Hand-Intensive Jobs

Effectively evaluating risk levels

By Stephen Bao

PLANT ERGONOMISTS AND SH&E SPECIALISTS are often asked whether a job may cause work-related musculoskeletal disorders (MSDs)—one of the most costly injuries at many companies. Often, they may use their professional judgment to make this determination. However, because they know this judgment may differ from that of others, they may not really be sure whether their determination is correct. Does this scenario sound familiar?

SH&E practitioners are often asked, "How much is too much for a specific job hazard?" Ergonomics research has found sufficient evidence linking certain job risk factors (e.g., highly repetitive hand motions, high hand force, awkward hand/wrist postures) to work-related MSDs (e.g., hand/wrist tendonitis, carpal tunnel syndrome) (NIOSH). While definitive quantitative relationships between job risk factors and work-related MSDs may never be found, just as with most other human diseases, relationships between quantitative or semiquantitative measures of job risk factors and the likelihood of developing certain work-related MSDs do exist. Based on those relationships, methods and criteria have been developed to help ergonomists and SH&E practitioners evaluate jobs and determine risk levels.

This article describes three methods that can be used to evaluate hand-intensive jobs: 1) sections related to hand activities in the Washington State Ergonomics Rule (Washington State Dept. of Labor and Industries); 2) the hand activity level (HAL) threshold limit value (TLV) adopted by the American Conference of Governmental Industrial Hygienists (ACGIH); and 3) the Strain Index (SI) method developed by Moore and Garg. This article presents comparisons of these methods applied to several jobs so that readers may be better informed when they need to decide how to evaluate jobs for musculoskeletal risks. These comparisons are based on results of exercises in a workshop in which participants evaluated seven different jobs using the three methods, as well as based on their own professional judgment.

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Washington State Ergonomics Rule

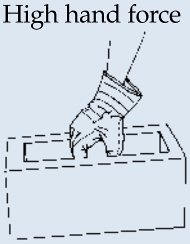
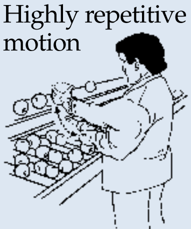
The state of Washington introduced an ergonomics rule in 2000 (Washington State Dept. of Labor and Industries). Although voters in the state recently approved a measure that rescinds the rule, criteria detailed in the rule remain applicable to this discussion. The rule covered many common workplace risk factors (e.g., awkward postures, high hand force, highly repetitive motion, repeated impact, heavy/frequent/awkward lifting and hand-arm vibration) that may cause MSDs. The rule defined quantitative threshold limits as "caution zone" and "hazard zone" based on the level of the risk factor (e.g., hand force amplitude in pounds), frequency (e.g., number of times lifting an object) and duration (e.g., number of hours performing highly repetitive motion activities).

Details of the risk factor levels for the different zones follow. However, both force and repetition in the caution zone do not automatically place a job in the hazard zone. Jobs with exposure below the caution zone level are considered safe (or not covered by the rule) and employers need not do anything (under the rule). Jobs with exposure in the caution zone are considered to present some level of risk, but the jobs are not forbidden if the risk level does not reach the hazard level. Under the rule, employers would have been required to provide ergonomics awareness education to affected employees, and to conduct more detailed hazard evaluations on these jobs. If the jobs proved to have high risk levels based on the hazard zone criteria, their risk levels would need to have been reduced to a level within the caution zone or to the extent technologically or economically feasible.

Table 1 shows risk factors and limit criteria related to hand activities. Intensive keying, repeated impact and hand-arm vibration are excluded from

Table 1

Caution Zone & Hazard Zone Criteria

	Caution Zone	Hazard Zone
High hand force 	Pinching an unsupported object(s) weighing two or more pounds per hand, or pinching with a force of four or more pounds per hand, more than two hours total per day.	Pinching an unsupported object(s) weighing two pounds or more per hand, or pinching with a force of four pounds or more per hand: • without any other combined risk factors for more than four hours total per day; • with highly repetitive motion for more than three hours total per day; • with awkward hand/wrist postures (i.e., wrist flexion >30 degrees, wrist extension >45 degrees or wrist ulnar deviation >30 degrees), for more than three hours total per day.
High hand force 	Gripping an unsupported object(s) weighing 10 or more pounds per hand, or gripping with a force of 10 or more pounds per hand, more than two hours total per day.	Gripping an unsupported object(s) weighing 10 pounds or more per hand, or gripping with a force of 10 pounds or more per hand: • without any other combined risk factors for more than four hours total per day; • with highly repetitive motion for more than three hours total per day; • with awkward hand/wrist postures (i.e., wrist flexion >30 degrees, wrist extension >45 degrees or wrist ulnar deviation >30 degrees), for more than three hours total per day.
Highly repetitive motion 	Repeating the same motion with the neck, shoulders, elbows, wrists, or hands (excluding keying activities) with little or no variation every few seconds, more than two hours total per day.	Using the same motion with little or no variation every few seconds (excluding keying activities): • without any other combined risk factors, for more than six hours total per day; • with awkward hand/wrist postures (i.e., wrist flexion >30 degrees, wrist extension >45 degrees or wrist ulnar deviation >30 degrees), and high, forceful exertions with the hands, for more than two hours total per day.

Source: Washington State Ergonomics Rule.

this discussion. The caution zone risk level is determined by evaluating the hand force level or repetitive motion level together with the exposure duration. Caution zone threshold limits for hand force are two pounds unsupported weight if pinch gripped with one hand; four pounds pinch grip hand force; or 10 pounds weight or hand force with a power grip for more than two hours total per day.

The caution zone threshold limit for repetitive motion is determined by considering whether the wrist or hand is repeating the same motion with little or no variation every few seconds for more than two hours total per day. Hazard zone threshold limits are determined by considering the same risk factors, other combined risk factors and varied exposure durations (Table 1).

The following example illustrates how this method works. A worker picks up machine parts for an eight-hour shift with two 15-minute breaks (one hour lunch break is excluded). She grips machine parts with her fingers using a pinch grip. To determine the amount of hand force used in picking up the machine parts, an ergonomist asked her to memorize the amount of hand force she applied when picking up the part, then apply the same amount of force on a hand pinch dynamometer. The pinch hand force was determined to be 10 pounds. With a stopwatch, the ergonomist determined that the actual exertion time when the hand was picking up the part was about 60 percent of the task cycle. The work pace was about 25 machine parts per minute. With the workstation configurations, the worker bent her hand slightly, but the wrist flexion was less than 30 degrees. According to the plant manager, work efficiency is around 85 percent (i.e., 85 percent of the time the worker is actually performing this task, with the other 15 percent spent on preparation, machine interference, personal needs, etc.).

The following parameters are derived from the example and used in the risk level determination.

- Pinch hand force: 10 pounds > 4 pounds.
- Hand highly repetitive motion: Yes
- Wrist posture: Good (as defined by the rule)
- Duration of high hand force: 3.8 hrs. [(8 hrs. - 2 x 15-minute breaks) x 60 percent] x 85 percent efficiency
- Duration for repetitive hand motion: 6.4 hrs. (8 hrs. - 2 x 15-minute breaks) x 85 percent efficiency

Caution Zone Determination

This job would fall into the caution zone due to the hand force because the duration is more than two hours and hand pinch grip force is greater than four pounds. The job would also be in the caution zone based on the repetitive motion of the hand—

Table 2

Hand Activity Level

Hand activity level can be calculated using exertion frequency (or exertion period or duration) and duty cycle information.

Frequency (exertion/s)	Period (s/exertion)	Duty Cycle (%) 0-20	20-40	40-60	60-80	80-100
0.125	8.0	1	1	--	--	--
0.25	4.0	2	2	3	--	--
0.5	2.0	3	4	5	5	6
1.0	1.0	4	5	5	6	7
2.0	0.5	--	5	6	7	8

Figure 1

Hand Activity Level

Hand activity level can be rated using these guidelines.

Hand idle most of the time; no regular exertions	Consistent, conspicuous, long pauses; or very slow motions	Slow, steady motions/ exertions; frequent brief pauses	Steady motions/ exertions; infrequent pauses	Rapid, steady motions/ exertions; no regular pauses	Rapid, steady motions/difficulty keeping up or continuous exertions

Source: Latko, et al.

Figure 2

Borg Scale

The Borg Scale can be used to rate the peak hand force by the worker.

10	**Maximum**
9	**Very, very hard**
8	**Very hard**
7	**Hard**
6	
5	**Somewhat hard**
4	**Moderately hard**
3	
2	**Light**
1	**Very light**
0.5	**Very, very light**

the worker is repeating the same motion with her hand with little variation every few seconds for more than two hours per day. This determination process is relatively simple without the need to consider combined risk factors.

Hazard Zone Determination

All three parameters—hand force, repetitive motion and duration—must be examined when conducting the hazard zone determination. Because of the high hand force (pinch grip force greater than four pounds) combined with highly repetitive motion for more than three hours total per day, this job is considered a hazard zone job (Table 1). Assuming that the job was improved so that the pinch grip force required was less than four pounds, the job would no longer be a hazard zone job due to the hand force. However, it is still not possible to conclude that the job is not in the hazard zone because the risk factor of repetitive motion must still be examined separately. The hazard zone duration limit for highly repetitive motion is six hours (Table 1). Because the duration of repetitive motion is 6.4 hours (as determined above), the job would still be classified in the hazard zone, even if hand force were reduced.

ACGIH's Hand Activity Level TLV

ACGIH's hand activity level (HAL) TLV is based on epidemiological, psychophysical and biomechanical studies; it is intended for "mono-task" jobs performed for four or more hours per day. The TLV specifically considers two parameters: HAL and normalized peak hand force (ACGIH).

HAL is based on the frequency of hand exertions and the duty cycle (percentage of exertion time and cycle time). It can be determined with ratings by a trained observer, using the scale shown in Figure 1. It can also be calculated using information on the frequency of exertions and the duty cycle (Table 2). For example, for a job with hand exertion frequency of 0.5 exertions/second (or an exertion period of two seconds/exertion) and a duty cycle of 50 percent, HAL is 5 (Table 2). However, this table is not complete. HAL values are not available for certain frequency (or period) and duty cycle combinations where the scale shown in Figure 1 should be used instead.

Peak hand force is normalized on a scale of 0 to 10, which corresponds to 0 to 100 percent of the applicable population reference strength. Peak force can be determined with ratings by a trained observer; rated by workers using a Borg Scale (Figure 2); measured using instrumentation; or calculated with biomechanical methods. After obtaining HAL and normalized peak hand force, the risk level can be determined using Figure 3. Two limit values exist for this method: action limit and threshold limit value (TLV), which are analogous by the meanings of the ratings to the caution zone level and the hazard zone level of the Washington State Ergonomics Rule, respectively.

The same example job can be used to illustrate application of this method as well. Using the 10 pound pinch force required for the task, and knowing that the average pinch force strength is about 20 pounds (Bao; Mathiowetz, et al), one can calculate that the normalized peak hand force is 5 (10/20 x 10). With an exertion frequency of 0.42 times/second (or 25 machine parts per minute), and duty cycle of 60 percent (as described earlier), HAL is determined to be 5. Using Figure 3, it is determined that this risk level is just above the TLV level; therefore, this job is considered a hazardous job.

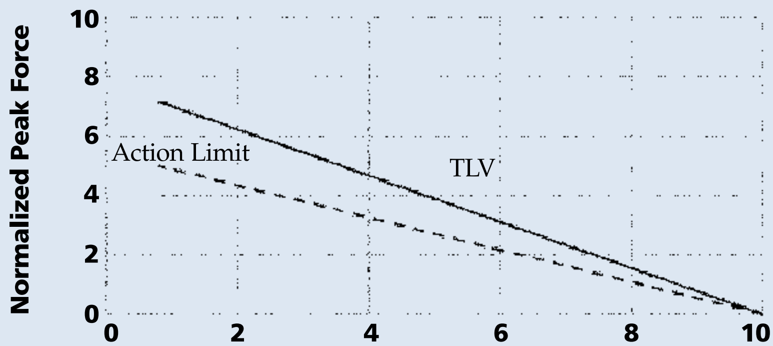
The Strain Index Method

The Strain Index (SI) method is a semiquantitative job analysis method developed by Moore and Garg based on physiology, biomechanics and epidemiology of distal upper extremity disorders (Moore and Garg). Six parameters are estimated and used to calculate a score (the SI) to quantify the risk level. Each parameter is rated using a scale of 1 to 5 (Table 3). This method is applicable to mono-task jobs.

Figure 3

Reduction of MSDs

The TLV for reduction of work-related MSDs is based on hand activity level (HAL) and normalized peak hand force. The top line depicts the TLV. The bottom line is an action limit for which general controls are recommended.



Source: ACGIH.

Intensity of exertion is an estimate of a task's force requirements and is defined as the percentage of maximum strength required to perform the task once. The intensity of exertion can be estimated by an analyst using the verbal anchors described in Table 3, or by other methods as described in the ACGIH method, such as the Borg Scale reported by a worker or direct force measurement.

Duration of exertion is equivalent to duty cycle described in the ACGIH method, and reflects the percent of time that the hand is exerting force. The rating is linked to the percentage of the exertion time (Table 3). Efforts/minute (or frequency) is the number of exertions per minute, and reflects the repetitiveness of hand activities. Hand and wrist posture refers to the anatomical position of the wrist or hand relative to neutral position. A rating is assigned by comparing the verbal anchors in Table 3.

Speed of work estimates perceived pace of the job. It is an overall work pace estimation rather than specific to the hand exertion. The latter is estimated by the efforts per minute. Speed of exertion is subjectively estimated by an analyst using the verbal anchors in Table 3. Duration per day reflects the total number of hours that the job is performed per day. The corresponding rating is then assigned according to Table 3.

Once all six parameters are rated, multipliers are obtained using Table 4. SI is the product of all six multipliers. Jobs with SI scores less than or equal to 3 are probably safe; those with scores equal to or greater than 7 are probably hazardous (Moore and Garg). Therefore, the SI scores of 3 and 7 are analogous to the caution zone and hazard zone levels in the Washington State rule, or the action level and TLV level in ACGIH's method.

Returning again to the example job, the intensity of the exertion can be rated as 3 because using about 50 percent of the pinch grip strength should be considered hard (Table 3). Rating of the duration of exertion is 4, given that the duty cycle was 60 percent. Rating of efforts/minute is 5 as handling frequency is 25 times/minute, which is greater than 20 times/minute. Hand/wrist posture is rated a 3, as the worker only bent her wrist slightly and should be considered as fair (hand posture). The speed of work might be rated as fast or a 4 as the worker was able to keep up even though the work pace was high. A shift time of eight hours is rated as a 4.

Table 3

Rating Criteria of the Strain Index Method

Rating	Intensity of Exertion	Duration of Exertion (% of cycle)	Efforts/ Minute	Hand/Wrist Posture	Speed of Work	Duration Per Day (hours)
1	light	<10	<4	very good	very slow	≤1
2	somewhat hard	10-29	4-8	good	slow	1-2
3	hard	30-49	9-14	fair	fair	2-4
4	very hard	50-79	15-19	bad	fast	4-8
5	near maximal	≥80	≥20	very bad	very fast	>8

Source: Moore and Garg.

Table 4

Multiplier Table of the Strain Index Method

Rating	Intensity of Exertion	Duration of Exertion (% of cycle)	Efforts/ Minute	Hand/Wrist Posture	Speed of Work	Duration Per Day (hours)
1	1	0.5	0.5	1.0	1.0	0.25
2	3	1.0	1.0	1.0	1.0	0.50
3	5	1.5	1.5	1.5	1.0	0.75
4	9	2.0	2.0	2.0	1.5	1.00
5	13	3.0*	3.0	3.0	2.0	1.50

**If duration of exertion is 100 percent, efforts/minute multiplier should be set to 3.0.*

Source: Moore and Garg.

Using Table 4, the following multipliers can be obtained:

- Intensity of exertion = 5 (rating of 3)
- Duration of exertion = 2.0 (rating of 4)
- Efforts/minute = 3.0 (rating of 5)
- Hand/wrist posture = 1.5 (rating of 3)
- Speed of work = 1.5 (rating of 4)
- Duration per day = 1.0 (rating of 4)

Table 5

Evaluation Results

Evaluation results using different assessment methods (number of participants: 16 to 23, shown in parentheses).

Job	Risk Level*	Professional Judgment	ACGIH HAL	Strain Index	WA Ergo Rule
Wire cutting	Safe	0.0% (0)	0.0% (0)	11.8% (2)	0.0% (0)
	Caution	43.5% (10)	0.0% (0)	5.9% (1)	22.7% (5)
	Hazard	56.5% (13)	100.0% (23)	82.4% (14)	77.3% (17)
Paper moving	Safe	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)
	Caution	39.1% (9)	0.0% (0)	0.0% (0)	45.5% (10)
	Hazard	60.9% (14)	100.0% (23)	100.0% (16)	54.5% (12)
Electronic assembly	Safe	60.9% (14)	100.0% (23)	94.4% (17)	4.5% (1)
	Caution	26.1% (6)	0.0% (0)	5.6% (1)	27.3% (6)
	Hazard	13.0% (3)	0.0% (0)	0.0% (0)	68.2% (15)
Laundry	Safe	17.4% (4)	0.0% (0)	0.0% (0)	0.0% (0)
	Caution	65.2% (15)	8.7% (2)	0.0% (0)	8.7% (2)
	Hazard	17.4% (4)	91.3% (21)	100.0% (18)	91.3% (21)
Sawmill	Safe	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)
	Caution	4.3% (1)	0.0% (0)	0.0% (0)	4.3% (1)
	Hazard	95.7% (22)	100.0% (23)	100.0% (19)	95.7% (22)
Pharmacist	Safe	73.9% (17)	100.0% (23)	100.0% (18)	8.7% (2)
	Caution	26.1% (6)	0.0% (0)	0.0% (0)	87.0% (20)
	Hazard	0.0% (0)	0.0% (0)	0.0% (0)	4.3% (1)
Poultry processing	Safe	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)
	Caution	4.3% (1)	0.0% (0)	0.0% (0)	0.0% (0)
	Hazard	95.7% (22)	100.0% (23)	100.0% (18)	100.0% (23)

**"Safe" means below the action level for the ACGIH method; SI < 3; or below the caution zone level of the Washington State Ergonomics Rule. "Caution" is between the action level and the TLV; 3 ≤ SI < 7; or in the caution zone of the Washington State rule. "Hazard" is above the TLV level; SI ≥ 7; or in the hazard zone of the Washington State rule.*

The SI for this job is: 67.5 (5 x 2 x 3 x 1.5 x 1.5 x 1), which is much greater than 7. Therefore, the job is considered hazardous.

Comparing the Methods

The three methods discussed give quantitative/semiquantitative limit values that indicate when risk is considered to be too great. From the example applications, it can be seen that some methods may be easier to use than others. This leads to two additional questions: 1) How consistent are the methods when different analysts conduct the evaluations? 2) Are the same conclusions (i.e., this job is/is not hazardous) always obtained when the different methods are used?

To answer these questions, an experiment was conducted. The 23 workshop participants used each of the three methods to evaluate seven different jobs independently. This experiment was part of a half-day workshop on physical exposure assessment of hand activities, during which the three methods were taught. Participants were ergonomists, physical and occupational therapists, safety consultants, kinesiologists and students in ergonomics. Most participants reported having good knowledge of ergonomics assessment. On a scale of 1 (low) to 10 (high), the average self-reported knowledge level was 6.1 (range 2 to 9). Information on knowledge of using the three methods was not obtained.

Before the methods were explained, participants were asked to observe seven different jobs, then to evaluate those jobs using their professional judgment. Jobs were to be placed in one of three categories: safe, caution and hazard. After the initial job evaluation, each of the three methods was taught, with examples given to help the participants feel comfortable using them. The participants then reviewed the same seven jobs and applied the methods to the evaluation.

The seven jobs included two simulated jobs that volunteer participants performed in the classroom, and five real jobs from various industries that were captured on video and shown to participants. These five jobs were selected because they covered a variety of hand forces and repetitions. When performing the job evaluations, participants were able to ask any relevant questions of volunteer participants and the instructor, just as if they were performing an actual workplace assessment. Among these questions were inquiries about the perceived hand force required to perform the job, the number of hours of the shift, break times, etc.

In the first simulated job, the volunteer used a wire cutter to cut metal wires with a frequency of approximately 20 times per minute. A power grip posture was assumed for this task. In the second simulated job, the volunteer moved reams of copy paper from one location to another. The frequency of the task was about 30 times per minute, with a hand pinch grip used. Both jobs were performed for several minutes, until all participants were able to observe details of performance. Shift duration was assumed to be eight hours for both jobs.

The videotaped jobs were: 1) an electronic assembly job, where a worker placed an anode on a TV's CRT unit; 2) a laundry job, where a worker pulled clothes from a pile to fold; 3) a sawmill job, where a worker constantly handled a stack of fence boards on a conveyor chain; 4) a pharmacist job, where a worker checked prescriptions, wrote notes and entered data into a computer; and 5) a poultry processing job, where a worker pulled off chicken skins by hand on a moving conveyor. Each job differed in terms of hand force, frequency and exertion duty cycle.

Results show that the evaluations were not always consistent among participants (Table 5). This was particularly obvious when they evaluated jobs using their own professional judgment. For example, using professional judgment, 17.4 percent considered the laundry job safe, 65.2 percent caution level and 17.4 percent hazard level. The variation was smaller when a structured method was used. Using the laundry job as an example, most participants (more than 91 percent) considered the job a hazard when any one of the three structured methods was used.

The variation between analysts was not as obvious when risk level was apparently high. For example, most participants (more than 95 percent) considered the sawmill and poultry processing jobs as hazardous, even when based on their own professional judgment.

Jobs with a repetitive nature but very low hand force may still be considered caution zone jobs when evaluated using the Washington State Ergonomics Rule, while they might be considered safe when other methods were used. For example, when participants used the state rule, 87 percent considered the pharmacist's job to be a caution zone job due to the repetitive motions involved, even though the job required minimal hand force (Table 5). However, most participants (74 percent) considered it safe when using professional judgment; all of them also concluded that the job was safe when the ACGIH and SI methods were used.

It might also be noticed from Table 5 that the number of participants was different for each method. This is because some participants were not able to complete their evaluations within the time allowed for the exercise (between two and five minutes for each method). Time needed to complete each exercise was not recorded at the individual level. The least number of participants completed the evaluations using the SI method, which might suggest that this method is the most complicated of the three.

To examine the issue of comparability between the different methods, the agreement between the methods was calculated (Table 6). The bold number in the middle of the cell indicates the percent agreement between the two methods (column vs. row). The number in the upper right corner of the cell indicates the percent of participants who concluded that the jobs were more risky when using the method in the column than in the row. The italic number in the lower left corner of the cell indicates the percent of participants who concluded that the jobs were more risky when using the method in the row than in the column.

Table 6

Comparisons of Evaluations

Comparisons of evaluations using different methods by all participants on all jobs (percent agreement in bold, percent of method in the column more protective than the row in plain type, percent of method in the row more protective than the column in italic).

	Professional Judgment	ACGIH HAL	Strain Index	WA Ergo Rule
Professional Judgment		24.2 **66.5** *9.3*	21.8 **66.9** *11.3*	41.1 **51.3** *7.6*
ACGIH HAL			2.4 **95.2** *2.4*	27.8 **60.8** *11.4*
Strain Index				28.5 **61.8** *9.8*
WA Ergo Rule				

How to read the table
% of column more protective
% agreement
% of row more protective

Using any of these three methods, one can determine whether a job is safe; may not be safe, meaning further evaluation is needed; or hazardous. As the exercises described show, the different methods may not always produce identical results.

The highest agreement was found between the ACGIH and SI methods. More than 95 percent of participants reached the same conclusion using these two methods. An equal number of participants (only 2.4 percent) concluded there was higher risk with one of the methods than the other. The agreement of comparisons between other methods was similar, around 50 to 70 percent. Evaluations conducted using professional judgment were almost always less protective compared to those based on the structured methods. The Washington State rule seemed to be the most protective when compared to the other methods.

Discussion & Conclusions

Using any of the three systematic methods described, it is possible to know whether a job is safe (exposure level below caution zone, action limit or SI score of 3); may not be safe, meaning further evaluation is needed (exposure level between caution zone and hazard zone, action limit and TLV, or SI score between 3 and 7); or hazardous (exposure level in the hazard zone, above TLV or SI score of 7).

TLVs in the Washington State rule and the ACGIH method are derived from available studies where some dose-response relationships between exposure parameters (e.g., hand force) and health outcomes (e.g., carpal tunnel syndrome) are available. A research consortium (including Washington State) is currently conducting a large-scale prospective epidemiological study on work-related upper extremity MSDs (Silverstein, et al). In this study, the three exposure evaluation methods are being used and health outcomes (incidences of the upper extremity MSDs) are being collected. This study will be able to provide updated information on the relationships between the injury incidence and the TLVs of the three methods. The threshold limit scores of the SI were based on some preliminary assessment of incidence rates of the upper extremities (Moore and Garg).

These exercises also show that different exposure evaluation methods may not always produce identical results. Some may be more protective than others under certain circumstances. It may also be concluded that different analysts using the same methods may reach different conclusions. This may be because most of the methods require an analyst to subjectively rate certain aspects of the job. Due to job complexity and previous work experience, the analysts may have different points of reference as well, which may lead them to rate risk factors differently. The present study design did not allow further analysis of the relationships between the differences in ratings and the various job- and analyst-related factors. These may need to be investigated in future studies. To calibrate subjective judgment and increase the consistency of ratings among analysts, it may be helpful to provide training with job examples of varied exposure levels.

Ergonomists often use professional judgment or expert opinion when conducting job evaluations. Such an approach may be easy in that the evaluation is processed in the analyst's brain, with no specific measurements or calculations needed. Conclusions might be comparable to structured methods when the risk level is high; such was the case for the sawmill and poultry processing jobs.

The variability between different analysts is high as well. This is particularly true when either the hand force level or the repetitive movement level is not very high. This variability may be due to the analysts' previous work experience. As noted, analysts may have different points of reference when using professional judgment, and these references may not be definable. Thus, using professional judgment may result in underestimating the risk.

ACGIH's HAL method is relatively easy to apply. Only two parameters are used, both of which are continuous variables, so the analyst could assign a value depending on the relative risk level of the exposure. This is not possible for methods that use only dichotomous values (such as the Washington State rule). In addition, no complicated calculations are involved. One need only refer to a simple chart to obtain evaluation results once the values for the normalized peak hand force and HAL are determined.

This method seems to be sensitive enough to distinguish jobs as safe, caution (action level) and hazardous levels (TLV level), although the actual association between these levels and work-related MSDs has not been formally validated. This method is also likely to produce similar results from different analysts. In other words, it may be concluded that this method has good reproducibility. However, one limitation is that this method is designed for mono-task jobs performed for four or more hours per day.

The SI method seems to reach conclusions comparable to those obtained via the ACGIH method. SI is also sensitive and has good reproducibility. However, it requires the analyst to consider six different parameters, convert values from ratings to multipliers and perform multiplication calculations. Therefore, its application is more difficult and time-consuming. This method is also developed for mono-task jobs.

The method from the Washington State rule is easy to use, as only a few parameters with dichotomous values must be considered. It is applicable to both mono-task and multi-task jobs. It is also a structured method, giving the analyst specific threshold values to facilitate reaching conclusions rather than using wild guesses. However, it is not as sensitive or reproducible as the ACGIH and SI methods, so there is a trade-off between simplicity, sensitivity and reproducibility. In addition, this method is more protective compared to the others, particularly when jobs are repetitive but have low hand force. It is difficult to conclude whether this is overprotective or whether the ACGIH and SI methods underestimate the risk. Further epidemiological study results are needed to answer this question. ■

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