Full research article

Comparison of ten widely-use ergonomic risk assessment tools based on evaluations of various manual materials handling activities

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Abstract

Ergonomic risk assessment tools are commonly used to evaluate the risk of musculoskeletal injuries during manual material handling (MMH) activities. This study aimed to compare and evaluate the performance of ten widely-used ergonomic risk assessment tools (REBA, RULA, QEC, NIOSH, WISHA, ManTRA, MAC, Washington state, ACGIH-TLV, and Snook's tables) in assessing risk of injury to workers during various lifting, lowering, pulling, pushing, carrying, and prolonged static activities. Twenty-one different MMH activities including one- and two-handed, stoop/squat, symmetric/asymmetric tasks with various hand-load horizontal and vertical positions, weights, vibration, and task frequencies were assessed using the foregoing ten ergonomic risk assessment tools. A unique risk level classification was introduced to compare the outcomes of these tools. For a given MMH activity, the estimated levels of risk by different tools were found to be more consistent between the tools for high- and low-demanding tasks, and less consistent and in some cases contradictory for moderately-demanding tasks. RULA, ACGIH TLV, REBA, and QEC were the most and MAC and WISHA were the least conservative tools in their assessments. Comparison of these risk assessment tools revealed their similarities/dissimilarities and strengths/limitations thereby providing users with a comprehensive guideline for proper selection of these tools in practical applications.

Keywords: occupational biomechanics, ergonomics, musculoskeletal injuries, lifting, lowering, pushing, pulling, carrying

1. Introduction

Musculoskeletal disorders, experienced by workers during their occupational activities, are prevalent and costly [1]. Manual material handling (MMH) activities (e.g., lifting, lowering, pulling, pushing, carrying, and prolonged static) have been identified as one of the main biomechanical causes of musculoskeletal disorders [2,3]. Practitioners in the field of occupational biomechanics quantify risk of occupational injuries by evaluating the body posture [4–7] and subsequently estimating body joint loads during these daily activities using different biomechanical models [8–15]. These models are, however, difficult to implement in occupational workstations as this usually requires posture/motion data collection as well as professional expertise in biomechanical modeling. Moreover, our investigation on the comparison of six biomechanical models, that directly estimate joint loads during MMH activities (e.g., the AnyBody modeling system (AnyBody Technology, Aalborg, Denmark) [16]), indicates that these models predict significantly different joint loads and thus risk of injuries during a given MMH activity [17,18].

Alternatively, ergonomic risk assessment tools (ERATs) are available to evaluate the risk of work-related musculoskeletal disorders based on job characteristics and with no need to estimate body joint loads [19–22]. Several ERATs have thus far been developed based on different biomechanical, physiological, and psychophysical criteria. Diverse criterions used to develop the ERATs are assumed to result in their inconsistent assessments of the level of risk in occupational activities. For instance, some ERATs do not differentiate between one- and two-handed load-handling activities, do not provide precise guidelines for their implementation thereby making them vulnerable to inter-rater variabilities, and/or do not consider details of job characteristics [23,24]. Comparison of five ERATs when implemented to lifting/lowering MMH activities has indicated the disagreement between their risk assessments [25,26]. Although our investigations indicate that significantly different results are obtained when nine different ERATs are applied to assess a single lowering MMH activity [27], a thorough comparison of these ERATs over a wide range of occupational activities that indicates 1) to what extent the evaluations of these tools differ and 2) how the tools respond to tasks for which they have not been ideally designed remains to be carried out.

This study, therefore, aims to compare the performance of ten widely-used ERATs in assessing injury risk during twenty-one different MMH activities so as to reveal their similarities/dissimilarities and strengths/limitations as well as provide a comprehensive guideline for practitioners when implementing these ERATs. The selected MMH activities include lifting (LF), lowering (LW), pulling (PL), pushing (PS), carrying (CR), and prolonged static (ST) tasks with different hand-load positions/weights and also using different lifting (i.e., stoop or squat) and handling (i.e., one- or two-handed) techniques. The included ERATs are the Revised National Institute for Occupational Safety and Health (NIOSH) lifting equation [19], Snook's tables [20], The lifting threshold limit value of the American Conference of Governmental Industrial Hygienists (ACGIH TLV) [28], Rapid upper limb assessment (RULA) [21], Rapid entire body assessment (REBA) [22], Quick Exposure Check (QEC) [29,30], Washington State ergonomics and MSD risk assessment checklists (Washington State) [31], Washington Industrial Safety and Health Act (WISHA) lifting calculator [32], Manual task risk assessment (ManTRA) [33], and Manual Handling Assessment Charts (MAC) [34]. It is hypothesized that, due to their inherent limitations and different development criteria, these ERATs predict different levels of risk for an identical

MMH activity. Determining the extent of these differences is the objective of the present study.

2. Methods

2.1. MMH Tasks: The subjects analyzed in this study were workers of Maleabel Saipa Company and Iran Khodro Company (IKCO); two car manufacturing companies in Tehran, Iran. An on-site visit was made to their workplaces and images of fifteen male workers were captured for the subsequent analyses. Some workers performed multiple tasks which led to a total of twenty-one manual material handling (MMH) tasks for this study. Before capturing the motion data, the participants were informed about the nature of the research, following which they provided written informed consent. Task frequency and duration were recorded and documented as well. The first 3 authors of the manuscript analyzed all tools for all tasks independently, and the evaluations were finalized in a group discussion (see Appendix A, Figures A1 to A21 in the supplementary materials for photos of some of the in-site activities). Twenty-one MMH activities including nine LF, two CR, two LW, two PL, two PS, and four ST tasks were considered (Table 1). The tasks included one- and two-handed, stoop and squat, as well as symmetric and asymmetric load-handling activities. Each task was classified according to its frequency (less or more than 60 times per hour) and hand-load mass (smaller or larger than 10 kg). Classification of tasks as stoop or squat lifting techniques was based on the worker's knee flexion [35,36]. The vertical position of the hand-load was also a parameter of the task condition: standing without any trunk flexion (the vertical position of the hand-load was higher than 90 cm, i.e., approximately the height of the pelvis), mid-flexion (the trunk was flexed while the vertical position of the hand-load was between 40 and 90 cm, i.e., higher than the height of the knees and lower than the height of the pelvis), and deep-flexion (the trunk was flexed while the vertical position of the hand-load was lower than 40 cm, i.e., the height of the knees). Task vibration was also a parameter of interest. Finally, the horizontal position of the hand-load from the ankles was considered as a parameter of the task condition: close to the body (the horizontal distance of the hand-load was lower than 30 cm), mid-distance (the horizontal distance of the hand-load was between 30 and 60 cm), and far away (the horizontal distance of the hand-load was higher than 60 cm) (Table 1). These task parameters are presented in Table 1 as general specifications of each task. The analyses were performed on the captured images from real workstations thus providing a complete understanding and visualization of each task. Joint angles, as required in some risk assessment tools, were calculated from these images (see Appendix A, Figures A1 to A21 in the supplementary materials) and were used in the tools to evaluate the risk of injury.

2.2. Levels of risk: While most ERATs have their risk factor classification methods [19,21,22,29–33,37] some do not provide any specific thresholds or interpretations for their outcomes [20,28,34]. As a unique classification method was required to compare outcomes of these tools, three risk levels were assumed in this study: “1” for the safe zone indicating an activity with no or low risk of injury, “2” for a moderate risk of injury that has to be managed in the future, and finally “3” for a high risk of injury that needs immediate intervention. However, some ERATs classify their outcomes into more than three risk levels [21,22,29,30,37]. In this case, some risk levels were combined and assumed to be in one risk level (Table 2). On the other hand, some ERATs classify their outcomes into two risk levels [33]. In this case, we split one of the risk levels into two. Few ERATs do not classify their risk levels and leave the conclusion to users [20,28,33,34].

2.3. Ergonomic Risk Assessment Tools (ERATs): Ten widely-used ERATs were used to investigate the risk of injuries in different MMH tasks including:

2.3.1. REBA: Rapid Entire Body Assessment (REBA) is a postural analysis tool that focuses on assessing the whole-body risk of injury during MMH tasks [22]. REBA provides a scoring system for different body segments determined by static, dynamic, unstable, or rapidly changing postures. It can evaluate only one side of the body at a time while suggesting five action levels; the first two levels were considered as the safe zone and the last two levels comprised the high-risk zone (Table 2).

2.3.2. RULA: Using the same principles as REBA, Rapid Upper Limb Assessment (RULA) is a survey method to evaluate risks of musculoskeletal injuries to the upper limbs [21]. RULA provides a quick assessment of the posture and external loads without requiring any special equipment. It only evaluates one side of the body at a time while suggesting four levels of risk. In this study, the second and third levels were combined to constitute the moderate risk zone (Table 2).

2.3.3. QEC: The Quick Exposure Check (QEC) tool includes 15 questions about trunk/upper limb postures and movements, handled loads, duration of the task, visual stress, hand force, and work rhythm/stress [29,30]. This tool involves both the workers and practitioners in its assessment by giving each a separate survey and then utilizing both outcomes to conclude the total risk score for each body region. While the questions include psychosocial aspects, the emphasis is on the physical risk factors. The scores of all body areas are summed up and normalized to constitute the QEC whole body percentage [38]. In this study, the first two classes of intervention were considered as the safe zone thus leaving the other two levels as the moderate and high-risk zones (Table 2).

2.3.4. NIOSH: The revised NIOSH lifting equation aims to assess the risk of lifting-related low back injuries based on biomechanical, physiological, and psychophysical criteria [19]. The recommended weight limit in hands is estimated based on the horizontal/vertical/asymmetry position of the hand-load, its vertical travel distance, lifting frequency, and the quality of hand-to-load coupling. A lifting index is subsequently calculated by dividing the actual lifted weight to the recommended weight limit. A lifting index smaller than 1 represents a safe zone meaning that 75% of the women population (~90% of the men population) are able to perform the task without any risk of injury [19]. Moreover, a lifting index between 1 and 3 represents a moderate risk zone, and a lifting index larger than 3 a high-risk zone (Table 2).

2.3.5. WISHA: The WISHA Lifting Calculator is based on an adaptation of the Revised NIOSH Lifting Equation [19]. It investigates the risk of low-back injuries during lifting and lowering tasks [32]. Compared to the Revised NIOSH Equation, WISHA uses less precise (discrete rather than continuous) vertical and horizontal distance measurements and assumes an unadjusted weight limit for twelve different hand-load spatial positions (three horizontal and four vertical sections). Subsequently, the unadjusted weight limit is multiplied by the lifting frequency, total working time, and twisting multipliers to constitute the weight limit. Its lifting index is calculated by dividing the actual lifted weight by the weight limit. A lifting index of 1 represents a safe zone, between 1 and 1.5 a moderate risk level, and larger than 1.5 a high-risk level (Table 2).

2.3.6. ManTRA: Manual Tasks Risk Assessment (ManTRA) aims to evaluate the exposure to musculoskeletal disorders associated with MMH tasks [33]. The body is assumed to consist of four regions while assessing risk factors of each region independently. While different factors such as time, frequency, speed of movement, force, posture, and vibration are incorporated, details on some of these factors are missing. The repetition risk is calculated from two factors; the time of a job cycle and the duration of continuously performing the tasks without any rest break. The two numbers assigned to force and speed constitute the exertion risk of the task. Finally, the total time, repetition risk, exertion risk, awkwardness, and vibration scores are summed up to generate a cumulative risk between 1 and 25 for each body region. The tool suggests that action is required when the cumulative risk is 15 or greater. Here, this range is divided into two zones: a cumulative risk under 20 is considered as a moderate risk, and above or equal to 20 is a high risk (Table 2).

2.3.7. MAC: The Manual Handling Assessment Charts (MAC) help assess the most common risk factors in lifting, lowering, carrying, and team handling operations [34]. Hand load, task frequency, hand distance from the lower back, vertical lift zone, torso twisting and side bending, and postural constraints are among the inputs of MAC. Unlike most tools, MAC considers the quality of grip on the load, floor surface condition, and environmental factors by assigning a risk score to each. The total score is calculated by adding up the scores of the foregoing risk factors. MAC identifies the factors that need to be modified thereby prioritizing action by addressing the task with the highest total score. In the present study, the MAC total score is divided into three equal ranges (Table 2).

2.3.8. Washington State: Washington State Ergonomic and MSD Risk Assessment Checklists are two versions of pre-configured checklists; one addresses the caution zone and the other represents the hazard zone [31]. Each checklist includes subgroups such as awkward postures, high hand forces, highly repetitive motions, repeated impacts, heavy, frequent, or awkward liftings, and moderate to high hand-arm vibrations. Each field has a list of tasks, and a mark is put next to the task when its description is similar to the task under consideration. The user should first use the caution zone checklist. The task is safe when none of the items are checked. If at least one item is checked, the user must investigate the hazard zone checklist. In this case, if any of the items on the hazard zone checklist are checked or the weight lifted is more than the lifting limit, the risk of injury is high, and if none is checked, the task has a moderate risk. A checked item in the caution zone or hazard zone checklist indicates that the task needs to be, respectively, investigated or resolved immediately (Table 2).

2.3.9. ACGIH TLV: ACGIH Lifting Threshold Limit Values (ACGIH TLV) aims to reduce the occurrence of shoulder and lower back disorders [28]. It assesses two-handed mono-lifting tasks with a maximum of 30° load asymmetry from the sagittal plane. This tool divides MMH activities into three different groups according to the task frequency and duration of the work. It uses a separate table for each group to determine the recommended lifting weight limit while considering the horizontal and vertical regions of the hand load in three and four distance levels, respectively. Subsequently, the lifting index for each task is estimated in a similar way to the Revised NIOSH equation (section 2.3.4). Since the ACGIH TLV tool does not provide any risk level classification, the NIOSH risk level classification method was used in this study (Table 2).

2.3.10. Snook's tables: Liberty Mutual Manual Materials Handling tables (Snook's tables) are developed to perform ergonomic assessments of two-handed lifting, lowering, pushing, pulling, and carrying tasks based on psychophysical criteria [20]. These tables provide both the male and female population percentages capable of performing MMH tasks without any risk of overexertion. Snook's tables use the start and end horizontal and vertical positions of the hand load, task frequency, and hand-load weight as inputs to assess injury risk. They also use horizontal carrying distance for carrying tasks and initial/sustained required force for assessing pulling and pushing tasks. This tool, however, does not provide any risk level classification. It is therefore assumed that a task is safe when it can be performed by 90% of the men population (similar to NIOSH). Moreover, 50% of capable men were assumed to be the boundary of the moderate- and high-risk zones (Table 2).

3. Results

The ten ERATs estimated different and even contradictory levels of injury risk in each of the twenty-one MMH tasks (Table 3). RULA, ACGIH TLV, REBA, and QEC were more conservative in their risk assessments as they evaluated all tasks to be either in moderate or high-risk zones. On the other hand, MAC and WISHA assessed most tasks to have no or low risk. Furthermore, different ERATs expressed considerable contradictions in their job assessments. For instance, REBA, RULA, and QEC evaluated LF 8 task as a high-risk activity while WISHA, ManTRA, and MAC predicted low or no risk. Such inconsistent risk assessments were more pronounced in pushing and pulling tasks whereas more consistency existed for lowering and carrying tasks. Moreover, the ERATs showed more consistency when assessing high- and low-demanding tasks, i.e., their assessments tended to diverge for moderately-demanding tasks. For example, almost all ERATs indicated a high level of risk for LW 2 (a high-demanding task) and a low level of risk for LF 4 (a low-demanding task), but evaluations were inconsistent for LF 6 (a moderately-demanding task) (Tables 1 and 3). The Washington State and Snook’s tables appeared to be more extreme in their risk assessments (they classified most tasks as either low or high risk) while QEC assessed most tasks to have a moderate risk of injury. Some ERATs such as NIOSH and ACGIH TLV were unable to assess the risk of injury in most tasks (dash symbols in the white color background of Table 3) due to their inherent limitations (Table 4).

4. Discussion

Ten ERATs were used to assess the occupational injury risk of twenty-one different MMH activities and showed inconsistent/contradictory levels of risk. These tools are frequently employed by ergonomists and practitioners in the field of occupational biomechanics to assess the risk of injuries among workers. Some ERATs are generally used in a variety of applications and industries while others are developed for use in a given type of activity (e.g., NIOSH for lifting tasks) or for a specific body segment (e.g., RULA for upper limb) thus likely resulting in a more comprehensive risk assessment of that task/body segment. This may, however, reduce the usability of an ERAT to limited workstations/tasks. Consequently, while an ERAT should be easy to use in different working environments, there is a trade-off between its focus on details and its field of applicability. Understanding the limitations of each ERAT is, hence, important and can help improve the accuracy of job assessments (Table 4).

4.1. Analysis of results: The estimated levels of risk by different ERATs were found inconsistent and even contradictory (Table 3). Although in some lifting tasks the worker lifted extremely heavy objects, some tools predicted little or no risk of injury. For instance, in LF 3 task (Table 1), despite the fact that the worker lifted a 40 kg hand-load (much heavier than the allowable limit by some tools such as NIOSH [19]), WISHA, MAC, ManTRA, and Snook's tables reported no or low risk of injury (Table 3). This stems from the fact that these tools mainly focus on the worker's posture, task duration, and frequency. On the other hand, RULA, ACGIH TLV, REBA, and QEC showed to be conservative as they assessed most of the tasks as high risk and none of the tasks as no/low risk (Table 3). This was in agreement with the findings of a recent systematic comparison between various risk assessment tools [39]. Even a low-demanding task such as LF 4 was assessed as 'moderate-risk' according to these tools. Some tools that consider the position of the hand load with respect to the worker's body have a threshold distance in their classification. For instance, NIOSH assessed a task as high risk if the horizontal distance of the hand-load was larger than 63 cm [19], even in non-demanding tasks where the hand-load was very light. In task LF 6, although the task was symmetric, in mid-flexion, and with a small hand load of 6.8 kg, NIOSH identified the task to be high risk solely due to the large horizontal distance (80 cm) of the hand-load (Table 1). There exists a different discrete classification of distance in WISHA, where the horizontal distance above 12 inches (~30 cm) does not affect the evaluated risk of injury. The conversion of this classification (e.g., larger/smaller than 63 cm in NIOSH or 30 cm in WISHA) to a continuous range may help eliminate these borderline effects.

Although NIOSH, WISHA, and ACGIH TLV originate from the same source [19,28,32], they were inconsistent in their assessments. In two-handed lifting tasks, WISHA evaluated a lower risk level (lower lifting index) as compared to NIOSH and ACGIH TLV. Moreover, unlike NIOSH and ACGIH TLV, WISHA was capable of analyzing one-handed lifting and lowering tasks [32]. In the static task ST 2, only ManTRA predicted a high risk of injury (Table 3) likely since it includes the effect of vibration [33]. Neglecting the effect of vibration on the risk of injury served as a limitation of almost all other ERATs (Table 4). ManTRA also paid great attention to task frequency. For instance, tasks ST 1 and ST 2 (similar in conditions as indicated in Table 1) were assessed by ManTRA to have different risk levels solely because of their different task frequencies. In addition, Snook's tables also greatly valued the task frequency. For instance, despite pushing a lighter object in task PS 2 as compared to PS 1, the risk of PS 2 was evaluated at a higher level due to the marginal difference in their frequencies (Table 3).

4.2. A guideline for the selection of ERATs: According to our findings, in many MMH activities, the ERATs reported different risks of injury for a given activity. Some ERATs were more conservative while others generally provided a lower risk of injury thus indicating the importance of selecting the most appropriate ERAT in different job assessments. For instance, when the risk of musculoskeletal injuries should be highly avoided, the use of more conservative ERATs such as RULA, ACGIH TLV, REBA, or QEC is recommended. On the other hand, using MAC or WISHA is recommended when little concerns exist as to the risk of musculoskeletal injuries. Other ERATs discussed in this study fall between these two extremes. When the focus is to assess/manage low back injuries (as the most prevalent musculoskeletal injuries among workers), it is more appropriate to use NIOSH, WISHA, ACGIH TLV, MAC, or Snook's tables as the primary basis for the development of these tools had been low back injuries. On the contrary, ERATs such as REBA and ManTRA perform their assessments by considering the risk of injury to all body segments. Nevertheless, while REBA ultimately reports a single score for risk of injury, ManTRA provides distinct outcomes for four different body segments. In addition, for risk assessments of the upper body, RULA appears to be the best choice and provides accurate investigations.

To determine whether an ERAT can assess a type of MMH activity, the user must refer to Table 4. For instance, for a particular type of MMH activity such as pulling, the selection must be made only from the tools capable of evaluating this activity. While NIOSH, ACGIH TLV, and Snook's tables are unable to assess one-handed tasks, many of the remaining tools do not differentiate between one-handed and two-handed tasks either. When the task consists of vibration (as an important risk factor) ManTRA and Washington State tools that consider the risk of vibration are recommended. However, as there are no distinct guidelines for some of the scoring factors of ManTRA (e.g., force or awkwardness) [33], different users may have inconsistent risk assessments. In addition, MAC can evaluate the environmental risk factors such as light, pollution, and ground surface conditions. MAC is also practical when the primary goal of the job assessment is to improve the worker's posture as the main focus of this tool is on the worker's posture rather than hand force/load. When the goal is to assess and reduce body joint loads (especially low back loads) NIOSH and ACGIH TLV are appropriate choices. Finally, age and gender are two factors for determining a worker's physical ability and thus risk of injury, i.e., selecting people with an appropriate physical ability to perform a given activity is known to be a helpful administrative intervention. However, in none of the studied ERATs, these two factors are considered when assessing risk of injury (only Snook's tables differentiate between workers of different genders).

4.3. Limitations: The relatively low number of assessed MMH tasks, especially in lowering, carrying, pulling, and pushing tasks with respect to the number of ERATs may serve as a limitation. Furthermore, a unified risk factor classification was assumed to compare the evaluations of different ERATs, but almost all investigated ERATs either had a unique risk level classification (e.g., REBA and RULA [21,22]) or had no classification at all (e.g., MAC and Snook's tables [20,34]). Therefore, assigning custom risk levels to some of these ERATs may have influenced our comparisons.

5. Conclusions

Comparison and evaluation of ten ergonomic risk assessment tools were carried out by investigating twenty-one MMH activities. Results indicated different assessments for injury risk levels throughout the tools thus emphasizing the need to fully understand the limitations and strengths of each tool for an accurate job assessment. While RULA, ACGIH TLV, REBA, and QEC were the most conservative tools in their evaluations, MAC and WISHA were the least conservative tools. Although ManTRA lacked a distinct guideline and threshold in some of its parameters, the consideration of vibration as an independent parameter can be considered as an advantage. A checklist format based on predefined examples in Washington State limited its application. NIOSH and ACGIH TLV had important limitations, i.e., they were unable to analyze many types of MMH activities.

The supplementary data is available at:

file:///C:/Users/user/Downloads/Supplementary%20material-1.pdf

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Table captions

Table 1. Characteristics and classifications (shown by check marks) of the considered MMH activities based on the task frequency, hand-load mass, task symmetry or asymmetry, vibration, load vertical position (from the floor), load horizontal position (from feet), lifting technique, and handling technique.

Table 2. Risk levels of different ERATs. Level “1” represents a low-risk (or no-risk) zone, level “2” a moderate-risk zone, and level “3” a high-risk zone.

Table 3. The evaluated risk level of injury for each MMH activity using different ERATs. “1” is used for a no- or low-risk zone, “2” demonstrates a moderate-risk zone, and “3” represents a high-risk zone. The outcome score of each tool for each task is also given in parentheses. A dash symbol is used when an ERAT is unable to assess a given task.

Table 4. Important limitations of the ERATs.

Table 1

MMH activity	Task code	Task frequency (per hour)		Hand-load mass (kg)		Symmetric	Asymmetric	Vibration	Load vertical position (cm)			Load horizontal distance (cm)			Lifting technique		Handling technique	
		≤60	60<	≤10	10<				Standing (90<)	Mid-flexion (40<, ≤90)	Deep-flexion (≤40)	Close to body (≤30)	Mid-distance (30<, ≤60)	Far from body (60<)	Stoop	Squat	One-handed	Two-handed
Lifting	LF 1		130		20	✓					10		40		✓			✓
	LF 2		150		37	✓				70			40		✓			✓
	LF 3	1			40	✓			100			20			✓			✓
	LF 4	28		10		✓			100			30			✓			✓
	LF 5	28		10		✓			150			30			✓			✓
	LF 6		120	6.8		✓				60				80	✓			✓
	LF 7		130		20	✓					30		40		✓		✓	
	LF 8	28			23	✓					30	30				✓	✓	
	LF 9	60			13		✓			90			40			✓		✓
Lowering	LW 1	28			23		✓		100			25			✓			✓
	LW 2		150		37	✓					30			95		✓		✓
Carrying	CR 1	28			23	✓				80		30			✓		✓	

	CR 2	28			23	✓				80		30			✓			✓
Pulling	PL 1		75		40		✓			70				65	✓		✓	
	PL 2		75		40		✓			70				65	✓			✓
Pushing	PS 1	1			36	✓			100			20			✓			✓
	PS 2		75		36	✓			120				52		✓			✓
Prolonged Static	ST 1	28		1		✓			160			30			✓			✓
	ST 2		240	3.4		✓		✓	100			20			✓			✓
	ST 3		130	5			✓	✓	100			25			✓			✓
	ST 4		270	5		✓					10		45			✓	✓	

Table 2

ERAT	Evaluation criteria	Risk level		
		1	2	3
REBA	REBA score	1-3	4-7	8-14
RULA	RULA score	1-2	3-6	7
QEC	QEC total percentage	≤50%	51%-70%	>70%
NIOSH	Lifting index	<1	1-3	>3
WISHA	Lifting index	<1	1-1.5	>1.5
ManTRA	Cumulative risk	<15	15-19	20-25
MAC	MAC total score	0-10	11-20	21-30
Washington State	Caution and hazard zone checklists	0 caution	≥1 caution(s) 0 hazard	≥1 hazard(s)
ACGIH TLV	Lifting index	<1	1-3	>3
Snook's tables	Percentage of capable men	>90%	50%-90%	<50%

Table 3

Task code	Risk Level (ERATs assessment outcomes)									
	REBA	RULA	QEC	NIOSH	WISHA	ManTRA	MAC	Washington State*	ACGIH TLV	Snooks tables
LF 1	3 (11)	3 (7)	3 (71%)	2 (2.3)	2 (1.48)	2 (17)	2 (15)	3	3 (inf)	1 (>90%)
LF 2	2 (5)	3 (7)	2 (62%)	3 (4.5)	3 (2.28)	2 (18)	2 (14)	3	3 (4.1)	3 (32%)
LF 3	2 (5)	3 (7)	2 (69%)	2 (1.9)	1 (0.98)	1 (8)	1 (7)	3	2 (2.2)	1 (>90%)
LF 4	2 (5)	2 (5)	2 (56%)	1 (0.8)	1 (0.37)	1 (12)	1 (1)	1	1 (0.7)	1 (>90%)
LF 5	3 (8)	2 (6)	2 (63%)	2 (1.1)	1 (0.65)	2 (18)	1 (7)	1	3 (inf)	1 (>90%)
LF 6	3 (10)	3 (7)	2 (63%)	3 (inf)	1 (0.58)	2 (17)	2 (12)	3	3 (inf)	2 (83%)
LF 7	2 (7)	3 (7)	2 (67%)	-	2 (1.48)	2 (17)	2 (19)	3	-	-
LF 8	3 (8)	3 (7)	3 (76%)	-	1 (0.43)	1 (14)	1 (7)	2	-	-
LF 9	3 (10)	3 (7)	2 (66%)	2 (1.9)	1 (0.69)	2 (15)	1 (8)	1	2 (1.4)	1 (>90%)
LW 1	3 (10)	3 (7)	3 (74%)	-	2 (1.4)	2 (19)	2 (14)	3	-	1 (>90%)
LW 2	3 (10)	3 (7)	3 (78%)	-	3 (3.59)	3 (20)	2 (18)	3	-	3 (<1%)
CR 1	2 (5)	3 (7)	2 (63%)	-	-	1 (13)	1 (8)	1	-	-
CR 2	2 (4)	2 (5)	2 (56%)	-	-	1 (12)	1 (7)	1	-	1 (>90%)
PL 1	2 (7)	3 (7)	3 (74%)	-	-	2 (17)	-	1	-	-
PL 2	2 (6)	3 (7)	3 (74%)	-	-	2 (17)	-	1	-	3 (29%)
PS 1	2 (5)	3 (7)	2 (69%)	-	-	1 (8)	-	3	-	1 (>90%)
PS 2	2 (7)	3 (7)	3 (74%)	-	-	2 (17)	-	1	-	3 (39%)

ST 1	2 (5)	2 (6)	2 (61%)	-	-	2 (17)	-	3	-	-
ST 2	2 (5)	2 (5)	2 (54%)	-	-	3 (21)	-	2	-	-
ST 3	2 (5)	2 (5)	2 (54%)	-	-	2 (19)	-	2	-	-
ST 4	2 (7)	2 (5)	2 (62%)	-	-	2 (15)	-	3	-	-

***** No outcome score is available for this tool

Table 4

Limitations	REBA	RULA	QEC	NIOSH	WISHA	ManTRA	MAC	Washington State	ACGIH TLV	Snooks tables
Fails to assess pushing/pulling tasks				*	*		*	*	*	
Fails to assess carrying tasks				*	*				*	
Fails to assess static tasks				*	*		*		*	*
Only focuses on low back risk of injury				*	*		*		*	*
No distinct guidelines for scoring factors						*				
Limited to a checklist of predefined hazardous tasks examples								*		
Considers only one side of the body	*	*								
Fails to differentiate between one- and two-handed MMH	*	*	*		*		*	*		
Fails to assess one-handed tasks				*					*	*
Fails to consider lifting techniques (i.e., stoop or squat)			*	*	*			*	*	*
Fails to consider duration of the task	*	*					*			*
Fails to consider frequency of the task										

Fails to assess MMH tasks with seated or kneeling body postures				*	*		*		*	*
Fails to consider the worker's age/experience	*	*	*	*	*	*	*	*	*	*
Fails to consider the worker's gender	*	*	*	*	*	*	*	*	*	
Fails to consider both the origin and destination of the task	*	*	*		*	*	*	*		
Fails to consider the effect of vibration	*	*	*	*	*		*		*	*

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