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Comparison of Ergonomic Risk Assessment Output in Four Sawmill Jobs

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The objectives of this study were to examine the agreement between 5 ergonomic risk assessment methods calculated on the basis of quantitative exposure measures and to examine the ability of the methods to correctly classify 4 at risk *jobs. Surface electromyography and electrogoniometry were used to record the physical exposures of 87 sawmill workers performing 4 repetitive jobs. Five ergonomic risk assessment tools (rapid upper limb assessment [RULA], rapid entire body assessment [REBA], American conference of governmental industrial hygienist's threshold limit value for mono-task hand work [ACGIH TLV], strain index [SI], and concise exposure index [OCRA]) were calculated. Dichotomization of risk to* no risk *and* at risk *resulted in high agreement between methods. Percentage of* perfect *agreement between methods when 3 levels of risk were considered was moderate and varied by job. Of the methods examined, the RULA and SI were best (correct classification rates of 99 and 97% respectively). The quantitative ACGIH-TLV for mono-task hand work and Borg scale were worst (misclassification rates of 86 and 28% respectively).*

physical ergonomics   exposure assessment   musculoskeletal risk assessment   job analysis   prevention and control

1. INTRODUCTION

Industrial musculoskeletal injury (MSI) prevention initiatives require risk assessment tools which accurately identify jobs at increased risk for injury. Accurate identification of *at risk* jobs requires a model of MSI causation which considers relevant physical exposures in an integrated framework which assigns the correct relative role to those exposures. Ergonomic risk assessments are based on integrated models of MSI causation which account for the role of physical exposures in the precipitation of MSIs. Descriptions of several ergonomic risk assessments have been published and many of the methods have demonstrated predictive validity [1, 2]. Consensus among the authors of the risk assessments as to which exposures should be considered and the relative role of the exposures in the causation of MSI has not been reached however.

Prior to calculating ergonomic risk assessments the evaluator is required to record the physical exposures required to perform the job. Traditionally the assessment of exposure is performed based on observation. A body of evidence is now present which calls into question the ability of observational assessments to accurately record exposures [3, 4]. Few studies are available which have examined the comparability of risk output derived from multiple ergonomic risk assessments and no studies are available which have calculated the methods on the basis of quantified exposure assessments [5, 6].

Given the common use of ergonomic risk assessments in industrial ergonomic initiatives evaluation of the agreement between methods

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based on quantified exposure assessment is of primary importance.

The objectives of this study were to examine (a) the agreement between five ergonomic risk assessment methods which have been calculated on the basis of quantitative exposure measures and (b) the ability of the methods to identify four *at risk* jobs. The five ergonomic risk assessment methods evaluated in this study are the rapid upper limb assessment (RULA) [7], rapid entire body assessment (REBA) [8], the quantitative American conference of governmental industrial hygienist's threshold limit value for mono-task hand work (ACGIH TLV) [9], the strain index (SI) [1], and the concise exposure index (OCRA) [2, 10].

2. METHODS

Workers 18–65 years of age performing four sawmill occupations observed to be associated with upper extremity MSIs were recruited from four sawmill facilities in Alberta, Canada. Ninety-three workers volunteered to take part in the study out of the population of 93 (100% participation rate). Subjects were excluded from the study if they reported injury to the upper extremity within the past 12 months, generalized musculoskeletal or neuromuscular problems, or the inability to understand and follow instructions. Complete datasets enabling analysis and calculation of risk using all assessments methods on all subjects for each job was done for each of the 87 subjects. The experimental protocol was approved by the University Health Research Ethics Board.

2.1. Occupation Description

*2.1.1. Board-edger operator (*n *= 14)*

The board-edger position is a repetitive mono-task job responsible for sorting boards cut in rough depth dimension immediately after logs have been cut to square dimension and divided into multiple boards. The primary task of the board-edger operator is turning boards to position the round side of the board up to enable further processing. Incidence rates in the board-edger position calculated on the basis of person-year estimates from the facilities examined averaged .78 recordable musculoskeletal upper extremity incidents per person-year in the period examined (1997–2002).

*2.1.2. Lumber grader (*n *= 29)*

The lumber grader is responsible for assigning a product grade to each piece of dimensional lumber leaving the sawmill. The primary task of the lumber grader is to turn boards to enable inspection and grade assignment. Incidence rates in the lumber grader position calculated on the basis of person-year estimates from the facilities examined averaged .19 recordable musculoskeletal upper extremity incidents per person-year in the period examined (1997–2002).

*2.1.3. Saw filer (*n *= 15)*

The primary function of the saw filer position is to maintain the condition of the round saws, band saws, and chipper blades (knives). The primary task of the saw filer is the hammering of round saw blades to correct imperfections and tension the blade. Incidence rates in the saw filer position calculated on the basis of person-year estimates from the facilities examined averaged .43 recordable musculoskeletal upper extremity incidents per person-year in the period examined (1997–2002).

*2.1.4. Trim-saw operator (*n *= 29)*

The trim-saw operator is responsible for sorting and positioning boards which have been cut into width dimension before the dimensional lumber enters the trim-saw to be cut into length dimension. The primary task of the trim-saw operator is turning boards to position the round side of the board up to enable further processing. Incidence rates in the trim-saw position calculated on the basis of person-year estimates from the facilities examined averaged .44 recordable musculoskeletal upper extremity incidents per person-year in the period examined (1997–2002).

2.2. Exposure Assessment

2.2.1. Motion and posture

Motion and posture required to perform the jobs assessed were recorded during actual job performance on the production line. Five minutes of job performance of board-edger operators, lumber graders, and trim-saw operators and 15 min of the job performance of the saw filers was recorded. Only the upper extremity used to perform the primary job task was assessed. A Biometrics bi-axial SG-65 and uni-axial Q-150 electrogoniometers (Biometrics, UK) were applied to the task-dominant upper extremity as per the users' manual recommendations [11]. Postures required to perform the jobs were defined by randomly selecting 10 repetitions of the primary task, recording the maximum deviation in the plane of interest, and averaging the values in each subject. Where body regions other than the forearm and wrist were considered (REBA, RULA, OCRA) the peak postures observed during the observation period in the body region of interest were recorded and input. In activities where parts of the body did not contribute, they were not assigned any score and thereby did not contribute to the risk score. This was considered a faithful calculation of appropriate risk. The activities were dynamic and were not broken into arbitrary static components. The data from relevant segments of activities were extracted. Repetition was defined on the basis of primary task cycles. Further details regarding the methodology used, and motion and posture variable definitions are described by Jones and Kumar [12, 13].

2.2.2. Exertion

In some cases the ergonomic risk assessments examined allow exertion to be defined either by psychophysical or quantitative methods (Borg Cr-10 or percentage of maximum voluntary contraction) [14]. In this study both psychophysical and quantitative measures of exertion were used to calculate the ACGIH TLV, SI, and OCRA methods to examine agreement within and across methods. The risk level distributions of the SI when calculated with psychophysical or quantitative measures of exertion were not significantly different. For this reason only the risk level distribution of the SI considering the quantitative exertion variable is described.

2.2.3. Psychophysical assessment

Following motion data collection the workers were asked whether during the cycle there were job actions that required muscular effort of the upper limbs. They were then asked to rate the actions on the Borg CR-10 1–10 scale [14]. Borg ratings were then averaged and used in the ACGIH TLV, SI, and OCRA assessments.

2.2.4. Quantitative assessment

Surface electromyography (EMG) was used to determine the magnitude of muscle activity associated with maximum and job simulated exertions in static trials for the forearm musculature involved in performance of the primary task of the job being examined. Job simulated and maximum EMG trails were performed at a location removed from the production line. Only the task dominant upper extremity was assessed. A Bagnoli™ 8 EMG system (Delsys, USA) was used to record the muscle activity of all muscles assessed in each trial. For the board edger, lumber grader, and trim-saw operators the flexor carpi radialis, flexor carpi ulnaris, flexor digitorum superficialis, and pronator terres were evaluated to assess the exertion required to turn a board. For the saw filer job the extensor carpi radialis, flexor carpi radialis, and flexor carpi ulnaris were evaluated to assess the exertion required to perform a forceful hammer strike. The job simulated EMG values were divided by the peak EMG values obtained on the maximum voluntary contraction (MVC) trials to arrive at %MVC required to perform the primary task. Single differential bipolar electrodes with parallel bar shaped silver detection surfaces (1 cm length × 1 mm width) spaced 1 cm apart were used in the EMG trials and oriented perpendicular to the muscle fibers. The data acquisition system consisted of an analog-to-digital board with a 100-kHz sampling capacity.

The EMG channels [4] were sampled at 1 kHz in real time. The sampled signals were stored on a laptop computer. The EMG traces obtained during job simulated and maximum trials were full-wave rectified and linear envelope-detected from the raw EMG signals. Further details regarding methodology used to collect exertion information are described by Jones and Kumar [12, 13].

2.3. Risk Assessment Calculation

Methodologies used to compare the risk assessment methods are based on those described by the primary literature describing their application [1, 7, 8, 9, 10]. To enable a comparison of the RULA and REBA to the other assessments, the risk levels of the former two had to be reclassified into three levels. Table 1 describes the scheme used to reclassify RULA and REBA risk levels.

TABLE 1. Risk Level Classification of the Ergonomics Risk Assessment Methods

	Risk Index Scores		
Risk Assessment	**Level 1**	**Level 2**	**Level 3**
RULA	1, 2	3–6	7
REBA	0	2–7	8–15
ACGIH TLV (%MVC)	1	2	3
ACGIH TLV (Borg)	1	2	3
SI	0–3	3.1–7.0	>7.1
OCRA (%MVC)	<.75	>.75–4.0	>4.0
OCRA (Borg)	<.75	>.75–4.0	>4.0

Notes. RULA—rapid upper limb assessment [7], REBA—rapid entire body assessment [8], ACGIH TLV—quantitative American Conference of Governmental Industrial Hygienist's threshold limit value for mono-task hand work [9], %MVC—percentage of maximum voluntary contraction, Borg—Borg Cr-10 scale [14], SI—strain index [1], OCRA—concise exposure index [2, 10].

2.4. Statistical Analysis

Univariate analysis with the Wilcoxin Signed Ranks test (significance level of .01) was used to determine whether the differences observed between risk level distributions were significant. Percentage agreement between methods was assessed by comparing the risk level scores assigned by each method to individual workers. Percentage agreement was assessed using two techniques. Percentage of *at risk* agreement was calculated by dichotomizing risk level output into *no risk* (level 1) and *at risk* (level 2 or 3) comparisons. Risk level output of the ergonomic risk assessment is used in industrial ergonomic initiatives to prioritize jobs for intervention. The implication of disagreement between methods is the inappropriate assignment of risk leading to inappropriate intervention. Given the important implication of disagreement between methods it is necessary to evaluate the percentage of perfect agreement in addition to *at risk* agreement. Percentage of *perfect* agreement was calculated by considering only cases of exact agreement. Figure 1 illustrates the calculation of percentage of *at risk* and *perfect* agreement. Both percentage agreement considering all workers assessed and the range of values considering the jobs individually are presented. The range of percentage agreement values considering the jobs individually is presented to illustrate the variation resulting from the different exposure profiles of the four jobs considered.

Method 2 risk level assigned \ Method 1 risk level assigned	1	2	3
1	a	b	c
2	d	e	f
3	g	h	i

perfect agreement: (a/87) + (e/87) + (i/87)
at risk agreement: (e/87) + (f/87) + (h/87) + (i/87)

Figure 1. Percentage agreement calculation.

3. RESULTS

3.1. Risk Level Comparisons

Significantly different risk level distributions were obtained by each methodology examined with the exception of the RULA/SI, REBA/OCRA %MVC, and REBA/OCRA Borg comparisons.

3.2. Percentage of Agreement

3.2.1. Percentage of at risk *agreement*

Table 2 presents percentage of agreement between methods considering all workers assessed. Table 3 presents ranges of values considering minimum and maximum percentage of agreement between methods specific to each job. Generally, there were high levels of agreement that the jobs were *at risk*. Low percentage of agreement in *at risk* scores was observed between both methods of quantified ACGIH TLV calculation (exertion defined with %MVC and Borg Cr-10) and the other methods, however. The range of percentage agreement values observed between jobs suggests the methods differ in their suitability to the exposure profiles of the different jobs.

3.2.2. Percentage of perfect *agreement*

Percentage of *perfect* agreement between risk assessment methods was observed in all cases to be lower than percentage of *at risk* agreement. The exception to this trend was the percentage *perfect* agreement observed between the ACGIH TLV methods when risk levels generated with the %MVC criteria were compared to those generated with the Borg criteria. The exception

TABLE 2. Percentage of Agreement. All Workers

	RULA	REBA	ACGIH TLV (%MVC)	ACGIH TLV (Borg)	SI	OCRA (%MVC)	OCRA (Borg)
RULA	—	100 (66)	13 (3)	72 (44)	99 (98)	98 (61)	98 (83)
REBA	100 (66)	—	14 (3)	72 (33)	99 (67)	98 (44)	98 (52)
ACGIH TLV (%MVC)	13 (3)	14 (3)	—	14 (36)	14 (5)	14 (8)	14 (7)
ACGIH TLV (Borg)	72 (44)	72 (33)	14 (36)	—	72 (45)	71 (54)	72 (48)
SI	99 (98)	99 (67)	14 (5)	72 (45)	—	97 (61)	97 (83)
OCRA (%MVC)	98 (61)	98 (44)	14 (8)	71 (54)	97 (61)	—	98 (69)
OCRA (Borg)	98 (83)	98 (52)	14 (7)	72 (48)	97 (83)	98 (69)	—

Notes. Percentage of *at risk* agreement no parentheses. Percentage of *perfect* agreement in parentheses. RULA—rapid upper limb assessment [7], REBA—rapid entire body assessment [8], ACGIH TLV—quantitative American Conference of Governmental Industrial Hygienist's threshold limit value for mono-task hand work [9], %MVC—percentage of maximum voluntary contraction, Borg—Borg Cr-10 scale [14], SI—strain index [1], OCRA—concise exposure index [2, 10].

TABLE 3. Percentage of Agreement. Range of Values Between Jobs

	RULA	REBA	ACGIH TLV (%MVC)	ACGIH TLV (Borg)	SI	OCRA (%MVC)	OCRA (Borg)
RULA	—	100 (14–100)	0–38 (0–10)	47–86 (20–55)	97–100 (93–100)	93–100 (27–83)	93–100 (60–93)
REBA	100 (14–100)	—	0–38 (0–10)	47–86 (21–48)	97–100 (14–100)	93–100 (20–62)	93–100 (14–83)
ACGIH TLV (%MVC)	0–38 (0–10)	0–38 (0–10)	—	0–38 (21–53)	0–38 (0–10)	0–38 (0–14)	0–38 (0–14)
ACGIH TLV (Borg)	47–86 (20–55)	47–86 (21–48)	0–38 (21–53)	—	47–86 (20–59)	47–86 (20–71)	47–86 (27–59)
SI	97–100 (93–100)	97–100 (14–100)	0–38 (0–10)	47–86 (20–59)	—	93–100 (27–83)	93–100 (60–93)
OCRA (%MVC)	93–100 (27–83)	93–100 (20–62)	0–38 (0–14)	47–86 (20–71)	93–100 (27–83)	—	93–100 (50–83)
OCRA (Borg)	93–100 (60–93)	93–100 (14–83)	0–38 (0–14)	47–86 (27–59)	93–100 (60–93)	93–100 (50–83)	—

Notes. Percentage of *at risk* agreement no parentheses. Percentage of *perfect* agreement in parentheses. RULA—rapid upper limb assessment [7], REBA—rapid entire body assessment [8], ACGIH TLV—quantitative American Conference of Governmental Industrial Hygienist's threshold limit value for mono-task hand work [9], %MVC—percentage of maximum voluntary contraction, Borg—Borg Cr-10 scale [14], SI—strain index [1], OCRA—concise exposure index [2, 10].

in this case resulted from the methods agreeing *no risk* was present (risk level 1), and this cell not being considered in the *at risk* agreement calculation (cf. Figure 1). Modest levels of agreement between methods confirm risk level output will depend on the method used and there is a meaningful risk of disagreement between methods. Again, consideration of the range of values between jobs suggests the methods differ in their suitability to the exposure profiles of the different jobs.

3.3. Risk Level Classification

The four sawmill jobs assessed in this study were observed to be commonly associated with musculoskeletal injuries in the upper extremity. Given this finding all jobs may be considered *at risk*. Table 4 presents risk levels assigned by method. Of the methods examined the RULA and SI methods were best able to correctly classify the jobs with correct classification rates of 99 and 97% respectively. The ACGIH TLV calculated with %MVC and the ACGIH TLV calculated with Borg were least able to correctly classify the jobs assessed with misclassification rates of 86 and 28% respectively.

4. DISCUSSION

The results of this study confirm that the risk output of each method depends on the exposures considered (e.g., exertion, posture, repetition) and their magnitude. Given each method weights the relative importance of the exposures considered differently (e.g., repetition is the most heavily weighted variable for the OCRA assessment), agreement between methods can be expected to change as the exposure profile of the job changes. The findings of this study emphasize the limited agreement between published ergonomic risk assessment methods and the need for studies able to examine the predictive validity of the methods in the same worker population to identify the current best model. The implication of this disagreement is the incorrect assessment of risk and/or identification of problem exposures. Our findings of limited agreement are similar to those reported by Bao, Howard, Spielholz, et al. [6] and opposed to those reported by Drinkaus, Sesek, Bloswick, et al. [5]. Drinkaus et al. found limited agreement between the RULA and the SI methods (κ score .11). The Drinkaus et al. study however examined 244 assembly tasks of varying levels of risk. Given our study examined only high-risk jobs, conclusions regarding the agreement between the SI and the RULA across varying levels of risk may not be drawn. Bao et al. report agreement of 74.1% between the SI and the ACGIH TLV. Our findings indicate a considerably lower agreement of 11% (ACGIH TLV calculated on the basis of %MVC) and 60% (ACGIH TLV calculated on the basis of Borg scale scores) between the ACGIH TLV and the SI. It is important to note however that the Bao et al. article compared the observational ACGIH

TABLE 4. Risk Level (RL) Classifications by Risk Assessment

Risk Assessment	*Safe* (RL 1) (%)	*Moderate* (RL 2) (%)	*At Risk* (RL 3) (%)
RULA	0 (0)	1 (1)	86 (99)
REBA	0 (0)	31(36)	56 (64)
ACGIH TLV (%MVC)	75 (86)	9 (10)	3 (3)
ACGIH TLV (Borg)	24 (28)	24 (28)	39 (45)
SI	1 (1)	2 (2)	84 (97)
OCRA (%MVC)	2 (2)	33 (38)	52 (60)
OCRA (Borg)	2 (2)	12 (14)	73 (84)

Notes. RULA—rapid upper limb assessment [7], REBA—rapid entire body assessment [8], ACGIH TLV—quantitative American Conference of Governmental Industrial Hygienist's threshold limit value for mono-task hand work [9], %MVC—percentage of maximum voluntary contraction, Borg—Borg Cr-10 scale [14], SI—strain index [1], OCRA—concise exposure index [2, 10].

TLV method and not the quantitative method used here. Importantly, the authors of the ACGIH TLV state that professional judgment should be used to recommend TLV reductions when there are risk factors not considered by the TLV (such as posture) [9]. No risk level reductions due to the presence of risk factors not considered by the original models were performed in this study. Limitations of this study include the small sample size and the inclusion of *at risk* jobs only. Strengths of this study include the largely quantified exposure assessments from which the methods examined were calculated.

5. CONCLUSION

This study has demonstrated the limited agreement between published ergonomic risk assessment methods used to assess four *at risk* sawmill jobs. Considerable variation in the ability to identify *at risk* jobs as *at risk* was identified between methods. Variation in agreement present when the jobs were considered individually indicates the appropriateness of the methods may be affected by the exposure profile of the job.

REFERENCES

1. Moore JS, Garg A. Participatory ergonomics in a red meat packing plant. Part II: case studies. Am Ind Hyg Assoc J. 1997; 58(7):498–508.
2. Grieco A. Application of the concise exposure index (OCRA) to tasks involving repetitive movements of the upper limbs in a variety of manufacturing industries: preliminary validations. Ergonomics. 1998; 41(9):1347–56.
3. Lowe BD. Accuracy and validity of observational estimates of wrist and forearm posture. Ergonomics. 2004;47(5):527–54.
4. Marshall MM, Armstrong TJ. Observational assessment of forceful exertion and the perceived force demands of daily activities. J Occup Rehabil. 2004;14(4):281–94.
5. Drinkaus P, Sesek R, Bloswick D, Bernard T, Walton B, Joseph B, et al. Comparison of ergonomic risk assessment outputs from rapid upper limb assessment and the strain index for tasks in automotive assembly plants. Work. 2003;21(2):165–72.
6. Bao S, Howard N, Spielholz P, Silverstein B. Quantifying repetitive hand activity for epidemiological research on musculoskeletal disorders—part II: comparison of different methods of measuring force level and repetitiveness. Ergonomics. 2006;49(4):381–92.
7. McAtamney L, Nigel Corlett E. RULA: a survey method for the investigation of work-related upper limb disorders. Appl Ergon. 1993;24(2):91–9.
8. Hignett S, McAtamney L. Rapid entire body assessment (REBA). Appl Ergon. 2000;31(2):201–5.
9. Armstrong TJ. ACGIH TLV for mono task handwork; 2009. Retrieved November 13, 2009, from: http://ioe.engin.umich.edu/ioe463/ACGIH_TLV.doc
10. Colombini D. An observational method for classifying exposure to repetitive movements of the upper limbs. Ergonomics. 1998;41(9):1261–89.
11. Goniometer and torsiometer operating manual. Cwmfelinfach, Gwent, UK: Biometrics; 2002.
12. Jones T, Kumar S. Assessment of physical demands and comparison of multiple exposure definitions in a repetitive high risk sawmill occupation: saw-filer. Int J Ind Ergon. 2006;36(9):819–27.
13. Jones T, Kumar S. Assessment of physical exposures and comparison of exposure definitions in a repetitive sawmill occupation: trim-saw operator. Work. 2007;28(2): 183–96.
14. Borg GAV. A category scale with ratio properties for intermodal comparison. In: Geissler HG, Petzold P, editors. Psychophysical judgment and process of perception. Berlin, Germany: VEB Deutscher Verlag der Wissenschaften; 1982. p. 25–34.