average daily production. The entire cycle time was used for the calculation of the time dependent multipliers.

Each task was scored according to the method described by Drs. Moore and Garg [5].

2.1.1. The maximum task method

This method requires only that the maximum task SI score be determined. The maximum score is then used as the metric for the ergonomic risk of the job.

2.1.2. NIOSH CLI

Because the CARD method for combining task level risks into a job level risk assessment is similar to the NIOSH CLI, a quick review of the CLI is useful. This is intended to be a review of the 1994 Revised NIOSH Lifting Equation; the reader is encouraged to read the original paper [6].

The method used in the NIOSH Revised Lifting Guide to estimate the stress associated with a job comprised of more than one lifting task is based on the stress associated with the most stressful task plus increments based on the stresses associated with the other tasks and the relative frequencies of the tasks:

$$\text{CLI} = \text{STLI}_1 + \sum \Delta\text{LI}, \quad (3)$$

where

$$\begin{aligned} \sum \Delta\text{LI} = {} & (\text{FILI}_2 \text{X}(\frac{1}{\text{FM}_{1,2}} - \frac{1}{\text{FM}_1}) \\ & + \text{FILI}_3 \text{X}(\frac{1}{\text{FM}_{1,2,3}} - \frac{1}{\text{FM}_{1,2}}) \\ & + \text{FILI}_4 \text{X}(\frac{1}{\text{FM}_{1,2,3,4}} - \frac{1}{\text{FM}_{1,2,3}}) \\ & + \ldots\text{FILI}_n \text{X}(\frac{1}{\text{FM}_{1,2,3,4,\ldots,n}} - \frac{1}{\text{FM}_{1,2,3,..(n-1)}}). \end{aligned} \quad (4)$$

There are two measures of primary importance in this calculation:

1. The Frequency Independent Lifting Index (FILI) for a task is the calculated

stress for that task without consideration of the task frequency.
2. The Single Task Lifting Index (STLI) for a task is the calculated stress for that task as if it were the only manual material handling task performed on the job.

This method modifies the biomechanical elements of the lift (FILI) with the physiological aspects of the lifts. The ergonomic risk of the physiological aspects is represented by the frequency multiplier which is a function of job duration and frequency of effort. It should be noted that while a lift may increase the CLI, or add nothing, an additional lift, no matter how infrequent, will not decrease the CLI.

This approach is used to adapt the SI to jobs with more than one task. That is, the maximum single-task SI score is modified by incremental increases. One method of determining the incremental increase for the SI is explored in this paper. This method begins with the maximum individual task SI score for the job.

2.1.3. CARD

This approach creates new multipliers for the DEM and the EMM by adding the durations and frequencies of the new task to those of the previous tasks and determining adjusted multipliers based on the sums of frequencies and durations. The new multiplier may be equal to or greater than the previous multipliers. Therefore, as with the CLI, these additions can never be negative. Equation 5 illustrates the CARD calculation for a job with 5 different tasks:

$$\begin{aligned} \text{CARD} = {} & \text{STSI}_{max} + \text{FEDISI 2} \bullet [(\text{EM12} \bullet \text{DEM12} - \text{EM1} \bullet \text{DEM1})] + \text{FEDISI 3} \\ & \bullet [(\text{EM123} \bullet \text{DEM123} - \text{EM12} \bullet \text{DEM12})] + \text{FEDISI 4} \bullet [(\text{EM1234} \bullet \text{DEM1234} \\ & - \text{EM123} \bullet \text{DEM123})] + \text{FEDISI 5} \bullet [(\text{EM12345} \bullet \text{DEM12345} - \text{EM1234} \\ & \bullet \text{DEM1234})], \end{aligned} \tag{5}$$

where STSI is the Single Task Strain Index score, FEDSI is the Frequency And Effort Duration Independent Strain Index score, EM12 is the SI efforts per minute multiplier when adding the efforts per minute of tasks 1 and 2, DEM12 is the SI duration of effort multiplier determined using the sum of the effort durations for tasks 1 and 2. Each of these methods (maximum task and CARD) was modified by the busy ratio.

The product of the result of each of these methods and the busy ratio became the risk metric for the job. That is,

$$\text{Max Busy} = \text{Max SI Score} \bullet \text{Busy Ratio},$$
$$\text{CARD Busy} = \text{CARD Score} \bullet \text{Busy Ratio}.$$

2.2. Statistics

Receiver operator curves (ROC) were created for each method using SPSS version 11.5. The area under the curve (AUC) can be used as a metric for comparing two methods. The ROC curves were compared using MedCalc for Windows software, version 3.1 (MedCalc Software, Belgium).

Using various cut points, 2 × 2 matrices were created for each method. Sensitivities, specificities, odds ratios, and Fisher's Exact Tests were used to determine optimal cut points.

2.3. Cut Points

Because each of these methods is a modification of the SI, it is expected that new cut points for risk identification need to be established for multi-task jobs. Establishing cut points is very difficult, and the choice of cut points is a reflection of the real and perceived (quantitative and qualitative) tradeoffs between classifying a job as hazardous when, in fact, it is not and classifying a job as safe when it is not. There is no agreed upon algorithm for weighing the consequences of a misdiagnosed job.

To the extent that cut points can be quantitatively described, sensitivity, specificity, positive predictive values, and negative predictive values can be good metrics. In addition, Fisher's Exact Test can be used to determine the significance of these cut points.

3. RESULTS

The AUC of both of these analysis tools were significantly different ($p < .05$) from the null hypothesis of an area of 0.5.

Using MedCalc software, it was determined that the areas were not significantly different from each other. It is possible that this is due to the small sample size of this pilot study.

Two graphs for each tool are provided. The first graph illustrates how the specificity, sensitivity, positive predictive value (PPV), and negative predictive value (NPV) vary with changing cut points. The second graph illustrates how the chi-square and the odds ratio vary by cut point. The choice of cut points is also illustrated on these graphs.

Figures 1 and 2, and Table 3, represent the results for the maximum task busy analysis. With this analysis there does not appear to be an easily recognizable second cut point and one was not selected. The 2 × 2 matrix for the cut point 1.0 is presented in Table 3.

At a cut point of 1.0, the sensitivity is .7, the specificity is .8, the odds ratio is 10.8 (CI = 1.7 to 68.9), and the *p* value from Fisher's Exact Test is .02.

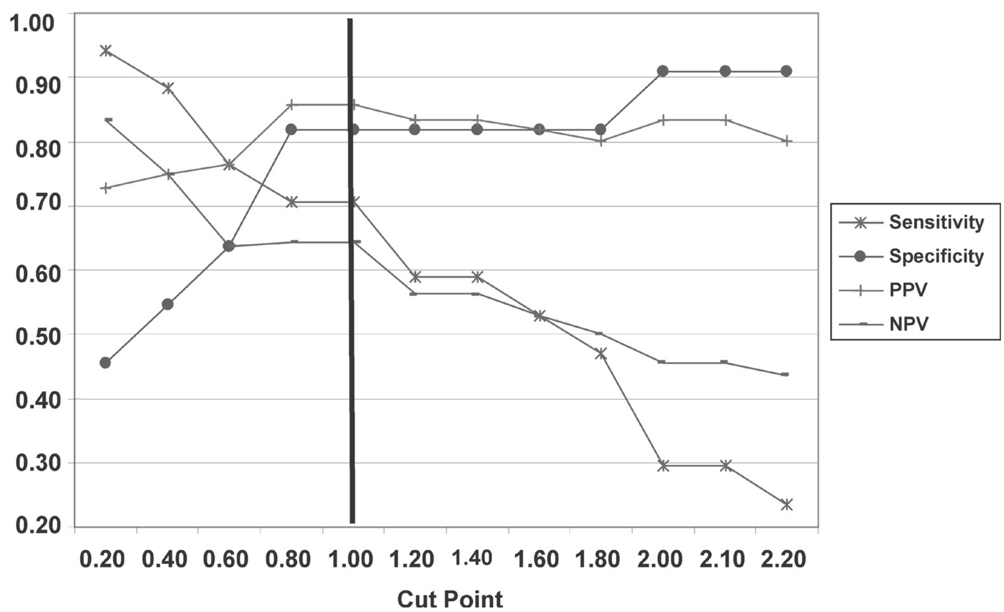

Figure 1. Maximum task busy: sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV).

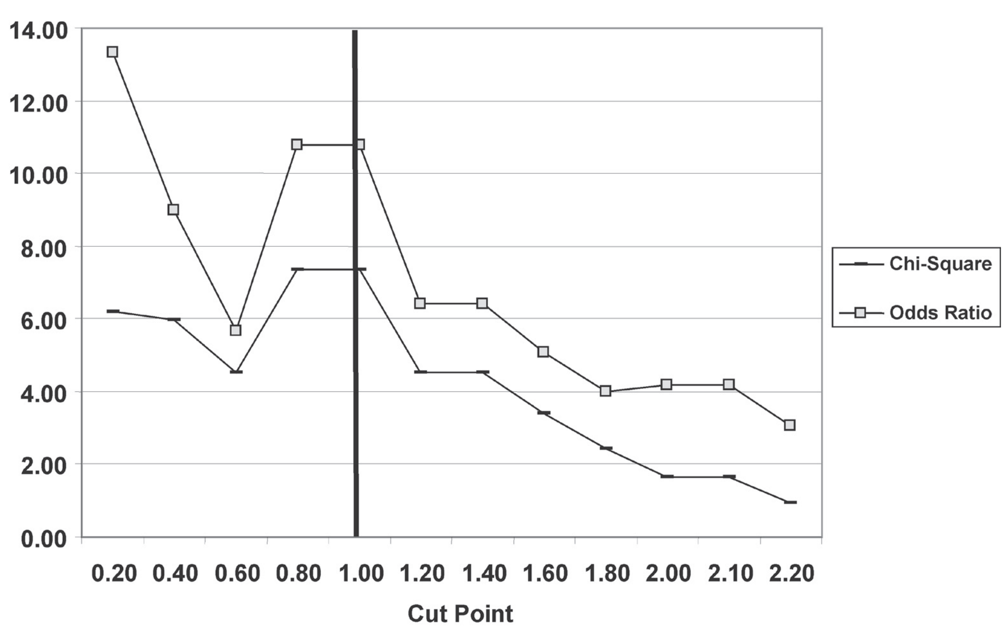

Figure 2. Maximum task busy: chi-square and odds ratio.

Figures 2 and 3, and Tables 4 and 5, represent the results from the CARD analysis. The 2 × 2 matrix for the CARD cut point of 1.1 is presented in Table 4 and the 2 × 2 matrix for a cut point of 2.8 is presented in Table 5.

At a cut point of 1.1, the sensitivity is .9, the specificity is .5, the odds ratio is 19.2 (CI = 1.8 to 200), and the *p* value from Fisher's Exact Test is .01.

At a cut point of 2.8, the sensitivity is .9, the specificity is .7, the odds ratio is 24 (CI = 2.4 to 240), and the *p* value from Fisher's Exact Test is < .01.

Table 6 is the 2 × 2 matrix for the dual cut points, 1.1 and 2.8, for the CARD analysis.

Using the dual cut points of 1.1 and 2.8, accounts for 20 of the 27 subjects. The odds ratio is 72 (CI = 3.8 to 1,362). This indicates that a job with a CARD score greater than 2.8 is 72 times more likely to be a case than a job with a score less than 1.1.

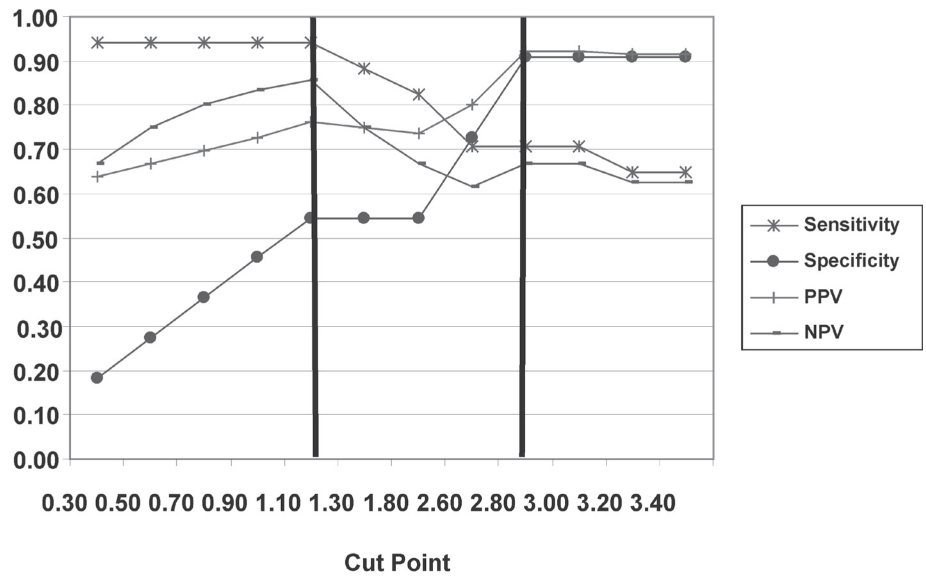

Figure 3. CARD busy: sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV). *Notes.* CARD—Cumulative Assessment of Risk to the Distal Upper Extremity.

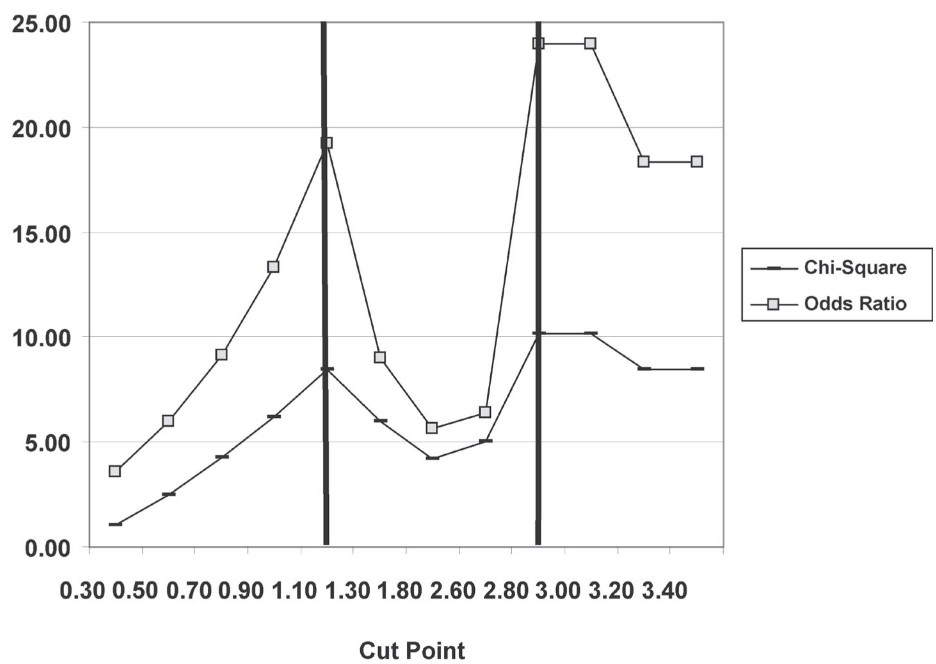

Figure 4. CARD busy: chi-square and odds ratio. *Notes.* CARD—Cumulative Assessment of Risk to the Distal Upper Extremity.

TABLE 3. 2 × 2 Matrix for Single Cut Point Used in Maximum Task Busy

Cut Point 1.0		Actual Case	Control
Test	High	12	2
	Low	5	9

TABLE 4. 2 × 2 Matrix for Cut Point 1.1 for CARD Busy

Cut Point 1.1		Actual Case	Control
Test	High	16	5
	Low	1	6

Notes. CARD—Cumulative Assessment of Risk to the Distal Upper Extremity.

TABLE 5. 2 × 2 Matrix for the Cut Point 2.8 for CARD Busy

Cut Point 2.8		Actual Case	Control
Test	High	12	5
	Low	1	10

Notes. CARD—Cumulative Assessment of Risk to the Distal Upper Extremity.

TABLE 6. 2 × 2 Matrix for the Dual Cut Points for CARD Busy

Dual Cut Points		Actual Case	Control
Test	>2.8	12	1
	<1.1	1	6

Notes. CARD—Cumulative Assessment of Risk to the Distal Upper Extremity.

4. DISCUSSION

4.1. Maximum Task Busy

This is a relatively easy approach and requires only that the SI score be determined for each task and the maximum score chosen to represent the multi-task job.

This approach was always significantly different from the null, and its ROC AUC was not significantly different from the CARD Busy.

The Maximum Task Busy did not lend itself to dual cut points. By choosing a cut point of 0.8, these data indicate that 82% of the jobs with scores less than 0.8 were controls and that 71% of the jobs with scores greater than 0.8 were cases. This indicates that 18% of the jobs that were below the cut point were cases. That is, 18% of the cases were misclassified as safe.

It is often argued that taking the maximum task as a representation of the ergonomic risk of a job is too conservative, that is, perhaps a job is less hazardous than the maximum SI score would indicate because other tasks within the job are not as risky.

In contrast, the unmodified SI maximum task may underestimate the risk of job with low intensity but little rest. This concern may be minimized by using the busy ratio, which may account for additional risk presented when tasks have lower SI scores, but decrease the amount of rest available to the worker.

4.2. CARD Busy

The CARD Busy creates new duration of effort and efforts per minute multipliers by adding the duration of effort of the present task to the previous tasks with higher SI scores. The efforts per minute variable is calculated in the same way.

This tool appears to lend itself to two cut points. The first, 1.1, the second cut point, 2.8.

Using dual cut points, when feasible, is useful in determining which jobs need immediate attention (those above the high cut point) and those that may be less hazardous (those below the low cut point). The jobs that score between the high and low cut points are the most difficult to assign risk to and may need further research. These intermediate or "grey" jobs are not necessarily moderately risky but are unknown and may require expert analysis (opinion) and a review of operational indicators, such as employee symptoms or injuries, productivity, scrap and error rates, employee turnover, or worker satisfaction.

The odds ratios associated with these dual points also give insights into the relative risk. For example, jobs with a CARD score greater than 2.8 were 76 times more likely to have an injury associated with them than jobs with scores less than 1.1. This can be very helpful in first allocating resources to the jobs most likely to be hazardous.

The discrete nature of the SI multipliers can lead to relatively large differences for relatively small changes in the efforts per minute or the duration of effort counts. Using continuous functions for the SI multipliers, might smooth the data and minimize "jumps" in SI scores for relatively modest changes in efforts per minute or duration of effort.

5. RECOMMENDATIONS

From this pilot study, it appears that using the maximum SI score alone can be used to determine the ergonomic risk associated with a multi-task job. If the maximum SI score is used, it should be modified by the busy ratio to account for the addition of other tasks. Without the busy ratio, adding additional tasks with lower SI scores would reduce the amount of rest associated with the job without a corresponding increase in assessed risk.

CARD's appeal lies in the fact that it had the largest ROC area (though not significantly different from the maximum task busy). In particular, it recognizes that if the product of the new duration of effort and efforts per minute is larger than the previous product of the multipliers, the additional task may increase the risk of the job.

While the CARD may give a better result than the maximum task alone, the additional work required may not always justify the possible improvement of tool performance.

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.

6. SAMPLE CALCULATIONS

Tables 7 and 8 list the variables necessary to complete the SI and the previously discussed approaches to assessing the risk of a two-task job.

Calculations for tasks 1 and 2 for the right and left side are illustrated below, (recall, allocated time is defined as proportional to busy time):

Note: The subscripts indicate which side (R—right, L—left) and which task (1—task 1, 2—task 2). For example, the subscript R2 means that this is the score for the right side, task 2. Subscripts with two letters and/or two numbers indicate that the calculation is for both sides and/or both tasks:

$$\text{Allocated Time (s)} = \frac{\text{Time Busy}_i}{\sum_{i=1}^{j} \text{Time Busy}_i} \bullet \text{CT},$$

$$\text{Allocated Time}_{RL1} \text{ (s)} = \frac{6}{6+11} \bullet 40 = 14 \text{ (s)},$$

$$\text{Allocated Time}_{RL2} \text{ (s)} = \frac{11}{6+11} \bullet 40 = 26 \text{ (s)}.$$

Note: In this example each hand was busy for the same amount of time. This is not always the case.

Tables 7 and 8 can then be used to determine the ratings and the multipliers for each of these variables.

TABLE 7. Variables for Tasks 1 and 2, Right and Left Hands

Cycle Time (s)	Task No.	Side	Allocated Time (s)	Busy Time (s)	Effort Time (s)	Intensity Rating	Intensity Multiplier	% Duration of Exertion Calculated	% Duration of Exertion Rating	% Duration of Exertion Multiplier
40	1	R	14	6	5	1	1	12.5	2	1.0
	1	L	14	6	1	1	1	2.5	1	0.5
	2	R	26	11	6	2	3	15.0	2	1.0
	2	L	26	11	5	1	1	12.5	2	1.0
Total		R	40	17	11					
		L	40	17	6					

TABLE 8. Variables for Tasks 1 and 2, Right and Left Hands (*continued*)

Cycle Time (s)	Task No.	Side	Efforts Count /Cycle	Efforts /Min	Efforts Rating	Efforts Multiplier	Hand/Wrist Posture Rating	Hand/Wrist Posture Multiplier	Speed of Work Rating	Speed of Work Multiplier	SI Score
40	1	R	5	7.5	2	1.0	2	1.0	3	1	1.00
	1	L	1	1.5	1	0.5	1	1.0	3	1	0.25
	2	R	4	6.0	2	1.0	3	1.5	3	1	4.50
	2	L	3	4.5	2	1.0	2	1.0	2	1	1.00

TABLE 9. Review of Strain Index (SI) Task Ratings and Multipliers for Sample Calculation

	Task 1 Left		Task 1 Right		Task 2 Left		Task 2 Right	
Variable	Rating	Multiplier	Rating	Multiplier	Rating	Multiplier	Rating	Multiplier
Intensity	1	1.0	1	1	1	1	2	3.0
% Duration of Effort	1	0.5	2	1	2	1	2	1.0
Efforts per Minute	1	0.5	2	1	2	1	2	1.0
Hand/Wrist Posture	1	1.0	2	1	2	1	3	1.5
Speed of Work	3	1.0	3	1	2	1	3	1.0
Duration per Day	4	1.0	4	1	4	1	4	1.0

$$\%\ \text{Duration of Exertion} = \%\text{DoE} = \frac{\text{Duration of Effort}}{\text{Cycle Time}} \bullet 100,$$

$$\%\ \text{DoE}_{R1} = \frac{5}{40} \bullet 100 = 12.5\%,$$

$$\%\ \text{DoE}_{L1} = \frac{1}{40} \bullet 100 = 2.5\ \%,$$

$$\%\ \text{DoE}_{R2} = \frac{6}{40} \bullet 100 = 15.0\%,$$

$$\%\ \text{DoE}_{L2} = \frac{5}{40} \bullet 100 = 12.5\%.$$

$$\text{Efforts per Minute} = \text{EpM} = \frac{\text{No. of Efforts per Cycle}}{\text{Cycle Time (min)}},$$

$$\text{EpM}_{R1} = \frac{5\ \text{efforts per cycle}}{\frac{40\ \text{s per cycle}}{60\ \text{s per min}}} = 7.5\ \text{efforts per min},$$

$$\text{EpM}_{L1} = \frac{1\ \text{effort per cycle}}{\frac{40\ \text{s per cycle}}{60\ \text{s per min}}} = 1.5\ \text{efforts per min},$$

$$\text{EpM}_{R2} = \frac{4\ \text{efforts per cycle}}{\frac{40\ \text{s per cycle}}{60\ \text{s per min}}} = 6.0\ \text{efforts per min},$$

$$\text{EpM}_{L2} = \frac{3\ \text{efforts per cycle}}{\frac{40\ \text{s per cycle}}{60\ \text{s per min}}} = 4.5\ \text{efforts per min}.$$

The SI score is the product of all of the multipliers. (Note: for the purpose of this study, DDM was assumed to be 1 because workers worked an 8-hr day.) The SI rankings and multipliers used in the sample calculation are provided in Table 9.

$$\text{SI score}_i = \text{IEM}_i \bullet \text{DEM}_i \bullet \text{EMM}_i \bullet \text{HPM}_i \bullet \text{SWM}_i \bullet \text{DDM}_i\ ,$$
$$\text{SI score}_{L1} = 1 \bullet 0.5 \bullet 0.5 \bullet 1 \bullet 1 \bullet 1 = 0.25,$$
$$\text{SI score}_{R1} = 1 \bullet 1 \bullet 1 \bullet 1 \bullet 1 \bullet 1 = 1,$$
$$\text{SI score}_{L2} = 1 \bullet 1 \bullet 1 \bullet 1 \bullet 1 \bullet 1 = 1,$$
$$\text{SI score}_{R2} = 3 \bullet 1 \bullet 1 \bullet 1.5 \bullet 1 = 4.5.$$

Job Level Analyses:

Maximum SI Score: Take maximim SI score across tasks and hands: 4.5. CARD:

$$\text{CARD} = \text{STSI}_{max} + \text{FEDISI 2} \bullet [(\text{EM12} \bullet \text{DEM12} - \text{EM1} \bullet \text{DEM1})] + \text{FEDISI 3} \bullet [(\text{EM123} \bullet \text{DEM123} - \text{EM12} \bullet \text{DEM12})] + \text{FEDISI 4} \bullet [(\text{EM1234} \bullet \text{DEM1234} - \text{EM123} \bullet \text{DEM123})] + \text{FEDISI 5} \bullet [(\text{EM12345} \bullet \text{DEM12345} - \text{EM1234} \bullet \text{DEM1234})].$$

Left Side:

$\text{STSI}_{max} = 1$,
$\text{FEDISI}_2 = 1 \bullet 1 \bullet 1$,
$\text{EM}_{12} = 1$ = multiplier for ($1.5 + 4.5 = 6$ efforts/min),
$\text{DEM}_{12} = 1$= multiplier for ($2.5 + 12.5 = 15\%$, rating 2, multiplier 1).

Therefore:

$$\text{CARD} = 1 + 1 \bullet (1 \bullet 1 - 1 \bullet 1) = 1.$$

Right Side:

$\text{STSI}_{max} = 4.5$,
$\text{FEDISI}_2 = 1 \bullet 1 \bullet 1$,
$\text{EM}_{12} = 1.5$ = multiplier for ($7.5 + 6 = 13.5$ efforts/min),
$\text{DEM}_{12} = 1$= multiplier for ($12.5 + 15 = 27.5\%$).

Therefore:

$$\text{CARD} = 4.5 + 1 \bullet (1.5 \bullet 1 - 1 \bullet 1) = 5.$$

The maximum CARD score for both right and left sides is 5.0, therefore the CARD score is 5.0.

TABLE 10. Review of Job Level Analysis Outputs for Sample Calculation

Tool	Left	Busy Ratio	Left Busy Score	Right	Busy Ratio	Right Busy Score	Job Score
Maximum Task	1.0	0.42	0.4	4.5	0.42	1.9	1.9
CARD	1.0	0.42	0.4	5.0	0.42	2.1	2.1

Notes. CARD—Cumulative Assessment of Risk to the Distal Upper Extremity.

Each of job level score was modified by the ratio of busy time over the cycle time. The busy ratio is defined as:

$$\text{Busy Ratio} = \frac{\sum_{i=1}^{j} \text{Time Busy}_i}{\text{CT}} = \frac{\text{Time Busy}_1 + \text{Time Busy}_2}{\text{CT}},$$

$$\text{Busy Ratio}_R = \frac{6+11}{40} = 0.42,$$

$$\text{Busy Ratio}_L = \frac{6+11}{40} = 0.42.$$

Multiplying each score by the appropriate busy ratio, a new score is created for each side. The maximum side is the metric used to define the ergonomic risk of the job. These scores are presented in Table 8. Table 10 provides the tool score and busy ratio for the sample calculation. The final column lists the final score for Maximum Task Busy and Card.

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