HAND ACTIVITY

TLVs®

Although work-related musculoskeletal disorders can occur in a number of body regions (including the shoulders, neck, low back, and lower extremities), the focus of this TLV is on the hand, wrist, and forearm.

The TLV shown in Figure 1 is based on epidemiological, psychophysical, and biomechanical studies and is intended for jobs performed from four to eight hours per day. The TLV specifically considers average Hand Activity Level (HAL) and Normalized Peak Force (NPF) to represent conditions to which it is believed nearly all workers may be repeatedly exposed without adverse health effects.

HAL is based on the frequency of hand exertions and the duty cycle (distribution of work and recovery periods). HAL can be determined by trained observers based on exertion frequency, rest pauses and speed of motion using the rating scale shown in Figure 2. Only hand exertions greater than 10% of posture specific strength should be considered. HAL can also be calculated based on empirical studies of expert ratings, hand exertion frequency and duty cycle (exertion time/(exertion + rest time) × 100%). HAL can be calculated as:

$$\mathrm{HAL} = 6.56 \ln D \left[\frac{F^{1.31}}{1 + 3.18\, F^{1.31}}\right]$$

(D = duty cycle [%] and F = hand exertion frequency [exertions/s]) or estimated from Table 1. Calculated HAL values should be rounded to the nearest whole number.

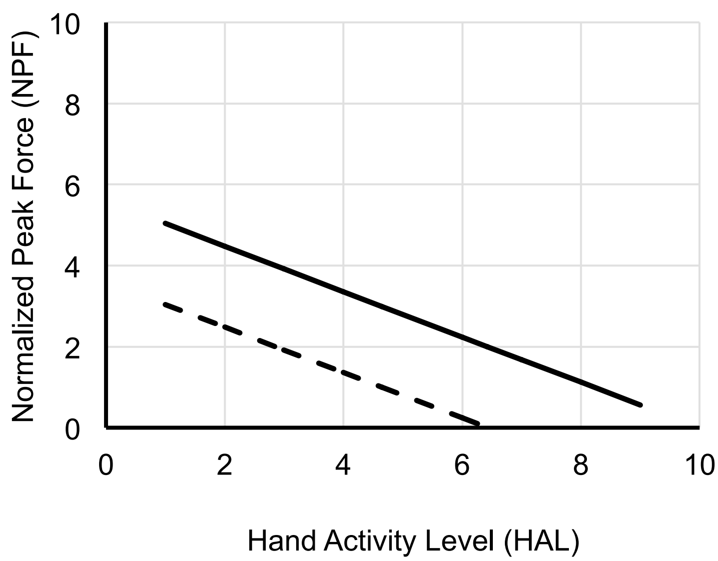


FIGURE 1. The Hand Activity TLV® for reduction of work-related musculoskeletal disorders based on hand activity level (HAL) and normalized peak hand force. The top line depicts the TLV®. The bottom line is the Action Limit (AL) for which general controls are recommended.

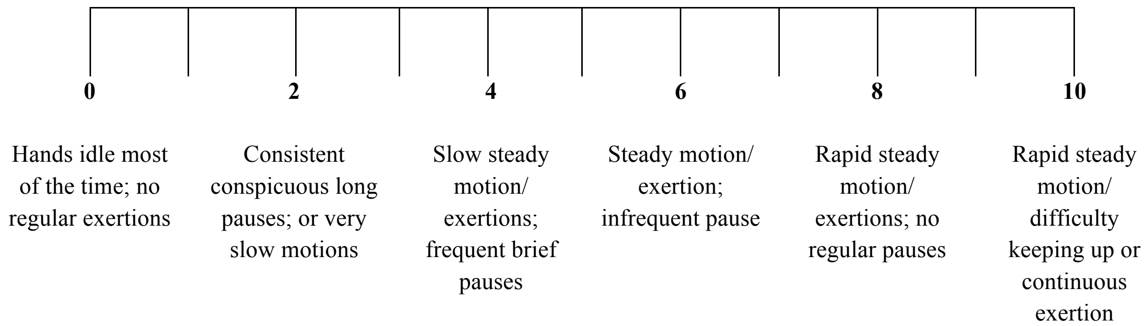


FIGURE 2. Hand Activity Level (HAL) (0–10) can be rated using the above guidelines.

TABLE 1. Hand Activity Level (HAL) (0–10) is Related to Hand Exertion Frequency and Duty Cycle (percent of work cycle where hand force is greater than 10% of posture specific strength)

Frequency (exertions/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	5
1.0	1.0	4	5	6	7	7
2.0	0.5	–	6	7	8	8

Notes:
1. Round HAL values to the nearest whole number.
2. Use Figure 2 to obtain HAL values outside of those listed in the table.

Peak hand force (PF) is a typically high value of hand force, generally taken to be the 90th percentile force exerted by the hand over the task period. Peak hand force is normalized to a scale of 0 to 10, which corresponds to 0% to 100% of the posture-specific strength for the applicable population (males, females, young, old, office workers, factory workers, etc.):

Normalized Peak Force (NPF) = (Peak force/ Posture specific referent strength) × 10

PF and NPF can be estimated using ratings by a trained observer, rated by workers using a Borg or visual analog scale (*see* TLV® *Documentation* for definition), or measured using instrumentation, e.g., strain gauges or electromyography. In some cases, it can be calculated using biomechanical methods. These methods are intended to measure recurring peak forces. Random force peaks associated with noise that occur less than 10% of the time are disregarded.

Posture is included in the TLV to the extent that it affects strength. For instance, strength is reduced by the use of a pinch posture, wrist deviation, or forearm rotation and consequently normalized peak force will be increased.

The solid line in Figure 1 represents those combinations of force and hand activity level associated with a significantly elevated prevalence of musculoskeletal disorders. Appropriate control measures should be employed so that the force for a given level of hand activity is below the upper solid line in Figure 1. It is not possible to specify a TLV that protects all workers in all situations without profoundly affecting work rates. Therefore, an Action Limit is prescribed above for which general controls, including surveillance and training, are recommended.

Process

1. Identify the hand-activity tasks performed during the workday. There may be one or more and they should cumulatively

represent four or more hours of work.

2. For each task, select a period of the task that represents an average activity. The selected period should include several complete work cycles. Videotapes may be used for documentation purposes and to facilitate rating of the job.
3. Rate the Hand Activity Level using the scale shown in Figure 2. Independent rating of jobs and discussion of results by three or more people can help produce a more precise rating than individual ratings.
4. Observe the job to identify forceful exertions and corresponding postures. Evaluate postures and forces using observer ratings, worker ratings, biomechanical analysis, or instrumentation. Normalized peak force is the required peak force divided by the representative maximum force for the posture multiplied by 10.
5. For jobs with multiple tasks, time-weighted averaging (TWA) may be used. One method is to determine the TWA of HAL across tasks and use the highest NPF observed among the tasks. A second method is to determine a TWA on the Peak Force Index (PFI) for each task (*see* Notes). A third method is to determine the TWA for NPF across all tasks and separately a TWA for HAL across all tasks.

Consideration of Other Factors

Professional judgment should be used to reduce exposures below the Action Limit if one or more of the following factors is present:

- sustained non-neutral postures such as wrist flexion, extension, wrist deviation, or forearm rotation;
- contact stresses;
- low temperatures; or
- vibration

Employ appropriate control measures any time the TLV is exceeded or an elevated incidence of work-related musculoskeletal disorders is detected.

Notes:

The actual TLV and Action Limit (AL) are represented by Figure 1. There are alternative methods for expressing the limit values, and some are described here. In all cases, they are limited to the range of HAL between 1 and 9.

1. **Equations for Lines**
   TLV: NPF = 5.6 – 0.56 × HAL
   Action Limit: NPF = 3.6 – 0.56 × HAL

   Or, equivalent description of lines:
   $NPF_{TLV} = 0.56\ (10 – HAL)$
   $NPF_{AL} = NPF_{TLV} – 2$
2. **Peak Force Index (PFI)**
   A value greater than 1.0 means that the respective limit is exceeded
   $PFI_{TLV} = NPF/NPF_{TLV}$
   $PFI_{AL} = NPF/NPF_{AL}$

DOCUMENTATION

Introduction

Upper extremity musculoskeletal disorders (MSDs) include primarily soft tissue disorders of the muscles, tendons, ligaments, peripheral nerves, joints, cartilage, bones and supporting blood vessels in the neck, shoulder, arm, elbow, forearm, hand or wrist. Examples of specific disorders include tension neck syndrome, cervical syndrome, rotator cuff tendinitis, epicondylitis, peritendinitis, and carpal tunnel syndrome (CTS). While these disorders may involve different mechanisms and manifestations, there are many similarities that support a common approach for prevention. These similarities include the gradual onset of pain and other symptoms, and the involvement of personal and work-related factors. Conditions that involve both work and personal factors are commonly referred to as “work-related.”

“Work-related diseases” are those for which the etiologic factors include conditions within the work environment and those associated with the performance of work, even when the etiology is multifactorial, i.e., a number of risk factors (occupational or not) contribute to the causation of disease (WHO, 1985). When MSDs are caused or aggravated by workplace risk factors such as repeated or sustained exertions of the body and are not the result of instantaneous events (slips or falls), they are called work-related musculoskeletal disorders (WMSDs). Considerable research has provided evidence that workplace factors, both working conditions and the performance of work, play a major role in the development of musculoskeletal disorders. Often these features of work interact in a multifactorial fashion to contribute to the development of MSDs. In 1997, the U.S. National Institute for Occupational Safety and Health (NIOSH) published a comprehensive literature review of the epidemiologic literature on MSDs and occupational exposures (Bernard, 1997). NIOSH concluded that there was adequate evidence for causal relationships between MSDs of several body regions and repetitive motion, forceful exertions, non-neutral postures, vibration, and combinations of occupational exposures.

The relationship between WMSDs and workplace risk factors cannot be represented by a straightforward one-to-one mapping. WMSDs can result from an interaction of physiologic, mechanical, individual, and organizational factors. As a result of exposure to a number of stressors in the workplace, repeated or continuous insult may take place in musculoskeletal tissues, affecting their integrity and their ability to function normally resulting in WMSDs. These insults may either occur locally (e.g., from direct pressure or friction) or involve central neural mechanisms (e.g., inflammatory responses, pain modulation). The end result may be strengthening of some tissues and degenerations of others. In some cases, the hypertrophy of one tissue may lead to mechanical insult and damage to another (Armstrong et al., 1993). Similar risk factors acting on different parts of the musculoskeletal system have similar effects. In general, those risk factors that overload the soft tissues, combined with inadequate recovery time for those tissues, are likely to lead to MSDs (Armstrong et al., 1993). Models that describe the relationship between work factors and tissue loads and the relationship between tissue loads and physiological responses provide a framework for designing and interpreting psychophysical and epidemiological studies to determine acceptable exposure limits.

Recommended Exposure Limit

For exposures between 4 and 8 hours of repetitive hand work per day, ACGIH recommends the TLVs shown in Figure 1. The TLVs are intended for mono-task-type jobs, but might be extended to multi-task jobs by using time-weighted exposures.

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
- contact stresses
- low temperatures
- vibration

Action Limit

Because use of the hands is fundamental to work, establishing a TLV that will protect all workers is not feasible. Persons applying the TLV should be aware of the strength differences among occupational groups, genders, and ages. The TLV–PA Committee believes that at the TLV there will still be some individuals who experience symptoms. Therefore, an action limit is also specified that requires administrative controls, including education and surveillance, so that musculoskeletal disorders can be identified and appropriate interventions implemented while disorders are in their earliest stages.

Hand Activity Level (HAL)

Hand repetition or hand exertions are characterized using the 0 to 10 Hand Activity Level (HAL) scale (where 0 = completely idle and 10 = the greatest level of repetition imaginable) proposed by Latko (1997) and Latko et al. (1997) (*see* Figure 2).

HAL values are based on average values for the entire job. HAL values may be time weighted (TWA) in cases where the job can be divided into discrete homogeneous tasks. Forces are based on a peak or 90% value for the job (Jonsson, 1988). The 90th percentile value can be determined from the force frequency distribution of the entire job or from the combined force frequency distributions for each discrete task.

A nonlinear regression model was produced from the data published by Latko et al. (1997) for 33 jobs (Radwin et al., 2015) where the dependent variable was HAL, and the independent variables were exertion frequency F (exertion/s) and duty cycle D (exertion time/(exertion time + rest time)):

$$\mathrm{HAL} = 6.56 \ln D \left[\frac{F^{1.31}}{1 + 3.18\, F^{1.31}} \right]$$

HAL values (0–10) corresponding to different combinations of exertion frequency, period, and duty cycle, based on the regression model, are shown in Table 1.

Since the HAL scale is anchored against speed of hand motion/exertions and rest pauses, an equation was also developed (Akkas et al., 2015) for estimating hand activity level (HAL) directly from tracked RMS hand speed (S) and duty cycle (D):

$$\text{HAL} = 10\left[\frac{e^{-15.87+0.02\,D+2.25\ln S}}{1+e^{-15.87+0.02\,D+2.25\ln S}}\right]$$

(R^2 = 0.97 with a residual range ± 0.5 HAL. This equation may be more suitable when using instruments to directly measure HAL.)

Normalized Peak Force

Normalized peak force is a fraction of the individual or population strength and should be adjusted according to the population of interest.

$$\text{Normalized Peak Force} = \frac{\text{Peak force}}{\text{Strength}} \times 10$$

where:

Peak force = the peak force for the job or task under study and is expressed in kilogram-force (kg-f), pound-force (lb-f), or newtons (N)

Strength = the individual or population strength (e.g., maximum grip force) under study using same hand/wrist posture as observed for the task for the peak force element

Normalized peak force (NPF) is the peak force divided by the strength of the work population to which the standard is applied. Although the term "peak" is used, as a practical matter, it is a 90^{th} percentile value. The 90^{th} percentile was used so that the peak force would not be driven by random or spurious measurements or work elements.

Tables 2 and 3 summarize the epidemiological data that provided quantitative risk estimates for hand repetition rate and hand force. As can be seen from Table 2, there is significant risk of MSDs from exposures to high repetition, especially forceful repetition, for more than 4 hours per day.

The mean force values for elevated risk in the studies by Silverstein et al. (1987), Stetson et al. (1993), and Chiang et al. (1993) can be roughly compared to the population values for maximum grip and pinch strength values reported by Mathiowetz et al. (1985) and represent approximately 10% to 14% MVC. Roquelaure et al. (1997) identified increased risk of CTS when pinching objects exceeding 10 N in weight. Fransson-Hall et al. (1995, 1996) and Byström and Fransson-Hall (1994) also identified repetitive forceful pinching as increasing risk. Silverstein and Roquelaure also reported increased risk of CTS with increasing number of risk factors.

Recent large prospective studies are included in Tables 2 and 3 and provide greater precision of risk estimate for repetition rates and duty cycle for forceful hand exertions and CTS. In the Harris-Adamson et al. study (2015), hazard ratios were increased with forceful hand repetition rates greater than 2.6/s and the risk increased in a dose-response pattern. (Forceful hand exertions were those requiring > 9 N pinch force or > 45 N power grip force.) Similarly, the hazard ratio for duty cycle for forceful pinch or grip increased when the duty cycle was greater than 11% in a dose-response pattern. Analyst peak force ratings greater than 2.5 (0–10 Visual Analog) were also associated with increased risk. A large prospective study from Italy (Bonfiglioli et al., 2013) reported a linear increased risk at 2 and above on the 0–10 HAL repetition scale. In these recent longitudinal studies, the prior Action Limit (HAL = 0.56) was not protective (Violante, 2016). The data used in the Harris-Adamson et al. study (2015) was also evaluated relative to the prior TLV and supports a change in the slope of the TLV and AL to acknowledge the importance of hand force in the risk models (Kapellusch et al., 2014). The Kapellusch et al. (2014) analysis also supports a change in the intercept for AL.

While these studies were of carpal tunnel syndrome, similar findings have been observed for chronic tendon disorders and nonspecific pain (Silverstein et al., 1987; Armstrong et al., 1987; Latko et al., 1999; Harris et al., 2011). Also, it can be shown through biomechanical arguments that exertions of the hand produce stresses on both the finger flexor tendons and the median nerve inside the wrist and that these stresses are

TABLE 2. Level of Exposure to Repetitive Manual Work at Which Increased Risk of Upper Extremity Musculoskeletal Disorders was Found

Repetitiveness	Duration	References
Work cycle < 30 seconds	Full shift*	Armstrong et al., 1987; Chiang et al., 1993; Ohlsson et al., 1995; Silverstein et al., 1986, 1987
More than 50% of work time in fundamental cycle	Full shift	Armstrong et al., 1987; Chiang et al., 1993; Silverstein et al., 1986, 1987
Work cycle 35 seconds (median value)	Full shift	Punnett et al., 1985; Punnett and Keyserling, 1987
Work cycle < 10 seconds	4–8 hrs/day	Leclerc et al., 1998
Shortest elementary operation < 10 seconds	Full shift (7.5 hrs/day)	Roquelaure et al., 1997
Median angular velocity (wrist) 41°/second and pauses = 0.6% of work time	Full shift	Ohlsson et al., 1995
Hand exertion rate 2 or greater on HAL repetition scale	Full shift	Bonfiglioli et al., 2013
Forceful hand exertions > 2.6/s or duty cycle > 11%	TWA – full shift	Harris-Adamson et al., 2015
Repetitive hand and/or finger movements (“many times per minute”) and/or manual precision requirements	> 4 hrs/day	Fransson-Hall et al., 1995
Keying-intensive visual display unit work (e.g., data entry)	> 2 hrs/day > 3 hrs/day > 5 hrs/day > 6 hrs/day	Burt et al., 1990; Faucett and Rempel, 1994; Oxenburgh et al., 1985; Polanyi et al., 1997; Bernard et al., 1997
Medium repetitiveness (average rating 5.4 on a 0 to 10 scale) — corresponds to approximately 0.75 exertions/sec and 30% recovery per cycle	Full shift	Latko et al., 1999
External constraints on work pace		
Piece-rate wage system	Full shift	Brisson et al., 1989
Lack of change in task or breaks during > 15% of work time	Full shift (7.5 hrs/day)	Roquelaure et al., 1997
Just-in-time production system	4–8 hrs/day	Leclerc et al., 1998

* “Full shift” implied or assumed to mean a work day of 7.5 to 8 hours in length.

associated with thickening of connective tissues around both the tendons and the nerves. Histological changes of the nerve may be a primary effect of repetitive loading, a secondary effect of tendon sheath thickening or both.

There is biomechanical and epidemiological evidence that certain postures also are risk factors of hand, wrist and forearm musculoskeletal disorders. The risk due to posture can be accounted for through its affect on strength. A pinch grip as compared to a power grip, wrist deviation from neutral, forearm rotation all change grip strength and thus increase the normalized finger force for a given exertion. Professional judgment should be used to lower the values in the TLV when prolonged extreme postures are observed.

Recommended Exposure Limits: based on available data, a TLV and Action Limit are recommended as follows:

TLV: $NPF \le 5.6 - 0.56 \times HAL$; for $1 \le HAL \le 9$ **(1)**

Action Limit: $NPF \le 3.6 - 0.56 \times HAL$; for $1 \le HAL \le 9$ **(2)**

The recommended TLV and Action Limit are shown graphically in Figure 1.

Normalized Peak Force and Hand Activity Level should be rounded to the nearest whole number. Hand Activity Levels less than 1 were omitted because they are not considered repetitive work and are outside the scope of this TLV. A Hand Activity Level of 10 is defined as "Rapid steady motion/difficulty keeping up or continuous exertion" and is not sustainable. It is recommended that Hand Acivity Levels never exceed 9.

Some studies in Table 3 characterized force exposure as an average value while others use a peak normalized value. The average force has been shown to be related to the peak force. Silverstein et al. (1987) reported that the 97.5 percentile force was two to four times greater than the average value. Gerard et al. (1996) reported that the 90th percentile force for keyboard work was about two times the average value.

Comparison of TLV® for Hand Activity with TLV® for Upper Limb Localized Fatigue

The ACGIH TLV for Upper Limb Localized Fatigue considers duty cycle and force. The TLV (maximum acceptable normalized peak force) based on Equation 1 was computed for each combination of frequency and duty cycle shown in Table 1 and for the corresponding duty cycles using ACGIH TLV for Upper Limb Localized Fatigue (Table 4). It can be seen that the two TLVs approach the same values as the exertion rate increases. The two TLVs are all within the nearest whole number at exertions of 2/s.

TABLE 3. Level of Exposure to Manual Exertion at Which Increased Risk of Upper Extremity Musculoskeletal Disorders was Found

Manual Forces	Duration and/or Frequency	References
> 40 N average hand forces*	Full shift	Armstrong et al., 1987; Silverstein et al., 1986, 1987
> 30 N average hand forces	Full shift	Chiang et al., 1993
> 27 N kg object weight per hand	Routine gripping > 1/3 work shift	Stetson et al., 1993
> 40 N object weight, carried	Full shift: "usually"	Stetson et al., 1993
> 10 N object weight, handled	> 4 hrs/day	Fransson-Hall et al., 1995
> 10 N object weight, handled by pinching and fine prehensile finger motions	Full shift (7.5 hrs/day): > 10 times/hr	Roquelaure et al., 1997
> 2 on 0–10 force scale	Full shift	Bonfiglioli et al., 2013
≥ 9 N pinch or ≥ 45 N power grip force	Full shift with TLV weighting	Harris et al., 2011
≥ 9 N pinch or ≥ 45 N power grip force	Full shift with TLV weighting	Harris-Adamson et al., 2015
≥ 9 N pinch or ≥ 45 N power grip force	Full shift with TLV weighting	Kapellusch et al., 2014
Forceful Wrist/Hand Motions		
Grocery checking	> 5 hrs/day	Baron and Habes, 1992
Repeated grasping and wrist flexion/extension	> 4 hrs/day	Osorio et al., 1994
Forearm rotation while exerting very high forces	18 min/day (avg)	Hughes et al., 1997
"Excessive" manual force	> 1 hr/day	Atroshi et al., 1999

* N.B. "adjusted force" was 6 kg by EMG; approx. equal to 4 kg cut-off in initial job selection.

Assessing Force

"Normalized peak hand force" is expressed on a scale of 0 to 10, where 0 corresponds to no effort and 10 corresponds to 100% maximum effort. Normalized peak hand force is determined for a given task by:

1. Measuring hand forces and corresponding postures.
2. Obtaining strength data for that posture and that worker or work population. In most cases, strength values can be obtained directly or extrapolated from the literature.
3. 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

Worker Ratings

Visual analogue scales and the Borg scales are commonly used to obtain worker ratings on a scale of 0 to 10 (Borg, 1982). A visual analogue scale is shown in Figure 3. It typically consists of a 10 cm horizontal line. The left end of the scale is labeled "no effort"; the right end of the scale is labeled as "greatest effort imaginable." The worker is simply asked to draw a horizontal line through the scale at the location that most closely corresponds with the peak effort associated with their job. The job is scored by measuring the distance of the mark from the left end of the scale. The Borg scale (Table 5) is a series of nonlinearly distributed verbal anchor points. The worker is asked to identify the descriptor that most closely approximates the peak effort associated with his or her job.

Both the Borg and visual analog scales assess the effort of the individual performing the rating. While this may be important information about that person, it is necessary to know the strength of that individual with respect to the rest of the population to calculate the normalized force. For example, suppose that a female worker rates the job grip strength requirements as a 4. The worker's maximum grip strength is then measured and found to be 300 N, but the fifth percentile female grip strength is approximately 183 N and the fifth percentile male strength is approximately 383 N. (It is common practice to design for lower percentiles; however, the normalized force can be adjusted for other individuals, occupational groups, and other percentiles by selecting appropriate strength values from Table 6. The fifth percentile male is an estimate, based on an average coefficient of variation of 19.2% from data reported in Table 6 and the average female strength of industrial applicants as reported in Schmidt and Toews (1970)). The peak force rating on the 10-point scale can then be estimated as:

$$\text{5\%ile female normalized hand force} = \frac{(4 \bullet 300\,\text{N})}{183\,\text{N}} = 6.6$$

$$\text{5\%ile male normalized hand force} = \frac{(4 \bullet 300\,\text{N})}{383\,\text{N}} = 3.1$$

The precision of worker ratings can be improved by averaging the normalized ratings of multiple workers doing the same job.

Observer Ratings

Observers can use visual analog scales to rate force exposures (Figure 3). Zero, the left end of the scale, corresponds to "no perceptible force." In this case, the worker's hands would be resting on his or her lap, a work surface, keyboard, etc. Ten, the right-hand end of the scale, corresponds to the "greatest force imaginable." In this case, the worker would demonstrate visible strain, tensed muscles, jerking, etc. Videotaped examples of jobs that represent the extremes and points in between are helpful and can establish reference points. These may be used to develop suitable verbal reference points for the occupation or industry of concern. As a practical matter, it may only be possible to group jobs into 3 to 5 intervals between 0 and 10. Having multiple observers rate the job and discuss their results can increase the precision of observer ratings. Factors that should be considered include:

- Strength of the observed worker versus the population of interest
- Weight, shape and friction of work object
- Posture
- Glove fit and friction
- Mechanical assist
- Torque specifications of power tools
- Quality control
- Equipment maintenance

Professional judgment based on a basic understanding of hand biomechanics is required for reliable force estimates.

Biomechanical Calculations

Biomechanics entails the use of mechanics to estimate the load on the fingers. A biomechanical analysis should begin with a free-body diagram of the object being grasped. The vector sum of the forces and moments must add up to zero. In most cases, the analysis can be simplified by using a two-dimensional approximation of the work object. Figure 4 shows two examples.

Case A presents the worker holding an object with a hook grip. In this case, the load on the fingers will be equal to the force of gravity on the object:

$$F_{grip} = W_{object}$$

If the object weighs 25 N, then F_{grip} = 25 N. The hook grip strength is very close to power grip strength. As listed in Table 6, the average male and female power-grip strength for industrial applicants is 503 N and 311 N, respectively. Therefore, on the 10-point scale, the normalized force to hold the book ranges from 0.5 to 0.8 for the average female to average male. As a practical matter, the values might be increased one point each to account for acceleration.

Case B worker is holding a book in a vertical pinch grip. In this case, the fingers must apply enough contact force to the sides of the book to produce enough friction force to overcome the force of gravity. The required pinch force is related to the weight and friction by the following inequality:

$$F_{pinch} \geq \frac{W_{book}}{2\,\mu}$$

The coefficient of friction depends on the surface material and moisture of the skin (Table 7). The skin often loses moisture to the work objects and dries out. The coefficient of friction is approximately 0.5 for moist skin and paper, and approximately 0.25 for dry skin. The pinch force can be calculated as:

$$\text{Moist skin: } F_{pinch} \geq \frac{25}{(2 \bullet 0.50)} = 25 \text{ N}$$

$$\text{Dry skin: } F_{pinch} \geq \frac{25}{(2 \bullet 0.25)} = 50 \text{ N}$$

The calculated values are then compared with the corresponding hand strength. In this case, the hand is in a pinch posture. From Swanson et al. (1970), pinch strength is approximately 15% of power grip strength (*see* Figure 5). Therefore, the normalized peak forces on the 10-point scale will be:

For the Female

$$\text{Moist skin: } \left[\frac{25 \text{ N}}{(0.15 \bullet 311 \text{ N})}\right] \bullet 10 = 5.4$$

$$\text{Dry skin: } \left[\frac{50 \text{ N}}{(0.15 \bullet 311 \text{ N})}\right] \bullet 10 > 10$$

For the Male

$$\text{Moist skin: } \left[\frac{25 \text{ N}}{(0.15 \bullet 503 \text{ N}}\right] \bullet 10 = 3.3$$

$$\text{Dry skin: } \left[\frac{50 \text{ N}}{(0.15 \bullet 503 \text{ N})}\right] \bullet 10 = 6.7$$

Females with average strength and dry skin would not be able to hold the book in a pinch posture. These are only the minimum force requirements for a static exertion. Often workers are found to exert more than the necessary force (Frederick and Armstrong, 1995; Westling and Johansson, 1988). In addition, the force requirements must be increased to compensate for acceleration. As a practical matter, these values should be rounded to the nearest whole number.

Force Gauges

In some cases, force gauges can be incorporated into a work object or tool to measure grip force. As a practical matter, these methods require custom instrumentation; for example, they can be incorporated into a pipette to measure thumb force. They can be used to measure the force required for tightening bolts. In many instances, there are significant technical barriers to incorporating force sensors into a work object. The technical details to use and calibrate these gauges is beyond the scope of this document.

TABLE 4. Comparison of Maximum Acceptable Normalized Peak Force Values (0–10) for Hand Activity TLV and Upper Limb Localized Fatigue TLV at Different Duty Cycles.

		Duty Cycle (%)				
	Exertion/s	**10**	**30**	**50**	**70**	**90**
HA TLV®	**0.125**	5.0	5.0			
	0.25	4.5	4.5	3.9		
	0.5	3.9	3.4	2.8	2.8	2.8
	1.0	3.4	2.8	2.2	1.7	1.7
	2.0		2.2	1.7	1.1	1.1
Fatigue TLV®		4.0	2.5	1.7	1.3	0.9

FIGURE 3. Scale for rating peak hand force (Latko et al., 1997).

TABLE 5. Borg Category–Ratio Scale for Estimating Hand Forces

Score	Verbal Anchor
0	Nothing at all
0.5	Extremely weak (just noticeable)
1	Very weak
2	Weak (light)
3	Moderately
4	
5	Strong (heavy)
6	
7	Very strong
8	
9	
10	Extremely strong (almost maximal)
•	Maximal

Electromyography

Electromyography involves using the electrical activity of the muscles to estimate the force exertion of the hand. While this method is widely used in laboratory and field settings, it requires specialized equipment and training. Key issues include:

- selection of the appropriate muscle group
- proper placement of surface electrodes
- calibration
- data acquisition and processing
- data analysis and interpretation

Armstrong et al. (1982) have demonstrated how this equipment can be used to estimate hand forces as a function of time in poultry processing. Other investigators have subsequently proposed methods for summarizing electromyography (EMG) data using probability distributions (Jonsson, 1988; Mathiassen and Winkel, 1991). EMG data can be calibrated as a fraction of an individual's maximum strength, which, for practical purposes, corresponds to the normalized hand force. Bao et al. (1995) describes several techniques for EMG calibration. The user should be aware that there is significant variation in EMG

TABLE 6. Power Grip Strengths in Newtons (N) from Several Studies: Mean (Standard Deviation). Subject Age is Expressed as a Range with Mean and/or Standard Deviation Listed Where Available

	Dominant/Right	Non-Dom/Left	n	Subject Age	Population	References
Male	463.5 (nr)*	398.9 (nr)	(nr)	18–65	Office workers	Nemethi, 1952
	532.1 (nr)	474.3 (nr)	(nr)	18–65	Laborers	
	556.6 (nr)	514.5 (nr)	(nr)	18–65	Skilled	
	589.0 (nr)	532.1 (nr)	(nr)	18–65	Semi-skilled	
	502.7 (72.5)	488.0 (73.5)	1128	18–62	Steel mill applicants	Schmidt and Toews, 1970
	466.5 (nr)	441.0 (nr)	50	17–60	U.S. adults	Swanson et al., 1970
	428.3 (63.7)	409.6 (71.5)	34	18–67	U.S. adults	Young et al., 1989
	343.0 (68.6)	nr	35	16–28 22.5 (2.1)	College students	Balogun et al., 1991
	609.6 (106.8)	574.3 (98.0)	105	16–63 32 (nr)	U.S. adults	Crosby et al., 1994
	479.2 (82.3)	nr	80	20–69	Chinese	Su et al., 1994
	446.9 (84.3)	427.3 (85.3)	55	60–69	U.S. adults	Desrosiers et al., 1995
	415.5 (89.2)	396.9 (83.3)	48	70–79		
	338.1 (70.6)	314.6 (68.6)	40	80+		
	481.2 (73.5)	457.7 (70.6)	40	18–84	U.S. adults	Richards, 1997
	451.8 (nr)	410.6 (nr)	34	19–45	Office workers	Josty et al., 1997
				29 (nr)		
	514.5 (nr)	496.9 (nr)	38	16–56	Light manual (garage workers)	
				30 (nr)	Heavy manual (farmers)	
	526.3 (nr)	525.3 (nr)	32	17–65		
				43 (nr)		
Female	281.3 (nr)	218.5 (nr)	(nr)	18–65	U.S. adults	Nemethi, 1952
	310.7 (nr)	284.2 (nr)	80	18–52	Steel mill applicants	Schmidt and Toews, 1970
	241.1 (nr)	219.5 (nr)	50	17–60	U.S. adults	Swanson et al., 1970
	240.1 (43.1)	214.6 (42.1)	61	18–67	U.S. adults	Young et al., 1989
	210.7 (54.9)	nr	26	16–28 19.1 (1.6)	College students	Balogun et al., 1991
	360.6 (71.5)	334.2 (71.5)	109	16–63 32 (nr)	U.S. adults	Crosby et al., 1994
	273.4 (55.9)	nr	80	20–69	Chinese	Su et al., 1994
	247.9 (47.0)	231.3 (46.1)	56	60–69	U.S. adults	Desrosiers et al., 1995
	232.3 (50.0)	215.6 (46.1)	59	70–79		
	196.0 (42.1)	181.3 (43.1)	29	80+		
	289.1 (60.8)	272.4 (5.7)	34	18–84	U.S. adults	Richards, 1997

* Statistics not reported in the study are listed as "nr"

data and, therefore, signal-processing routines that filter the data are required.

Like worker ratings, these data provide information about an individual person. It may be necessary to adjust the findings based on the ratio of the strength of the individuals to that of the population.

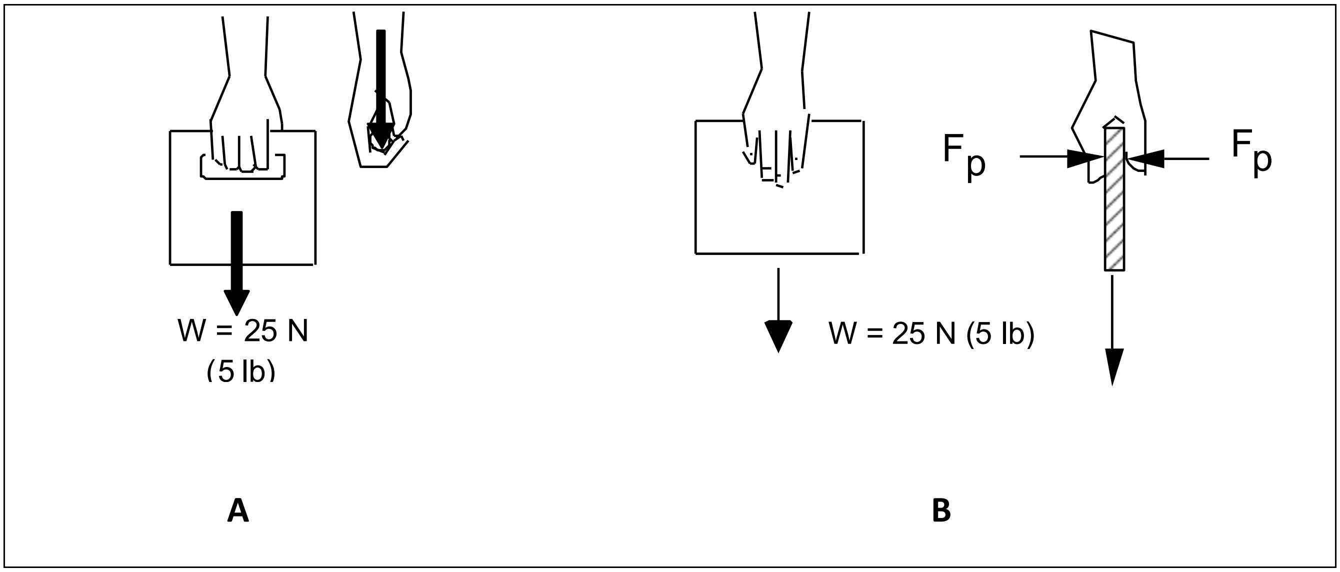
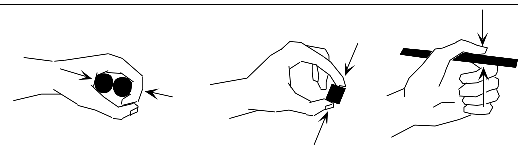


FIGURE 4. In **A**, the worker must flex his fingers to oppose the weight of gravity on the object. In **B**, the object must be pinched hard enough, $\mathbf{F}_p$, to produce sufficient friction, $\mathbf{F}_f$, to overcome the weight, **W**.

TABLE 7. Coefficients of Friction for Human Palmer Skin against Various Materials (n = 7 subjects) (Buchholz et al., 1988)

Material	Dry (n = 42)	Moist (n = 42)	Combined (n = 84)
Sand paper (#320)	—	—	0.61 ± 0.10
Smooth vinyl	—	—	0.53 ± 0.18
Textured vinyl	—	—	0.50± 0.11
Adhesive tape	0.41 ± 0.10	0.66 ± 0.14	—
Suede	0.39 ± 0.06	0.66 ± 0.11	—
Aluminum	—	—	0.38 ± 0.13
Paper	0.27 ± 0.09	0.42 ± 0.07	—



	Male		Female	
	Major	**Minor**	**Major**	**Minor**
Grip Strength	466.5	441.0	241.1	219.5
Chuck Pinch	77.4	73.5	51.0	48.0
Pulp Pinch:				
Digits I–II	51.9	47.0	53.3	32.3
Digits I–III	54.9	55.9	37.2	33.3
Digits I–IV	37.2	35.3	24.5	23.5
Digits I–V	22.5	21.6	16.7	15.7
Lateral Pinch	73.5	69.6	48.0	46.1

FIGURE 5. Average male and female hand strength in newtons for selected postures (Swanson et al., 1970).

Example 1

In this example, a worker uses both hands to get a flattened shipping carton from a stack next to the work station, erects it, and places it between himself and the end of the conveyor. He then alternates right and left hands to get boxes of products weighing 8 N each from the end of the conveyor and places them in the shipping carton. He then uses both hands to close the flaps on the carton and push it aside into an automatic taping machine.

- Get and erect shipping carton: 5 s, right and left hands used together (100% work, based on observation)
- Pack six 8 N boxes: 15 s, alternate use of right and left hands (40% work)
- Close case and aside into taping machine: 2 s, right and left hands used together (100% work)

Cycle Time = Time to construct carton
+ time to pack carton
+ time to close & aside carton
= 5 s (3 exertions)
+ 15 s (3 exertions)
+ 2 s (2 exertions)
= 22 s
= 22 s/8 exertions
= 2.75 s/exertions

$$\textit{Duty Cycle} = \frac{\left[\begin{array}{c}(100\%\text{work} \times 5\text{ s}) + (40\%\text{work} \times 15\text{ s}) \\ + (100\%\text{work} \times 2\text{ s})\end{array}\right]}{22\text{ s}}$$

= 60%

Hand Activity Level: Because the job involves conspicuous rest pauses and the worker does not have to hurry, HAL has been rated a 4, based on observation, using Figure 2. Alternatively, using Table 1 along with the time per exertion and the duty cycle calculated previously, the HAL is estimated to be 4.

Force is exerted to get and erect the cartons, to pack and to aside the case. The greatest forces are associated with picking up the boxes using a pinch grip. Approximately 8 N of force are required to pick up the carton. The fifth percentile pinch strength for a female work population is estimated as 27 N (0.15 • 183 N), based on ratio of grip-to-pinch strength, as reported by Swanson et al. (1970) in Table 5. Normalized hand force = [(8 N/27 N) • 10], or approximately 3. From Figure 1, the worker is below the Action Limit.

EXAMPLE 2: CASE PACKING: SELF-PACED

This case is the same as the above, except that the worker is paid on an incentive according to how much he or she packs. Although the worker is able to keep up, the 9 seconds of recovery time for each hand that occurred during the packing step has been eliminated, so that the duty cycle is 100%.

$$
\begin{aligned}
\textit{Cycle Time} &= 5\text{ s (3 exertions)} + 6\text{ s (3 exertions)} \\
&\quad + 2\text{ s (2 exertions)} \\
&= 13\text{ s} \\
&= 13\text{ s/8 exertions} \\
&= 1.6\text{ s/exertions}
\end{aligned}
$$

$$
\textit{Duty Cycle} = \frac{\begin{bmatrix}(100\%\text{work} \times 5\text{ s}) + (100\%\text{work} \times 6\text{ s}) \\ (100\%\text{work} \times 2\text{ s})\end{bmatrix}}{13\text{ s}}
$$

$$= 100\%$$

Using the scale in Figure 2, repetition has been rated as 6: "steady motion/exertion; infrequent pauses." Alternatively, using Table 1, along with the time per exertion and the duty cycle calculated previously, the HAL also is estimated to be 6. While the force to hold the box is the same, it is reasonable to increase the required hand force one or two points to account for the inertial effect. The normalized peak hand force then becomes 4. From Figure 1, the worker is now above the Action Limit.

TLV® Chronology

2000: *proposed*
2001: Adopted
2009: *Documentation* updated. No change to TLV value
2016: *Documentation* updated and TLV and Action Limit values revised
2017: *proposed*: Revision to the TLV; addition of alternate methods for expressing the limit values; addition of information comparing the TLVs for Hand Activity and Upper Limb Localized Fatigue; addition of new references

References

Akkas O; Azari DP; Chen CHE; et al.: A hand speed–duty cycle equation for estimating the ACGIH hand activity level rating. Ergonomics 58(2):184–194 (2015).

Armstrong T; Foulke J; Joseph B; et al.: Investigation of Cumulative Trauma Disorders in a Poultry Processing Plant. Am Ind Hyg Assoc J 43(2):103–116 (1982).

Armstrong TJ; Fine LJ; Goldstein SA; et al.: Ergonomics Considerations in Hand and Wrist Tendinitis. J Hand Surg [Am] 12A[2 Pt 2]:830–837 (1987).

Armstrong TJ; Buckle P; Fine LJ; et al.: A Conceptual Model for Work-Related Neck and Upper-Limb Musculoskeletal Disorders. Scand J Work Environ Health 19:73–84 (1993).

Atroshi I; Gummesson C; Johnsson R; et al.: Prevalence of Carpal Tunnel Syndrome in a General Population. JAMA 282(2):153–158 (1999).

Balogun JA; Akomolafe CT; Amusa LO: Grip Strength: Effects of Testing Posture and Elbow Position. Arch Phys Med Rehabil 72:280–283 (1991).

Bao S; Mathiassen E; Winkel J: Normalizing Upper Trapezius EMG Amplitude: Comparison of Different Procedures. J Electromyogr Kinesiol (1995).

Baron S; Habes DJ: Occupational Musculoskeletal Disorders among Supermarket Cashiers. Scand J Work Environ Health 18(Suppl 2):127–129 (1992).

Bernard BP (Ed): Musculoskeletal Disorders and Workplace Factors: A Critical Review of Epidemiologic Evidence for Work-Related Musculoskeletal Disorders of the Neck, Upper Extremity, and Low Back. DHHS (NIOSH) Pub No 97-141. US National Institute for Occupational Safety and Health, Cincinnati, OH (1997).

Bernard B; Sauter S; Petersen M; et al.: Health Hazard Evaluation Report: Los Angeles Times, Los Angeles, CA, HETA-90-013-2277, 1993. US National Institute for Occupational Safety and Health. In: NIOSH Health Hazard Evaluations: 1990–1996 CD-ROM. DHHS (NIOSH) Pub No 97-144; NTIS Pub No PB98-500317. National Technical Information Service, Springfield, VA (1997).

Bonfiglioli R; Mattioli S; Armstrong T; et al.: Validation of the ACGIH TLV for hand activity in the OCTOPUS cohort: a two-year longitudinal study of carpal tunnel syndrome. Scand J Work Environ Health 39(2):155–63 (2013).

Borg G: Psychophysical Bases of Perceived Exertion. Med Sci Sports Exerc 14(5):377–381 (1982).

Brisson C; Vinet A; Vezina M; et al.: Effect of Duration of Employment in Piecework on Severe Disability among Female Garment Workers. Scand J Work Environ Health 15:329–334 (1989).

Buchholz B; Frederick L; Armstrong T: An Investigation of Human Palmar Skin Friction and the Effects of Materials, Pinch Force and Moisture. Ergonomics 31(3):317–325 (1988).

Burt S; Hornung R; Fine LJ: Hazard Evaluation and Technical Assistance Report: Newsday Inc, Melville, NY, HHE 89-250-2046. US National Institute for Occupational Safety and Health, Cincinnati, OH (1990).

Byström S; Fransson-Hall C: Acceptability of Intermittent Handgrip Contractions Based on Physiological Response. Human Factors 36(1):158–171 (1994).

Chiang HC; Ko YC; Chen SS; et al.: Prevalence of Shoulder and Upper-Limb Disorders among Workers in the Fish-Processing Industry. Scand J Work Environ Health 19(2):126–131 (1993).

Crosby CA; Wehbe MA; Mawr B: Hand Strength: Normative Values. J Hand Surg [Am] 19(4):665–670 (1994).

Desrosiers J; Bravo G; Hebert R; et al.: Normative Data for Grip Strength of Elderly Men and Women. Am J Occup Ther 49(7):637–644 (1995).

Faucett J; Rempel D: VDT-Related Musculoskeletal Symptoms: Interactions Between Work Posture and Psychosocial Work Factors. Am J Ind Med 26:597–612 (1994).

Fransson-Hall C; Byström S; Kilbom A: Self-Reported Physical Exposure and Musculoskeletal Symptoms of the Forearm-Hand among Automobile Assembly-Line Workers. J Occup Environ Med 37(9):1136–1144 (1995).

Fransson-Hall C; Byström S; Kilbom A: Characteristics of Forearm-Hand Exposure in Relation to Symptoms among Automobile Assembly Line Workers. Am J Ind Med 29:15–22 (1996).

Frederick LJ; Armstrong TJ: An Investigation of Friction and Weight on Pinch Force. Ergonomics 38(12):2447–2454 (1995).

Gerard M; Armstrong T; Foulke J; et al.: Effects of Key Stiffness on Force and the Development of Fatigue while Typing. Am Ind Hyg Assoc J 57:849–854 (1996).

Harris C; Eisen E; Goldberg R; et al.: Workplace and individual factors in wrist tendinosis among blue-collar workers — the San Francisco study. Scand J Work Environ Health 37(2):86–98 (2011).

Harris-Adamson C; Eisen EA; Kapellusch J; et al.: Biomechanical Risk Factors for Carpal Tunnel Syndrome: A Pooled Study of 2474 Workers. Occup Environ Medicine 72:33–41 (2015).

Hughes RE; Silverstein BA; Evanoff BA: Risk Factors for Work-Related Musculoskeletal Disorders in an Aluminum Smelter. Am J Ind Med 32:66–75 (1997).

Jonsson B: The Static Load Component in Muscle Work. Eur J Appl Physiol 57:305–310 (1988).

Josty IC; Tyler MPH; Shewell PC; et al.: Grip and Pinch Strength Variations in Different Types of Workers. J Hand Surg [Br] 22(2):266–269 (1997).

Kapellusch JM; Gerr F; Malloy EJ; et al.: Exposure-response relationships for the ACGIH TLV for hand activity level: results from a pooled data study of carpal tunnel syndrome. Scand J Work Environ Health 40(6):610–20 (2014).

Latko W: Development and Evaluation of an Observational Method for Quantifying Exposure to Hand Activity and Other Physical Stressors in Manual Work. PhD Dissertation, The University of Michigan, Ann Arbor (1997).

Latko W; Armstrong TJ; Foulke JA; et al.: Development and Evaluation of an Observational Method for Assessing Repetition in Hand Tasks. Am Ind Hyg Assoc J 58:278–285 (1997).

Latko WA; Armstrong TJ; Franzblau A; et al.: Cross-Sectional Study of the Relationship Between Repetitive Work and the Prevalence of Upper Limb Musculoskeletal Disorders. Am J Ind Med 36:248–259 (1999).

Leclerc A; Franchi P; Cristofari MF; et al.: Carpal Tunnel Syndrome and Work Organisation in Repetitive Work: A Cross-Sectional Study in France. Study Group on Repetitive Work. Occup Environ Med 55(3):180–187 (1998).

Mathiassen E; Winkel J: Quantifying Variation in Physical Load Using Exposure-versus-Time Data. Ergonomics 34(12):1455–1468 (1991).

Mathiowetz V; Kashman N; Volland G; et al.: Grip and Pinch Strength: Normative Data for Adults. Arch Phys Med Rehabil 66:69–73 (1985).

Nemethi CE: An Evaluation of Hand Grip in Industry. Ind Med Surg 21(2):65–66 (1952).

Ohlsson K; Attwell RG; Palsson B; et al.: Repetitive Industrial Work and Neck and Upper Limb Disorders in Females. Am J Ind Med 27:731–747 (1995).

Osorio AM; Ames RG; Jones J; et al.: Carpal Tunnel Syndrome Among Grocery Store Workers. Am J Ind Med 25:229–245 (1994).

Oxenburgh M; Rowe SA; Douglas DB: Repetitive Strain Injury in Keyboard Operators, Successful Management Over a Two-Year Period. J Occup Health Safety [Australia/New Zealand] 1(2):106–112 (1985).

Polanyi MFD; Cole DC; Beaton D; et al.: Upper Limb Work-Related Musculoskeletal Disorders among Newspaper Employees: Cross-Sectional Survey Results. Am J Ind Med 32:620–628 (1997).

Punnett L; Robins JM; Wegman DH; et al.: Soft tissue disorders in the upper limbs of female garment workers. Scand J Work Environ Health 11:417–425 (1985).

Punnett L; Keyserling WM: Exposure to ergonomic stressors in the garment industry: application and critique of job-site work analysis methods. Ergonomics 30:1099–1116 (1987).

Radwin RG; Azari DP; Lindstrom MJ; et al.: A frequency–duty cycle equation for the ACGIH hand activity level. Ergonomics 58:173–183 (2015).

Richards LG: Posture Effects on Grip Strength. Arch Phys Med Rehabil 78:1154–1156 (1997).

Roquelaure Y; Mechali S; Dano C; et al.: Occupational and Personal Risk Factors for Carpal Tunnel Syndrome in Industrial Workers. Scand J Work Environ Health 23(5):364–369 (1997).

Schmidt RT; Toews JV: Grip Strength as Measured by the Jamar Dynamometer. Arch Phys Med Rehab, pp 321–327 (1970).

Silverstein BA; Fine LJ; Armstrong TJ: Hand Wrist Cumulative Trauma Disorders in Industry. Br J Ind Med 43:779–784 (1986).

Silverstein BA; Fine LJ; Armstrong TJ: Occupational Factors and Carpal Tunnel Syndrome. Am J Ind Med 11:343–358 (1987).

Stetson DS; Silverstein BS; Keyserling WM; et al.: Median Sensory Distal Amplitude and Latency: Comparison Between Nonexposed Managerial/ Professional Employees and Industrial Workers. Am J Ind Med 24:175–189 (1993).

Su C; Lin J; Chien T; et al.: Grip Strength in Different Positions of Elbow and Shoulder. Arch Phys Med Rehabil 75:812–815 (1994).

Swanson AB; Matev IB; de Groot G: The Strength of the Hand. Bull Prosth Res, pp 145–153 (1970).

Violante FS; Farioli A; Graziosi F; et al.: Carpal tunnel syndrome and manual work: the OCTOPUS cohort: results of a 10-year longitudinal study. Scand J Work Environ Health 42(4):280–290 (2016).

Westling G; Johansson R: Factors Influencing the Force Control during Precision Grip. Exp Brain Res 53:277–284 (1988).

World Health Organization (WHO): Identification and Control of Work-Related Diseases, pp 7–11. Technical Report No 174. WHO, Geneva (1985).

Young VL; Pin P; Kraemer BA; et al.: Fluctuation in Grip and Pinch Strength among Normal Subjects. J Hand Surg [Am] 14(1):125–129 (1989).