# THE HAND ACTIVITY LEVEL: USING TASK LEVEL OUTPUTS TO EVALUATE JOB RISK

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## ABSTRACT

Upper extremity cumulative trauma disorders are prevalent in the workplace. These problems have both economic and quality of life repercussions. Existing ergonomic analysis tools are primarily intended to estimate the ergonomic risk associated with single-task jobs, however, in today's workplace many jobs contain more than one task and some may include job rotation, which further complicates analysis. This paper explores one method of modifying an existing tool, The ACGIH Hand Activity Level TLV (HALTLV), to assess the ergonomic risk of multi-task jobs in a case control setting. The HALTLV requires two independent variables; one measures the normalized peak force and the other measures hand activity level. This TLV proposes different methods for determining these variables, also investigated are the metrics proposed by the Strain Index. In all, over 900 variations were considered. Intensity of Exertion and Speed of Work metrics were used in place of NPF and hand activity level. Using the metrics proposed in the Strain Index for Intensity of Effort and Speed of Work (replacing HALTLV's normalized peak force and hand activity level, respectively) and using the equation $NPFTLV = -0.2 * SISW * 2 + 2$ and the busy ratio, an odds ratio of 11.2 (CI 1.2-84.6) was achieved. These results indicate that the HALTLV may estimate the risk of multi-task jobs; however, further research is needed.

## INTRODUCTION

Today's workplace is increasingly dynamic and demanding. As time constraints tighten and medical costs increase, job descriptions get larger. This increase in variation is a reflection of more effective production design and the belief that increased variation in activities may reduce ergonomic injuries.

As the complexity of jobs increases ergonomic analysis tools need to be developed that reflect this complexity. A preliminary step may be to determine if existing ergonomic analysis tools, originally developed for single-task jobs, can be modified to estimate the risk of multi-task jobs. This paper explores one method of aggregating the risk of multi-task jobs from task level ACGIH Hand Activity Level Threshold Limit Value (HALTLV) outputs.

## STUDY BACKGROUND

Two automotive plants were selected from the six plants originally included in a larger study sponsored by UAW-Ford. The original study collected data for 677 jobs. Job analysis included collection of weights, forces, distances and other data including worker feedback, speed of work and other qualitative and quantitative data. Each job was videotaped.

Two workers from each job were asked to fill out symptom surveys. Occupational health nurses (OCHNS) administered these surveys. Occupational health doctors (OCMDs) administered physical exams on two workers from each job. (This study does not incorporate the physical exam results.) First time office visits (FTOV's) and injuries associated with each job were also collected from each plant's medical data base. FTOV's were limited to reports for the twelve months previous to the site visit. This time frame was used because jobs and job descriptions may change with every model year.

The two plants used in this study were selected for two primary reasons: 1) the job cycle times were consistent within these plants; 2) there was little job rotation at these plants. That is, while each job was multi-task in nature, the workers did not rotate between jobs. This lack of rotation helps to minimize confounders that exist when an employee performs different jobs during the workday.

### ACGIH Hand Activity Level Threshold Limit Value (HALTLV)

The following is an overview of the ACGIH HAL TLV, which was proposed in 2000 and adopted in 2001. This is not intended to replace the original documentation and the reader is encouraged to read the original publication (ACGIH 2003). The reader should be aware that the HAL is an independent variable in the ACGIH HAL TLV. This can lead to some confusion so care must be taken when reading, discussing or writing about this TLV. In this paper, ACGIH TLV will refer to the entire process. HAL will refer exclusively to the independent hand activity level.

The ACGIH TLV addresses mono-task jobs that take place longer than 4 hours a day. A mono-task job may be defined as a job that requires performing the same set of motions and/or exertions repeatedly (ACGIH 2003). The two independent variables used in the ACGIH TLV are the Hand Activity Level and the Normalized Peak Force.

The Hand Activity Level (HAL) characterizes repetition on a scale from 0 to 10. Where 0 is completely idle and 10 is the greatest level of repetition imaginable. This scale was proposed by Latko et al. (Latko 1997; Latko, Armstrong et al. 1997) HAL is a function of both frequency and speed of work. Table 1 and Figure 1 illustrate the quantitative and qualitative approaches to determining the hand activity level.

Table 1: Illustrates how Hand Activity Level (0-10) is related to Exertion Frequency and Duty Cycle (% of work cycle where force is greater than 5% of maximum).

| 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 |

Notes:

1. Shaded values are the HAL scores associated with that frequency (or period) and percent duty cycle.
2. Round HAL values to the nearest whole number
3. Use Figure 1 to obtain HAL values outside of those listed in the table

| 1 | 2 | 4 | 6 | 8 | 10 |
|---|---|---|---|---|---|
| Hand idle most of the time; no regular exertions | Consistent, conspicuous, long pauses; or very slow motions | Slow, steady motion/exertions; frequent, brief pauses | Steady motion/exertion; infrequent pause | Rapid, steady motion/exertions; no regular pauses | Rapid, steady motion/difficulty keeping up or continous exertion |

Figure 1: HAL can also be determined with these qualitative guidelines.

Normalized Peak Force is the peak hand force required to perform the task normalized on a scale of 0 to 10, which corresponds to 0% to 100% of the applicable population reference strength. The normalized peak hand force is determined for a task by:

- Measuring hand forces and corresponding postures,
- Obtaining strength data for that posture and that worker or worker population. In most cases, strength values can be obtained directly or extrapolated from the literature, and
- Calculating "Normalized Peak Hand Force" by dividing required force by strength.

Methods for assessing hand force include:

- Worker ratings
- Observer ratings
- Biomechanical analyses
- Force gauges
- Electromyography

After determining the HAL and the NPF for a task, draw a vertical line from the HAL value and a horizontal line from the NPF value as shown in Figure 2. The relationship between the intersection of these two lines with respect to the TLV and AL lines (defined below) determines the ACGIH HALTLV measure of ergonomic risk of the task.

If the intersection of these two lines is below the Action Limit (AL) (the dashed line in Figure 2) the mono-task job is probably safe. If the intersection is above the AL and below the Threshold Limit Value (TLV) (the solid line in Figure 2) then the job has a significantly greater risk of injury associated with it. If the intersection is above the TLV then the job should be changed.

For example, if the task has a HAL rating of 4 and a NPF of 6, then the intersection is above the TLV. The ACGIH HAL TLV for the mono-task job would recommend that the job be modified. These lines are included in Figure 2. In this example, the intersection is above the TLV line.

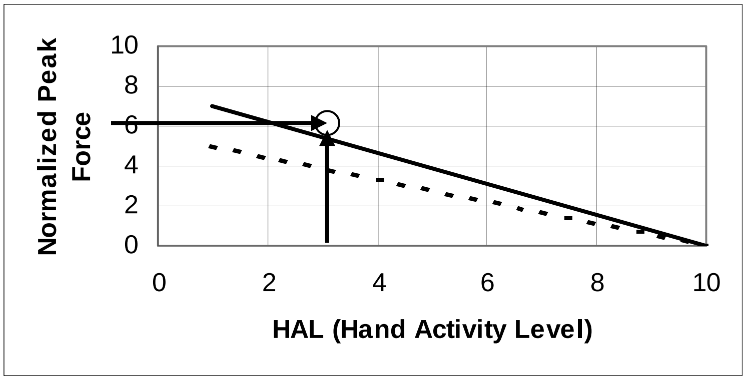


Figure 2: Hand, wrist, and forearm TLV (solid line) and Action Limit (dashed line) recommended for administrative and engineering controls. The arrows illustrate a task with a NPF of 6, and a HAL of 4.

Limitations of HAL TLV:

- Applicable to mono-task jobs that last 4 or more hours per day.

Professional Judgment and TLV modifications are required for:

- Sustained non-neutral postures such as wrist flexion, extension, wrist deviation, or forearm rotation;
- Contact Stresses;
- Low Temperatures;
- Vibration.

## METHODS

### Data Collection

Case and control jobs were identified. A job was considered to be a case when every person interviewed by the nurses reported a symptom from that job and there had been at least one FTOV that attributed the reported injury to that job during the past 12 months. A control job was defined as a job on which no participants reported symptoms and there had been no FTOV associating that job as a source of injury for the past 12 months.

Video data from each plant was collected from the UAW-Ford archives for a case/control study. These jobs were randomly mixed so that the observers would not know if a particular job was considered a case or a control.

Videos of each job were observed. Each job was divided into work elements or tasks. Tasks are contiguous activities of a job that could be removed from the job and transferred to another workstation.

Hand Activity Levels (HAL), and observer ratings of the NPF were estimated from these videos, and grip type was recorded. Also recorded, were the ratings from the Strain Index (SI) for speed of work (SISW) and intensity of effort (SII) for each task. These metrics were used to determine if the operationalization of HAL and the NPF could be improved. The weights of objects and the forces required to perform the task had already been measured during the original plant visits.

During the video analysis, task attributes were timed with a stopwatch. The first attribute was "time busy." Time busy was defined as time during which the operator was occupied performing that task and would be unable to perform another task at that time with that hand. This metric is useful in many ways. The ratio of busy time to cycle time provides insight into how much "non-busy" time is available to the worker. This "non-busy" time may be used for rest or it may provide "slack time" if an error occurs. Such a ratio may also give insight into the psychophysical and psychosocial demands of a job. For the purpose of this study, busy time was used to determine the "allocated time" for each task. Allocated time for a task is the amount of time a person is busy plus the amount of rest associated with that task.

The ratios of busy time to cycle time and effort time to cycle time were used in this study to modify the task level HALTLV scores.

## Calculations

Normalized Peak Force: this study did not use EMG or worker ratings to estimate NPF and these methods will not be discussed here. In this study, observer ratings and biomechanical analyses were used to determine the NPF and these will be discussed exclusively.

Biomechanical Normalized Peak Force uses the forces required, the grip type and for grip and pinch data provided in the ACGIH HAL TLV documentation (ACGIH 2003). This data provides grip strengths for males and females, and for the dominant and non-dominate hands using various grips. The average of the 4 values was used because women and men performed the jobs used in this analysis. Also, because the major and minor hands (handedness) may not necessarily be the choice of the operator, the average of major and minor was used.

$$Grip\ Strength = \frac{466.5 + 441.0 + 241.1 + 219.5\ N}{4} = 342.1\,\text{N} \qquad \text{(Equation 1)}$$

$$Pinch\ Strength = \frac{51.9 + 47.0 + 35.3 + 32.3\ N}{4} = 41.8\ N \qquad \text{(Equation 2)}$$

Note: This study assumes that most pinches were between digits I-II (thumb and index finger). While this may not always be the case, it is often difficult to determine which fingers are active in the pinch process.

**Determine the equation of the TLV line**

Equation of the Threshold Limit Value:

Assume:
Points (10,0) and (1,7) are on the TLV line
Then the equation of the line is

$$y = -\frac{7}{9} * x + 7\frac{7}{9} \qquad \text{(Equation 3)}$$

Therefore, the normalized peak force for the TLV (NPFTLV) = -7/9*HAL+7.78

To determine if the task fell below the the HAL was placed into the TLV equation and the Actual Normalized Peak Force (NPFACT) (the y-axis) was compared with the NPF allowed (NPFTLV).

For example, If a task required a grasp grip of 22.7 N and had a HAL of 4.

TLV:

$$\text{NPFACT} = \frac{\text{Actual Grip Force}}{\text{Average Woker Population Strength}}$$

$$\text{NPFACT} = \frac{22.7\ \text{N}}{342.1\ \text{N}} * 10 = 0.66$$

$$NPFTLV = -\frac{7}{9} * HAL + 7.78 = -\frac{7}{9} * 4 + 7.78 = 4.67$$

$$NPFACT - NPFTLV = 0.66 - 4.67 = 4.01$$

Because the difference between the NPFACT-NPFTLV is negative, the point (4, 0.66) is below the TLV. This difference is also the vertical distance from the TLV to the intersection of the actual HAL and NPF.

$$Difference = NPFACT - NPFTLV \qquad \text{(Equation 4)}$$

From this it can be concluded that if this difference is negative, the task is below the line in question TLV and it the predicted risk to UECD is not high. If the difference is positive, the task is above the line in question and the risk of the job is predicted to be high.

In addition to the vertical distance, a ratio between NPFACT and NPFTLV was also created. This ratio is defined as:

$$Ratio = \frac{NPFACT}{NPFTLV} \qquad \text{(Equation 5)}$$

For example, using the numbers above,

$$Ratio_{TLV} = \frac{NPFACT}{NPFTLV} = \frac{0.66}{4.67} = 0.14$$

$$Ratio_{AL} = \frac{NPFACT}{NPFTLV} = \frac{0.66}{3.34} = 0.20$$

From this, it can be concluded that if this ratio is less than 1, the task is below the line in question and it the predicted risk to UECD is not high. If the ratio is greater than 1, the task is above the line in question and the job is predicted to be high risk.

The HAL TLV for each task will be calculated various ways:

1. As originally intended by the authors for single task jobs.
2. Modifying the HAL score when a tool is held throughout the task (to avoid overestimating risk).
3. Using the metrics as proposed in the Strain Index (SI).
    i. Using Speed of Work in place of HAL (normalized to 10).
    ii. Using the Intensity Rating in place of normalized peak force (normalized to 10).
    **iii. Using Speed of Work Rating and Intensity Rating (both normalized to 10) in place of both the HAL and the NPF. *****

## ESTABLISHING JOB LEVEL RISK FROM TASK LEVEL DATA

Several methods will be explored to determine if the HALTLV, developed for single-task jobs lasting 4 or more hours a day, can be modified to estimate the ergonomic risk of multi-task jobs to the upper extremities.

Method 1: Taking the average distance from the TLV for each task. If this average is negative then the job is considered low risk.

Method 2: Taking the maximum difference for each task across the job. That is, taking the largest difference (largest positive number, or, if all the distances are negative, the smallest negative number) between the allowable NPF and the actual NPF to determine if the job is hazardous or not. This method is similar to taking the maximum (riskiest) task as the metric for the job. If this maximum is negative then the job is considered low risk.

Method 3: Modify the equation or final distance by the Busy Weighted Ratio (BWR) or the Effort Weighted Ratio (EWR)

i. Using the amount of time that the task requires divided by the cycle time (CT). This time is called the "busy time", and is the time that the employee is occupied by that task and is unable to perform another task. This ratio is multiplied to both the independent variable, HAL, and the distance and ratio task outputs.

$$\text{Busy Weighted Ratio}_{\text{Ti}} = BWR_{\text{Ti}} = \frac{\text{Time Busy}_{\text{Ti}}\ \text{(s)}}{\text{Cycle Time (s)}} \qquad \text{(Equation 6)}$$

This ratio was incorporated into the NPFTLV equation:

$$NPFTLV_{TiBWR} = -\frac{7}{9} * (HAL_{Ti} * BWR_{Ti}) + 7\frac{7}{9} \qquad \text{(Equation 7)}$$

The ratio was also used to modify the distance. That is,

$$\text{Distance}_{\text{TiBWR}} = \text{Distance}_{\text{Ti}} * \text{BWR}_{\text{Ti}} \ *** \qquad \text{(Equation 8)}$$

ii. Using the amount of time that the task requires effort.

$$\text{Effort Weighted Ratio}_{\text{Ti}} = \text{EWR}_{\text{Ti}} = \frac{\text{Effort Duration}_{\text{Ti}}\ \text{(s)}}{\text{Cycle Time (s)}} \qquad \text{(Equation 9)}$$

This ratio was incorporated into the NPFTLV equation:

$$NPFTLV_{TiEWR} = -\frac{7}{9} * (HAL_{Ti} * EWR_{Ti}) + 7\frac{7}{9} \qquad \text{(Equation 10)}$$

The ratio was also used to modify the distance. That is,

$$\text{Distance}_{\text{TiEWR}} = \text{Distance}_{\text{Ti}} * \text{EWR}_{\text{Ti}} \qquad \text{(Equation 11)}$$

Using these weighed average methods, the sum of the differences from the allowable TLV for the tasks within the job is calculated. If the sum was less than zero then the job was considered safe, if the sum was zero or greater the job was considered risky.

Similarly, when using the ratio outputs, if the output was less than one, the job was not considered risky. If the output was greater than or equal to one, then the job was considered risky.

The third aspect of this study was to determine if a modification of the ACGIH TLV line would improve the results. For this study we assumed that the anchor point of a HAL of 10 and a NPF of 0 was appropriate. That is, at the most busy or continuous activity a worker cannot exert force. The slope and the y-intercept were modified so that each line would go through the point (10,0). This is similar to creating new cut points, or a cut point "line". The equations for each line were:

$$
\begin{aligned}
& y = -\frac{7}{9} * x + 7\frac{7}{9}\ (TLV) \\
& y = -0.7 * x + 7 \\
& y = -0.6 * x + 6 \\
& y = -0.5 * x + 5 \\
& y = -\frac{5}{9} * x + 5\frac{5}{9}\ (AL) \qquad \text{(Equation12 a-i)} \\
& y = -0.4 * x + 4 \\
& y = -0.3 * x + 3 \\
& y = -0.2 * x + 2 *** \\
& y = -0.1 * x + 1
\end{aligned}
$$

***indicates that this was a part of the methodology that returned the highest odds ratio.

Note that the y-intercept was decreased by about 1 for each equation (except for the TLV and the AL) . These equations were used in a similar fashion as indicated in the example calculations and are illustrated in Figure 3.

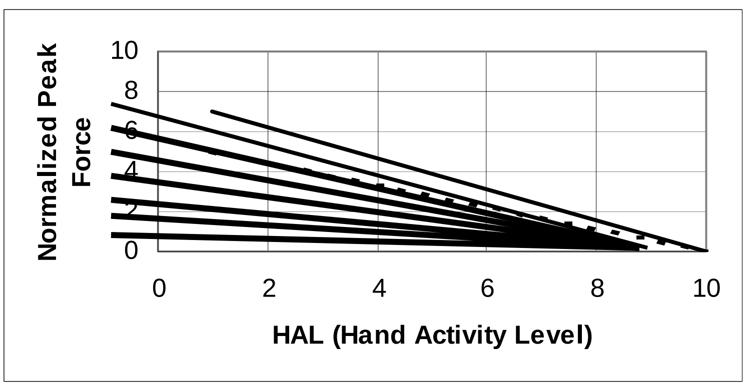


Figure 3: Illustration of alternative TLV lines investigated.

## RESULTS

Using the SI Speed of Work as the hand activity metric, weighted by the busy ratio, using the maximum task distance from the line $NPFTLV_i = -0.2 * SISW_i * 2 * BWR_i + 2$, returns a significant odds ratio of 11.2 (CI 1.4-84.6).

That is:

Use SISW as the metric for hand activity level. Use SII for the actual normalized peak force. Use Equation 5 to determine the ratio of the observed point from the TLV line defined as $NPFTLV_i = -0.2 * SISW_i * 2 * BWR_i + 2$. If the maximum task result was greater than 1, then the job was expected to be associated with injuries, if the largest ratio was less than or equal to 1, the job was not expected to be associated with injuries. Using this algorithm returns an odds ratio of 11.2 (CI 1.4-84.6).

## CONCLUSION

These results indicate that this method of aggregation the ergonomic risk to the DUE for a multi-task job may be useful.

## DISCUSSION

All of the significant results used different metrics for the SII metric for the NPF, and some modification of the HAL (modified HAL or SISW). That only a few of the 900 combinations were significant may not be surprising because this ACGHI HAL TLV was developed for mono-task jobs that last over four hours a day. If an employee, working an eight-hour day, has evenly divided tasks, the highest number of four-hour mono-tasks would be two. Only a few of our multi-task jobs were limited to two tasks.

There are a number of possible explanations why alternative metrics for the HAL and the NPF appeared to better predict risk than those proposed in this TLV. The first explanation is that the observers were not trained properly in the application of this ACGIH TLV. While this may be true, every attempt was made to learn not only the letter of the ACGIH TLV but also its spirit. Discussions with the original authors were initiated to ensure that the ACGIH TLV interpreted and applied correctly.

However, using the biomechanical approach to determine the NPF did not seem to improve the outcomes. Whereas using the SII did. It is difficult to get grip strengths for non-neutral grips. As stated in the TLV documentation "Professional judgment should be used to recommend TLV reductions when exposures include work related risk factors of musculoskeletal disorders such as….sustained non-neutral postures such as flexion, extension, or forearm rotation.." That is, ergonomists must make a qualitative judgment about how much the NPF should be modified for extreme postures. This is not trivial, nor do ergonomists necessarily agree on the magnitude of the modification. Because non-neutral postures are often used in the automotive industry populations, strengths for non- neutral postures will be necessary to apply the biomechanical approach to estimate the NPF.

Modifying the HAL ratings when a tool or part was held did not make the results significant. However, the method using the SISW appeared to provide the best results.

This may indicate that our observers need to modify the application of the NPF and HAL, however, this does not explain why using the TLV alone did not seem to work as well. This is made even more confusing because both the Strain Index and ACGIH HAL TLV indicate that the Borg Scale may be used for intensity of work or normalized peak force, respectively.

The preliminary results of this study indicate that the methods proposed here for modifying the ACGIH TLV may be adequate for determining the ergonomic risk of a multi-task job. Further research should be conducted to determine if this method can be improved or if there are other, more appropriate methods of modifying this TLV for multi-task jobs.

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