SENSITIVITY ANALYSIS OF SUBJECTIVE ERGONOMIC ASSESSMENT TOOLS: IMPACT OF INPUT INFORMATION ACCURACY ON OUTPUT (FINAL SCORES) GENERATION

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SENSITIVITY ANALYSIS OF SUBJECTIVE ERGONOMIC ASSESSMENT TOOLS: IMPACT OF INPUT INFORMATION ACCURACY ON OUTPUT (FINAL SCORES) GENERATION

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ABSTRACT

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Subjective ergonomic assessment tools are widely used by practitioners to detect existing or potentially hazardous conditions. Their output scores are used to design, implement, and evaluate measurements and controls in work environments. The objective of this study was to examine three ergonomic assessment tools and determine which input variables are critical for the outcome generation (final score calculation for hazard level classification). Fifteen tools were initially analyzed according to four criteria: (1) type of input and output data (mainly quantitative); (2) type of assessment yielded (mainly subjective); (3) data collection method/self reporting potential; and (4) the focus of their variables (mainly posture based). RULA, REBA, and JSI were the tools ultimately selected for the study. A data set for each tool was created, iterating its input variables within their range of values originating all possible combinations and their corresponding final hazard scores. Pearson's correlation tests were run on the data sets and the sensitive variables were identified. The sensitive variables were used to perform a sensitivity analysis, following the principles of the brute force method and simple linear regression model. The brute force method was applied on RULA and REBA. Using this method, individual variables were manipulated while the rest remained constant, being set to their expected values. The disturbance was compared to the base case, comprised of all input variables' expected values and their associated final hazard score. A simple linear regression model was created for JSI. The critical variables for each tool were selected according to their level of impact on final hazard level classification. For RULA and REBA, the modified correlations were used to rank the critical variables from most to least critical. RULA's ordered list of critical variables was: (1) upper arm, (2) neck, (3) trunk, and (4) legs. REBA's ordered list of critical variables was: (1) trunk, (2) upper arm, (3) legs, (4) neck, and (5) wrist. For JSI, modified coefficients of regression were obtained to rank critical variables from most to least critical: (1) intensity of exertion, (2) hand/wrist posture, (3) speed of work, (4) duration of exertion and efforts/minute, and (5) duration per day. A discussion of research opportunities, limitations of the study, and the self-reporting applicability to the tools studied were also included.

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INTRODUCTION

The focus of subjective posture-based ergonomic assessment tools, commonly used in industry, is to detect existing or potentially hazardous conditions to which a worker could be exposed while performing a specific task, or activity, on the job. The estimation of posture-based variables is made by means of direct observation or self-reporting. The use of direct measuring devices to measure postures is rare outside a laboratory setting. These tools are mainly focused on postural conditions and may reach higher levels of subjectivity than those using methods to ensure exact measurements. Although subjectivity may account for disadvantages such as observer/evaluator bias and lack of accuracy and repeatability, the advantages of using this type of tools (i.e. they have relatively low cost, are highly effective, and are user-friendly) make them popular for ergonomic practitioners. The subjective posture-based ergonomic assessment tools follow straight-forward processes to compute final hazard scores or to guide the evaluator to the final hazard estimation. Nonetheless, the tools assume that the input information provided has been collected accurately. The accuracy and validity of the results obtained by using a tool will directly depend on the accuracy and validity of the input information collected. Consequently, the level in which a mistake is made while gathering input information for a posture-based variable, potentially affects the final score computation, and may change from one input variable to another.

This investigation was derived from the perceived need of evaluating the levels of accuracy required when collecting information for input posture-based variables. The objective of this inquiry was to determine the effects input posture-based variables have on the final hazard level classification, when using subjective ergonomic assessment tools. An extensive review of the literature related to ergonomic assessment tools was completed and the description of 15 ergonomic tools is presented. Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), and the Job Strain Index (JSI) were selected for further evaluation. These tools were chosen from a group of fifteen ergonomic assessment tools reviewed, according to (1) their input and output data (mainly quantitative), (2) type of assessment yielded (mainly subjective), (3) their data collection method/self reporting potential (use of observational methods), and (4) focus of their variables (mainly posture-based). RULA and REBA perfectly matched the selection criteria. Though JSI did not fit as well as the other tools, its popularity made it appropriate to be included in the study. These tools use numeric values (scores) as input information, determined from a subjective assessment. The entire population of variable combinations (data set) was assessed for each tool. The combinations considered were comprised of the complete range of values for input variables and its corresponding output scores. A sensitivity analysis (brute force method and simple linear regression) was applied to the data sets. With the graphical and statistical results of the analysis, the critical variables, those that modify the final outcomes with their changes, were identified. An extensive evaluation of these critical posture-based variables was performed, in order to rank them according to the degree of influence each has on the final hazard level classification. Finally, the potential to self-report such variables is discussed.

LITERATURE REVIEW

Overview

A review of the basic concepts associated with the project is presented in this section. Three major topics are covered: (1) ergonomic assessment tools, (2) sensitivity analysis, and (3) statistical analysis. Regarding ergonomic assessment tools, the selection criteria applied in this project is described, as well as concepts such as tool validity, reliability, and error. Key factors for selecting ergonomic tools are also discussed. A description of sensitive and critical variables is introduced, and the explanation of the techniques applied in the study, the brute force method and the simple linear regression model, are reviewed. In the statistical analysis section, an introduction to basic descriptive statistics and analysis of correlation, specifically the Pearson's method, are covered, and the importance of statistical significance in correlation analyses is presented.

Ergonomic Assessment Tools

Ergonomic assessment tools are used to detect risk factors or unsafe conditions that might result in work-related musculoskeletal disorders (WMSD). Risk factors such as force/load, posture, frequency of movement and vibration, besides individual stressors affecting the worker are thought to directly increase the risk level for occupationally related musculoskeletal disorders (Li & Buckle, 1999). When the conditions of a specific job expose the worker to one or more of these stressors, or to any other factor such as inadequate coupling conditions, mechanical stresses or extreme temperatures, the job needs to be analyzed from an ergonomic perspective. Moore & Garg (1995) describe one of the various tools to determine whether a job is potentially safe or hazardous. Job Strain Index (JSI) consists of the collection of epidemiological data that associates job, task, and/or individual variables with some manifestation of increased risk of a musculoskeletal disorder. Although ergonomic assessment tools have the main purpose of identifying risk factors associated with the onset of occupational illnesses, they can be accurately applied to jobs that may be considered safe. Ergonomic assessment tools can help identify the conditions surrounding the worker and exposure to potential hazards beyond those previously analyzed. Working on a safe job means working on a job that is not deemed hazardous. However, working on a safe job does not mean working on a job with no exposure to risk factors (Moore & Garg, 1995). Therefore, the application of ergonomic tools can be performed without exception. These tools can be used as part of a preventative alternative, or as part of a corrective measure.

Some factors must be considered to select the appropriate ergonomic assessment tool. According to Waters, Putz-Anderson, & Baron (1997), the factors that guide the tool selection process are: (1) level of ease to use; (2) level of training required for the data collector; (3) type of application of the results; (4) economic issues; (5) time requirements and limitations; (6) type of equipment required; (7) level of work disruption needed; and (8) the need for a statistical, data, or programming analyst.

The selection of the appropriate tool may seem simple. However, because some of them, especially the posture-based methods, may share similar classification, evaluation, and scoring procedures (Juul-Kristensen, Fallentin, & Ekdahl, 1997), the selection of an inadequate tool could easily be made. A key factor to consider when choosing an ergonomic tool is its usability. That is, (1) how appropriate the tool is for the particular exposure under study, (2) the validity for the measurements to be taken, and (3) the ease of calculation and interpretations of the results obtained (Waters, Baron, & Kemmlert, 1998).

Tool Selection:

Depending upon the specific needs of the ergonomic analysis, several types of ergonomic assessment tools can be applied. The tools can be classified according to the (1) type of required data, (2) type of assessment, (3) data collection method, and (4) main focus of the input variables.

Input and Output Data. The tool can be quantitative, qualitative, or both. Moreover, the system used to gather the data can help classify a tool. The tool may use readily available information, data generated by an investigator (such as interviews, observations, surveys, experiments, etc.), or data collected but not developed for research purposes (such as surveillance, injury records, etc.) that has to be adapted to the study to handle potential gaps (Faragasanu & Kumar, 2002).

Assessment Yielded. The tool can be objective or subjective. Because of its nature, a subjective ergonomic tool is more predisposed to observer bias (Faragasanu & Kumar, 2002). Generally, these subjective methods are less disruptive for workers, however some methods are participatory (Faragasanu & Kumar, 2002).

Data Collection Method/Self-Reporting Potential. Different types of tools are classified under this category: (1) observational methods, (2) direct methods, and (3) self-reporting methods (Li & Buckle, 1999; Dempsey, McGorry, & Maynard, 2005; Winnemuller, Spielholz, Daniell, & Kaufman, 2004). Observational methods require the use of a trained evaluator who will observe the worker's job conditions and select, from the tool, the appropriate classification. Nevertheless, some problems may be encountered using this type of method. Although the use of an evaluator will facilitate low levels of work disruption, behavioral observation could become a problem, because the evaluator would need to perceive and interpret the observations to make inferences based on them (Kerlinger, 1973). This bias may also increase when a great interpretative burden is assigned to the observer, negatively affecting the tool's validity (Kerlinger, 1973). As stated by Faragasanu & Kumar (2002), other disadvantages can include: (1) lack of focus on data collection; (2) questionable reliability; (3) halo effect; and (4) others, such as errors of leniency and severity.

Direct methods use manual devices or electronic equipment (goniometers, accelerometers, etc.) to evaluate risk exposure by means of measuring postural and muscular conditions, motion, force, and body angles (Winnemuller et al, 2004). Whereas these methods are generally inexpensive and easy to use, and the risk factors under investigation can be described in detail, these techniques may not be suitable for jobs where continuous motion monitoring is required (Li & Buckle, 1999).

Self-reporting methods are mainly used to assess levels of physical work load, body discomfort, or work stress (Li & Buckle, 1999). Self-reports are important sources of information regarding risk exposure, but they are highly dependent on their validity (Lapièrre, Messing, Couture, & Stock, 2005). Self-assessment (1) provides valuable insight into working conditions not accomplished by any other method, (2) may be the only practical way of obtaining information in sufficient quantity for very large case/control or cohort studies, and finally, (3) is a low cost, low risk, cost effective method (Marley & Kumar, 1996; Woodcock, 1986; Ramsay, 1993; Andrews, Norman, & Wells, 1996; Faragasanu & Kumar, 2002). Yet, self-reporting (1) may be biased due to social/psychological factors, job-related factors, or demographic factors, and (2) may have low validity and/or low reliability in relation to the needs and requirements for ergonomic assessments (Jacobs, 1998; Li & Buckle, 1999).

It should be noted that self-assessment has been successfully used in epidemiological studies to collect information associated with musculoskeletal discomfort (Joines & Sommerich, 2001). For this reason, self-reporting might be a preferred method to use in ergonomic assessments after considering if the benefits outweigh the relatively few disadvantages.

Focus of the Tool's Variables. Each ergonomic assessment tool is comprised of a series of variables whose values can be assigned in different ways, depending on the type of tool considered. The tool's variables may be focused on postural conditions, force/load, repetition, or other risk factors, as well as on a combination of some or all of them.

Validity and Reliability:

Depending upon the type of methods or techniques used, the individuals involved, and the level of objectivity included, the tool's validity and reliability can be affected. The higher the reliability and validity of a tool, the greater its strength and confidence (Faragasanu & Kumar, 2002).

Reliability. It is the level of precision a tool has with respect to its target measurement. Reliability could be defined as the property of a tool to replicate measurements of the same factor in a study and to obtain accurate and consistent results (Faragasanu & Kumar, 2002). The more consistent its results after a series of trials, the more reliable the tool. An ergonomic assessment tool can have inter-observer reliability (when different observers produce consistent results over the same trial) or intra-observer reliability (when an observer produces consistent results over different trials).

For ergonomic assessments, the minimal acceptable reliability must be higher than 0.80 (Faragasanu & Kumar, 2002). When ergonomic decisions are based on a tool, both reliability and validity are expected to be much higher, reaching values near 0.90 (Faragasanu & Kumar, 2002). A value of 0.90 for reliability in a study means that the tool produces consistent results between trials and within trials (if inter- and intra-reliability are considered) 90% of the time, if used properly.

Validity. A tool is considered valid when it measures what it intends to measure (Faragasanu & Kumar, 2002). Thus, a valid tool gives results close enough to the expected outcomes, and it is considered sufficiently robust to be applied to different circumstances or scenarios (Moore & Garg, 1995). A tool is expected to have content validity (consistent with physiological, epidemiological, and biomechanical principles), predictive validity (ability to correctly identify a job as hazardous), and external validity (or robustness) (Moore and Garg, 1995; Stephens, Vos, Stevens, & Moore, 2006).

<u>Error:</u>

Faragasanu & Kumar (2002) describe methods to control errors while applying an ergonomic tool during data collection. When selecting an ergonomic tool, it is important to research evidence of its reliability and validity in previous applications, applied to similar populations. Regarding data collection, the authors define two different types of error: (1) random error, non-systematic error that may be treated by means of statistical procedures, and (2) bias, which systematically affect the measurements for the variable or variables being studied. Both the tool and the data sources need to ensure lack of bias.

Key Factors for Selecting an Ergonomic Tool:

In ergonomic interventions, the main considerations regarding the selection of an ergonomic assessment tool must be (1) simplicity: the tool needs to be simple enough to be used by non-expert personnel, and (2) exactitude: the tool needs to be concise enough to avoid ambiguous answers (Karhu, Kansi, & Kuorinka, 1977).

Sensitivity Analysis

A sensitivity analysis is performed to understand the impact of individual variables on final outcomes (Evans & Olson, 2003). After selecting the variables that significantly impact the outcomes and initiating a data set for further evaluation, a parameter trend analysis (Chien & Tseng, 2004) can be performed. Detecting the trend for the variable's behavior exposes the level of impact that each variable has on the final outcome.

Sensitive Variable. A variable is considered sensitive when its change produces a subsequent change in the outcome. For this study, the sensitive values will be those that have significant linear association with the final hazard level classification of the evaluated subjective ergonomic assessment tools.

Critical Variable. For purposes of this project, a variable will be considered critical when its change produces a subsequent change in hazard level estimation. Though a critical variable must be sensitive, a sensitive variable may not be critical. A sensitive but not critical variable will change the outcomes when its values are altered; however, a change in hazard level classification will not result.

The Brute Force Method:

The subjective ergonomic assessment tools considered in this study have discrete input values as well as discrete outcomes. Because the inputs and outputs are non-continuous independent and non-continuous dependent variables, respectively, most sensitivity analysis' methods cannot be applied. For this reason, the brute force method (Dunker, Yarwood, Ortmann, & Wilson, 2002; Jantz & Goetz, 2005) will be used in the study. This method allows unitary changes in the input variable in order to observe the changes in the outcome. The brute force method analyzes sensitivity perturbing the discrete inputs, after the range of values for each input variable is provided (Dunker et al, 2002; Jantz & Goetz, 2005). The model iterates using every combination of values in the data set (Jantz & Goetz, 2005).

The iteration of combinations will be compared to a base case, comprised of the expected values for each input variable and their associated output (Brigham & Ehrhart, 2002; Park, 2002). While performing the sensitivity analysis, one variable will be modified below and above its base case values, while the other variables remain constant, set to their expected values (Park, 2002).

The brute force method has been extensively used in fields such as finance, engineering, economics, and computer science, for optimization purposes.

Statistical Analysis

A statistical analysis will be performed to the data sets for the subjective ergonomic assessment tools within this study. The basic statistical concepts applied are: (1) absolute frequency, (2) relative frequency, and (3) expected value.

Absolute Frequency. For any particular value *X*, the absolute frequency is the number of times that value occurs in the data set (Devore, 2000).

Relative Frequency. For any particular value *X*, the relative frequency is the fraction or proportion of time the value occurs in the data set (Devore, 2000).

Expected Value. For any particular discrete variable *X*, with probability distribution *p(X)*, within a region D, the expected value or mean value of *X* is equal to:

$$E(X) = \mu_X = \sum_{X \in D} X * p(X)$$

Figure 1. Expected value of a discrete variable *X* (Devore, 2000)

In this investigation, the expected value will be calculated for all the discrete variables considered for each ergonomic assessment tool, using the relative frequencies as probability distributions.

<u>Analysis of Correlation (Pearson's Correlation):</u>

The correlation factor ρ (Pearson's correlation) is a measure of linear relationship between two variables (Devore, 2000). It can take values from -1.0 to 1.0. A value of zero indicates no linear association (or relation) between the variables. The limit values reflect the strongest association possible. In this investigation, the correlation is applied to each variable and its associated outcome, to determine if the analyzed variable can be classified as sensitive or not.

Pearson's correlation has been designed to be used on continuous data sets.

However, the data sets created for purposes of this study are discrete. Yet, due to the large data sets considered (for each ergonomic assessment tool, data sets ranging from approximately 2,000 to 10,400 combinations, were included), an assumption of continuity can be appropriately made. Besides Pearson's ρ, there are other correlation methods that may be used on these data sets, such as Spearman's (ρ), Kendall's (τ), among others (Conover, 1999). These measures of rank correlation are designed the same as Pearson's for continuous data, and follow similar principles.

Statistical Significance. Every correlation factor calculated for each pair of variables under evaluation must have statistical significance, if any association between variables is to be determined. Because this study evaluates entire data sets instead of samples, any correlation value encountered for a pair of variables will have statistical significance. The level of confidence used is 99%.

Simple Linear Regression:

A linear relationship between independent and dependent variables is the simplest deterministic mathematical association (Devore, 2000). Given a set of independent variables $X_1, X_2, \ldots, X_n$ drawn from a population (like the data sets included in this investigation) and a dependent variable Y obtained from certain interaction of the independent factors, a linear relationship can be assessed with the following equation:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + \varepsilon$$

Figure 2. Simple linear regression model (Devore, 2000)

Where the values for $\beta_1, \beta_2, \ldots, \beta_n$ are the coefficients associated with each independent variable, and β_0 is the constant for the model. The value ε is the error, which is a random variable assumed to be normally distributed with $E(\varepsilon) = 0$ and $V(\varepsilon) = \sigma^2$

(Devore, 2000).

One of the ergonomic assessment tools to be evaluated in this study (JSI) has both discrete input variables and outcomes. The nature of the calculations required to compute its final hazard scores makes the brute force method less than adequate. Therefore, the input variables' behavior will be measured using a simple linear regression model.

Coefficient of Determination. Devore (2000) defines the coefficient of determination R^2 as the proportion of observed *Y* variation that can be explained by the simple linear regression model. The larger the value of R^2, the better the model is thought to be.

SUBJECTIVE ERGONOMIC ASSESSMENT TOOLS

Overview

In this section, the methodology followed for the selection of subjective ergonomic assessment tools used in the study and the description of the tools that were chosen, ise presented. The selection process was applied to a pre-selected group of 15 ergonomic tools, known in the ergonomics field and widely used in industry. These tools were described according to their main objective, input and output information required, limitations, validity, reliability, sensitivity, and potential for self-reporting. Moreover, the input variables related to the assessment of each tool were described in terms of the range of values they can adopt. Finally, based upon the selection criteria established for the study, RULA, REBA, and JSI were chosen.

Ergonomic Assessment Tools

Fifteen ergonomic assessment tools were considered in the study, because of their potential or current-self reporting applicability:

1. Revised NIOSH Lifting Equation (Waters, Putz-Anderson, Garg, & Fine, 1993; Waters et al, 1998; Dempsey, 2002; Chaffin, Anderson, & Martin, 1999)
2. Rapid Upper Limb Assessment (RULA) (McAtamney & Corlett, 1993; Hedge,

2000)

3. Rapid Entire Body Assessment (REBA) (Hignett & McAtamney, 2000; Bernard, 2001)
4. Ovako Working Posture Analysis System (OWAS) (Karhu et al, 1977; Buchholz, Paquet, Punnet, Lee, & Moir, 1996)
5. Posture, Activity, Tools and Handling (PATH) (Buchholz et al, 1996; Pan, Gardner, Landsittel, Hendricks, Chiou, & Punnett, 1999)
6. Liberty Mutual Tables for Lifting, Carrying, Pushing, and Pulling (Snook Tables) (Snook & Ciriello, 1991)
7. Job Strain Index (JSI) (Moore & Garg, 1995; Moore, Rucker, & Knowx, 2001)
8. ACGIH TLV for Hand Activity (ACGIH, 2001)
9. ACGIH TLV Screening Tool for Lifting (ACGIH, 2001)
10. Rodgers Muscle Fatigue Analysis (Rodgers, 1992; Rodgers, 1988)
11. Borg Scale for Rating of Perceived Exertion (Borg, 1982)
12. OSHA Screening Tool – VDT Checklist (OSHA form)
13. WISHA Lifting Analysis (Bernard, 2002)
14. WISHA Hand-Arm Vibration Analysis (Bernard, 2002)
15. WISHA Checklist for Work-Related Musculoskeletal Disorders (Bernard, 2002)

Analysis and Classification

The ergonomic assessment tools were defined in terms of their nature, validity, accuracy, limitations, risk factors evaluated, areas of body addressed, sensitivity, potential input information required, output information obtained, and existing or appropriateness for self-reporting appropriateness. The detailed description of each tool is included in Appendix (A). For each ergonomic assessment tool, the list of variables and their required input information were determined. The list is shown in Appendix (B).

<u>Final Classification:</u>

Based on the previous analysis, and following the selection criteria described in the literature review section, the final classification for the fifteen tools was made, and is presented in Table (1).

No.	Criteria for Classification	
	Qualitative	**Quantitative**
1	Ovako Working Posture Analysis System (OWAS) Posture, Activity, Tools and Handling (PATH) Job Strain Index (JSI) (partial) Rodgers Muscle Fatigue Analysis Borg Scale of Perceived Exertion OSHA Screening Tool – VDT Checklist WISHA Lifting Analysis WISHA Hand-Arm Vibration Analysis WISHA Checklist for Work-Related Musculoskeletal Disorders	Revised NIOSH Lifting Equation Rapid Upper Limb Assessment (RULA) Rapid Entire Body Assessment (REBA) Liberty Mutual Tables for Lifting, Carrying, Pushing and Pulling (Snook Tables) Job Strain Index (JSI) (partial) ACGIH TLV for Hand Activity ACGIH TLV Screening Tool for Lifting
	Subjective Assessment	**Objective Assessment**
2	Rapid Upper Limb Assessment (RULA) Rapid Entire Body Assessment (REBA) Ovako Working Posture Analysis System (OWAS) Posture, Activity, Tools and Handling (PATH) Job Strain Index (JSI) (partial) ACGIH TLV for Hand Activity ACGIH TLV Screening Tool for Lifting Rodgers Muscle Fatigue Analysis Borg Scale of Perceived Exertion OSHA Screening Tool – VDT Checklist WISHA Lifting Analysis WISHA Checklist for Work-Related Musculoskeletal Disorders	Revised NIOSH Lifting Equation Liberty Mutual Tables for Lifting, Carrying, Pushing and Pulling (Snook Tables) Job Strain Index (JSI) (partial)

3	**Self-Reporting Potential As an Overall Observation**	**No Self-Reporting Potential As an Overall Observation**
	Rapid Upper Limb Assessment (RULA) Rapid Entire Body Assessment (REBA) Ovako Working Posture Analysis System (OWAS) Posture, Activity, Tools and Handling (PATH) Liberty Mutual Tables for Lifting, Carrying, Pushing and Pulling (Snook Tables) Job Strain Index (JSI) ACGIH TLV for Hand Activity Rodgers Muscle Fatigue Analysis Borg Scale of Perceived Exertion OSHA Screening Tool – VDT Checklist WISHA Lifting Analysis WISHA Hand-Arm Vibration Analysis WISHA Checklist for Work-Related Musculoskeletal Disorders	Revised NIOSH Lifting Equation ACGIH TLV Screening Tool for Lifting
4	**Variables Mainly Focused on Body Postures**	**Variables Mainly Focused on Others than Body Postures**
	Rapid Upper Limb Assessment (RULA) Rapid Entire Body Assessment (REBA) Ovako Working Posture Analysis System (OWAS) Posture, Activity, Tools and Handling (PATH)	Revised NIOSH Lifting Equation Liberty Mutual Tables for Lifting, Carrying, Pushing and Pulling (Snook Tables) Job Strain Index (JSI) ACGIH TLV for Hand Activity ACGIH TLV Screening Tool for Lifting Rodgers Muscle Fatigue Analysis Borg Scale of Perceived Exertion OSHA Screening Tool – VDT Checklist WISHA Lifting Analysis WISHA Hand-Arm Vibration Analysis WISHA Checklist for Work-Related Musculoskeletal Disorders

Table 1. Final classification

Tools Selected for the Study

For this investigation, the tools chosen were required to: (1) be mainly quantitative; (2) be mainly subjective; (3) have self-reporting potential, and use observational methods; and finally, (4) focus, mainly, on body postures, which are variables prone to be assessed by subjective methods. The only tools that perfectly matched the criteria were RULA and REBA, and thus, they were selected for the study.

JSI was chosen to complete the set of tools to investigate, even though it did not absolutely match the selection criteria as RULA and REBA did. However, this tool matched almost all the selection criteria, is commonly used, and is widely applicable, which made it of interest for this study. Furthermore, it is one of the few validated tools, and for this reason, an analysis of sensitivity for its input variables was more than adequate. Determining critical variables for JSI could provide useful information for users applying the tool in industry for hazard level assessment.

RULA, REBA, and JSI

Rapid Upper Limb Assessment (RULA):

RULA has been developed to assess the severity of postural loading. It is particularly applied to assess risk levels in sedentary jobs (McAtamney & Corlett, 1993). The tool uses numbers (scores) and an associated coding system (Li & Buckle, 1999).

RULA is comprised of three tables, A, B, and C. To perform a hazard level assessment using RULA, the evaluator needs to select from the different values, the ones that most define the activity, task, or job being studied. Scores are provided for each variable. *Upper arm*, *lower arm*, *wrist*, and *wrist position* are input variables for table A. Two modifiers, *muscle use* and *force/load* from the upper extremities perspective, are added to the score gathered from the table. *Neck, trunk*, and *legs* are input variables for table B. Two modifiers, *muscle use* and *force/load* from the neck, trunk and lower extremities perspective, are added to the score obtained from the table. The resulting values from tables A and B are inputs for table C, which outputs the final score used for the hazard level classification. The classification consists of four different levels: (1)

scores 1-2: acceptable risk level; (2) scores 3-4: further investigation is needed; (3) scores 5-6: further investigation is needed and changes must be made soon; and (4) score 7: investigation is required and changes must be made immediately. A RULA Employee Assessment Worksheet (Hedge, 2000) is shown in Appendix (C).

<u>Rapid Entire Body Assessment (REBA):</u>

REBA was developed based on the principles of RULA. However, as Li & Buckle (1999) state, the tool is more applicable to the evaluation of tasks that include both dynamic and static postures, as well as to significant postural changes. Similar to RULA, the evaluator needs to observe the task, evaluate the posture and score various body positions (Hignett & McAttamney, 2000).

When the body parts have a score assigned, tables A and B are used. *Trunk*, *neck*, and *legs* are input variables for the value obtained from table A. *Upper arm*, *lower arm*, and *wrist* are input variables to gather the value from table B. Two modifiers, *load/force* and *coupling*, are required in the assessment. The score selection is similar to the process used with tables A and B. The modifiers are added to the values obtained from tables A and B. The resulting values are input to obtain the resulting score from table C. An additional modifier, *activity*, is added to score C. This new score, the REBA score, is used to determine the hazard level assessed for that particular activity, task or condition. For REBA, there are five hazard level classifications: (1) score 1: negligible risk level, where no action is required; (2) scores 2-3: low risk level, when an action may be necessary; (3) scores 4-7: medium risk level, when an action is necessary; (4) scores 8-10: high risk level, when an action is necessary soon; and (5) scores 11-15: very high risk level, when action is necessary immediately. A REBA Assessment Worksheet (Bernard, 2001) is shown in Appendix (D).

Job Strain Index (JSI):

JSI focuses on the risk detection of distal upper extremity musculoskeletal disorders, derived from principles related to physiology, biomechanics, and epidemiology (Stephens et al, 2006). Risk factors such as force, repetition, posture, recovery time, and type of grasp are important in the occurrence of such conditions (Moore & Garg, 1995).

The JSI score is obtained from the product of six multipliers: *intensity of exertion*, *duration of exertion*, *exertions per minute*, *hand/wrist posture*, *speed of work*, and *duration of task per day*. Each variable has five levels comprising all the possibilities for any task. According to the level per variable selected, a value for the multiplier is assigned. For the six variables, the equation providing the resulting score level is:

$$JSI = IE * DE * EM * HWP * SW * DD$$

Figure 3. JSI equation (Moore & Garg, 1995)

IE = intensity of exertion; DE = duration of exertion; EM = exertions per minute; HWP = hand/wrist posture; SW = speed of work; DD = duration per day. For JSI, the threshold value to determine if the evaluated job may be considered safe or needs to be investigated further due to its existing or potential risk conditions is equal to five (5). That is, a JSI equal to or greater than five (5) is predictive of hazardous jobs (Moore & Garg, 1995). A JSI lower than five (5) can be classified as safe. However, a safe classification does not mean that the job is free of exposure to risk factors not considered by the tool (Moore & Garg, 1995). The JSI's range of values is presented in Appendix (E).

SENSITIVITY ANALYSIS: RAPID UPPER LIMB ASSESSMENT (RULA)

Overview

RULA's data set was created iterating its variables among their range of values, resulting in a group of all possible combinations. Only RULA's posture-based variables were iterated in the study, excluding the modifiers (set to their minimum levels) for this and the subsequent stages of the investigation. Pearson's correlation was run on the data set and according to the strength of its bi-variate linear association, the sensitive variables were identified. Last, the brute force method was applied, and the critical variables were determined and their behavior discussed.

Input Variables

Seven posture-based variables and two modifiers are required to compute RULA's final hazard level classification. Their range of values is shown below:

Variable	Values
Upper Arm	1 – 2 – 3 – 4 – 5 – 6
Lower Arm	1 – 2 – 3
Wrist	1 – 2 – 3 – 4
Wrist Twist	1 – 2
Neck	1 – 2 – 3 – 4 – 5 – 6
Trunk	1 – 2 – 3 – 4 – 5 – 6
Legs	1 – 2
Muscle Use	0 – 1
Force/Load	0 – 1 – 2 – 3

Table 2. Values for RULA's input variables

Data Set

Only the seven posture-based input variables were iterated within their corresponding range of values to create the data set. The modifiers were set to their minimum levels. This exclusion was made because the purpose of the investigation was to detect the influence level of subjective input variables on the final classifications, and assuming that the modifiers may be easily assessed by means of objective methods. Using this approach, the modifiers can be assessed with higher levels of precision. That is, the modifiers can be identified as RULA's objective inputs. All possible combinations were included in the data set. In total, there were 10,368 combinations. The following statistics were obtained:

Hazard Level	Absolute Frequency	Relative Frequency
Scores 1 and 2 → Acceptable	84	0.81%
Scores 3 and 4 → Investigate Further	2,010	19.39%
Scores 5 and 6 → Investigate Further and Change Soon	4,924	47.49%
Score 7 or higher → Investigate and Change Immediately	3,350	32.31%
Total	**10,368**	**100.00%**

Table 3. Statistics for RULA's data set

Microsoft Excel XP© was used.

Analysis of Correlation

The input variables were compared to their corresponding scores by conducting a Pearson's bi-variate correlation test. If any correlation was encountered, the variable was considered sensitive. Pearson's test was run on the input variables with their associated scores and on tables A and B with the final score, score C. The test results are shown in Tables (4), (5), and (6). SPSS 12.0 for Windows was used in this process.

Variable	Correlation with Score A
Upper Arm	0.88
Lower Arm	0.15
Wrist	0.29
Wrist Twist	0.09

0.01 level of significance.

Table 4. Correlations using RULA's score A

Variable	Correlation with Score B
Neck	0.74
Trunk	0.56
Legs	0.11

0.01 level of significance.

Table 5. Correlations using RULA's score B

Variable	Correlation with Score C
Score A	0.62
Score B	0.67

0.01 level of significance.

Table 6. Correlations using RULA's score C

All variables are correlated in some level with their corresponding score, as well as scores A and B are correlated with score C. For this reason, RULA's seven posture-based variables are identified as significant (or sensitive) in the calculation of the hazard level classification.

Sensitivity Analysis

The brute force method was applied to RULA's sensitive variables. This technique required making unitary changes in each of the input variables within its range of values, in order to analyze the changes that were produced as a consequence of such iterations. The individual changes were compared to a base case, derived from the calculation of each input variable's expected value. The base case was calculated using the following procedure:

a) The absolute frequency for each value per input variable per hazard level classification (scores 1-2, scores 3-4, scores 5-6, and scores 7-higher) was calculated.

b) The relative frequency per value per input variable per hazard level classification was estimated.

c) The new absolute frequency was found, making the summation of the absolute frequencies multiplied by the corresponding relative frequencies previously computed.

d) The new relative frequency was computed, derived from the absolute frequency found in step (c) of this procedure.

e) The expected value for a single variable was found performing the summation of the relative frequencies described in step (d) multiplied by their corresponding value (from the input variable's range of values). If this number was a decimal, it was rounded to the nearest integer.

Appendix (F) includes the numerical results for the application of this procedure. RULA's base case is shown in Table (7).

Variable	Upper Arm	Lower Arm	Wrist	Wrist Twist	Neck	Trunk	Legs	Score A	Score B	Score C
Expected Value	4	2	3	2	3	3	2	4	5	5

Table 7. Base Case for RULA

Following the brute force methodology, the sensitive variables were plotted and their iterations were compared to the base case, allowing the critical variables to be identified. As previously defined, the sensitive variables are considered critical when their change produces a hazard level classification change. In the graphics shown below, the critical changes of input values were marked in red and the consequent changes in hazard level classification were circled using the same color.

Upper Arm:

RULA's upper arm was critical. Two different changes in input values, from 2 to 3 and from 4 to 5, produced an increase in hazard level classification.

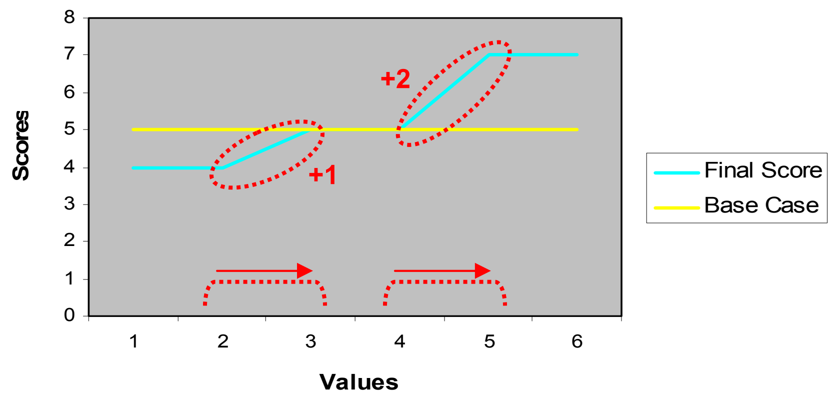

Figure 4. Iterations for RULA's upper arm

Lower Arm:

RULA's lower arm was not critical.

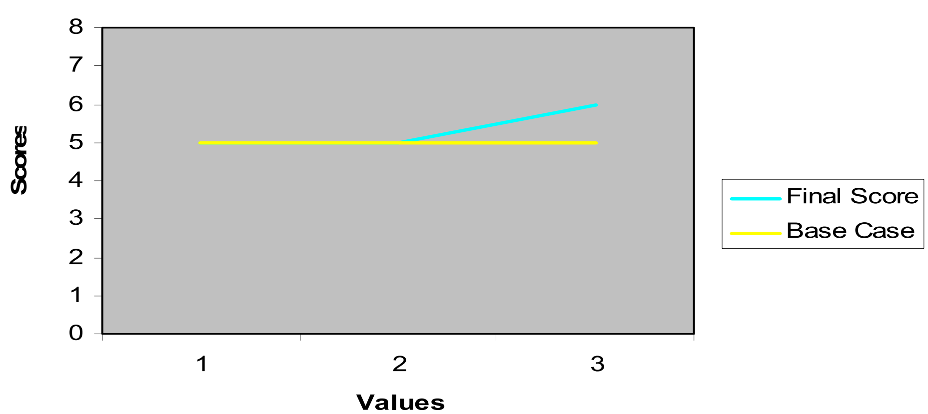

Figure 5. Iterations for RULA's lower arm

Wrist:

RULA's wrist was not critical.

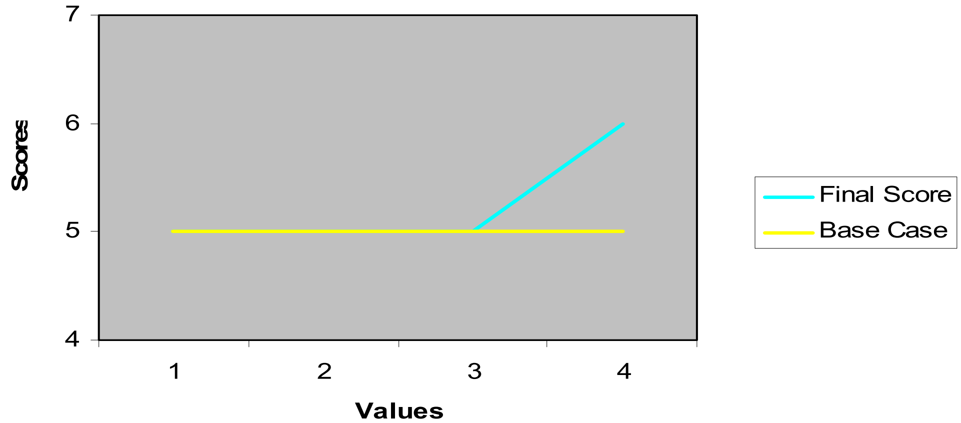

Figure 6. Iterations for RULA's wrist

Wrist Twist:

RULA's wrist twist was not critical. Its behavior was identical to that found for the base case. Therefore, it is hidden behind the expected values for RULA final score.

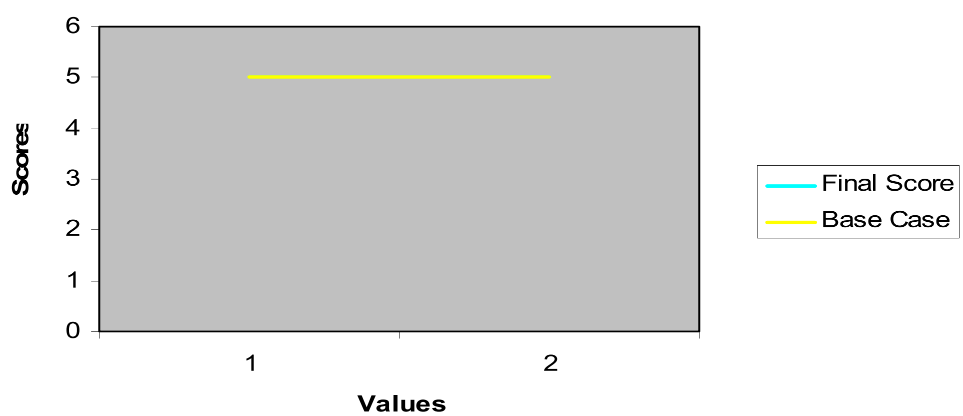

Figure 7. Iterations for RULA's wrist twist

Neck:

RULA's neck had a critical impact on the final hazard level classification when its values changed from 1 to 2.

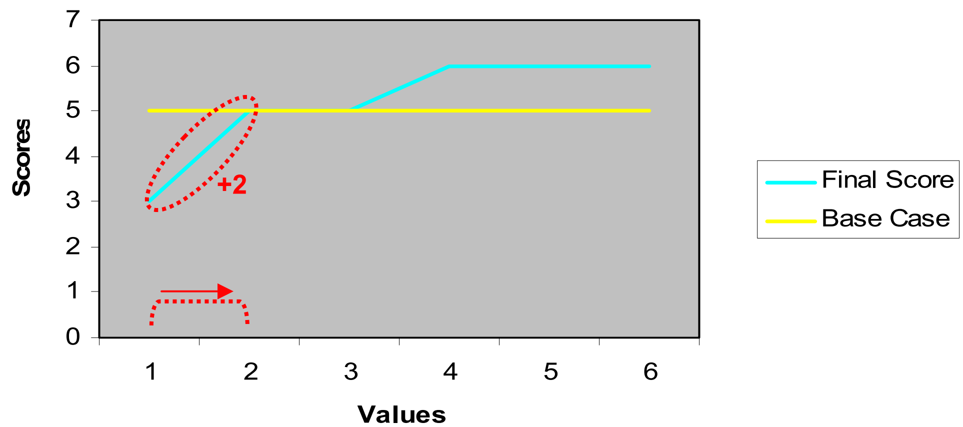

Figure 8. Iterations for RULA's neck

Trunk:

RULA's trunk was a critical variable. Critical changes occurred when the input values changed from 2 to 3.

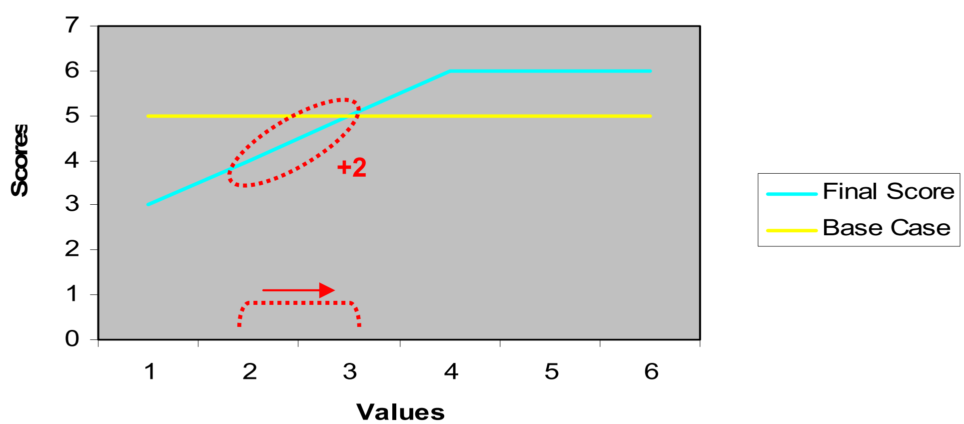

Figure 9. Iterations for RULA's trunk

Legs:

Because only one change in input value was possible, RULA's legs was a critical variable for its entire range.

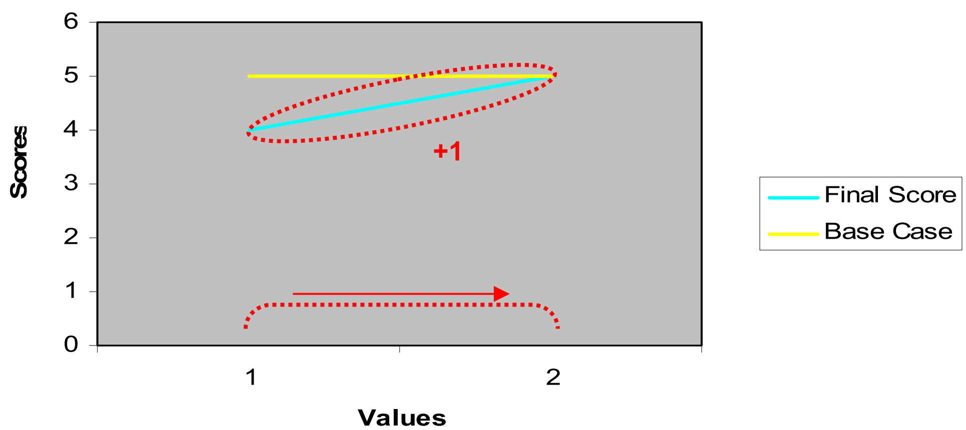

Figure 10. Iterations for RULA's legs

Critical Variables

These figures portray the graphical results of applying the brute force method. The red circled areas show the change of input values that produced a consequent change in hazard level classification. *Upper arm*, *neck*, *trunk*, and *legs* were found to be critical. These critical variables required further analysis, comprised of a detailed evaluation of the specific values in which the variable produced a hazard level change. Therefore, a detailed study of each variable's conditions and the different values where the scores became critical for the final hazard level assessment was performed.

Upper Arm:

Two different increments in hazard level classifications occurred under the conditions set for this study. That is, having all the variables, except for upper arm, set to their expected values. When the posture was assumed to be under such characteristics, a misclassification of its value from 2 to 3, or from 4 to 5 produced an increment in final score.

Change from 2 to 3. The score assessment became critical when (1) conditions such as shoulder raised and shoulder abducted were added to a neutral posture; (2) an upper arm with flexion less than 15° was misclassified as being flexed above this value; (3) a shoulder raised or abducted was added to an upper arm with flexion below 15°; and (4) an upper arm flexed below 45° was scored as having flexion below this angle. Either change produced an increment of hazard level classification from 3-4 to 5-6.

Change from 4 to 3. The upper arm variable became critical when (1) flexion below 90° was misclassified as being flexed above this level, and (2) flexion below 90° had conditions such as shoulder raised or abducted conditions added. Either change produced an increment of hazard level classification from 5-6 to 7-higher.

Among the conditions described, misclassifications may more likely be encountered when an upper arm is already flexed with an angle near 45°, or near 90°, because it is thought to be more difficult to estimate accurately a flexion angle as being above or below a threshold when it is almost reaching this limit. Shoulders raised or abducted, or both, may be easier to detect under normal conditions.

Neck:

If all the input variables, except for the neck, are set to their expected values, the critical changes occurred when a neutral neck posture was (1) misclassified as having a flexion angle above 10°, or (2) was considered as being twisted or side-bended, or both, changing the input values from 1 to 2. Such mistakes changed the hazard level classification from 3-4 to 5-6. It may be more probable to misclassify a neutral posture increasing the flexion angle than adding neck twisting or bending, because of the relative ease to detect the latter conditions.

Trunk:

Being that the entire group of input posture-based variables were set to their expected values, changes from 2 to 3 in RULA's trunk produced an increment of hazard level classification from 3-4 to 5-6. These changes occurred when (1) a neutral posture was also considered as having trunk twisted or side-bended, or both, and (2) a neutral posture was assumed to have trunk flexion above 20°. Again, it is thought to be more likely to have misclassifications when scoring the trunk flexion if this body part's posture is close to neutral.

Legs:

Any change in legs' posture incremented the hazard level classification from 3-4 to 5-6, if the remaining variables were set to their expected values.

Final Analysis

The procedure followed by RULA is relatively easy and user-friendly. However, in order to have accurate and valid RULA scores, it is necessary to have accurate and valid input values. The analysis performed on the input variables may provide valuable information regarding which variables require additional attention when being assessed. This analysis considered any posture that is assumed to be close to the one described by the base case. When a posture is described by these expected values, changes in the critical variables will produce changes in the outcome. All the posture-based variables required for the RULA assessment are sensitive, however, if the posture is near the base case, only the critical variables will directly change the final hazard level classification. In other words, focusing on the critical variables is imperative.

During the analysis of RULA's critical variables, the minimum changes in conditions that change final hazard levels were described. Thus, it could follow that a larger mistake in the assessment will produce less accurate results than those presented.

The critical values described in this section have referred to increments in final hazard level classification. However, assigning a score to a critical input variable that is below the appropriate input value will also produce a change of final hazard level classification. In this case, a decrement in final score will result.

Ranking:

The critical variables were ranked according to their Pearson's combined correlation values. The combined correlation was calculated multiplying the direct correlation of the variable with its associated score and the correlation between its associated score and the final score. The ranks are presented below.

Critical Variable	Combined Correlation
Upper arm	0.54
Neck	0.49
Trunk	0.37
Legs	0.07

Table 8. Combined correlations for RULA's critical variables

Upper arm is, according to the ranks, the most critical variable for RULA assessment, followed by *neck*, *trunk*, and *legs*, as determined by the criteria set for this study.

SENSITIVITY ANALYSIS: RAPID ENTIRE BODY ASSESSMENT (REBA)

Overview

The sensitivity analysis performed on REBA follows the same principles and methodology to the one applied to RULA. The data set was created from the entire group of combinations made from iterating each input variable within its range of values. Only posture-based variables were included in the study, excluding the modifiers, which were set to their minimum levels. Pearson's correlation test was run on the data and the sensitive variables were identified. Moreover, the base case was computed and used while applying the brute force method. Finally, the critical variables were selected and their behavior was discussed.

Input Variables

Six posture-based variables and three modifiers are required to calculate REBA's final hazard level classification. Their range of values is presented in Table (9).

Variable	Values
Trunk	1 – 2 – 3 – 4 – 5
Neck	1 – 2 – 3
Legs	1 – 2 – 3 – 4
Load/Force	0 – 1 – 2 – 3
Upper Arm	1 – 2 – 3 – 4 – 5 – 6
Lower Arm	1 – 2
Wrist	1 – 2 – 3
Coupling	0 – 1 – 2 – 3
Activity	0 – 1 – 2 – 3

Table 9. Values for REBA's input variables

Data Set

The six posture-based input variables were simultaneously iterated within their range of values, and each of the combinations obtained was included in the data set. Because the modifiers can be measured with relative objectivity, they were not considered as an active part of the sensitivity analysis. Instead, they were set to their minimum levels. In total, there were 2,160 combinations. The statistics for the data set are shown below:

Hazard Level	Absolute Frequency	Relative Frequency
Score 1 → Negligible	28	1.30%
Scores 2 and 3 → Low	220	10.19%
Scores 4 to 7 → Medium	944	43.70%
Scores 8 to 10 → High	920	42.59%
Scores 11 to 15 → Very High	48	2.22%
Total	**2,160**	**100.00%**

Table 10. Statistics for REBA's data set

Microsoft Excel XP© was used.

Analysis of Correlation

A bi-variate correlation test (Pearson's) was run on the data set. If any level of correlation was found between an input variable and its corresponding score, such variables were considered sensitive. Correlations were also run between scores A and B with the final score C. SPSS 12.0 for Windows was used and the test results are presented in Tables (11), (12), and (13).

Variable	Correlation with Score A
Trunk	0.71
Neck	0.40
Legs	0.56

0.01 level of significance

Table 11. Correlations using REBA's score A

Variable	Correlation with Score B
Upper Arm	0.94
Lower Arm	0.17
Wrist	0.25

0.01 level of significance

Table 12. Correlations using REBA's score B

Variable	Correlation with Final Score
Score A	0.80
Score B	0.56

0.01 level of significance

Table 13. Correlations using REBA's score C

All variables were found to be sensitive. That is, all six posture-based variables had relevant impact in the hazard level classification computation.

Sensitivity Analysis

The sensitive variables were used as input for the brute force method. The procedure followed to calculate the base case was identical to the one used for RULA and therefore, it is not explained in this section. However, the results for each step of the base case computation process are included in Appendix (G). REBA's base case is presented in Table (14).

Variable	Trunk	Neck	Legs	Upper Arm	Lower Arm	Wrist	Score A	Score B	Score C
Expected Value	3	2	2	4	2	2	5	6	7

Table 14. Base Case for REBA

The sensitive variables were plotted and their behavior was compared to the base case, according to the principles of the brute force method, and with the purpose of identifying REBA's critical variables. The red circled areas mark the change of input values that produced a consequent change in hazard level classification.

<u>Trunk:</u>

REBA's trunk was critical. A change in input value from 2 to 3 produced a change in final hazard level classification from 4-7 to 8-10.

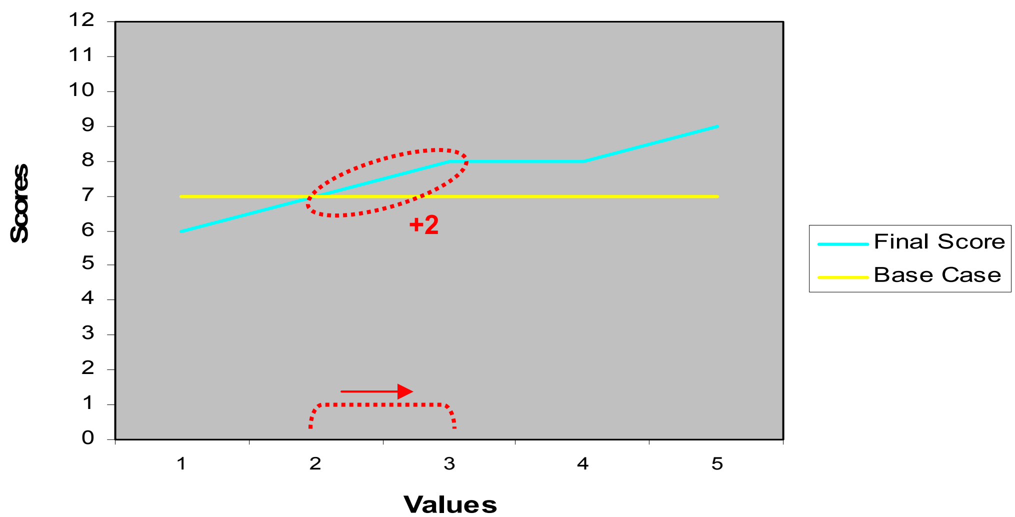

Figure 11. Iterations for REBA's trunk

<u>Neck:</u>

REBA's neck was found to be critical. If the input value was changed from 2 to 3, it produced a change in the final score from 4-7 to 8-10.

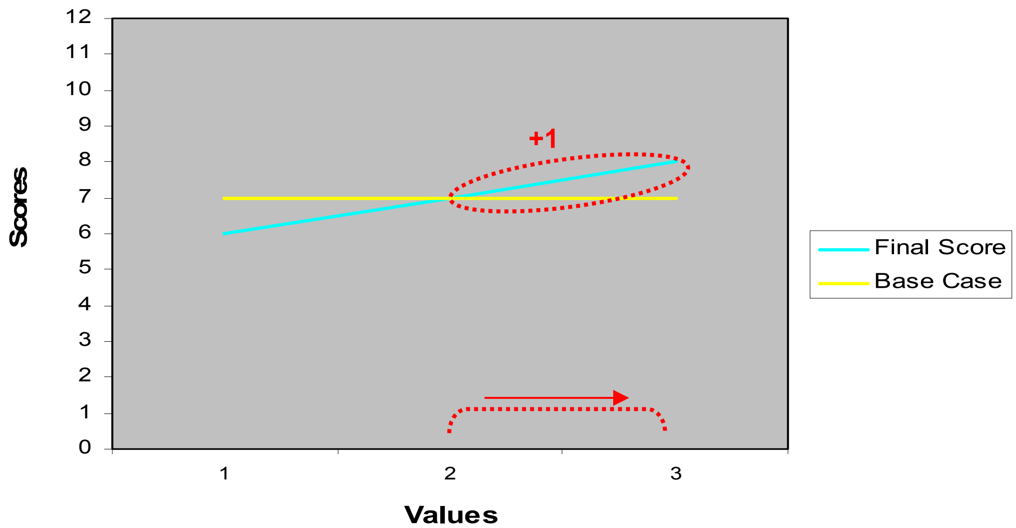

Figure 12. Iterations for REBA's neck

Legs:

REBA's legs were found to be critical. A change of input value from 2 to 3 produced a change in the hazard level classification from 4-7 to 8-10.

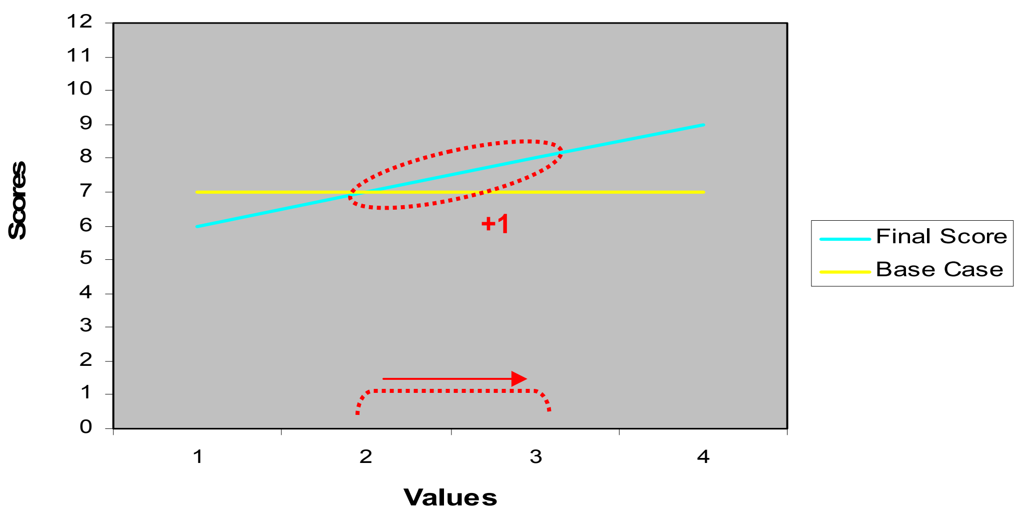

Figure 13. Iterations for REBA's legs

Upper Arm:

REBA's upper arm was a critical variable. A change in input values from 4 to 5 changed the final hazard level classification from 4-7 to 8-10.

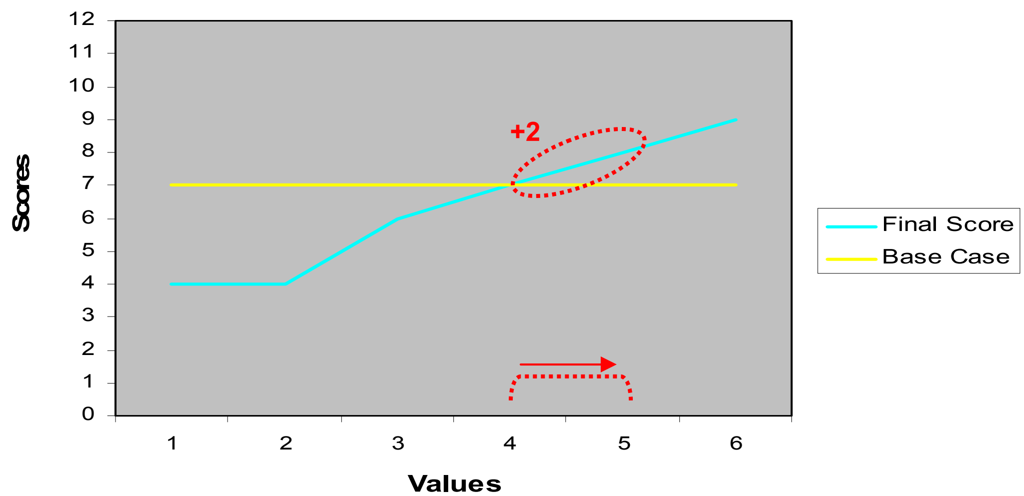

Figure 14. Iterations for REBA's upper arm

Lower Arm:

REBA's lower arm was not found to be critical.

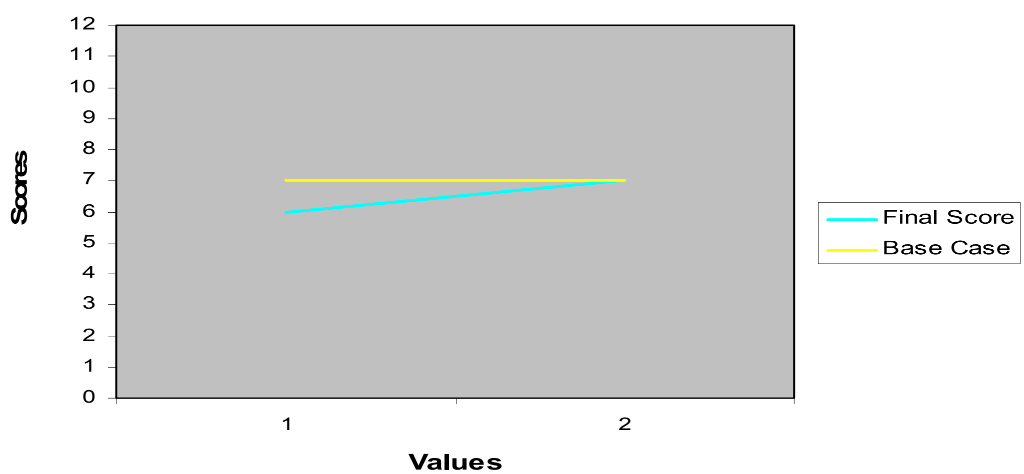

Figure 15. Iterations for REBA's lower arm

Wrist:

REBA's wrist was found to be a critical variable. A change in input value from 2 to 3 produced a change in the hazard level classification from 4-7 to 8-10.

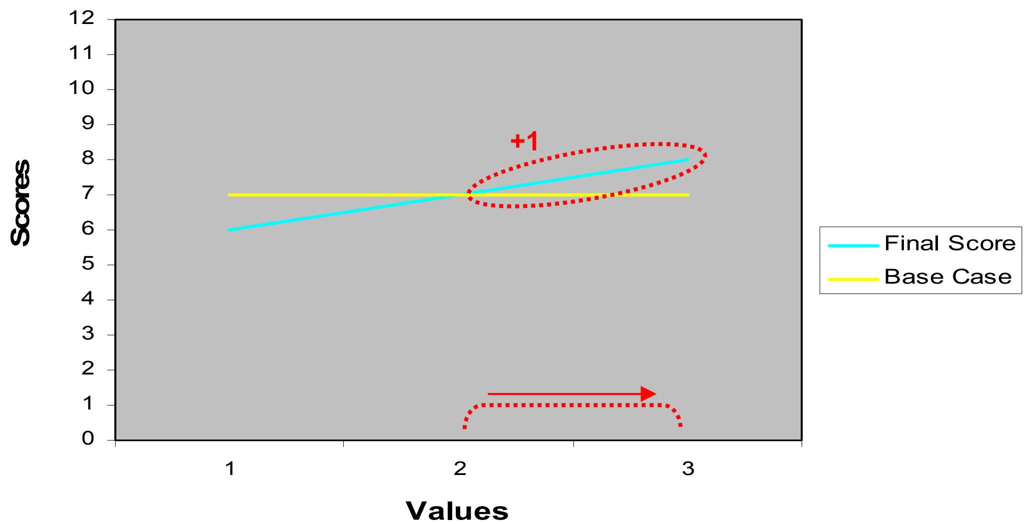

Figure 16. Iterations for REBA's wrist

Critical Variables

The figures previously shown are the graphical results for the sensitivity analysis performed. The circled areas mark the critical input values for each variable. *Trunk*, *neck*, *legs*, *upper arm*, and *wrist* were identified as critical. A more detailed analysis was made on the critical variables to determine the conditions that, if incorrectly assessed, increment the final hazard level classification.

Trunk:

If all the variables are set to their expected values, except for the trunk, a misclassification of this variable from 2 to 3 produced a change in the final score from 4-

7 to 8-10. This change in hazard level classification occurred when (1) conditions such as back twist or tilt to side were added to a neutral posture; (2) a flexed trunk below 20° was estimated to have a flexion angle above this value; and (3) an extended trunk below 20° was scored as having an extension angle above this value.

A mistake may more likely be encountered when the trunk is flexed near the 20° limit of separation between scores, because of the level of accuracy required to estimate the actual posture. Neutral postures may be easier to identify and differentiate from those that are affected by awkward positions. Moreover, an extended trunk may also be easier to identify because of its extreme condition.

Neck:

When a flexed or extended neck above 20° was considered as also being twisted or tilted to the side, with all the remaining variables set to the base case, a change in its input value from 2 to 3 produced a consequent change of hazard level from 4-7 to 8-10.

Legs:

Two different conditions produced a change in this variable's input value from 2 to 3, producing also a change of hazard level classification from 4-7 to 8-10: (1) when the posture was estimated as bilateral standing, walking, or sitting and having knees flexed above 60°, and (2) when the standing was estimated to be unilateral or unstable and the knees flexed between 30° and 60°.

Upper Arm:

When the inputs values for upper arm changed from 4 to 5, with all the remaining variables were set to their expected values, the hazard level classification changed from

4-7 to 8-10. The input value changes occurred when (1) an upper arm flexed above 90° was considered to be under conditions such as arm abduction or shoulder raised, and (2) an upper arm flexed below 90° is considered to be under both of the above mentioned conditions. It is thought to be more probable to make a mistake estimating the flexion angle when it is near the score change threshold. If a mistake is made during this assessment, the consideration of the shoulder raised or arm abduction conditions will likely change the final hazard level classification.

Wrist:

If the wrist posture was considered flexed, or extended, above 15° and twist or deviation were added to the estimation, and the input value changed from 2 to 3, then this changes the final hazard level classification from 4-7 to 8-10. Except for wrist, all the variables were set to their base case.

Final Analysis

REBA follows the same principles as RULA. Therefore, the levels of accuracy and validity desired for REBA's final scores and their comparison to the levels of accuracy and validity required for the input values have the same association as RULA's. The analysis made offers information regarding the critical conditions under which the hazard levels may change. However, it is important to note that these changes are considered for postures that are near the input variables' expected values. Furthermore, it is important to note that both increments and decrements in final hazard classifications may occur with critical input variables misclassifications.

For this reason, analysts should focus on REBA's critical variables to ensure accurate and valid results.

Ranking:

REBA's critical variables were ranked according to Pearson's combined correlation values. The ranks are presented in Table (15).

Critical Variable	Combined Correlation
Trunk	0.56
Upper arm	0.52
Legs	0.45
Neck	0.32
Wrist	0.14

Table 15. Combined correlations for REBA's critical variables

According to the ranks, trunk is the most critical variable for REBA assessment, followed by upper arm, legs, neck, and wrist, as determined by the criteria set for this study.

SENSITIVITY ANALYSIS: JOB STRAIN INDEX (JSI)

Overview

The iteration of six multipliers generated the JSI's data set. All possible combinations were included in this population. The data set was analyzed by running a Pearson's correlation test and the sensitive variables were identified. Although JSI has discrete input and output variables, the required procedure to calculate the final score (direct multiplication) allows the use of a simple linear regression model, in order to detect the level of impact each multiplier has on the final outcome. For this reason, this technique was applied instead of the brute force method. With the simple linear regression model, the critical variables were identified and ranked according to their level of impact on the JSI final score.

Input Variables

Six multipliers are used to obtain the JSI score for hazard level. Their range of values is shown below.

Variable	Values
Intensity of Exertion	1 – 3 – 6 – 9 – 13
Duration of Exertion	0.5 – 1 – 1.5 – 2 – 3
Efforts/Minute	0.5 – 1 – 1.5 – 2 – 3
Hand/Wrist Posture	1 – 1 – 1.5 – 2 – 3
Speed of Work	1 – 1 – 1 – 1.5 – 2
Duration per Day	0.25 – 0.5 – 0.75 – 1 – 1.5

Table 16. Values for JSI's input variables

Data Set

The six input variables were iterated within their range of values to create the data set. All possible combinations were included in the data set. In total, 7,500 combinations were found. The following statistics were obtained:

Hazard Level	Absolute Frequency	Relative Frequency
Score ≤ 5 → Safe	1,826	24.35%
Score > 5 → Hazardous	5,674	75.65%
Total	**7,500**	**100.00%**

Table 17. Statistics for JSI's data set

Microsoft Excel XP© was used.

Analysis of Correlation

Although it is already known that all the variables will have some level of correlation with the final score, because of their direct multiplication to obtain the JSI score, the Pearson's correlation test was run to provide some information regarding the level of influence each multiplier has on the final hazard score. The results of the test are shown below:

Variable	Correlation with Final Score
Intensity of Exertion	0.40
Duration of Exertion	0.32
Efforts/Minute	0.32
Hand/Wrist Posture	0.23
Speed of Work	0.16
Duration per Day	0.32

0.01 level of significance.

Table 18. Correlations for JSI

Sensitivity Analysis

The brute force method could have been applied to the data set. However, because of the procedure followed to calculate the final score, more information can be gathered using other techniques, such as the simple linear regression model. Within this model, for each variable, a coefficient is computed. That is, it can be exactly determined how significant its influence is on the dependent variable (JSI score). For any specific variable, the smaller its coefficient is, the greater its influence on the final score may be. For this study, the model's results were supported by the *F Statistic* and the *Student-t* results, as it can be observed in Appendix (H). The model obtained is:

$$JSI = 5.76IE + 23.04(DE + EM) + 19.66HWP + 24.58SW + 46.08DD - 184.32$$

Figure 17. JSI's simple linear regression model

IE = intensity of exertion, DE = duration of exertion, EM = efforts per minute, HWP = hand/wrist posture, SW = speed of work, and DD = duration per day. All results were highly significant, obtaining a model from which a ranking, from most to least significant, was made. The student-t statistics found support the rank, shown below:

Rank	Variable	Coefficient
1	Intensity of Exertion	5.76
2	Hand/Wrist Posture	19.66
3	Duration of Exertion	23.04
	Efforts/Minute	
4	Speed of Work	24.58
5	Duration per Day	46.08

Table 19. Rank for JSI's input variables

The coefficient of determination (R^2) was 54.30%, which means that only this proportion of the effects on the JSI score can be explained by the simple linear regression model. This number might seem low. However, because the analysis was made over the entire population or data set, the fact that more than half of the behavior of the dependent variable can be explained by the interaction of its independent multipliers is a good indicator for a robust model.

Final Analysis

The analysis performed on JSI's data set was quite different from that under which RULA and REBA were studied. A simple linear regression model was obtained and the levels of criticality for each variable were detected.

<u>Ranking:</u>

A modified coefficient was also calculated for JSI, multiplying the coefficient of each variable by its correlation value with the final score. The final rank is presented in Table (20).

Critical Variable	Modified Coefficient
Intensity of Exertion	2.30
Speed of Work	5.30
Hand/Wrist Posture	6.29
Duration of Exertion	7.37
Efforts/Minute	
Duration per Day	14.75

Table 20. Modified coefficients for JSI's critical variables

(1) *Intensity of exertion* it the most critical variable, followed by (2) *hand/wrist posture*, (3) *speed of work*, (4) *duration of exertion* and *efforts/minute*, and (5) *duration per day*. This order must also be followed when determining the level of focus an evaluator needs to assign to each variable. The more critical a variable, the more accuracy is required for its assessment.

RESULTS

RULA and REBA. RULA and REBA were analyzed in a similar manner. Data sets were created for both tools, iterating each input variable (only posture-based variables were iterated while the modifiers, those variables that are directly added to the final scores, were set to their minimum levels) within its range of values. For RULA, 10,368 combinations were created. For REBA, 2,160 combinations were computed. According to RULA's statistics, approximately 48% of the combinations had scores of 5-6, about 32% were scored as 7-higher, and only near 20% of the combinations were in the lowest hazard levels. According to REBA's statistics, approximately 44% of the combinations were scored in the 4-7 level; about 43% had scores in the 8-10 level; and close to 11% of the total combinations belonged to the lowest hazard levels. Finally, only 2% was part of the highest hazard level classification.

The sensitive postured-based variables were identified by means of Pearson's ρ correlation. Any correlation found between the input variable and its associated score was considered important, identifying such variable as sensitive. The modifiers were excluded from the study because of their objective nature. These variables are relatively easy to estimate, and these values are obtained by objective assessment or direct measurements.

The brute force method was applied to the data sets, and each variable was analyzed, detecting changes in its input values which produced consequent changes in the final hazard level classification. If a change occurred, the variable was identified as critical. The brute force method disturbed individual variables while the rest remained constant, set to the base case, comprised of the input variables' expected values. For RULA, in order from most to least critical, (1) *upper arm*, (2) *neck*, (3) *trunk*, and (4) *legs* were found critical for the hazard level assessment. For REBA, ordered from most to least critical, (1) *trunk*, (2) *upper arm*, (3) *legs*, (4) *neck*, and (5) *wrist*, were identified as critical.

The critical variables for each tool were extensively analyzed, with the purpose of finding the specific conditions that once changed, produced a consequent change in the final hazard level classification. The results obtained using this analysis were evaluated for one variable, while the rest were set to their expected values, obtaining conclusions only for tasks of activities that could be described as being close to these conditions. In summary, it could be stated that increments in hazard level classifications were frequently found when, to any posture, additional conditions increasing its awkwardness (side-bending, instability, twists, etc.) were added. Furthermore, when scoring a posture-based variable as neutral, it was imperative to be accurate in the estimation. Manipulating factors such as additional awkward conditions or the presence of flexions or extensions not detected in the assessment may produce an incorrect final RULA or REBA score. It was also noted that the more awkward or extreme the posture was for any specific body part, the more sensitive the final hazard level classification to any chance in its input value became.

JSI. JSI's data set was created applying the process used with RULA and REBA. 7,500 combinations were developed. Approximately, 76% of the combinations were scored as hazardous. Only about 24% of the combinations were considered safe. A Pearson's correlation test was run on the data set, and all variables were identified as sensitive. A simple linear regression model was made for the data set, using statistical software. Approximately, 54% of the effects of the model could be explained by its input variables. This value is sufficiently strong to consider this model as representative of the JSI and its variables behavior. The coefficients found in the model were modified adding the correlation effects obtained between input values and JSI score. JSI's critical variables, ordered from most to least critical were (1) *intensity of exertion*, which was selected as the most critical variable by Moore & Garg (1995), (2) *speed of work*, (3) *hand/wrist posture*, (4) *duration of exertion* and *efforts per minute*, and (5) *duration per day*. The most critical variables require, obviously, more attention and care when being assessed. It was noted that the most critical variables for JSI are the subjective factors (JSI is both objective and subjective). The objective part of the assessment corresponds to the least critical variables.

Preliminary Studies

Preliminary studies were conducted for RULA and REBA, and a complimentary study was performed for JSI.

RULA and REBA. RULA's and REBA's preliminary data sets were comprised of all their input variables, including modifiers. The size of the data sets increased to more than 180,000 combinations for RULA and more than 55,000 combinations for REBA. The effects of the modifiers hid some of the posture-based variables' effects and became sensitive, or even critical. Some of the posture-based variables identified as critical in the main study were not included in the preliminary group of critical variables. These preliminary results differed from those found in the main study because of the direct impact of the modifiers on the final scores. As its name defines it, a modifier is directly added to the scores to modify its value. They do not input information in the same manner the posture-based variables do. Therefore, their effects on the final scores become highly significant, hiding the effects from the posture-based variables.

After removing the modifiers, the data set was analyzed as described in the methodology for sensitive and critical variables detection. However, not only unitary disturbance was considered, but also paired changes. That is, all different combinations of pairs of posture-based variables were analyzed. The results were consistent with those obtained for individual variables' analyses. The effects of one variable grouped with a second variable were additive, producing the same results already presented. As previously stated, a posture that is close to the base case, was more sensitive to changes in input values when incrementing its awkwardness. It was encountered that if two critical variables increased in value simultaneously, the final hazard level also increased, in a proportional manner. Therefore, it is assumed that other grouped analyses will provide similar results.

JSI. The data set used in the complimentary study was exactly the same as the one used for the main evaluation. The difference between studies occurred when building the regression model. R^2 was found to be approximately 54% for a model of 7,500 combinations but it had only six degrees of freedom. In order to add degrees of freedom to the model and try to obtain a larger coefficient of determination, new variables consisting of the square of the input variables were also included. After doing so, the identical R^2 was found. The data set was left with only the six initial input variables and the complimentary study was discarded.

A summary of the results obtained for both preliminary studies and the JSI's complimentary analysis are offered in Appendix (I).

DISCUSSION

Karhu et al (1977) consider simplicity and exactitude as the main criteria to select an ergonomic assessment tool. Simplicity could be translated as being user-friendly, and exactitude could be renamed as validity and accuracy. RULA, REBA, and JSI are considered user-friendly and simple to use by an untrained evaluator. RULA and JSI were identified as valid for some specific jobs by McAttamney & Corlett (1993), Li & Buckle (1995), and Stephens et al (2006). The sensitivity analysis performed in this investigation confirmed that the validity (and accuracy) of the tool will directly depend on the validity (and accuracy) of the values collected for its input variables, as suggested by Faragasanu & Kumar (2002), when defining the validity of a tool. The tool will only produce valid outcomes if the input values are valid,. For this reason, conducting a study similar to the one presented here, to determine the variables that must be valid and accurate in order to obtain valid results, becomes imperative.

Various researchers have already addressed the importance of accurately assessing input values to obtain valid results when conducting an ergonomic intervention, and the need for training when considering critical variables on such evaluation (Waters et al, 1997; Lapièrre et al, 2005; Faragasanu & Kumar, 2002). Nonetheless, no study was found similar to the one described in this document. To date, the tools have been described in terms of validity after conducting experiments in which observers or self-reporters used subjective estimations as inputs for all the variables required by the tool and computed the final outcomes following the tool's methodology. The validity of the tool was measured comparing the empirical results with the real values, measured by using devices, trained practitioners, etc. All input variables were considered, thus, as having the same importance and criticality and equal time and efforts were assumed to be required for all of them. However, after conducting this study, it was found that assuming all input variables as equivalent regarding their importance and impact on final scores was an incorrect approach. Evaluation of RULA should begin with upper arm posture assessment while evaluation of REBA should start with trunk posture assessment, and last, evaluation of JSI should focus on intensity of exertion estimation.

Techniques Used for Sensitivity Analysis:

This study does not contend to change the procedure to measure validity of a subjective tool. Its objective was to identify the main points of attention, caution, and training (if necessary) when gathering input information for any of the three ergonomic assessment tools evaluated. Using techniques which are not commonly applied in the ergonomic assessment field, but intensively used in finance and optimization, the brute force method and simple statistical analyses such as correlation tests and a linear regression model, aided this study's main objective.

Statistical Analysis:

The data sets were statistically analyzed to calculate both frequencies and correlations. The correlations were used to identify the sensitive variables for each tool and the absolute and relative frequencies were inputs for the base case computation.

The base cases calculated had final hazard levels that lay within the group of scores with highest relative frequencies since a base case is, essentially, the representation of expected values. The expected final scores described a hazardous job that required rapid changes (RULA), a medium hazard level (REBA), and a hazardous job (JSI). These results could also have been inferred, from observation of the frequencies encountered (from which the base case was derived). The proportion of jobs being classified as safe for the three tools is relatively low, when compared to the proportions of hazardous jobs. For RULA, only 0.81% of the total combinations describe a safe job, and adding the probability of finding a job that requires further analysis (scores 3 and 4); the total proportion is not greater than 21%. For REBA, only 1.30% of the total combinations describe a safe job. If safe and low hazard jobs are added, less than 12% is obtained. Finally, for JSI, only 24.35% of the data set represents safe working conditions.

It is obvious that the greatest proportions of combinations describe jobs with higher levels of hazard. Although these statistics do not reflect the general work environment (because the levels of hazards on the job will depend on the types of jobs analyzed), it suggests that it may not be very likely to find safe jobs. In order to identify a task or activity as “safe”, it is required to have neutral postures, or close to neutral, for the majority of body parts studied. If it is considered that a job is comprised of several tasks or activities, in order to have a “safe job”, it is necessary to have a majority of safe tasks and activities.

Perhaps before the study and evaluation of a tool’s validity is continued, it is necessary to study and evaluate the tool itself, to determine if the conditions under which a job reaches a hazard level are too conservative, significantly restricting the probability of finding a safe job. However, a very conservative approach could eliminate the possibility of detecting minor changes and improvements in working conditions.

Limitations and Further Research

This investigation provides valuable information for practitioners when deciding levels of research or accuracy required for the evaluators, if RULA, REBA, and/or JSI are used during an ergonomic assessment. However, it is only the beginning of the analysis of input variables of subjective ergonomic assessment tools. For this study, two techniques were used to perform a sensitivity analysis, which were simple to apply and understand. They may not be the only techniques that could be used for such evaluation and therefore, it would be adequate to continue studying these types of tools with diverse methods and techniques that are used not only in the ergonomics field but from other disciplines such as finance and economics, statistics, computer science, etc. In addition, it is recommended to extend the current research conducted for RULA, REBA, and JSI to other ergonomic subjective assessment tools, expanding and modifying the selection criteria established in the first stages of this investigation. Moreover, it would be interesting to observe the effects of the critical variables' changes on the final hazard level classification when the general body posture is not assumed to be close to the expected value. Postures close to neutral or near the extremes may change the results obtained in this study.

Self-Reporting

This study was conducted with the purpose of finding and ranking the critical variables for three ergonomic assessment tools, RULA, REBA, and JSI, which are predominantly subjective in nature. However, the results of this evaluation are not only applicable when selecting the variables to focus on when performing an ergonomic assessment. It is also useful when trying to evaluate how appropriate self-reporting would be if used during an assessment.

JSI's most critical variables were found to be the subjective contribution to the tool. The most critical variables include categories of alternatives related to intensity of exertion (light, somewhat hard, hard, very hard, near maximal), speed of work (very slow, slow, fair, fast, very fast), and hand and wrist posture (very good, good, fair, bad, very bad) which allow the self-reporter to select the values that best represent the conditions under he/she has to do the job. Previous literature has referred to subjective ergonomic assessment tools as being successful when trying to gather information about musculoskeletal discomfort (Joines & Sommerich, 2001) and by providing valuable insight into working conditions that may not be detected by other methods (Marley & Kumar, 1996: Woodcook, 1986; Ramsay, 1993; Andrews et al, 1996, Faragasanu & Kumar, 2002). The variables that most affect JSI's final scores are highly subjective and directly related to levels of discomfort. Therefore, it could be thought that the assessment of this input information may achieve acceptable levels of validity and accuracy that will ensure validity and accuracy of outcomes. This will also be a strong benefit of self-reporting while using this ergonomic assessment tool. JSI has already been identified as a valid and reliable tool (Moore & Garg, 1995; Stephens et al, 2006). For this reason, the results found in this study provide valuable additional information to practitioners when trying to apply the JSI methodology by means of self-assessment. These results help focus the worker training on task or activity self-reporting, in order to ensure that the critical values obtained will reflect the real conditions of the job under analysis.

Self-reporting strongly depends on its validity (Lapièrre et al, 2005), confirming the basis of this study and the detected need for identifying RULA's, REBA's and JSI's critical variables. This investigation provides an ordered list of critical variables, from most to least critical, for each of the three tools in the evaluation. Because it is known which variables cause the most impact on hazard level determination, methods to ensure accuracy and validity during their assessment can be successfully developed and implemented. Training for the self-reporter, and examination of the input values he/she would provide to describe the job, would target the critical postures. Although the ideal situation would be to have a self-reporter accurately assess every input variable, ensuring that the critical variables have been successfully assessed will offer a better understanding of the real working conditions, achieving one of the most important advantages of well-applied self-reporting, as described by Marley & Kumar (1996), Woodcook (1986), Ramsay (1993), Andrews et al (1996), and Faragasanu & Kumar (2002). Moreover, it could be more cost effective to focus only on the few variables that affect the final score the most, instead of focusing on the entire group of variables, when some of their changes may not affect the final outcome.

RULA's and REBA's posture-based variables may be assessed by means of self-reporting. However, the level of accuracy and validity achieved by means of self-assessment may be affected by biased estimations, as suggested by Jacobs (1998) and Li

& Buckle (1999). For this reason, it is imperative to determine, by empirical methods, if the worker is able to self-assess his/her critical postures.

CONCLUSIONS

The scope of this study was limited to only detect critical variables for the tools evaluated, considering the exclusion of the tools' modifiers. The critical variables for each tool were successfully identified. It is recommended that training for the observer or the worker (if self-reporting) focus on RULA's, REBA's, and JSI's most critical variables. Special attention to the subjective component of the assessment that contributes to the JSI score is required. Similar focus on the upper arm posture during RULA application, and on neck posture while using REBA in an ergonomic assessment, is important.

Several attempts were made to improve the results of this study. Preliminary and complimentary studies were conducted to determine if grouped changes (for RULA and REBA) provided different results for the final hazard level classification, and to strengthen JSI's simple linear regression model. Additive effects could be inferred from the grouped analysis and no improvements were found for JSI. Therefore, it can be concluded that the study provides the best results possible, considering its scope and limitations.

Further studies are suggested in order to determine how robust these tools (RULA, REBA, and JSI) are to detect and evaluate improvement or changes made to a job, and to expand such evaluations to other ergonomic assessment tools used in industry.

Furthermore, it is recommended that an empirical study to determine how effective workers are at self-reporting the critical variables found for RULA, REBA, and JSI, be conducted.

The results obtained in this study are important and should be used in industrial environments when performing subjective ergonomic assessments. The requirements for training and the selection of the tools to use should consider the critical levels encountered for RULA, REBA, and JSI, because of the direct and significant dependency of the final scores on the critical variables found for them. Practitioners need a basis for preparing effective self-reporting evaluators when using ergonomic assessment tools.

REFERENCES

American Conference of Governmental Industrial Hygienists (ACGIH). (2001). *Threshold limit values and biological exposure indices for 2001*. Cincinnati: ACGIH.

American Conference of Governmental Industrial Hygienists (ACGIH). (2001). *Threshold Limit Values for Lifting*. Cincinnati: ACGIH.

Andrews, D.M., Norman R.W., & Wells, R.P. (1996). Accuracy and repeatability of low back spine compression force estimates from self-reports of body postures during load handling. *International Journal of Industrial Ergonomics, 18,* 251-260.

Bernard, T.E. (2001). Rapid Entire Body Assessment (REBA). [form]. http://hsc.usf.edu/~tbernard/HollowHills/REBA_M11.pdf

Bernard, T.E. (2002). WISHA lifting analysis [form]. *State of Washington Department of Labor and Industrial Ergonomics Rule.* http://www.hsc.usf.edu/~tbernard/HollowHills/WISHA_Lifting.pdf

Bernard, T.E. (2002). WISHA hand-arm vibration analysis [form]. *State of Washington Department of Labor and Industrial Ergonomics Rule.* http://www.hsc.usf.edu/~tbernard/HollowHills/WISHA_HAV.pdf

Bernard, T.E. (2002). WISHA Checklist for work-related musculoskeletal disorders [form]. *State of Washington Department of Labor and Industrial Ergonomics Rule.* http://www.hsc.usf.edu/~tbernard/HollowHills/WISHA_WMSD_Checklist.pdf

Borg G. (1982). Psychological bases of perceived exertion. *Medicine and Science in Sports and Exercise, 14*(5), 377-381.

Brigham, E.F., & Ehrhart, M.C. (2002). *Financial Management, Theory and Practice, tenth edition.* USA: Southwestern.

Buchholz, B., Paquet, V., Punnet, L., Lee, D., & Moir, S. (1996). PATH: a work sampling-based approach to ergonomic job analysis for construction and other non-repetitive work. *Applied Ergonomics, 27*(3), 177-187.

Chaffin D.B., Anderson, G.B.J., & Martin, B. (1999). *Occupational Biomechanics, third edition.* USA: Wiley and Sons.

Chien, H.C., & Tseng, C.H. (2004). An automatic transmission for bicycles: a simulation. *International Journal of Industrial Ergonomics, 33,* 123-132.

Conover, W.J. (1999). *Practical non-parametric statistics, third edition.* USA: John Wiley & Sons, Inc.

Dempsey, P.G. (2002). Usability of the revised NIOSH lifting equation. *Ergonomics, 45*(12), 817-828.

Dempsey, P.G., McGorry, R.W., & Maynard, W.S. (2005). A survey of tools and methods used by certified professional ergonomists. *Applied Ergonomics, 36,* 489-503.

Devore, J.L. (2000). *Probability and Statistics for Engineering and the Sciences, fifth edition.* USA: Duxbury.

Dunker, A.M., Yarwoord, G., Ortmann, J.P., & Wilson, G.M. (2002). The decoupled direct method for sensitivity analysis in a three-dimensional air quality model: implementation, accuracy, and efficiency. *Environmental Science and Technology,* *36*(13), 2965-2976.

Evans, J.R., & Olson, D.L. (2003) *Statistics, Data Analysis, and Decision Modeling, second edition.* USA: Prentice Hall.

Faragasanu, M., & Kumar, S. (2002). Measurement instruments and data collection: a consideration of constructs and biases in ergonomics research. *International Journal of Industrial Ergonomics, 30,* 355-369.

Hedge, Alan (2000). RULA Employee assessment worksheet [form]. http://ergo.human.cornell.edu/Pub/AHquest/CURULA.pdf

Hignett, S., & McAtamney, L. (2000). Rapid entire body assessment (REBA). *Applied Ergonomics, 31,* 201-205.

Jacobs, J.A. (1998). Measuring time at work: are self-reports accurate? *Monthly Labor Review, December,* 42-53.

Jantz, C.A. & Goetz, S.J. (2005). Analysis of scale dependencies in an urban-use-change model. *International Journal of Geographical Information Science, 19*(2), 217-241.

Joines, S.M.B., & Sommerich, C.M. (2001). Comparison of self-assessment and partnered-assessment as cost-effective alternative methods for office workstation evaluation. *International Journal of Industrial Ergonomics, 28,* 327-340.

Juul-Kristensen, B., Fallentin, N., & Ekdahl, C. (1997). Criteria for classification of posture in repetitive work by observation methods: a review. *International Journal of Industrial Ergonomics, 19,* 397-411.

Karhu, O., Kansi, P., & Kuorinka, I. (1977). Correcting working postures in industry: a practical method for analysis. *Applied Ergonomics,* 8(4), 199-201.

Kerlinger, F.N. (1973). *Foundations of Behavioral Research, second edition.* USA: Holt, Rinehart and Winston, Inc.

Lapièrre, E., Messing, K., Couture, V., & Stock, S. (2005). Validation of questions on working posture among those who stand during most of the work day. *International Journal of Industrial Ergonomics, 35,* 371-378.

Li, G., & Buckle, P. (1999). Current techniques for assessing physical exposure to work-related musculoskeletal risks, with emphasis on posture-based methods. *Ergonomics, 42*(5), 674-695.

Marley, R.J., & Kumar, N. (1996). An improved musculoskeletal discomfort assessment tool. *International Journal of Industrial Ergonomics, 17,* 21-27.

McAtamney, L. & Corlett, E.N. (1993). RULA: a survey method for the investigation of work-related upper limb disorders. *Applied Ergonomics, 24*(2), 91-99

Moore, J.S., & Garg, A. (1995). The strain index: a proposed method to analyze job for risks of distal upper extremity disorders. *American Industrial Hygiene Association Journal, 56,* 443-458.

Moore, J.S., Rucker, N.P., & Knowx K. (2001). Validity of generic risk factors and the strain index for predicting non-traumatic distal upper extremity disorders. *American Industrial Hygiene Association Journal, 62,* 229-235.

OSHA Screening Tool – VDT Checklist. [Form]. http://www.ecu.edu/oehs/ERGOPAge/Basicscreeningtool.doc

Pan, C.S., Gardner, L. I., Landsittel, D.P., Hendricks, S.A., Chiou, S.S., & Punnett, L. (1999). Ergonomics exposure assessment: an application of the PATH systematic observation method to retail workers. *International Journal of Environmental Health, 5,* 79-87.

Park, C.S. (2002). *Contemporary Engineering Economics, third edition.* USA: Prentice Hall.

Ramsay, Jr., G.F. (1993). Using self-administered work sampling in a state agency. *Industrial Engineering, 25*(2), 44-45.

Rodgers, S.H. (1992). A functional job evaluation technique in ergonomics. *Occupational Medicine: State of the Arts Reviews, 7*(4), 679-711.

Rodgers, S.H. (1988). Job evaluation in worker fitness determination. *Occupational Medicine: State of the Arts Reviews, 3*(2), 219-239.

Snook, S.H. & Ciriello, V.M. (1991). The design of manual handling tasks: revised tables of maximum acceptable weights and forces. *Ergonomics, 34*(9), 1197-1213.

Stephens, J.P., Vos, G.A., Stevens, Jr., E.D., & Moore, S. (2006). Test-retest repeatability of the Strain Index. *Applied Ergonomics, 37,* 275-281.

Waters, T.R., Baron, S.L., & Kemmlert, K. (1998). Accuracy of measurements for the revised NIOSH Lifting Equation. *Applied Ergonomics, 29*(6), 433-438.

Waters, T.R., Putz-Anderson, V., & Baron, S. (1997). Ergonomic tools for evaluating manual material handling jobs. *Advances in Occupational Ergonomics and Safety II.* USA: IOS Press and Ohmsha.

Waters, T.R., Putz-Anderson, V., Garg, A., & Fine, L.J. (1993). Revised NIOSH equation for the design and evaluation of manual lifting tasks. *Ergonomics, 36*(7), 749-776.

Winnemuller, L.L., Spielholz, P.O., Daniell, W.E., & Kaufman, J.D. (2004). Comparison of ergonomist, supervisor, and worker assessments of work-related musculoskeletal risk factors. *Journal of Occupational and Environmental Hygiene, 1,* 414-422.

Woodcock, K. (1986). Ergonomic self-reporting: its role, decision criteria, and experiences with a prototype. *Proceedings of the 19th Annual Conference of the Human Factors Association of Canada.*

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APPENDICES

Appendix A. Description of Ergonomic Assessment Tools

Tool	Description	Validity, Accuracy, Limitations	Risk Factors Evaluated	Areas of Body Addressed
Revised NIOSH Lifting Equation	Assessment tool design to establish limits on lifting and lowering tasks and determine the recommended weight limit. The tool assumes two handed, smooth, in front of the body, hands at the same height or level, moderate-width loads, and evenly distributed load between hands. Environmental conditions must be within the allowable limits. Analysis in the saggital plane.	Not fully validated. Small inter-observer variability, especially for horizontal distances (most important factor). Training is needed to increase accuracy. Poor accuracy in coupling and asymmetric variables. Difficulties when measuring reference points for origin and destination of lift. The higher the level of complexity of the task, the lower the accuracy. Difficulties when following the algorithm to rate coupling. Difficulties when dividing the job in tasks and subtasks to perform the assessment. Assessment of tasks may be extrapolated to the entire job, depending on its complexity. The valid use may be limited to design, not risk assessment. Not applicable in one-handed lifts, lifting while seating and kneeling, in a constraint or restricted work space, lifting unstable loads, wheelbarrows and shovels, and pushing, pulling and carrying.	1. Force 2. Repetition 3. Awkward postures 4. Coupling conditions 5. Mechanical stress	Body in general. There is no assessment of specific body parts conditions.
Rapid Upper Limb Assessment (RULA)	It is a screening tool which assesses levels of risk mainly for sedentary workers. RULA was developed to investigate the exposure of individual workers to risk factors associated with work related upper limb disorders. The method uses diagrams of body postures and three scoring tables to provide the evaluation. RULA is based on OWAS. Analysis in the saggital plane.	RULA has been only validated for a few types of jobs, such as computer users and sewing machine operators. It requires no special equipment; it can also be done in confined spaces without workforce disruption. It is needed to assess the whole region in the body as well as the individual body parts. Confounding factors that must be included in the analysis are age and experience, workplace environment, and psychosocial variables.	1. Force 2. Repetition 3. Awkward postures	1. Arm 2. Wrist 3. Neck 4. Trunk 5. Leg

Rapid Entire Body Assessment (REBA)	Tool designed specifically to be sensitive to the type of unpredictable working postures found in health care and other service industries. It incorporates the dynamic and static loading factors, human-load interface (coupling), and a new concept of gravity-assisted upper limb position. It provides a scoring system for muscle activity caused by static, dynamic, rapid changing or unstable postures. 144 posture combinations. Tool based on NIOSH lifting equation, rated perceived exertion, body part discomfort survey, RULA, and OWAS.	REBA has not been validated. Lab setting experiment needed. Good inter-observer reliability except for upper arm category. REBA is not too sensitive to lower extremity postures.	1. Awkward postures 2. Force 3. Coupling conditions 4. Repetition	1.Trunk 2. Neck 3. Leg 4. Upper Arm 5. Lower Arm 6. Wrist
Ovako Working Posture Analysis System (OWAS)	The method consists of 2 parts: Observational technique for evaluating working postures. Set of criteria for the redesign of working methods and places. The method is based on work sampling (variable or constant interval sampling) which provides the frequency and time spent in each work posture. The classification is based on the subjective evaluation of discomfort and the health effect of each posture, as well as the practicability of observational analysis. It is comprised of 72 postures. Method extensively used in the steel company [10]. OWAS categorizes posture using codes for the back, arms and legs, and another code to categorize load/effort. The scientific basis of OWAS derives from work sampling.	The inter-worker and inter-observer reliability is fairly good. Tool has not been validated. The OWAS method provided a basis for recording worker posture, but lacked a systematic link between posture and worker activity.	1. Awkward postures.	1. Back 2. Upper limbs. 3. Lower limbs.

Posture, Activity, Tools and Handling (PATH)	PATH is a work sampling based approach, developed to characterize the ergonomic hazards at construction and other non-repetitive work. The posture codes are based on OWAS and other codes included describing work activity, tool use, loads handled and grasp type. PATH incorporates OWAS with a systematic link between posture and worker activity. Tool applicable to mining and agriculture. Saggital plane considered. The method is applicable in studies that require only fair crude distinctions among biomechanical stressor variables. The PATH method is based on OWAS, which estimates the proportions of time spent in working postures. The scientific basis of PATH and OWAS methods derives from work sampling. PATH is task oriented: ergonomic exposures are assumed to be a function of the tasks performed, so that an exposure profile for an individual is based on the distribution of exposures within a task and the proportion of time the individual spends performing the task.	The validity was tested only for trunk postures. Tool has not been validated. Intra-observer agreement is good for arm and leg postures, but not good for neck and trunk. Inter-observer agreement less than 80%. Well suited for characterization of ergonomic risks to the lower extremity, back, neck, and shoulders. It does not characterize ergonomic exposures to the distal upper extremity. PATH is better suited to non-repetitive work with long work cycles.	1. Awkward postures 2. Force	1. Trunk 2. Legs 3. Arms 4. Neck
Liberty Mutual Tables for Lifting, Carrying, Pushing and Pulling (Snook Tables)	The guidelines developed are for the evaluation and design of manual handling tasks, and they are consistent with the worker capabilities and limitations. Since the physiological cost of the combined task will be greater than the cost for individual components, it should be recognized that some of the combined tasks may exceed recommended physiological criteria for extended periods of time. The tables are intended to assist industry in the evaluation and design of manual handling tasks.	No validity studies have been performed. Subjective measurement. The values not included in the tables need to be inter- or extrapolated, affecting accuracy.	1. Force 2. Repetition 3. Awkward postures (when classifying the task in three categories).	Three sections of the body: 1. Floor level to knuckle. 2. Knuckle to shoulder. 3. Shoulder to arm reach.

Job Strain Index (JSI)	Semi-quantitative job analysis methodology which involves the measurement of estimation 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). The objective of the JSI is to discriminate between jobs that do versus jobs that do not expose workers to musculoskeletal risk factors (task variables) that cause different types of distal upper extremity disorders. The JSI is a semi-quantitative job analysis methodology that results in a numerical score (SI score) that is believed to correlate with the risk of developing distal upper extremity disorders. The index is based on multiplicative interactions among its task variables, consistent with physiological, biomechanical, and epidemiological principles. The estimation of intensity of exertion is similar to the Borg CR-10 scale. JSI is similar to the revised NIOSH guide for manual lifting.	Preliminary testing suggests that the methodology accurately identifies jobs associated with distal upper extremity disorders versus jobs that are not; however, large-scale studies are needed to validate and update the proposed methodology. Three of the six task variables rely on the analyst's subjective judgment (intensity of exertion, posture, and speed of exertion), which may cause differences in ratings from analyst bias, inexperience, and/or poor judgment. The proposed methodology should be subjected to further evaluation. Inter-rater consistency and test-retest reliability have not been formally assessed. The predictive validity of the methodology should be further evaluated with a prospective longitudinal study, or, if retrospective, in a study where the job analysts are blinded to the outcome measures. At this time, there is no proposed method for multiple task analysis. Currently, each task of a multitask job can be analyzed separately by considering duration of task per day. Not applicable to vibration related disorders, for disorders of the shoulder, shoulder girdle, neck or back. JSI evaluates jobs, not individuals.	1. Force 2. Repetition 3. Awkward posture	1. Hand 2. Wrist
ACGIH TLV for Hand Activity	Tool offered for the evaluation of job risk factors associated with musculoskeletal disorders of the hand and wrist. The evaluation is based on an assessment of hand activity and the level of effort for a typical posture while performing a short cycle task. The tool used the Borg scale to estimate the normalized peak force, and 10 scores for hand activity level rating.	It is based on a qualitative scale (Borg scale or Moore-Garg observational methods) which makes it highly subjective and with propensity to observer bias. It has not been validated.	1. Force 2. Repetition	1. Hand 2. Wrist 3. Forearm

ACGIH TLV Screening Tool for Lifting	Tool developed to determine if the task is within or exceeding the established TLV's. The tool utilizes tables, and each of them consists of 12 zones. Each table describes the type of lifting based on the conditions for the task, frequency, and distance between load and body, for standard and lower screening limits.	It has not been validated. The description of postures for scoring the task is very general, which can influence bias or subjective selections.	1. Force 2. Repetition 3. Awkward postures	1. Sections of the body divided in floor, low, chest, high, for lifting.
Rodgers Muscle Fatigue Analysis	Assessment of the amount of fatigue that accumulates in muscles during various work patterns within five minutes of work.	The categories used as levels for effort, duration and frequency are open to observer bias and are highly subjective. No specific criteria to determine levels for risk factors. Tool not validated.	1. Force 2. Repetition 3. Frequency 4. Awkward posture	1. Neck 2. Shoulders 3. Back 4. Arms 5. Elbows 6. Wrists 7. Hands 8. Fingers 9. Legs 10. Knees 11. Ankles 12. Feet 13. Toes
Borg Scale for Rating of Perceived Exertion	Subjective assessment of level of effort, considering also the influence of posture. The tool uses a 10 level scale to differentiate categories for force required.	Tool not validated. It is entirely subjective, based on the worker's perception of the task (ideally, the weakest worker).	1. Force 2. Awkward posture	1. Body in general
OSHA Screening Tool – VDT Checklist	Qualitative tool not validated. It estimates the risk for tasks based on qualitative assessment of job conditions.	Highly subjective. The postural conditions are not described in detail. Tool that may be used as reference or guide.	1. Repetition 2. Force 3. Awkward postures. 3. Mechanical stress. 4. Vibration.	1. Neck 2. Shoulders 3. Hands 4. Wrists 5. Arms 6. Back 7. Trunk 8. Hips 9. Legs 10. Knees 11. Ankles
WISHA Lifting Analysis	Tool that evaluates the level of hazard existing in a job which involves lifting. The tool examines the unadjusted weight limit and the recommended weight for the employee to lift.	It evaluates the worker performing the job, not the job itself. The tool has not been validated.	1. Force 2. Repetition 3.Awkward posture	1. Back 2. Shoulders 3. Hands 4. Above shoulder 5. Waist to shoulder 6. Knee to waist. 7. Below knee
WISHA Hand-Arm Vibration Analysis	Qualitative tool that estimates the level of hazard in jobs regarding hand-arm activities.	It is entirely qualitative, which increases the tendency to biased subjective observations. The tool is not validated. The tool does not consider hand-arm postures.	1. Vibration 2. Repetition	1. Hands 2. Wrists 3. Elbows

WISHA Checklist for Work-Related Musculoskeletal Disorders	Checklist (qualitative tool) that provides different body postures, task duration and conditions to determine the level of hazard the job involves. The tool includes the WISHA lifting analysis and WISHA Hand-Arm vibration analysis.	As same as any other qualitative tool, it is subject to observer's bias and subjective appreciations. The tools have not been validated. It does not consider coupling conditions.	1. Awkward posture. 2. Force 3. Repetition 4. Mechanical stress 5. Vibration	1. Shoulders 2. Neck 3. back 4. Knees 5.Arms 6. Wrists 7. Hands 8. Elbows

Table 21.Description of ergonomic assessment tools

Tool	Input Information Required	Output Information Obtained	Sensitivity	Self-Reporting
Revised NIOSH Lifting Equation	It is most sensitive to repetition and horizontal distances when handling loads.	1. Weight of load (average and maximum). 2. Hand location in horizontal and vertical references, at the origin and destination. 3. Asymmetry angle for the waist respect to the saggital plane, in the origin and destination. 4. Number of lifts per time unit. 5. Duration of the task. 6. Coupling conditions for the load.	1. Recommended weight limit for the task. 2. Lifting index for the task (level of risk for the task).	It is difficult to self-report the measures needed as input for the assessment. Variables such as frequency, coupling, and task duration may be self-reported more easily.
Rapid Upper Limb Assessment (RULA)	It is most sensitive to postures of arm, wrist, elbow, neck and trunk.	1. Upper and lower arm position. 2. Wrist position and twisting. 3. Duration for the adoption of the posture. 4. Load weight. 5. Frequency of weight holding. 6. Neck position. 7. Trunk position. 8. Leg position.	1. Score for hazard exposure level, which may vary from 1 to 7.	Almost all the variables required as input information can be self-reported. Variables such as load weight can be obtained as exact measures.
Rapid Entire Body Assessment (REBA)	Most sensitive to upper extremity postures.	1. Trunk position. 2. Neck position. 3. Legs position. 4. Upper arm position 5. Lower arm position. 6. Wrist position. 7. Load weight. 8. Coupling conditions. 9. Frequency for postures.	1. Score for hazard exposure level, which may vary from 0 to 4.	Almost all the variables used as input information can be gathered by means of self-reporting. Load weight can be accurately measured without the use of self-assessment.
Ovako Working Posture Analysis System (OWAS)	The tool is handy and easy to use. The postures are very general and do not involve high sensitivity.	1. Back position 2. Upper limbs position. 3. Lower limbs position.	1. Score for hazard exposure level for body postures, varying from 1 to 4.	All variables required as input information can be self-assessed.

Posture, Activity, Tools and Handling (PATH)	It is most sensitive to lower extremity, back, neck and shoulders.	1. Trunk position 2. Neck position 3. Leg position 4. Arms position. 5. Type of activity 6. Tool weight. 7. Load weight.	1. The observed frequencies of specific postures provide estimated of the proportion of time that workers are exposed to each of these factors.	Type of activity and body postures may be self-reported. Load and tool weights can be measured or gathered from standards.
Liberty Mutual Tables for Lifting, Carrying, Pushing and Pulling (Snook Tables)	It is most sensitive to force and repetition.	1. Task conditions (lifting, lowering, pushing, pulling, and carrying). 2. Load dimensions and weight. 3. Distances required for the task. 4. Percentage of industrial population. 5. Frequency for the task.	1. Maximum acceptable weight for the task, for males and females.	Self-reporting can be included in the application of tools, because all the variables are needed to be assessed by the observer or worker. Only the weight can be directly measured.
Job Strain Index (JSI)	The tool is most sensitive to intensity of exertion (the most critical variable), as well as efforts per minute. JSI is sensitive to hand/wrist posture.	1. Intensity of exertion. 2. Duration of exertion. 3. Exertions per minute. 4. Hand/wrist posture. 5. Speed of work. 6. Duration of task per day.	1. Score which determines how hazardous the job is (less than 5 safe, greater than five, problem).	The variables can be easily self-assessed.
ACGIH TLV for Hand Activity	Most sensitive to force and repetition.	1. Rating for force and repetition (hand activity level rating) 2. Estimated normalized peak force	1. Threshold limit value. 2. Action limit.	All ratings required as input information can be self-assessed.
ACGIH TLV Screening Tool for Lifting	Sensitive to repetition, force, and awkward postures.	1. Load weight 2. Body posture when performing the task. 3. Frequency of lifts 4. Task duration 5. Environmental conditions 6. Task conditions (one- or two-handed job) 7. Load condition	1. Threshold limit value for lifting.	The choices may be self-reported. Variables such as load weight, task duration and load conditions can be directly measured.
Rodgers Muscle Fatigue Analysis	Very sensitive to force and posture of body parts and body in general. Most sensitive to awkward postures.	1. Force and postural need for each task. 2. Duration of effort. 3. Frequency of task.	1. Score for potential for fatigue and priority for modifications and change.	Postural conditions can be self-reported, as well as durations and frequency.
Borg Scale for Rating of Perceived Exertion	Sensitive to force, but not in depth. Posture is only considered to increase level of effort, if necessary.	1. Worker's perception of effort required for task. 2. Posture needed to perform task.	1. Score for level of effort.	The tool uses self-reporting.
OSHA Screening Tool – VDT Checklist	Sensitive to all risk factors.	1. Frequency 2. Force required (load weight) 3. Task conditions 4. Body posture. 5. Requirement for using hands as tools. 6. Presence of vibration.	1. Score for VDT risk level	Variables used as input information can be easily self-reported.

WISHA Lifting Analysis	Sensitive to repetition, body posture and exertion.	1. Load weight. 2. Frequency of lifts. 3. Task duration. 4. Body posture when lifting. 5. Worker's weight. 6. Task conditions.	1. Level of hazard when comparing the adequate weight limit with the real weight lifted.	Input variables such as task conditions and body posture may be self-reported. Weights and duration of task can be directly measured.
WISHA Hand-Arm Vibration Analysis	Sensitive to vibration and repetition.	1. Tool type. 2. Task duration. 3. Vibration value for tool.	1. Level of hazard for the type of job the worker performs.	The values required as input variables can be directly measured. No self-reporting is needed.
WISHA Checklist for Work-Related Musculoskeletal Disorders	Most sensitive to posture and repetition.	1. Task conditions. 2. Task duration. 3. Body posture.	1. Classification for the task, if it has to be considered as Caution or Hazard, depending upon the choice for each variable and condition.	Self-assessment may be used for the estimation of all the variables.

Table 22. Description of ergonomic assessment tools (continuation)

Appendix B. Variables and Input Information

Tool	Variables	Input Information	Classification
Revised NIOSH Lifting Equation Provides the value of the recommended weight limit for lifting tasks and the number of times the actual weight exceeds this limit, result of the computation of values for the variables and the use of the lifting equation.	Horizontal Multiplier	Horizontal distance from the ankles (in) for origin and destination.	Quantitative. Objective assessment. Variables mainly associated to forces, distances and duration.
	Vertical Multiplier	Vertical distance from the floor (in) for origin and destination.	
	Distance Multiplier	Vertical distance load moved (in).	
	Asymmetry Multiplier	Angle of symmetry between the hands and feet (°).	
	Frequency Multiplier	Combination of lifts/min and duration of task provided by table in the tool.	
	Coupling Multiplier	Selection between three categories: good, fair, and poor, described in a table provided by the tool.	
Rapid Upper Limb Assessment (RULA) Selects values for each variable in order to obtain scores from different tables the tool provides. Scores: 1-2: acceptable; 3-4: investigate further; 5-6: investigate further and change soon; 7: investigate and change immediately.	Upper Arm position	Shoulder Flexion: -20° to +20° Shoulder Extension: >-20° Shoulder Flexion: +20° to +45° Shoulder Flexion: +45° to 90° Shoulder Flexion: 90°+ Shoulder raised? Yes or No Upper arm abducted? Yes or No Arm supported? Yes or No Person leaning? Yes or No	Quantitative. Subjective assessment. Variables mainly associated to body postures.
	Lower Arm position	Elbow Flexion: 60° to 100° Elbow Flexion: 0° to -60 Elbow Flexion: 100°+ Arm Position (in transversal plane) Arm working across midline of body? Yes or No Arm out to side of body? Yes or No	
	Wrist Position	Wrist Flexion: 0° Wrist Flexion: 0° to 15° Wrist Extension: 0° to 15° Wrist Deviation: Medial or Lateral	
	Wrist Twist	Wrist twisted mainly in mid-range? Yes or No Wrist twisted at or near end of twisting range) Yes or No	
	Muscle Use Score (Arm and Wrist Analysis)	Posture mainly static? Yes or No Action repeated 4 times per minute or more? Yes or No	
	Force/load (Arm and Wrist Analysis)	Load: <2 kg, 2-10 kg intermittent, 2-10 kg static or repeated, >10 kg or repeated or shocks.	
	Neck Position	Neck Flexion: 0° to 10° Neck Flexion: 10° to 20° Neck Flexion: 20°+ Neck extended? Yes or No Neck twisted? Yes or No	
	Trunk Position	Trunk well supported while seating? Yes or No Trunk Extension: 0° to -20° (standing or seated? Yes or No) Trunk Flexion: 0° to 20° Trunk Flexion: 20° to 60° Trunk Flexion: 60°+ Trunk twisted? Yes or No Trunk side-bending? Yes or No	
	Legs	Legs supported and balanced? Yes or No	

	Muscle Use Score (Neck, Trunk and Leg Analysis)	Posture mainly static? Yes or No Action repeated 4 times per minute or more? Yes or No	
	Force/Load (Neck, Trunk and Leg Analysis)	Load: <2 kg, 2-10 kg intermittent, 2-10 kg static or repeated, >10 kg or repeated or shocks.	
Rapid Entire Body Assessment (REBA) Selects values for each variable and according to them, scores from tables provided by the tool are chosen. Scores: 1: negligible; 2-3: low; 4-7: medium; 8-10: high; 11-15: very high.	Trunk Position	Trunk Upright? Yes or No Flexion: 0° to 20° or Extension: 0° to 20° Flexion: 20° to 60° or Extension >20° Flexion: >60° Back twisted or tilted to side? Yes or No	Quantitative. Subjective assessment. Variables mainly associated to body postures.
	Neck Position	Flexion: 0° to 20° Flexion: >20° or Extension: >20° Neck twisted or tilted to side? Yes or No	
	Legs Position	Bilateral with bearing, walk or sit? Yes or No Unilateral with bearing, unstable? Yes or No Knees Flexion: 30° to 60° Knees Flexion: >60°	
	Upper Arms (Shoulders) Position	Shoulder Flexion: 0° to 20° or Extension: 0° to 20° Shoulder Flexion: 20° to 45° or Extension: >20° Shoulder Flexion: 45° to 90° Shoulder Flexion: >90° Arm abducted or rotated? Yes or No Shoulder raised? Yes or No Arm supported? Yes or No	
	Lower Arms (Elbows) Position	Elbow Flexion: 60° to 100° Elbow Flexion: <60° or >100°	
	Wrists Position	Flexion: 0° to 15° or Extension: 0° to 15° Flexion: >15° or Extension: > 15° Wrist deviated or twisted? Yes or No	
	Load/Force	Weight: <5 kg (11 lb) Weight: 5-10 kg (11-22 lb) Weight: >10 kg (22 lb) Shock or rapid buildup? Yes or No	
	Activity Conditions	One or more parts static for longer than 1 min? Yes or No Repeat small range motions, more than 4 per min? Yes or No Rapid large changes in posture or unstable base? Yes or No	
	Coupling Conditions	Condition: good, fair, poor, unacceptable	
Ovako Working Posture Analysis System (OWAS) Tool based on work sampling, that focuses on postural conditions in order to determine the level of hazard an activity possesses. The combination of variables gives a total of 72 options for classification. A final score is obtained.	Back Posture	Straight (1); bent (2); straight and twisted (3); bent and twisted (4).	Qualitative. Subjective assessment. Variables mainly associated to body postures.
	Upper Limbs Posture	Both limbs on or below shoulder level (1); one limb on or above shoulder level (2); both limbs above shoulder level (3).	
	Lower Limbs Posture	Loading on both limbs, straight (1); loading on one limb, straight (2); loading on both limbs, bent (3); loading on one limb, net (4); loading on one limb, kneeling (5); body is moved by the limbs (6).	

Posture, Activity, Tools and Handling (PATH) The tool provides information about proportion of time spent in specific postures or with specific conditions that can be considered as hazardous or safe.	Trunk Posture	Forward Flexion, Lateral Bending and Twisting <20° Moderate Forward Flexion: 20° to 45° Severe Forward Flexion >45° Forward Flexion <20° and Lateral Bending or Twisting >20° Forward Flexion and Twisting >20°	Qualitative. Subjective assessment. Variables mainly associated to body postures and activity and tool conditions and characteristics.
	Legs Posture	Knee Flexion: < 35° One leg in air? Yes or No At Least One Knee Flexion: >35° Both Knees Flexion: >90° Walking? Yes or No At least one knee touching ground (kneeling)? Yes or No Worker seated, feet below buttocks? Yes or No Worker seated, feet at buttock height? Yes or No Working moving on hands and knees (crawling)? Yes or No Worker supported by something other than legs? Yes or No	
	Arms Posture	Both elbows below shoulder height? Yes or No One elbow above shoulder height? Yes or No Both elbows above shoulder height? Yes or No	
	Neck Posture	Flexion or Lateral Bending <30° or Twisting <45° Flexion or Lateral Bending >30° or Twisting: >45°	
	Activity	Divided in four subcategories: Manual material handling activities Activities common to most trades and operations Trade/operation specific activities Hand postures/activities	
	Tool Use	List of tools for each combination of trade and operation.	
	Handling	Load/weight of a tool, piece, or material handled.	
Liberty Mutual Tables for Lifting, Carrying, Pushing and Pulling (Snook Tables) Provides maximum values for weight that can be handled by workers according to the conditions stipulated by the variables.	Maximum Acceptable Weight of Lift for Males and Females (kg)	Load width (cm): dimension away from the body. Vertical distance of lift (cm). Percentage of industrial population. Frequency of lift (1 lift every x min): Floor level to knuckle height: x. Knuckle height to shoulder height: x. Shoulder height to arm reach: x.	Quantitative. Objective assessment. Variables mainly associated to forces, distances and duration.
	Maximum Acceptable Weight of Lower for Males and Females (kg)	Load width (cm): dimension away from the body. Vertical distance of lower (cm). Percentage of industrial population. Frequency of lower (1 lift every x min): Floor level to knuckle height: x. Knuckle height to shoulder height: x. Shoulder height to arm reach: x.	

	Maximum Acceptable Forces of Push for Males and Females (kg)	Height (cm): vertical distance from floor to hands. Percentage of industrial population. Frequency of push (1 push every x min): 2-1 m push: x. 7-6 m push: x. 15-2 m push: x. 30-5 m push: x. 45-7 m push: x. 61-0 m push: x. Other values can be obtained by means of interpolation or extrapolation.	
	Maximum Acceptable Forces of Pull for Males and Females (kg)	Height (cm): vertical distance from floor to hands. Percentage of industrial population. Frequency of pull (1 pull every x min): 2-1 m pull: x. 7-6 m pull: x. 15-2 m pull: x. 30-5 m pull: x. 45-7 m pull: x. 61-0 m pull: x. Other values can be obtained by means of interpolation or extrapolation.	
	Maximum Acceptable Forces for Carry (kg)	Height (cm): vertical distance from floor to hands. Percentage of industrial population. Frequency or carry (1 carry every x min): 2-1 m carry: x. 4-3 m carry: x. 8-5 m carry: x. Other values can be obtained by means of interpolation or extrapolation.	
Job Strain Index (JSI) Multiplies the factors to obtain a final score (SI). If SI is ≤5, the job can be identified as safe. Values for SI greater than 5 are classified as hazardous.	Intensity of Exertion	Type of exertion: light (1), somewhat hard (2), hard (3), very hard (4), near maximal (5).	Qualitative/Quantitative. Objective and subjective assessment, depending on the variable. Variables focused on conditions of exertion, task, and posture.
	Duration of Exertion	% of exertion during the cycle: <10% (1), 10-29% (2), 30-49% (3), 50-79% (4), ≥80% (5).	
	Efforts/Minute	Number of efforts per minute: < 4 (1), 4-8 (2), 9-14 (3), 15-19 (4), ≥20 (5).	
	Hand/Wrist Posture	Postural condition: very good (1), good (2), fair (3), bad (4), very bad (5).	
	Speed of Work	Velocity: very slow (1), slow (2), fair (3), fast (4), very fast (5).	
	Duration per Day	Time in hours: ≤ 1 (1), 1-2 (2), 2-4 (3), 4-8 (4), ≥8 (5).	
ACGIH TLV for Hand Activity Based on selections for the two variables considered and the computation of their ration, values for the Activity Level (AL) and Threshold Limit Values (TLV) can be obtained.	Hand Activity Level	Categories: continuous values from 0 to 10. Hand idle most of the time, no regular exertions (0); consistent conspicuous long pauses, or very slow motions (2); slow steady motion/exertions, frequent brief pauses (4); steady motion/exertion, infrequent pauses (6); rapid steady motion/exertions, no regular pauses (8); rapid steady motion/difficulty keeping up or continuous exertion (10).	Quantitative. Subjective assessment (although the estimations can be highly accurate). Variables focused on task conditions.
	Normalized Peak Force	Based on the Borg Scale (%MVC), from nothing at all (0), to extremely strong (10).	

ACGIH TLV Screening Tool for Lifting Checklist that provides information about the needs for further study of the task, based on the existence of significant risk factors, after selection of standard or lower screening limits. The standard and lower screening limits give the Threshold Limit Values (TLV) for the task (50th percentile).	Lifting Condition – Special Concern	Lifting frequency more than 360 lifts/hr? Yes or No Lifting tasks performed for longer than 8 hr/day? Yes or No Lifting or placing loads in trunk postures twisting >30°? Yes or No	Quantitative. Subjective assessment (although the estimations can be highly accurate) and mostly, objective assessment. Variables focused on task conditions, distances, and repetition and duration.
	Lifting Condition – Additional Risk: Lower Screening Limit (Gives criteria to determine if lower screening limits need to be used)	One-handed lifting? Yes or No Forward flexed trunk postures >30°? Yes or No Constrained overhead posture? Yes or No Lifting unstable objects? Yes or No Trunk Postures in which the normal curve in the low back is not maintained? Yes or No High heat and humidity? Yes or No	
	Standard Screening Limits: Infrequent Lifting (<2 hr/day and <120 lifts/day)	Diverse combinations for zones: High (52"-72"), Chest (32"-52"), Low (12"-32"), Floor (0"-12"); and Close (1"-12"), Middle (12"-24"), Far (24"-31").	
	Standard Screening Limits: Intermediate Lifting (>2 hr/day and <30 lifts/hr)	Diverse combinations for zones: High (52"-72"), Chest (32"-52"), Low (12"-32"), Floor (0"-12"); and Close (1"-12"), Middle (12"-24"), Far (24"-31").	
	Standard Screening Limits: Frequent Lifting (>2 hr/day and <360 lifts/hr)	Diverse combinations for zones: High (52"-72"), Chest (32"-52"), Low (12"-32"), Floor (0"-12"); and Close (1"-12"), Middle (12"-24"), Far (24"-31").	
	Lower Screening Limits: Infrequent Lifting (<2 hr/day and <120 lifts/day)	Diverse combinations for zones: High (52"-72"), Chest (32"-52"), Low (12"-32"), Floor (0"-12"); and Close (1"-12"), Middle (12"-24"), Far (24"-31").	
	Lower Screening Limits: Intermediate Lifting (>2 hr/day and <30 lifts/hr)	Diverse combinations for zones: High (52"-72"), Chest (32"-52"), Low (12"-32"), Floor (0"-12"); and Close (1"-12"), Middle (12"-24"), Far (24"-31").	
	Lower Screening Limits: Frequent Lifting (>2 hr/day and <360 lifts/hr)	Diverse combinations for zones: High (52"-72"), Chest (32"-52"), Low (12"-32"), Floor (0"-12"); and Close (1"-12"), Middle (12"-24"), Far (24"-31").	
Rodgers Muscle Fatigue Analysis Based on a combination of scores for the variables, the tool provides the level of fatigue the task can produce: low, moderate, high, very high.	Effort	Neck (light:1, moderate:2, heavy:3) Shoulders (light:1, moderate:2, heavy:3) Back (light:1, moderate:2, heavy:3) Arms/Elbows (light:1, moderate:2, heavy:3) Wrists/Hands/Fingers (light:1, moderate:2, heavy:3) Legs/Knees (light:1, moderate:2, heavy:3) Ankles/Feet/Toes (light:1, moderate:2, heavy:3)	Qualitative. Subjective assessment. Variables focused on exertion, duration and frequency of the task.
	Duration	Neck (light:1, moderate:2, heavy:3) Shoulders (light:1, moderate:2, heavy:3) Back (light:1, moderate:2, heavy:3) Arms/Elbows (light:1, moderate:2, heavy:3) Wrists/Hands/Fingers (light:1, moderate:2, heavy:3) Legs/Knees (light:1, moderate:2, heavy:3) Ankles/Feet/Toes (light:1, moderate:2, heavy:3)	

	Frequency	Neck (light:1, moderate:2, heavy:3) Shoulders (light:1, moderate:2, heavy:3) Back (light:1, moderate:2, heavy:3) Arms/Elbows (light:1, moderate:2, heavy:3) Wrists/Hands/Fingers (light:1, moderate:2, heavy:3) Legs/Knees (light:1, moderate:2, heavy:3) Ankles/Feet/Toes (light:1, moderate:2, heavy:3)	
Borg Scale of Perceived Exertion Based on the Maximum Voluntary Contraction (MVC) and using as reference the weakest worker or 70% of a sample mean, it provides a score for hazard classification, being 0 the lowest and 10 the highest (and most hazardous).	%MVC	0: Nothing at all (score: 0) 2: Extremely weak (score 0.5) 10: Very weak (score 1) 20: Weak (light) (score 2) 30: Moderate (score 3) 40: (score 4) 50: Strong (heavy) (score 5) 60: (score 6) 70: Very strong (score 7) 80: (score 8) 90: (score 9) 100: Extremely strong (almost maximal) (score 10)	Qualitative. Subjective assessment. Variables focused on exertion (worker's perception).
OSHA Screening Tool – VDT Checklist Checklist that provides the analyzer criteria to select the risk factors that are affecting the task and to which level or severity.	Repetition	Neck/Shoulder Hand/Wrist/Arm Back/Trunk/Hip Leg/Knee/Ankle	Qualitative. Subjective assessment. Variables focused on qualitative analysis of various risk factors.
	Force	Neck/Shoulder Hand/Wrist/Arm Back/Trunk/Hip Leg/Knee/Ankle	
	Awkward Postures	Neck/Shoulder Hand/Wrist/Arm Back/Trunk/Hip Leg/Knee/Ankle	
	Contact Stress	Neck/Shoulder Hand/Wrist/Arm Back/Trunk/Hip Leg/Knee/Ankle	
	Vibration	Neck/Shoulder Hand/Wrist/Arm Back/Trunk/Hip Leg/Knee/Ankle	
WISHA Lifting Analysis This part of the analysis is also included in the *WISHA Checklist for Work-Related Musculoskeletal Disorders*	Heavy, Frequent, or Awkward Lifting Back and Shoulders	Lifting ≥75 lb one or more times/day: caution Lifting ≥55 lb more than 10 times/day: caution Lifting >10 lb more than 2 times/min more than 2 hr/day: caution Lifting >25 lb above the shoulders, below the knees of at arm's length, more than 25 times/day: caution Actual weight greater than weight limit: hazard	Qualitative. Subjective assessment (although some variables can be measured or accurately estimated). Variables focused on qualitative analysis of various risk factors.
WISHA Hand-Arm Vibration Analysis This part of the analysis is also included in the *WISHA Checklist for Work-Related Musculoskeletal Disorders*	Moderate to High Hand-Arm Vibration	Using tools that have high vibration levels more than 30 min/day: caution Using tools that have moderate vibration levels more than 2 hr/day: caution Actual exposure time greater than hazard level exposure time: hazard	Qualitative. Subjective assessment (although some variables can be measured or accurately estimated). Variables focused on qualitative analysis of various risk factors.

WISHA Checklist for Work-Related Musculoskeletal Disorders Checklist that provides different criteria to the observer regarding diverse risk factors, in order to know if the conditions of the task represent caution or hazard.	Awkward Posture Shoulders, Neck, Back, Knees	More than 2 hr/day: caution More than 4 hr/day: hazard	Qualitative. Subjective assessment (although some variables can be measured or accurately estimated). Variables focused on qualitative analysis of various risk factors.
	High Hand Force – Pinch Arms, Wrists, Hands	More than 2 hr/day: caution More than 4 hr/day: hazard	
	High Hand Force – Grasp Arms, Wrists, Hands	More than 2 hr/day: caution More than 4 hr/day: hazard	
	Highly Repetitive Motion Neck, Shoulders, Elbows, Wrists, Hands	More than 2 hr/day: caution More than 6 hr/day: hazard	
	Repeated Impact Hands, Knees	More than 2 hr/day: caution Using the knee as a hammer >60 times/hr: hazard	
	Heavy, Frequent, or Awkward Lifting Back and Shoulders	Lifting $\geq$75 lb one or more times/day: caution Lifting $\geq$55 lb more than 10 times/day: caution Lifting >10 lb more than 2 times/min more than 2 hr/day: caution Lifting >25 lb above the shoulders, below the knees of at arm's length, more than 25 times/day: caution Actual weight greater than weight limit: hazard	
	Moderate to High Hand-Arm Vibration	Using tools that have high vibration levels more than 30 min/day: caution Using tools that have moderate vibration levels more than 2 hr/day: caution Actual exposure time greater than hazard level exposure time: hazard	

Table 23. Variables and input information

Appendix C. RULA Form

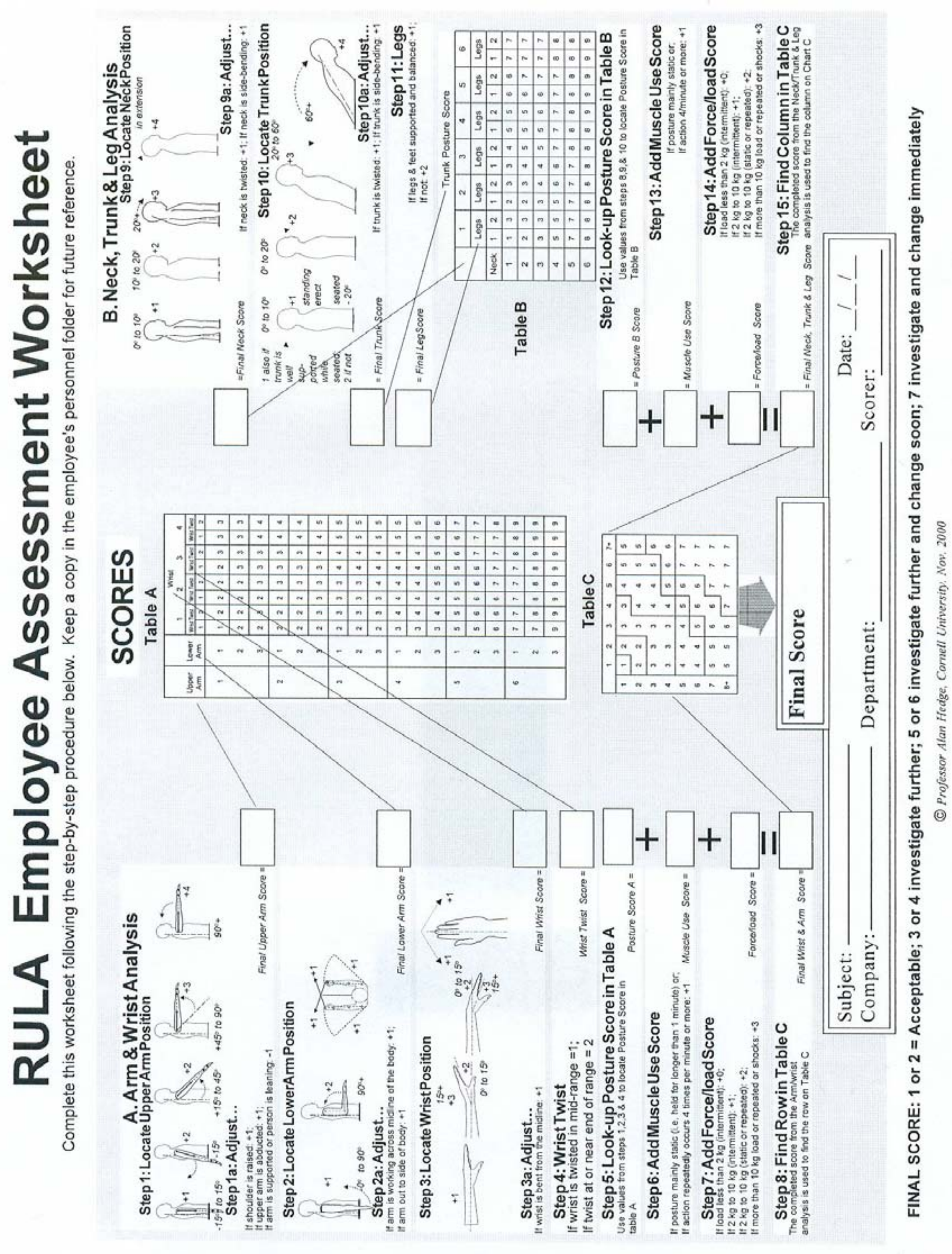

Figure 18. RULA form

Appendix D. REBA Form

REBA

Rapid Entire Body Assessment (REBA) Date: / /

Task	Analyst

Group A

Posture/Range	Score	Total
Trunk		
Upright	1	If back is twisted or tilted to side: +1
Flexion: 0-20° Extension: 0-20°	2	
Flexion: 20-60° Extension: >20°	3	
Flexion: >60°	4	
Neck		
Flexion: 0-20°	1	If neck is twisted or tilted to side: +1
Flexion: >20° Extension: >20°	2	
Legs		
Bilateral Wt Bearing; Walk; Sit	1	Knee(s) Flexion 30-60°: +1
Unilateral Wt Bearing; Unstable	2	Knee(s) Flexion >60°: +2
Score from Table A		
Load / Force		
< 5 kg < 11 lb	0	Shock or Rapid Buildup: +1
5 - 10 kg 11 - 22 lb	1	
> 10 kg > 22 lb	2	
Score A **[Table A + Load/Force Score]**		
Activity		
One or more body parts are static for longer than 1 minute		+1
Repeat small range motions, more than 4 per minute		+1
Rapid large changes in posture or unstable base		+1

Group B

Posture/Range	Score	Total: Left and Right
Upper Arms (Shoulders)		L R
Flexion: 0-20° Extension: 0-20°	1	Arm Abducted / Rotated: +1
Flexion: 20-45° Extension: >20°	2	Shoulder Raised: +1
Flexion: 45-90°	3	Arm Supported: -1
Flexion: >90°	4	
Lower Arms (Elbows)		L R
Flexion: 60-100°	1	No Adjustments
Flexion: <60° Flexion: >100°	2	
Wrists		L R
Flexion: 0-15° Extension: 0-15°	1	Wrist Deviated / Twisted: +1
Flexion: >15° Extension: >15°	2	
Score from Table B		L R
Coupling		L R
Good	0	No Adjustments
Fair	1	
Poor	2	
Unacceptable	3	Left Right
Score B **[Table B + Coupling Score]**		L R
Score C (from Table C)		L R
Activity Score		L R
REBA Score **[Score C + Activity Score]**		L R

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REBA

Table A

		Trunk 1	2	3	4	5
Neck = 1	Legs					
	1	1	2	2	3	4
	2	2	3	4	5	6
	3	3	4	5	6	7
	4	4	5	6	7	8
Neck = 2	Legs					
	1	1	3	4	5	6
	2	2	4	5	6	7
	3	3	5	6	7	8
	4	4	6	7	8	9
Neck = 3	Legs					
	1	3	4	5	6	7
	2	3	5	6	7	8
	3	5	6	7	8	9
	4	6	7	8	9	9

Table B

		Upper Arm 1	2	3	4	5	6
Lower Arm = 1	Wrist						
	1	1	1	3	4	6	7
	2	2	2	4	5	7	8
	3	2	3	5	5	8	8
Lower Arm = 2	Wrist						
	1	1	2	4	5	7	8
	2	2	3	5	6	8	9
	3	3	4	5	7	8	9

Table C

		Score A 1	2	3	4	5	6	7	8	9	10	11	12
Score B	1	1	1	2	3	4	6	7	8	9	10	11	12
	2	1	2	3	4	4	6	7	8	9	10	11	12
	3	1	2	3	4	4	6	7	8	9	10	11	12
	4	2	3	3	4	5	7	8	9	10	11	11	12
	5	3	4	4	5	6	8	9	10	10	11	12	12
	6	3	4	5	6	7	8	9	10	10	11	12	12
	7	4	5	6	7	8	9	9	10	11	11	12	12
	8	5	6	7	8	8	9	10	10	11	12	12	12
	9	6	6	7	8	9	10	10	10	11	12	12	12
	10	7	7	8	9	9	10	11	11	12	12	12	12
	11	7	7	8	9	9	10	11	11	12	12	12	12
	12	7	8	8	9	9	10	11	11	12	12	12	12

REBA Decision

REBA Score	Risk Level
1	Negligible
2 - 3	Low
4 - 7	Medium
8 - 10	High
11 - 15	Very High

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Figure 19. REBA form

Appendix E. JSI Tables

No.	Intensity of Exertion		Duration of Exertion (% of Cycle)		Efforts/Minute	
	Criteria	Value	Criteria	Value	Criteria	Value
1	Light	1	< 10	0.5	< 4	0.5
2	Somewhat hard	3	10-29	1	4-8	1
3	Hard	6	30-49	1.5	9-14	1.5
4	Very hard	9	50-79	2	15-19	2
5	Near maximal	13	≥ 80	3	≥ 20	3

Table 24. Values for JSI

No.	Hand/Wrist Posture		Speed of Work		Duration per Day (hrs)	
	Criteria	Value	Criteria	Value	Criteria	Value
1	Very good	1	Very slow	1	≤ 1	0.25
2	Good	1	Slow	1	1-2	0.5
3	Fair	1.5	Fair	1	2-4	0.75
4	Bad	2	Fast	1.5	4-8	1
5	Very bad	3	Very fast	2	≥ 8	1.5

Table 25. Values for JSI (continuation)

Appendix F. Source Values for RULA's Base Case

Steps a) and b)

Variable	Value	Scores							
		Score 1-2		Score 3-4		Score 5-6		Score 7-higher	
		Abs Freq	Rel Freq	Abs Freq	Rel Freq	Abs Freq	Rel Freq	Abs Freq	Rel Freq
Upper Arm	1	44	52.38%	560	27.86%	1,124	22.83%	-	0.00%
	2	28	33.33%	522	25.97%	1,132	22.99%	46	1.37%
	3	12	14.29%	458	22.79%	982	19.94%	276	8.24%
	4	-	0.00%	362	18.01%	952	19.33%	414	12.36%
	5	-	0.00%	108	5.37%	422	8.57%	1,198	35.76%
	6	-	0.00%	-	0.00%	312	6.34%	1,416	42.27%
Total		84	100.00%	2,010	100.00%	4,924	100.00%	3,350	100.00%
Lower Arm	1	36	42.86%	718	35.72%	1,680	34.12%	1,022	30.51%
	2	32	38.10%	682	33.93%	1,684	34.20%	1,058	31.58%
	3	16	19.05%	610	30.35%	1,560	31.68%	1,270	37.91%
Total		84	100.00%	2,010	100.00%	4,924	100.00%	3,350	100.00%
Wrist	1	52	61.90%	590	29.35%	1,326	26.93%	624	18.63%
	2	28	33.33%	558	27.76%	1,322	26.85%	684	20.42%
	3	4	4.76%	502	24.98%	1,332	27.05%	754	22.51%
	4	-	0.00%	360	17.91%	944	19.17%	1,288	38.45%
Total		84	100.00%	2,010	100.00%	4,924	100.00%	3,350	100.00%
Wrist Twist	1	60	71.43%	1,030	51.24%	2,486	50.49%	1,608	48.00%
	2	24	28.57%	980	48.76%	2,438	49.51%	1,742	52.00%
Total		84	100.00%	2,010	100.00%	4,924	100.00%	3,350	100.00%
Neck	1	42	50.00%	666	33.13%	679	13.79%	341	10.18%
	2	42	50.00%	619	30.80%	693	14.07%	374	11.16%
	3	-	0.00%	566	28.16%	738	14.99%	424	12.66%
	4	-	0.00%	159	7.91%	894	18.16%	675	20.15%
	5	-	0.00%	-	0.00%	960	19.50%	768	22.93%
	6	-	0.00%	-	0.00%	960	19.50%	768	22.93%
Total		84	100.00%	2,010	100.00%	4,924	100.00%	3,350	100.00%
Trunk	1	42	50.00%	686	34.13%	678	13.77%	322	9.61%
	2	42	50.00%	613	30.50%	701	14.24%	372	11.10%
	3	-	0.00%	446	22.19%	775	15.74%	507	15.13%
	4	-	0.00%	265	13.18%	850	17.26%	613	18.30%
	5	-	0.00%	-	0.00%	960	19.50%	768	22.93%
	6	-	0.00%	-	0.00%	960	19.50%	768	22.93%
Total		84	100.00%	2,010	100.00%	4,924	100.00%	3,350	100.00%
Legs	1	84	100.00%	1,085	53.98%	2,404	48.82%	1,611	48.09%
	2	-	0.00%	925	46.02%	2,520	51.18%	1,739	51.91%
Total		84	100.00%	2,010	100.00%	4,924	100.00%	3,350	100.00%

Table 26. Source values for RULA's base case – Steps a) and b)

Steps c), d), and e)

Variable	Value	Total Combined Absolute Frequency	Total Combined Relative Frequency	Base Case
Upper Arm	1	435.64	17.05%	4
	2	405.77	15.88%	
	3	324.66	12.71%	
	4	300.42	11.76%	
	5	470.39	18.41%	
	6	618.29	24.20%	
Total		2,555.17	100.00%	
Lower Arm	1	1,156.89	33.30%	2
	2	1,153.66	33.20%	
	3	1,163.87	33.50%	
Total		3,474.41	100.00%	
Wrist	1	678.69	24.83%	3
	2	658.83	24.10%	
	3	655.59	23.98%	
	4	740.66	27.09%	
Total		2,733.78	100.00%	
Wrist Twist	1	2,597.63	50.00%	2
	2	2,597.63	50.00%	
Total		5,195.25	100.00%	
Neck	1	370.02	17.77%	3
	2	350.91	16.86%	
	3	323.66	15.55%	
	4	310.90	14.93%	
	5	363.23	17.45%	
	6	363.23	17.45%	
Total		2,081.95	100.00%	
Trunk	1	379.43	18.54%	3
	2	349.06	17.06%	
	3	297.67	14.55%	
	4	293.84	14.36%	
	5	363.23	17.75%	
	6	363.23	17.75%	
Total		2,046.46	100.00%	
Legs	1	2,618.09	50.00%	2
	2	2,618.09	50.00%	
Total		5,236.18	100.00%	

Table 27. Source values for RULA’s base case – steps c), d), and e)

Appendix G. Source Values for REBA's Base Case

Steps a) and b)

Variable	Value	Scores									
		Score 1		Scores 2-3		Scores 4-7		Scores 8-10		Scores 11-15	
		Abs Freq	Rel Freq	Abs Freq	Rel Freq	Abs Freq	Rel Freq	Abs Freq	Rel Freq	Abs Freq	Rel Freq
Trunk	1	22	78.57%	128	58.18%	234	24.79%	48	5.22%	-	0.00%
	2	3	10.71%	54	24.55%	251	26.59%	124	13.48%	-	0.00%
	3	3	10.71%	19	8.64%	214	22.67%	196	21.30%	-	0.00%
	4	-	0.00%	16	7.27%	152	16.10%	252	27.39%	12	25.00%
	5	-	0.00%	3	1.36%	93	9.85%	300	32.61%	36	75.00%
Total		28	100.00%	220	100.00%	944	100.00%	920	100.00%	48	100.00%
Neck	1	17	60.71%	115	52.27%	376	39.83%	212	23.04%	-	0.00%
	2	11	39.29%	70	31.82%	319	33.79%	308	33.48%	12	25.00%
	3	-	0.00%	35	15.91%	249	26.38%	400	43.48%	36	75.00%
Total		28	100.00%	220	100.00%	944	100.00%	920	100.00%	48	100.00%
Legs	1	22	78.57%	115	52.27%	291	30.83%	112	12.17%	-	0.00%
	2	6	21.43%	64	29.09%	274	29.03%	196	21.30%	-	0.00%
	3	-	0.00%	35	15.91%	221	23.41%	272	29.57%	12	25.00%
	4	-	0.00%	6	2.73%	158	16.74%	340	36.96%	36	75.00%
Total		28	100.00%	220	100.00%	944	100.00%	920	100.00%	48	100.00%
Upper Arm	1	18	64.29%	76	34.55%	206	21.82%	60	6.52%	-	0.00%
	2	10	35.71%	76	34.55%	205	21.72%	69	7.50%	-	0.00%
	3	-	0.00%	45	20.45%	177	18.75%	138	15.00%	-	0.00%
	4	-	0.00%	21	9.55%	161	17.06%	174	18.91%	4	8.33%
	5	-	0.00%	2	0.91%	109	11.55%	229	24.89%	20	41.67%
	6	-	0.00%	-	0.00%	86	9.11%	250	27.17%	24	50.00%
Total		28	100.00%	220	100.00%	944	100.00%	920	100.00%	48	100.00%
Lower Arm	1	18	64.29%	123	55.91%	492	52.12%	427	46.41%	20	41.67%
	2	10	35.71%	97	44.09%	452	47.88%	493	53.59%	28	58.33%
Total		28	100.00%	220	100.00%	944	100.00%	920	100.00%	48	100.00%
Wrist	1	20	71.43%	99	45.00%	328	34.75%	261	28.37%	12	25.00%
	2	6	21.43%	65	29.55%	320	33.90%	313	34.02%	16	33.33%
	3	2	7.14%	56	25.45%	296	31.36%	346	37.61%	20	41.67%
Total		28	100.00%	220	100.00%	944	100.00%	920	100.00%	48	100.00%

Table 28. Source values for REBA's base case – steps a) and b)

Steps c), d), and e)

Variable	Value	Total Combined Absolute Frequency	Total Combined Relative Frequency	Base Case
Trunk	1	152.27	26.56%	3
	2	97.03	16.93%	
	3	92.23	16.09%	
	4	97.66	17.04%	
	5	134.03	23.38%	
Total		573.22	100.00%	
Neck	1	269.05	34.42%	2
	2	240.50	30.77%	
	3	272.16	34.82%	
Total		781.72	100.00%	
Legs	1	180.74	28.16%	2
	2	141.19	22.00%	
	3	140.72	21.92%	
	4	179.26	27.93%	
Total		641.91	100.00%	
Upper Arm	1	86.69	18.94%	4
	2	79.52	17.37%	
	3	63.09	13.78%	
	4	62.71	13.70%	
	5	77.94	17.03%	
	6	87.77	19.18%	
Total		457.72	100.00%	
Lower Arm	1	543.28	50.00%	2
	2	543.28	50.00%	
Total		1,086.56	100.00%	
Wrist	1	249.85	33.93%	2
	2	240.79	32.70%	
	3	245.67	33.37%	
Total		736.30	100.00%	

Table 29. Source values for REBA's base case – steps c), d), and e)

Appendix H. Simple Linear Regression Model
(From SPSS 12.0 for Windows)

Model	Variables Entered	Variables Removed	Method
1	Duration per Day, Speed of Work, Hand/Wrist Posture, Effors/Minute, Duration of Exertion, Intensity of Exertion(a)	.	Enter

a All requested variables entered.
b Dependent Variable: Final Score

Table 30. Variables entered/removed

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.737(a)	.543	.542	42.05631103

a Predictors: (Constant), Duration per Day, Speed of Work, Hand/Wrist Posture, Effors/Minute, Duration of Exertion, Intensity of Exertion
b Dependent Variable: Final Score

Table 31. Model summary

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	15717629.937	6	2619604.989	1481.063	.000(a)
	Residual	13253118.600	7493	1768.733		
	Total	28970748.536	7499			

a Predictors: (Constant), Duration per Day, Speed of Work, Hand/Wrist Posture, Effors/Minute, Duration of Exertion, Intensity of Exertion
b Dependent Variable: Final Score

Table 32. Anova table

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-184.320	2.813		-65.525	.000
	Intensity of Exertion	5.760	.114	.396	50.656	.000
	Duration of Exertion	23.040	.565	.319	40.813	.000
	Effors/Minute	23.040	.565	.319	40.813	.000
	Hand/Wrist Posture	19.661	.657	.234	29.940	.000
	Speed of Work	24.576	1.190	.161	20.660	.000
	Duration per Day	46.080	1.129	.319	40.813	.000

a Dependent Variable: Final Score

Table 33. Table of coefficients

Appendix I. Results for Preliminary and Complimentary Studies
(Using SPSS 12.0 for Windows and Microsoft Excel XP©)

Description	RULA	REBA
Variables Included	**Posture-based:** Upper arm Lower arm Wrist Wrist twist Neck Trunk Legs **Modifiers:** Muscle use Force/load	**Posture-based:** Trunk Neck Legs Upper arm Lower arm Wrist **Modifiers:** Load/force Coupling Activity
Data Set	185,965 combinations	139,203 combinations
Correlation test	**Correlations with Score A:** Upper arm = 0.54 Lower arm = 0.04 Wrist = 0.29 Wrist twist = 0.07 Muscle use = 0.21 Force/load = 0.48 **Correlations with Score B:** Neck = 0.33 Trunk = 0.47 Legs = 0.16 Muscle use = 0.10 Force/load = 0.43 **Correlations with Score C:** Score A = 0.62 Score B = 0.67	**Correlations with Score A:** Trunk = 0.61 Neck = 0.34 Legs = 0.47 Load/force = 0.44 **Correlations with Score B:** Upper arm = 0.85 Lower arm = 0.15 Wrist = 0.22 Coupling = 0.41 **Correlations with Score C:** Activity = 0.40 Score A = 0.62 Score B = 0.67
Sensitive Variables	**Posture-based:** Upper arm Wrist Neck Trunk Legs **Modifiers:** Muscle use Force/load	**Posture-based:** Trunk Neck Legs Upper arm Lower arm Wrist **Modifiers:** Load/force Coupling Activity
Critical Variables	**Posture-based:** Upper arm Wrist Neck Trunk Legs	**Posture-based:** Trunk Legs Load/force Upper arm **Modifiers:** Coupling

Combined Correlations	Upper arm = 0.33 Wrist = 0.18 Neck = 0.22 Trunk = 0.31 Legs = 0.11	Trunk = 0.38 Legs = 0.29 Load/force = 0.27 Upper arm = 0.57 Coupling = 0.27
Rank from most to least critical	1. Upper arm 2. Trunk 3. Neck 4. Wrist 5. Legs	1. Upper arm 2. Trunk 3. Legs 4. Load/force and coupling
Observations	Upper arm and trunk are the most critical variables for both RULA and REBA.	

Table 34. Results of preliminary studies for RULA and REBA

Description	JSI
Variables Included	Intensity of exertion Duration of exertion Efforts/minute Hand/wrist posture Speed of work Duration per day
Data Set	7,500 combinations
Input Variables for Regression Model	6 variables and the 6 new variables (square of JSI's variables)
Degrees of Freedom	12

Table 35. Complimentary study for JSI

Model	Variables Entered	Variables Removed	Method
1	DD ^2, SW ^2, HWP ^2, EM ^2, DE ^2, IE ^2, Intensity of Exertion, Effors/Minute, Duration of Exertion, Duration per Day, Hand/Wrist Posture, Speed of Work(a)	.	Enter

a All requested variables entered.
b Dependent Variable: Final Score

Table 36. Variables entered/removed

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.737(a)	.543	.542	42.07315939

a Predictors: (Constant), DD ^2, SW ^2, HWP ^2, EM ^2, DE ^2, IE ^2, Intensity of Exertion, Effors/Minute, Duration of Exertion, Duration per Day, Hand/Wrist Posture, Speed of Work

Table 37. Model summary

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	15717629.937	12	1309802.495	739.938	.000(a)
	Residual	13253118.600	7487	1770.151		
	Total	28970748.536	7499			

a Predictors: (Constant), DD ^2, SW ^2, HWP ^2, EM ^2, DE ^2, IE ^2, Intensity of Exertion, Effors/Minute, Duration of Exertion, Duration per Day, Hand/Wrist Posture, Speed of Work
b Dependent Variable: Final Score

Table 38. Anova table

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-184.320	10.325		-17.851	.000
	Intensity of Exertion	5.760	.465	.396	12.385	.000
	IE ^2	.000	.032	.000	.000	1.000
	Duration of Exertion	23.040	2.601	.319	8.856	.000
	DE ^2	.000	.717	.000	.000	1.000
	Effors/Minute	23.040	2.601	.319	8.856	.000
	EM ^2	.000	.717	.000	.000	1.000
	Hand/Wrist Posture	19.661	4.511	.234	4.358	.000
	HWP ^2	.000	1.096	.000	.000	1.000
	Speed of Work	24.576	12.424	.161	1.978	.048
	SW ^2	.000	4.122	.000	.000	1.000
	Duration per Day	46.080	5.211	.319	8.843	.000
	DD ^2	.000	2.871	.000	.000	1.000

a Dependent Variable: Final Score

Table 39. Table of coefficients