Guideline Threshold Limit Values (TLVs) for Discomfort in Repetitive Assembly Work

L. O'Sullivan, P. Clancy

Ergonomics Research Centre, University Of Limerick, Limerick, Ireland

ABSTRACT
This study focussed on two of the main occupational risk factors associated with WMSDs in light repetitive electronic assembly work, namely repetition and force. Present day evaluation techniques are primarily posture based and show low sensitivity with regard to rating repetition and force. Guidelines for acceptable workload are partly quantitative in the form of Threshold Limit Values (TLVs) for acceptable exposures. However, little experimental data about these risk factors have been generated.
A simulated assembly task was conducted to investigate the interactions of risk factors and the suitability of Hand Activity Level (HAL) and TLV values for electronics assembly work. Subjects completed the assembly task for three levels of repetition and force. Movement velocities and joint angles were recorded using electrogoniometers. For each treatment a subjective rating of discomfort was recorded. Repeated measures ANOVA identified repetition and force as highly significant factors in light electronic assembly work ($p<0.001$, $p<0.05$, respectively). The two-way interaction between the factors was not significant ($p>0.05$). However, through regression analysis posture was also found to be a significant predictor of discomfort ($p<0.05$). The task was also rated using HAL and Normalised Peak Forces (NPF). This study questioned the ability of TLVs in rating discomfort and amendments to the TLVs are suggested.

1.1 Introduction
There is a need for an integrated assessment of the contribution of the main occupational risk factors to Workrelated Musculo Skeletal Disorders (WMSDs). The risk factors involved in WMSDs are known to include repetition, force and posture (Putz-Anderson, 1988). The non-occupational factors significantly associated with the development of wrist disorders are: gender, chronical diseases, practise of sport involving the upper limbs, work judged as tiring, psychological factors, sport in general and previous accidents. Most of theses associations were observed in previous epidemiological studies (Hagberg et al., 1992).

1.2 Repetition
Highly repetitive work may directly damage tendons through repeated stretching and elongation, as well as increased the likelihood of fatigue and a decrease in the opportunity for tissues to recover (Armstrong, 1990). Siverstein et al. (1987) showed that workers on repetitive jobs had more than a five-fold greater risk of developing upper extremity Cumulative Trauma Disorders (CTDs) when compared to workers on low repetition, low-force jobs. A number of studies have demonstrated that repetitive wrist movements increase discomfort and risk of injury (Lin and Radwin, 1997; Snook et al., 1995; among others).

Objective measures of repetition include the use of kinematics. Kinematic metrics of the upper limb include calculating movement velocities (repetitiveness), joint deviations (posture) and forces exerted by muscles. According to Marras and Schoenmarklin

(1991) and Marras and Schoenmarklin (1993) the movement velocities are the most pertinent parameters for identifying risks of injury. However, little data is available relating these findings to estimates of discomfort for industrial tasks.

1.3 Force

Forceful hand exertions during work activities have been associated with increased risk of upper extremity WMSDs (Silverstein et al. 1987). The muscular effort has to increase in response to the loading of the task and this has the effect of reducing blood circulation to the muscles causing rapid fatigue (Putz-Anderson, 1988). Silverstein et al. (1986) defined high force as greater than 4kg for a power grip. According to Mathiassen and Winkel (1991); Kilbom, 1994 (and others); 15% of Maximum Voluntary Contraction (MVC) is the mean acceptable contraction intensity during work over an extended period of time.

1.4 Posture

Putz-Anderson (1988) defines awkward postures as any fixed or constrained body position. Awkward upper extremity postures such as pinch grips, wrist deviations such as radial/ulnar bending (Armstrong et al., 1982), flexion/extension (Smith et al., 1977) have been associated with a variety of upper extremity WMSDs (Armstrong, 1990). Working posture is influenced by the interaction of many occupational and individual factors including work station layout, equipment features and worker anthropometry.

1.5 Interaction between risk factors

There is little quantitative data on risk factors and their interactions (Snook et al. 1995). However, repetition is believed to have an association with WMSDs, especially when combined with other factors. Bernard (1997) and Silverstein et al. (1986) found that the combined effect of high force – high repetition substantially increased the magnitude of association between the risk factors and the injury more than the factors alone. Bernard (1997) showed that there was no evidence of an association between repetition and posture alone, but when these factors were combined with force they appear to contribute to risk of injury. Significant interactions between risk factors provide information on relationships that can show synergistic effects on discomfort (Moore et al. 1991). For example, studies have found a positive relationship between repetition and discomfort at the wrist (Snook et al., 1995; Lin and Radwin, 1997).

1.5 Threshold Limit Values for Discomfort Scores

There is a lack of information linking risk levels to discomfort data. Westgaard (2000) discussed the use of Threshold Limit Values (TLVs), such as are used in occupational hygiene for setting risk of occupational disease from hazardous substances. This approach can be used for the application of discomfort data to real tasks. The American Conference of Government Industrial Hygienists (ACGIH, 2003) published TLVs for prevention of hand and wrist disorders based on exposure to hand activity levels and peak finger forces for monotask manual work performed for four or more hours per day.

This guideline includes both a Threshold Limit Value (TLV), which should never be exceeded, and an action at which proactive control measures are recommended, e.g. worker training and inspection for other risk factors. To use this guideline, a Hand Activity Level (HAL) and Normalised Peak Force (NPF) is required (Figure 1). The HAL value is measured on a scale that ranges from 0 to 10 where 0 corresponds to completely idle and 10 corresponds to working as fast as possible with difficulty keeping up. HAL can be determined from visual observations or from exertion frequency and the ratio of work to cycle time. NPF is also measured on a 0 to 10 scale where 0 is no force and 10 is the greatest force imaginable for a given population. NPF can be estimated from observations or calculated using biomechanics. Both the TLV and the action limit are obtained via cross referencing the HAL and NPF with a graph

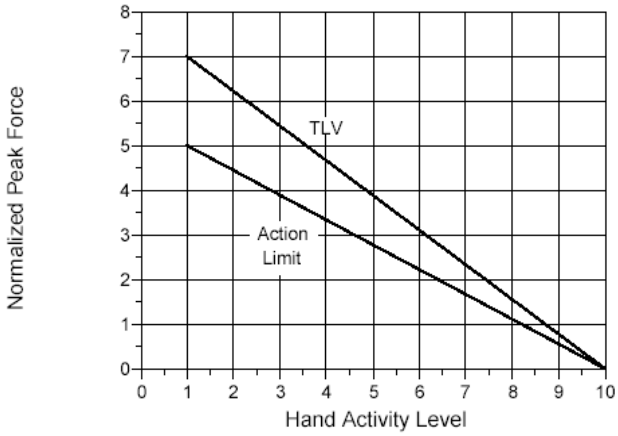

Figure 1: TLV for Hand Activity

1.6 Research Needs

One problem with WMSDs causation is that there is a paucity of information on risk factors so it is very difficult to accurately predict injuries in assembly work (Marras, 2004), thus evaluation techniques will inevitably differ. Leamon (1994) suggested that the reference value for the safety or potential risk of injury for jobs have not been adequately supported by epidemiological studies to warrant their use in job design. Further studies must be conducted into the causes of MSDs until a logical pattern of evidence is accumulated. The methods must be applied to repetitive assembly industries and similar risk scores generated. The ability of techniques to rate these risk factors should be assessed using Hill's Criteria which include: strength of association, consistency between observational studies, specificity of effect from a factor, temporality, dose response and experimental evidence and analogy with other known processes (Marras, 2004). This study demonstrates one approach of defining the dose response relationship between force and repetition with injuries for an industrial type task.

2. Method

2.1 Simulated Assembly Task

Nine right handed male student volunteers (mean age 23.5 yr) participated in the experiment. They were required to be symptom free for the session. As the study required subjects to report discomfort, a briefing before the experiment advised that symptoms of discomfort included aching, fatigue, soreness, warmth, cramping, pulling, numbness, tenderness, pressing or pain (Radwin et al., 1994).

To ensure product familiarity the nine subjects assembled domestic three-pin electrical plugs. Six of the eight plug components were positioned in bins on the table surface. The six bins were set on an arc about the fixture of radii 300mm (Figure 2). This reach distance corresponded to the minimum arc distance chosen by O'Sullivan and Gallwey (2002). The clip and fuse were placed in bins attached to the front of the table, as in the company, and remained the same for each test condition. A fixture was positioned to hold the component during assembly. The table surface height was set at 790mm and the seat at 600mm, based on industrial data. Subjects were positioned on a chair with

25mm clearance between their abdomen and the bins at the front of the table. Each plug assembly operation consisted of 17 elements. To avoid problems of simultaneous tasks with naive subjects, the task was performed with the right hand only.

Figure 2: View of Simulated Task

2.2 Experimental Design

The experimental design was adopted from a previous study by Silverstein et al. (1986) and the levels were based on the published findings of Carey and Gallwey (2002) and O'Sullivan and Gallwey (2002). A 3X3 full factorial design experiment with nine subjects was used. The treatments consisted of low, medium and high levels of force and repetition. A Latin Square order was used to determine the orders for the treatments for each subject. Pace was used as a measure of repetitiveness and repetition was defined as the number of exertions per minute.

Three levels of repetition were tested, 10, 15 and 20 exertions per minute. Lin et al. (1997) used values of 4 and 15 deviations. Similarly, Armstrong et al. (1984) reported that in a polishing task the fundamental cycle of "move and position" was performed 9200 times per shift, i.e. 19.2 times per minute for an 8 hour shift. As the subjects worked to the same three levels of pace the number of plugs produced was equal for each subject.

The three levels of force examined were 10N, 20N and 40N. Silverstein et al. (1986) defined high force jobs as those with estimated average hand force requirements of more than 4 kg and low force jobs were those with estimated average hand force requirements below 1 kg. Subjects exerted the required level force on the fixture while inserting the plug components. The dependent variable was subjective discomfort and was measured at the end of each session using a 10cm visual analog scale. The nine treatments for the nine subjects were conducted over a period of five days and each experimental session lasted approximately 1.5 hours. The treatment combinations are summarised in Table 1 with abbreviations.

Table 1 Experiment treatments

		Force		
		10N	20N	40N
		LF	MF	HF
Repetition	$10\ min^{-1}$ LR	LR:LF	LR:MF	LR:HF
	$15\ min^{-1}$ MR	MR:LF	MR:MF	MR:HF
	$20\ min^{-1}$ HR	HR:LF	HR:MF	HR:HF

2.3 Risk factor data collection

A Mecmesin FG100 force gauge was incorporated into the assembly fixture and this displayed the level of exertion in real time to the subject. Force of exertion by the Flexor Carpi Radialis (FCR) and Flexor Carpi Ulnaris (FCU) were measured using Biometrics EMG surface electrodes at a sampling frequency of 200Hz. Angular deviations and movement velocities were recorded for wrist flexion/extension, wrist radial/ulnar deviation and elbow flexion using Penny and Giles Biometrics electro-goniometers (model XM 110) also at a sampling frequency of 200Hz. Joint angle data were reduced and a summary analysis was performed on the data using customised software developed in the University.

2.4 Procedure

Each subject was fully informed of the content, the purpose and the length of the study and each gave their informed consent before participating. The goniometers were placed on the wrist and elbow and in the two planes of radial/ulnar deviation and flexion/extension according to the manufacturers instructions. EMG surface electrodes were placed on the medial side of the right forearm over the Flexor Carpi Radialis (FCR) and Flexor Carpi Ulnaris (FCU) to measure force. Maximum Range Of Motion was recorded in each plane. The subject was seated at a height adjustable chair and wrist flexion MVC was recorded.

An audio tone from the laptop signalled the start of each experimental treatment. The subject placed a component at the required exertion (10N, 20N, 40N) on hearing the beep. The pace of the exertions remained constant for each treatment. A trial run was performed at the beginning of each session. At the end of each treatment the subject rated discomfort on a 10cm visual analog scale) printed on paper. Subjects drew a line across the horizontal scale to indicate their perceived level of discomfort in the upper limb. Each treatment was performed for 5min with a 1min recovery period between treatments. This was repeated for all nine treatments.

3. Results

3.1 Discomfort data

Inspection of the discomfort data using a histogram and summary statistics (mean 5.83, median 6.00) revealed that it did not violate the assumption of a normal distribution. In addition Mauchly’s coefficient revealed that the data did not violate the test for sphericity. This verifies that the variance of the different scores in a within subject experimental design are equal across the group. Hence, parametric tests could be used to analyse the data. Repeated measures ANOVA was performed on the raw discomfort data (Table 2). The ANOVA table illustrates that both force ($p<0.05$) and repetition ($p<0.001$) significantly affected discomfort in the simulated task. However, the two way interaction between force and repetition was not significant ($p>0.05$).

Table 2: Repeated Measure ANOVA

Source	SS	df	Mean Square	F	Sig.
Repetition	72.4	2	36.2	24.4	0.001***
Force	12.4	2	6.2	4.14	0.035*
Repetition * Force	2.8	4	0.7	1.08	0.38
Residual (force)	23.9	16	1.5		
Residual (repetition)	23.6	16	1.4		
Residual (repetition*force)	20.7	32	0.6		

*P<0.05. ***P<0.001

The mean discomfort data (Table 3 and Figure 3) shows the increase in the discomfort scores with the increase in repetition and force level. The low & medium levels of repetition and force indicate moderate discomfort while the high levels of repetition and force are close to inducing extreme discomfort with a HRHF mean of 7.57. The general parallelism of the data between the risk factors supports the non-significant finding for the two-way interaction in the ANOVA.

Table 3: Mean Discomfort scores for each treatment level (SD in brackets)

	Force			
Repetition	Low	Medium	High	Mean
Low	4.00 (1.54)	4.73 (1.28)	5.22 (1.49)	4.65
Medium	5.82 (1.79)	5.49 (1.18)	6.31 (1.66)	5.87
High	6.50 (1.05)	6.83 (1.18)	7.57 (1.5)	6.97
Mean	5.44	5.69	6.37	

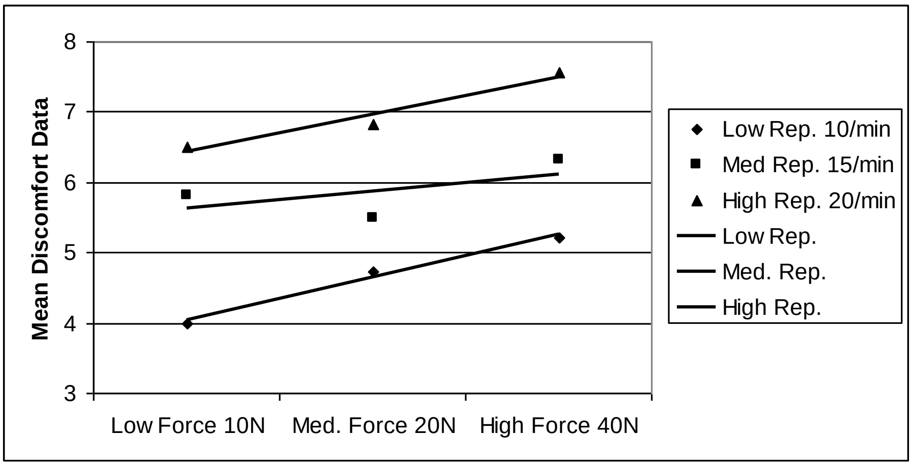

Figure 3: Mean Discomfort Data for each treatment level

3.2 Kinematic Data

A regression analysis was performed to develop a predicative model of discomfort based on the kinematic data. Standardised Discomfort Scores (SDSs) (Gescheider, 1988) were used as the dependent variable. The Backward Selection function in SPSS V11.0 was used to determine a suitable regression model (adjusted $R^2 = 0.221$, $p<0.001$). The significant variables (min $p<0.05$) in the model were radial/ulnar deviation (RU_DEG), radial/ulnar velocity (R_U_VEL) and flexion/extension velocity (F_E_VEL) and force (FCR_EMG). Posture proved the most significant factor, followed by force and then repetition.

$$SDS = 6.05 - 0.12(\overline{RU\_DEG}) - 1.54(\overline{R\_U\_VEL}) + 0.74(\overline{F\_E\_VEL}) + 0.02(\overline{FCR\_EMG})$$

3.3 Hand Activity Level (HAL) and discomfort scores

The bubble chart (Figure 4) plots the mean discomfort scores for each treatment on the TLV graph. It was found that the HAL values ranged from 2-6 across the nine treatments. Figure 4 illustrates that the three low level treatments fall below the action limit. The three medium level treatments fall below the action limit, within the action limit and above the TLV. However, each of the three high level treatments exceed the TLV limit.

The width of the bubbles correspond to the value of the discomfort score i.e. 5.82 is the mean discomfort score for a medium repetition low force assembly. The bubble chart indicates that 5.82 is within the safe limits of the TLV. The TLVs show a discomfort score of 5.49 (for MRMF) as not exceeding the TLV but contained within the action limit. The TLVs rate low repetition levels within the safe limits of the TLV with the exception of LRHF which just exceeds the action level. Figure 4 also indicates that a HRLF treatment may fall within the safe limits of the TLVs.

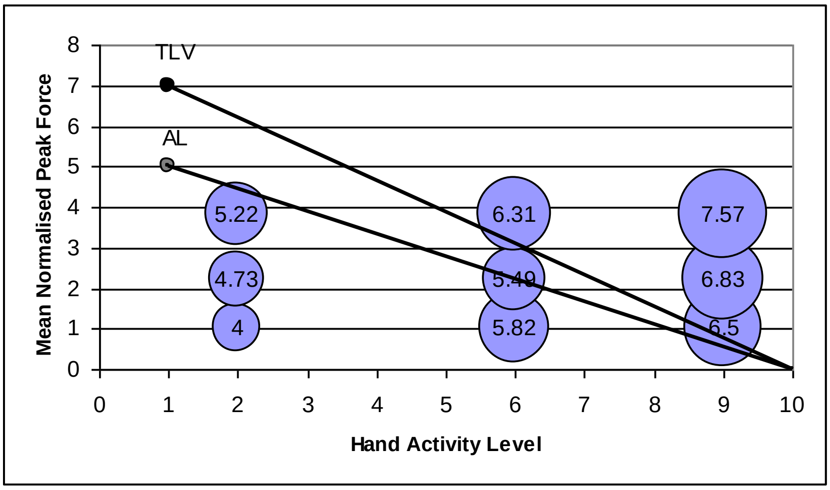

Figure 4: Threshold Limit Value for mean discomfort scores

4. Discussion

4.1 Discomfort Scores for the Simulated Assembly Task

The simulated task assembly produced a significant range of mean discomfort values. Discomfort was found to increase consistently with increased levels of repetition and force. This is in agreement with Silverstein et al. (1986) who found that the risk of injury in high repetition jobs was 1.9 and 3.6 times greater than for low repetition jobs. The discomfort means were plotted against each treatment exposure to identify the significant factors. The mean discomfort data supported findings by Lin et al. (1994) who recorded discomfort scores in the region of 2 to 8 between combined low and high levels of exertion and pace. Typical discomfort scores recorded by Carey and Gallwey (2002) for high treatment levels of pace and exertion were all in the range of a score of 6+.

4.2 Observed Risk Factors

The ANOVA found repetition and force to be the significant factors in the simulated assembly task. An interaction effect between force and repetition is suggested from Figure 3 but the ANOVA proves that no interaction was present. Repetition proved most significant ($p<0.001$) with a 50% increase in discomfort experienced between low to high levels of repetition. This result supports the Mathiassen and Winkel (1991) study where repetitiveness was considered they primary risk factor in light assembly tasks. Force was also a significant factor with a 17% increase in discomfort between the low and high levels. These results are consistent with the epidemiological studies of Siverstein et al. (1986) who showed that high force and high repetitiveness were positively associated with hand wrist CTDs.

The interaction between force and repetition was not significant ($p>0.05$). This finding was not in keeping with Silverstein, et al. (1987) who observed a combined effect between force and repetition for the prevalence of CTDs. The absence of an interaction as a significant factor may be due to the small sample size. However, Lin et al. (1997) reported similar findings where the main effects of exertion, angle and pace were significant for wrist discomfort, but the interactions between the factors were not.

4.3 Regression Analysis

Regression analysis was performed on the kinematic data to establish a predicative equation for discomfort. The model included posture, repetition, and force as significant factors. This supports the results from the ANOVA that also identified repetition and force as significant factors. Force was identified as a significant factor in this study, however it showed no significant correlations with the other factors. Typical force readings recorded through the EMG's were in the range of 10% to 35% of the persons maximum strength. These findings also support the Malchaire et al. (1997) study, where mean MVC levels of 21.7% were obtained for right handed people performing typical repetitive assembly tasks. Marras and Schoenmarklin (1993) studied 40 operators from eight industrial plants. The wrist motion parameters that were monitored for each subject were position, angular velocity, and angular acceleration in each plane of motion. However, only the velocity and acceleration parameters resulted in significant differences between low and high risk groups. Velocity and acceleration variables showed increases in high risk jobs of 46.2% and 67.1% over the low risk jobs. Hence, these findings show similarities with the results from this study. While the regression model was statistically significant, it only explained 22% of the variance in the discomfort data. This highlights the fact that many factors are related to postural discomfort and musculoskeletal problems.

4.4 Threshold Limit Values (TLV)

The HAL values for the simulated task assembly were calculated to be in the range of 2 to 6 while the NPFs ranged from 1 to 3.8. It was found that 40.7% of the exposure treatments exceeded the TLVs while only 7.4% of the treatments exceeded the action limit. These findings are consistent with a survey of HAL and NPF performed for 212 jobs at six Italian manufacturing sites of large home appliances, shoes, garments, and ceramic tile (Armstrong and Violante, 2003). The shoe assembly plants and the sewing plants were found to have average HAL values ranging from 4.7 to 5.2 on a scale of 10. Average peak finger forces were calculated to be 3.9 for both plants. It was found that 47% of the shoe assembly jobs exceeded the TLVs while 13% of the garment jobs exceeded the action limit.

The HAL and average NPFs obtained in this study found that jobs involving high repetitive hand activity exceeded the TLV limit. However, jobs that required high repetition and low to medium forces easily fall within the acceptable exposures of the current ACGIH TLVs. Also, the TLVs do not account for the effects of posture. These results question the ability of the TLVs to accurately rate the risk of injury in repetitive assembly work.

The action limit appears to originate from a very high HAL value. The results from this study suggest that if the action limit is moved parallel to the TLV line the graph has the desirable effect of rating discomfort at three level, low, medium and high (Figure 5). This modification also solves the limitation of rating high repetitive low force tasks as safe. Hence, these results support the use of the HAL technique in electronics assembly work but with a more conservative TLV limit.

The use of TLV values for industrial tasks provides for a better assessment of risk relative to task duration within a working day. The majority of workplace evaluation techniques, especially those used for the assessment of repetitive upper limb movements provide risk ratings based on the operator performing the same task continuously. However, the use of discomfort TLV values can be extended with further research to calculate acceptable time weighted exposures for tasks. This is a very beneficial aspect of discomfort TLVs as many tasks exist in industry that may have result in high discomfort levels but they may be performed for only short durations of time. Time weighted assessment of these tasks with discomfort TLVs would be of considerable benefit to industry.

It should be pointed out that the action limits derived from this study were based on a study of a relatively small group of young males. It is necessary to repeat this study on a larger group comprising both males and females across the working population age group so as to verify the validity and reliability of these results for tasks in industry.

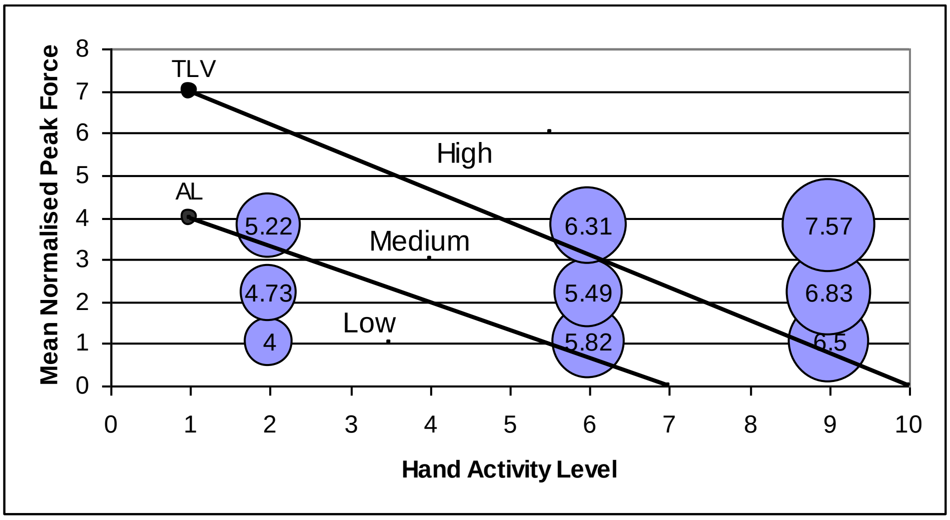

Figure 5: Proposed TLV limits

5. Conclusions

1. Repetition and force significantly affected discomfort in the simulated light electronic assembly task ($p<0.001$, $p<0.05$ respectively).
2. Discomfort increased by 50% between low to high levels of repetition and by 17% between low to high levels of force.
3. ANOVA found no significant interaction between repetition and force ($p>0.05$).
4. Posture was shown to be a significant factor ($p<0.05$) through regression analysis.
5. High levels of repetition and force were related to high HAL and NPF values.
6. New TLV limits are suggested which can be applied to a variety of industrial tasks as part of risk assessment.
7. Further research is needed on a larger group of both males and females to verify the TLV limits recommended in this study so as to determine the applicability of the limits for the general working population.

6. References

ACGIH, 2003, Hand Activity Level, Two Thousand Two Threshold Limit Values for Chemical Substances and Physical Agents Exposure Limits, Cincinnati, American Conference of Governmental Industrial Hygienists, 109-119.

Armstrong, T. J. 1990, Ergonomics and cumulative trauma disorders of the hand and wrist, in J.M. Hunter, L.H. Schneider, E. J. Mackin and A. D. Callahan (eds), Rehabilitation of the Hand Surgery and Therapy, Mosby Co, Philadelphia.

Armstrong, T.J., Foulke, J.A., Joseph, B.S. and Goldstein, S., 1982, An investigation of cumulative trauma disorders in a poultry processing plant, American Industrial Hygiene Association Journal, 43, 103-116.

Armstrong, T.J., Joseph, B.S., and Woolley, C., 1984, Analysis of jobs for control of upper extremity cumulative trauma disorders, Proceedings of the International Conference on Occupational Ergonomics, Toronto.

Armstrong, T.J., and Violante F.S., 2003, Normal Work Pace and Hand Activity Level at six Italian Manufacturing Sites, 8th International Conference on Human Aspects of Advanced Manufacturing Agility & Hybrid Automation, Rome.

Bernard, B.P., 1997, Musculoskeletal Disorders and Workplace Factors, 2nd Edition, DHHS (NIOSH) Publication No. 97-141, Cincinnati.

Carey, E. and Gallwey, T.J., 2002, Effects of wrist posture, pace and exertion on discomfort, International Journal of Industrial Ergonomics, 29, 85-94.

Fieldman, P.J., 1998, Isokinetic peak torque in women with unilateral cumulative trauma disorders and healthy control subjects, Archives in Physical Medicine and Rehabilitation 79, 816-820.

Gescheider, G.A., 1988, Psychophysical scaling, Annual Review of Psychology, 39, 169-200.

Hagberg, M., Morgenstern, J. and Kelsh, M., 1992, Impact of occupations and job tasks on the prevalence of carpal tunnel syndrome, Scandinavian Journal of Work Environment and Health, 18, 337-345.

Kilbom, A., 1994, Repetitive work of the upper extremity: Part 2, The scientific basis for the guide, International Journal of Industrial Ergonomics, 14: 59-86.

Leamon, T.B., 1994, Research to reality: a critical review of the validity of various criteria for the prevention of occupationally induced low back pain disability, Ergonomics, 37, 1959-1974.

Lin, M.L. Radwin, R.G. and Snook, S.H., 1997, A single metric for quantifying biomechanical stress in repetitive motions and exertions, Ergonomics, 40, 543-558.

Malchaire J.B., Cock, N.A., Piette, A., Dutra Leao, R., Lara, M. and Amaral., F., 1997, Relationship between work constraints and the development of musculoskeletal disorders of the wrist: A prospective study, International Journal of Industrial Ergonomics, 19, 471-482.

Marras, W.S., 2004, Editorial: State of the art research perspectives on musculoskeletal disorder causation and control: the need for an integrated understanding of risk, Journal of Electromyography and Kinesiology 14, 1-5.

Marras, W.S. and Schoenmarklin, R.W., 1991, Quantification of wrist motion in highly repetitive, hand intensive industrial jobs, Final Report, Grant nos. 1 R01 OH02621-01 and 02 funded by NIOSH.

Marras, W.S., Schoenmarklin, R.W., 1993, Dynamic capabilities of the wrist joint in industrial workers, International Journal of Industrial Ergonomics, 11, 207-224.

Mathiassen, S.E. and Winkel, J., 1991, Quantifying variation in physical load using exposure versus time data, Ergonomics, 34, 1455-1468.

Moore, A., Wells, R.,Ranney, D., 1991, Quantifying exposure in occupational manual tasks with cumulative trauma disorder potential, Ergonomics, 34, 1433-1453.

O'Sullivan, L.W. and Gallwey, T.J., 2002, Effects of gender and reach distance on risks of musculoskeletal injuries in an assembly task, International Journal of Industrial Ergonomics, 29, 61-71.

Putz-Anderson, V., 1988, Cumulative Trauma Disorders, Taylor and Francis, London.

Silverstein, B. A., Fine, L. J. and Armstrong, T.J., 1987, Occupational factors and carpal tunnel syndrome, American Journal of Industrial Medicine, 11, 343-358.

Silverstein, B.A., Fine, L.J. and Armstrong, T,J., 1986, Hand wrist cumulative trauma disorders in industry, British Journal of Industrial Medicine, 43, 779-784.

Smith, E., Sonnstegard, D. and Anderson, W., 1977, Contribution of flexor tendons to the carpal tunnel syndrome, Archives of Physical Medicine and Rehabilitation, 58, 379-385.

Snook, S.H., Vaillancourt, D.R., Ciriello, V.M., Webster, B.S., 1995, Psychophysical studies of repetitive wrist flexion and extension, Ergonomics, 38, 1488-1507.

Westgaard, R.H., 2000, Work-related musculoskeletal complaints: some ergonomics challenges upon the start of a new century, Applied Ergonomics, 31, 569-580.

Yen, T.Y. and Radwin, R.G., 2000, Comparison between using spectral analysis of electrogoniometers data and observational analysis to quantify repetitive motion and ergonomic changes in cyclical industrial work, Ergonomics, 43, 106-132.