Chapter 9
Ergonomics
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I. Manual Material Handling

A. NIOSH Lifting Equation

The NIOSH lifting equation is a tool for assessing the physical stress of two-handed manual lifting tasks. The revised NIOSH lifting equation[1] can be used to compute the recommended weight limit (RWL) and the lifting index (LI). The lifting equation is valid for lifts with the following components:

- Two-handed;
- Smooth;
- Worker is standing;
- Center of gravity of the object is fixed;
- Environment is favorable; and
- Foot/floor coupling is reasonable.

The equation does not apply if any of the following occurs:

- Manual material handling jobs other than lifting are not minimal and require significant energy;
- Unpredicted conditions, such as unexpected heavy loads, slips, or falls;
- Lifting or lowering with one hand;
- Lifting or lowering for more than eight hours;
- Lifting or lowering while seated or kneeling;
- Lifting or lowering in a restricted workspace;
- Lifting or lowering unstable objects (e.g., humans);
- Lifting or lowering while carrying, pushing, or pulling;
- Lifting or lowering with wheelbarrows or shovels;
- Lifting or lowering with "high speed" motion (faster than 76 cm/sec [30 in./sec]);
- Lifting or lowering with unreasonable foot/floor coupling (<0.4 coefficient of friction between the sole and the floor); and
- Lifting or lowering in an unfavorable environment (temperature significantly outside 19°C–26°C (66°F–79°F); relative humidity outside 35%–50% range).

The recommended weight limit can be computed by using the following equation:

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM \quad (1)$$

where: H = Horizontal distance of the hands from the midpoint between the ankles (cm or in.) (see Figure 9.1)
V = Vertical distance of the hands from the floor (cm or in.) (see Figure 9.1)
D = Vertical travel distance between the origin and destination of the lift (cm or in.)
A = Angular displacement of the load from the sagittal plane (°) (see Figure 9.2)

Table 9.1 — NIOSH Lifting Equation Definitions of Terms

Term	*SI Units*	*U.S. Customary*
LC – load constant	23 kg	51 lb.
HM – horizontal multiplier	25/H	10/H
VM – vertical multiplier	1 – (0.00·|V–75|)	1 – (0.0075·|V–30|)
DM – distance multiplier	0.82 + (4.5/D)	0.82 + (1.8/D)
AM – asymmetric multiplier	1 – (0.0032A)	1 – (0.0032A)
FM – frequency multiplier	from Table 9.2	from Table 9.2
CM – coupling multiplier	from Table 9.3	from Table 9.3

Table 9.2 — Frequency Multiplier (FM)*

	≤1 hour		*≤2 hour*		*≤8 hour*	
Frequency lifts/min	*V < 75 cm or 30 in.*	*V ≥ 75 cm or 30 in.*	*V < 75 cm or 30 in.*	*V ≥ 75 cm or 30 in.*	*V < 75 cm or 30 in.*	*V ≥ 75 cm or 30 in.*
0.2	1.00	1.00	0.95	0.95	0.85	0.85
0.5	0.97	0.97	0.92	0.92	0.81	0.81
1	0.94	0.94	0.88	0.88	0.75	0.75
2	0.91	0.91	0.84	0.84	0.65	0.65
3	0.88	0.88	0.79	0.79	0.55	0.55
4	0.84	0.84	0.72	0.72	0.45	0.45
5	0.80	0.80	0.60	0.60	0.35	0.35
6	0.75	0.75	0.50	0.50	0.27	0.27
7	0.70	0.70	0.42	0.42	0.22	0.22
8	0.60	0.60	0.35	0.35	0.18	0.18
9	0.52	0.52	0.30	0.30	0.00	0.15
10	0.45	0.45	0.26	0.26	0.00	0.13
11	0.41	0.41	0.00	0.23	0.00	0.00
12	0.37	0.37	0.00	0.21	0.00	0.00
13	0.00	0.34	0.00	0.00	0.00	0.00
14	0.00	0.31	0.00	0.00	0.00	0.00
15	0.00	0.28	0.00	0.00	0.00	0.00
>15	0.00	0.00	0.00	0.00	0.00	0.00

* Adapted from Waters et al., 1993.[1]

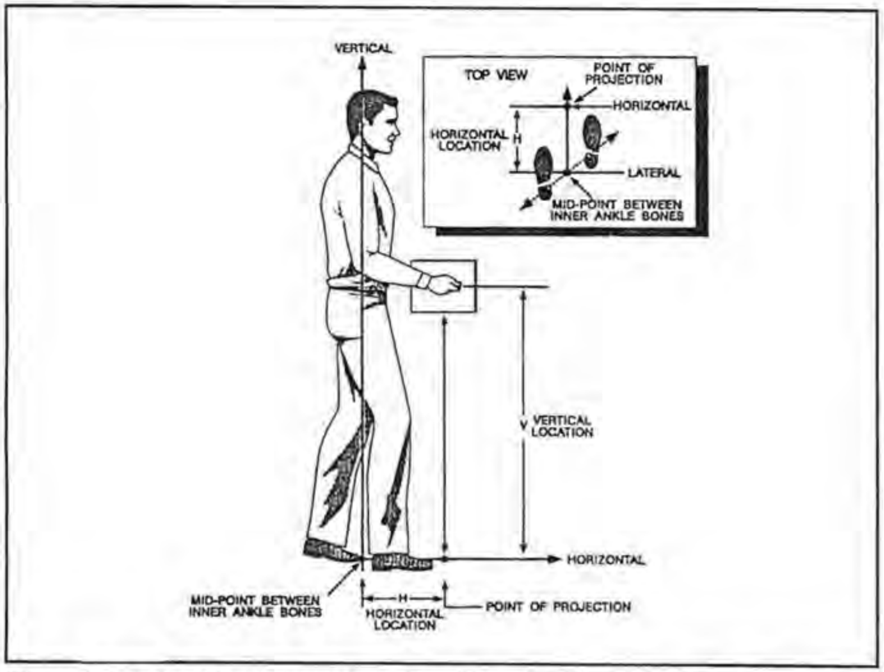

Figure 9.1 — Graphic representation of hand location. [Reprinted from Waters et al., 1994[2]]

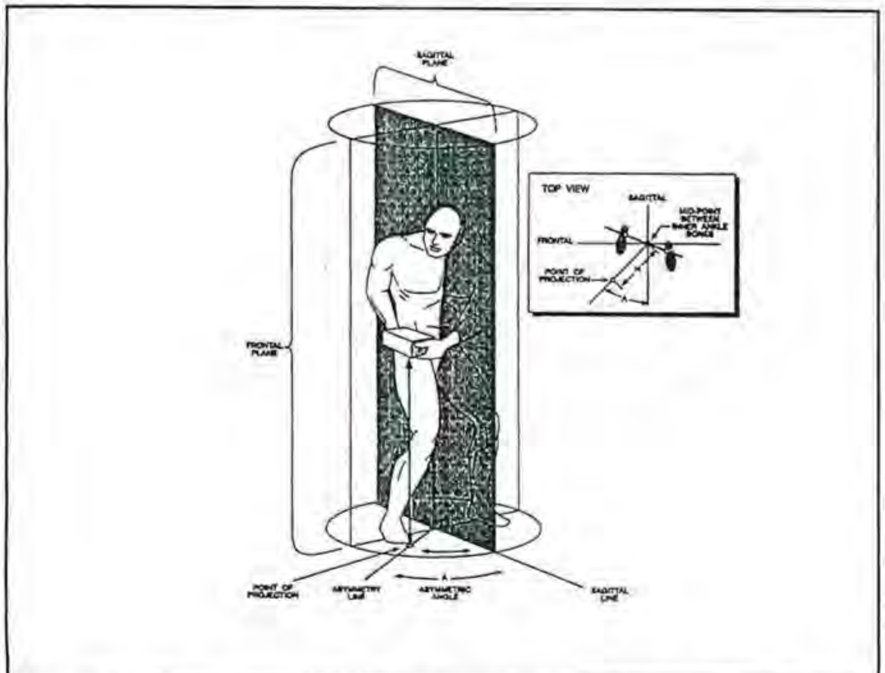

Figure 9.2 — Graphic representation of angle of asymmetry (A). [Reprinted from

Table 9.3 — Coupling Multiplier (CM)*

Couplings	*V < 75 cm (30 in.)*	*V ≥ 75 cm (30 in.)*
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90

Good = Object has handholds or handhold cut-outs, or object can be easily held by hands.
Fair = Object has handholds but they are too small, slippery, or otherwise less than optimal.
Poor = Object is bulky, hard to handle, or has sharp edges.

* Adapted from Waters et al., 1993[1]

The lifting index (LI) is calculated from the load weight (L) and the recommended weight limit (RWL):

$$LI = \frac{L}{RWL} \qquad (2)$$

If the lifting index is 1 or less, the lift is considered to be acceptable for 75 percent of female workers and 90 percent of male workers. Figure 9.3 is a job analysis worksheet that can be used to compute the task's recommended weight limit and lifting index. If the lifting index is more than 1, the lifting task poses an increased risk for lifting-related low back pain for some fraction of the work force. The goal should be to redesign the job to achieve a lifting index of 1 or less. General design or redesign suggestions to improve jobs with lifting indices greater than 1 are described in Table 9.4. Some experts believe that worker selection criteria may be used to identify workers who can perform potentially stressful tasks (LI > 1) without significantly increasing their risk of work-related injury. However, these experts usually agree that nearly all workers will be at an increased risk of work-related injury when performing highly stressful lifting tasks (LI > 3).

JOB ANALYSIS WORKSHEET

DEPARTMENT ______ JOB DESCRIPTION ______
JOB TITLE ______
ANALYST'S NAME ______
DATE ______

STEP 1. Measure and record task variables

Object Weight (lbs)		Hand Location (in.) Origin		Hand Location (in.) Dest.		Vertical Distance (in)	Asymmetric Angle (degrees) Origin	Asymmetric Angle (degrees) Dest.	Freq. Rate, lifts/min	Dura-tion, (hrs.)	Object Coupling
L (avg.)	L (max)	H	V	H	V	D	A	A	F		C

STEP 2. Determine the multipliers and compute the RWL's

	RWL	=	LC	x	HM	x	VM	x	DM	x	AM	x	FM	x	CM	=	
Origin:	RWL	=	51	x		x		x		x		x		x		=	Lbs.
Dest:	RWL	=	51	x		x		x		x		x		x		=	Lbs.

STEP 3. Compute the LIFTING INDEX

ORIGIN: LIFTING INDEX = OJECT WEIGHT (L) / RWL = ______ =

DESTINATION: LIFTING INDEX = OBJECT WEIGHT (L) / RWL = ______ =

Figure 9.3 — Job analysis worksheet. [Reprinted from Waters et al., 1994[(2)]]

Table 9.4 — General Design or Redesign Suggestions for Lifting Jobs Using the NIOSH Lifting Equation*

If HM is less than 1	Bring the load closer to the worker by removing any horizontal barriers or reducing the size of the object. Lifts near the floor should be avoided; if unavoidable, the object should fit easily between the legs.
If VM is less than 1	Raise/lower the origin/destination of the lift. Avoid lifting near the floor or above the shoulders.
If DM is less than 1	Reduce the vertical distance between the origin and the destination of the lift.
If AM is less than 1	Move the origin and destination of the lift closer together to reduce the angle of twist, or move the origin and destination further apart to force the worker to turn the feet and step, rather than twist the body.
If FM is less than 1	Reduce the lifting frequency rate, reduce the lifting duration, or provide longer recovery period (i.e., light work period).
If CM is less than 1	Improve the hand-to-object coupling by providing optimal containers with handles or handhold cut-outs, or improve the handholds for irregular objects.
If the RWL at the destination of the lift is less than at the origin	Eliminate the need for significant control[a] of the object at the destination by redesigning the job or modifying the container/object characteristics.

a Significant control — condition requiring "precision placement" of the load at the destination of the lift.

* Adapted from Waters et al., 1994.[(2)]

B. Pushing and Pulling[(3)]

- The upper force limit for whole body standing horizontal pushing and pulling should not exceed 225 N (50 lbs.); for kneeling, the limit for horizontal pushing and pulling should not exceed 188 N (42 lbs.); for sitting, pushing and pulling should not exceed 130 N (29 lbs.).
- The maximum load that should be manually pushed or pulled on a four-wheeled handcart is 227 kg (500 lbs.); on a two-wheeled handcart, the maximum load is 114 kg (250 lbs.).
- If handcarts are used more than 200 times a day or transported more than 33 m (100 ft), use of a powered truck should be considered.

II. Workstation Design Guidelines

Workstations should be adjustable to accommodate as many workers as possible and a variety of working positions.

A. Seated Workstations[(3)]

- Provide room for knees, thighs, and feet under the work surface.
- Chairs should ...

should be 30 cm (12 in.) in depth, and the height should range from 2 cm to 23 cm (1–9 in.).

- If the job requires writing or light assembly, the work surface should be at elbow height.
- For work requiring perception of fine detail, the work surface height should be raised to about 15 cm (6 in.) above the elbow.
- Provide assembly items within the forward reach of the smallest workers.

B. Standing Workstations[3]

- All handled items and controls should be positioned to eliminate excessive reaches, stooping or bending, and twisting of the body.
- One-handed reach distances should be about 46 cm (18 in.) or less in front of the body when the object is 110 cm to 165 cm (43–65 in.) above the floor.
- Avoid requiring the worker to lean, stretch, or stoop frequently or for extended periods when performing an extended reach.
- The standing workstation height should be 10 cm (4 in.) below elbow height for heavy work, at elbow height for light assembly work, and 10 cm (4 in.) above elbow height for precision work with supported elbows (elbow height is 109.9 cm (49.8 in.) for 50th percentile males and 101.2 cm (45.9 in.) for 50th percentile females).
- Allow foot and knee clearances for standing workers.
- If a standing workstation is used for most of the shift, provisions should be made for sitting down during machine time or other slack time.
- Try to minimize the static standing posture by allowing the operator to move outside the regular work area several times per hour but not as part of a short-duration, highly repetitive work cycle.
- Floor mats should be provided at the workplace to reduce discomfort for people whose job requires them to stand all day. If a floor mat cannot be used because of safety considerations, shoes with cushioned soles may increase a person's comfort while standing.

C. Video Display Terminal (VDT) Workstations[3]

- Reduce reflective glare by keeping the VDT screen away from windows and other sources of bright light.
- The top of the screen should be 15° below the worker's eye level. Constant viewing of material that is above the horizontal line of sight results in rapid fatigue of the neck and shoulders.
- Workers wearing bifocal glasses often must tilt their head back to read the screen through the lower segment of their glasses. A pair of special prescription glasses with a focal distance from the eye of 12–30 in. should be provided to enable these workers to read the screen through the upper segment of their glasses.
- The seat height, seat pan angle, and backrest angle of the chair should be adjustable. The seat pan should have a rounded front edge to avoid excessive pressure on the popliteal area. The backrest should provide support in the lumbar region.
- Palm or wrist rests should be optional. A palm rest should be the length of the keyboard, about 5 cm (2 in.) wide, padded, with rounded edges.

Tables 9.5 and 9.6 show some design parameters for VDT chairs and

Table 9.5 — Design Parameters for VDT Workstation Chairs*

Chair Component	*Guideline*	*Comments*
Swivel	Needed	
Legs	Five	Desired for stability
Casters	Needed	
Chair seat pan height	Should be adjustable 38–53 cm (15–21 in.)	When no footrest is provided
Seat pan width	40 cm (16 in.) minimum 46–48 cm (18–19 in.) preferred	
Seat pan length	40–46 cm (16–18 in.)	
Cover	Fabric	Eliminates slipping, and breathes to reduce perspiration
Forward edge	No hard or cutting surfaces	
Backrest height	46–51 cm (18–20 in.)	
Backrest width	35–40 cm (14–16 in.)	
Angle of backrest	Adjustable from 90° (vertical) to 120° (leaning backwards)	
Lumbar support height	10–20 cm (4–8 in.) above seat	
Armrests	Optional	
Armrest height	18–23 cm (7–9 in.) above seat	

* Adapted from Sauter et al., 1984,[4] and ASSE, 1985[5]

Table 9.6 — Design Parameters for VDT Workstations*

Workstation Component	*Guideline*	*Comment*
Display table height	Adjustable 58–84 cm (23–33 in.)	78 cm (31 in.) max, if not adjustable
Display height	84–109 cm (33–43 in.) from center of screen to floor	Gaze angle should be 10°–20° below horizontal
Keyboard table height	Adjustable 58–78 cm (23–31 in.) (elbow height)	If not adjustable, 63–66 cm (25–26 in.) is recommended
Placement of document holders	Same distance and height as display	
Viewing distance	About 46–51 cm (18–20 in.) from eyes to display	
Keyboard angle	Tilt forward about 20°–15°	
Vertical knee room	61 cm (24 in.) for fixed-height tables	Measured from floor to underside of table
Horizontal knee room	40 cm (16 in.) minimum	
Table edges	Rounded on front	
Wrist rests	Optional	
Footrests	Slope forward from 10–13 cm (4–5 in.) to 2–4 cm (1–1½ in.)	Often needed for a short person who must raise chair height to reach work surface

* Adapted from Sauter et al., 1984,[4] and ASSE, 1985[5]

III. Upper Extremity Cumulative Trauma Disorders

Upper extremity cumulative trauma disorders (CTDs) have been associated with a variety of industries, jobs, and specific tasks. Table 9.7 shows types of jobs where workers have exhibited evidence of CTDs; Tables 9.8 and 9.9 provide information about CTD disorders and recommended measures to avoid such disorders. Occupational factors often involve one or more of the following risk factors: awkward postures of the wrist or shoulders, excessive manual force, and high rates of manual repetition.

A. Posture

Posture is a significant risk factor in the development of CTDs. Awkward postures include any fixed or constrained body position. Postures that are considered undesirable include those that overload the muscles and tendons, load joints unevenly, or involve a static load on the musculature.

- Extreme flexion and extension of the wrist can cause CTDs.
- Ulnar and radial deviations of the wrist are associated with deQuervain's disease.
- Jobs that require the worker to reach behind or above his or her shoulder level repeatedly have been associated with thoracic outlet syndrome.
- Extreme flexion of the elbow is associated with cubital tunnel syndrome.
- Extreme rotation of the forearm is associated with medial and lateral epicondylitis.

B. Force

The force required to perform occupational tasks is a critical risk factor in the development of CTDs. The load required of the body tissues can be many times that required to perform the task. When a muscle must respond to a high task load, blood flow to the muscle decreases, causing more rapid muscle fatigue. Recovery time can exceed work time when force demands are high.

- Scissors that rub on the sides of the fingers may cause compression of the digital nerves in the fingers.
- Forceful gripping of tools with sharp edges on their handles is associated with trigger finger.
- Using the palm of the hand as a tool can result in Guyon tunnel syndrome.
- Forceful wrist movements may inflame the tendons in the wrist, causing carpal tunnel syndrome.
- Combined, forceful gripping, and hand twisting often causes deQuervain's disease.

Table 9.7 — Job, Identified Disorder, and Occupational Risk Factors*

Type of Job	*Disorder*	*Occupational Risk Factors*
Buffing/grinding	Tenosynovitis Thoracic outlet Carpal tunnel deQuervain's Pronator teres	Repetitive wrist motions, prolonged flexed shoulders, forceful ulnar deviation, repetitive forearm pronation.
Punch press operator	Tendinitis of wrist and shoulder deQuervain's	Repetitive forceful wrist extension/flexion, repetitive shoulder abduction/flexion, forearm supination. Repetitive ulnar deviation in pushing controls.
Overhead assembly (welders, painters, auto repair workers)	Thoracic outlet Shoulder tendinitis	Sustained hyperextension of arms. Hands above shoulders.
Belt conveyor assembly	Tendinitis of shoulder and wrist Carpal tunnel Thoracic outlet	Arms extended, abducted, or flexed more than 60 degrees, repetitive, forceful wrist motions.
Typing, keypunch, cashier	Tension neck Thoracic outlet Carpal tunnel	Static, restricted posture, arms abducted/flexed, high speed finger movement, palmar base pressure, ulnar deviation.
Sewers and cutters	Thoracic outlet deQuervain's Carpal tunnel	Repetitive shoulder flexion, repetitive ulnar deviation. Repetitive wrist flexion/extension, palmar base pressure.
Small parts assembly (wiring, bandage wrap)	Tension neck Thoracic outlet Wrist tendinitis Epicondylitis	Prolonged restricted posture, forceful ulnar deviation and thumb pressure, repetitive wrist motion, forceful wrist extension and pronation.
Musicians	Wrist tendinitis Carpal tunnel Epicondylitis	Repetitive forceful wrist motions, palmar base pressure, prolonged shoulder abduction/flexion, forceful wrist extension with forearm pronation.
Bench work (glass cutters, phone operators)	Thoracic outlet Ulnar nerve entrapment	Sustained elbow flexion with pressure on ulnar groove.
Operating room personnel	Thoracic outlet Carpal tunnel deQuervain's	Prolonged shoulder flexion, repetitive wrist flexion, ulnar deviation (holding retractors).
Packing	Tendinitis of shoulder and wrist Tension neck Carpal tunnel deQuervain's	Prolonged load on shoulders, repetitive wrist motions, overexertion, forceful ulnar deviation.
Truck drivers	Thoracic outlet	Prolonged shoulder abduction and flexion.
Core making	Tendinitis of the wrist	Repetitive wrist motions.

Type of Job	*Disorder*	*Occupational Risk Factors*
Housekeepers, cooks	deQuervain's Carpal tunnel	Scrubbing, washing, rapid wrist rotational movements.
Carpenters, bricklayers	Carpal tunnel Guyon tunnel (ulnar nerve entrapment)	Hammering, pressure on palmar base.
Stockroom, shipping	Thoracic outlet Shoulder – tendinitis	Reaching overhead. Prolonged load on shoulder in unnatural position.
Material handling	Thoracic outlet Shoulder – tendinitis	Carrying heavy load on shoulders.
Lumber/construction	Shoulder – tendinitis Epicondylitis	Repetitive throwing of heavy load.
Butcher/meat packing	deQuervain's Carpal tunnel	Ulnar deviation, flexed wrist with exertion.
Letter carriers	Shoulder problems Thoracic outlet	Carrying heavy load with shoulder strap.

* Adapted from Putz-Anderson, 1998[6]

Table 9.8 — Common Repetitive Strain Disorders and Syndromes*

Disorder	*Description*
Carpal tunnel syndrome (writer's cramp, neuritis, median neuritis)	The result of compression of the median nerve in the carpal tunnel of the wrist. This tunnel is an opening under the carpal ligament on the palmar side of the carpal bones. Through this tunnel pass the median nerve, the finger flexor tendons, and blood vessels. Swelling of the tendon sheaths reduces the size of the opening of the tunnel and pinches the median nerve and possibly blood vessels. The tunnel opening is also reduced if the wrist is flexed or extended, or ulnarly or radially pivoted.
Cubital tunnel syndrome	Compression of the ulnar nerve below the notch of the elbow: Tingling, numbness, or pain radiating into ring or little fingers. Caused by resting forearm near elbow on a hard surface and/or sharp edge, and also when reaching over an obstruction.
deQuervain's disease (or syndrome)	A special case of tendosynovitis that occurs in the abductor and extensor tendons of the thumb where they share a common sheath. This condition often results from combined forceful gripping and hand twisting, like in wringing clothes.
Epicondylitis ("tennis elbow")	Tendons attaching to the epicondyle (the lateral protrusion at the distal end of the humerus bone) become irritated. This condition is often the result of impacting or jerky throwing motions, repeated supination and pronation of the forearm, and forceful wrist extension movements. The condition is well known among tennis players, baseball pitchers, bowlers, and people who use hammers. A similar irritation of the tendon attachments on the inside of the elbow is called medical epicondylitis, also known as "golfer's elbow."

Disorder	*Description*
Ganglion	A tendon sheath swelling that is filled with synovial fluid, or a cystic tumor at the tendon sheath, or a joint membrane. The affected area swells and causes a bump under the skin, often on the dorsal or radial side of the wrist. (In the past, this also was called a "Bible Bump" because the area occasionally was the disciplinary target of blows from somebody wielding a Bible or heavy book.)
Neck tension syndrome	An irritation of the levator scapulae and trapezius group of muscles of the neck, commonly occurring after repeated or sustained overhead work.
Pronator (teres) syndrome	Result of compression of the median nerve in the distal third of the forearm, often where it passes through the two heads of the pronator teres muscle in the forearm; common with strenuous flexion of elbow and wrist.
Shoulder tendinitis (rotator cuff syndrome or tendinitis, supraspinatus tendinitis, subacromial bursitis, subdeltoid bursitis, partial tear of the rotator cuff)	This is a shoulder disorder at the rotator cuff. The cuff consists of four tendons that fuse over the shoulder joint where they pronate and supinate the arm and help to abduct it. The rotator cuff tendons must pass through a small bony passage between the humerus and the acromion, with a bursa as cushion.
Tendonitis (tendinitis)	An inflammation of a tendon. Often associated with repeated tension, motion, bending, being in contact with a hard surface, or vibration. The tendon becomes thickened, bumpy, and irregular in its surface. Tendon fibers may be frayed or torn apart. In tendons without sheaths, such as within the elbow and shoulder, the injured area may calcify.
Tendosynovitis (tenosynovitis, tendovaginitis)	This disorder occurs to tendons that are inside synovial sheaths. The sheath swells. Consequently, movement of the tendon within the sheath is impeded and painful. The tendon surfaces can become irritated, rough, and bumpy. If the inflamed sheath presses progressively onto the tendon, the condition is called stenosing tendosynovitis. DeQuervain's disease is a special case occurring in the thumb; the trigger finger condition occurs in flexors of the fingers.
Thoracic outlet syndrome (neurovascular compression syndrome, cervicobrachial disorder, brachial plexus neuritis, costoclavicular syndrome, hyperabduction syndrome)	A disorder resulting from compression of nerves and blood vessels between the clavicle and the first and second ribs, at the brachial plexus. If this neurovascular bundle is compressed by the pectoralis minor muscle, blood flow to and from the arm is reduced. This ischemic condition makes the arm numb and limits muscular activities.

Disorder	*Description*
Trigger finger or thumb	A special case of tendosynovitis where the tendon becomes nearly locked so that its forced movement is not smooth but in a snapping, jerking manner. This is a special case of stenosing tendosynovitis crepitans, a condition usually found with digit flexors at the A1 ligament. Occurs with hand tools with sharp edges pressing into the tissue or with handles too far apart for the user's hand so that the end segments of the fingers are flexed while the middle segments are straight.
Ulnar nerve entrapment (Guyon tunnel syndrome)	Results from the entrapment of the ulnar nerve as it passes through the Guyon tunnel in the wrist. It can occur from prolonged flexion and extension of the wrist and repeated pressure on the hypothenar eminence of the palm.
White finger ("dead finger," Raynaud's syndrome, vibrations syndrome)	Stems from insufficient blood supply bringing about noticeable blanching, (finger turns cold, numb, and tingles); sensation and control of finger movement may be lost. The condition is due to closure of the digit's arteries caused by vasospasms triggered by vibrations. A common cause is continued forceful gripping of vibrating tools, particularly in a cold environment. Also caused by using a tool too small for the hand.
Ulnar artery aneurysm	Weakening of a section of the wall of the ulnar artery as it passes through the Guyon tunnel in the wrist; often from pounding or pushing with the heel of the hand. The resulting "bubble" presses on the ulnar nerve in the Guyon tunnel.

* Adapted from Kroemer, 1992.[7]

ıble 9.9 — Recommended Measures to Avoid Common Repetitive Strain Injuries*

'D	*Avoid in General*	*Avoid in Particular*	*Do...*	*Design...*
ırpal tunnel syndrome	Rapid, often-repeated finger movements, wrist deviations	Dorsal and palmar flexion, pinch grip, vibrations between 10 Hz and 60 Hz		
ıicondylitis	"Bad backhand"	Dorsiflexion, pronation		
ɔnator syndrome	Forearm pronation	Rapid and forceful pronations, strong elbow and wrist flexion	use large muscles, but infrequently and for short durations	the work object properly
ɔulder tendonitis, ator cuff syndrome	Arm elevation	Arm abduction, elbow elevation		
ıdonitis	Often-repeated movements, particularly with force exertion; hard surface in contact with skin; vibrations	Frequent motions of digits, wrists, forearm, shoulder	let wrists be in line with the forearm	the job task properly
ıdosynovitis, Quervain's disease, glion	Finger flexion, wrist deviation	Ulnar deviation, dorsal and palmar flexion, radial deviation with firm grip	let shoulder and upper arm be relaxed	hand tools properly ("bend tool, not the wrist")
ɔracic outlet syndrome	Arm elevations, carrying	Shoulder flexion, arm hyperextension	let forearms be horizontal or more declined	round corners, pad
ɡger finger or thumb	Digit flexion	Flexion of distal phalanx alone		place work object properly
ar artery aneurysm	Pounding and pushing with heel of hand	Pounding and pushing with heel of hand		
ar nerve entrapment	Wrist flexion and extension	Wrist flexion and extension, pressure on hypothenar eminence		
ite finger vibration drome	Vibrations, tight grip, cold	Vibrations between 40 Hz and 125 Hz		
·k tension syndrome	Static head posture	Prolonged static head/neck posture	alternate head/neck postures	

ıapted from Kroemer, 1992.[7]

C. Repetition

Highly repetitive jobs contribute to the onset of CTDs because these jobs require the muscles to contract at a high rate. Muscles contracting at a high velocity develop less tension, causing more muscular effort and more recovery time. Therefore, jobs requiring high repetition might cause CTDs even when the required forces are minimal.

It is important to remember that:

- Highly repetitive jobs are associated with carpal tunnel syndrome.
- Workers performing machine-paced assembly work have higher rates of humeral tendinitis and tenosynovitis than workers with variable tasks.

IV. Cold Environments[8]

- Cold protective clothing appropriate for the level of cold and physical activity should be provided for workers to maintain a core body temperature above 36°C (96.8°F) if work is performed in temperatures below 4°C (39.2°F). [Note that the cooling power of wind must be considered — see Table 9.10.] Special precautions are required when the worker may become wet or workers are handling evaporative liquids.
- For working at temperatures below freezing, work and warm-up schedules should conform to current ACGIH threshold limit values (TLVs®).
- Workers with circulatory problems may require extra insulation or a decreased duration of exposure.
- For exposed skin, continuous exposure should not be permitted when temperatures drop below –32°C (–25.6°F) (again, the cooling power of the wind must be considered).
- Special protection for bare hands is required to maintain manual dexterity. At temperatures below 16°C (60.8°F), controls should be added to keep bare hands warm (e.g., warm air jets, radiant heaters). Metal handles of tools should be covered with insulation materials at temperatures below –1°C (30.2°F). Gloves should be worn when manual dexterity is not required.
- For temperatures below –7°C (19.4°F): 1) heated warm-up shelters should be provided; 2) the buddy system should be used; 3) the work rate should not induce sweating; 4) new employees should not be required to work an entire shift; 5) work should not require long periods of standing or sitting still; and 6) workers should be trained in proper rewarming procedures, proper clothing use, recognition of frostbite, proper eating and drinking habits, recognition of hypothermia, and safe work practices.
- Exposure to hand vibration will reduce the temperature of the hands; therefore, air-impermeable coverings for the hands should be provided when temperatures are below 0°C (32°F) and when wind velocities are greater than 8 kilometers per hour (5 mph).

ble 9.10 — Cooling Power of Wind on Exposed Flesh Expressed as Equivalent Temperature

stimated ind Speed		Actual Temperature Reading (°F)								Actual Temperature Reading (°C)							
ph	km/hr	50	40	20	10	0	-10	-30	-50	10	4.4	-6.7	-12.2	-17.8	-23.3	-34.4	-45.6
ım	calm	50	40	20	10	0	-10	-30	-50	10	4.4	-6.7	-12.2	-17.8	-23.3	-34.4	-45.6
[illegible]	8	48	37	16	6	-5	-15	-36	-57	8.9	2.8	-8.9	-14.4	-20.6	-26.1	-37.8	-49.4
[illegible]	16	40	28	4	-9	-24	-33	-58	-83	4.4	-2.2	-15.6	-22.8	-31.1	-36.1	-50.0	-63.9
[illegible]	32	32	18	-10	-25	-39	-53	-82	-99	0	-7.8	-23.3	-31.7	-39.4	-47.2	-63.3	-72.8
[illegible]	48	28	13	-18	-33	-48	-63	-94	-125	-2.2	-10.6	-27.8	-36.1	-44.4	-52.8	-70.0	-87.2
[illegible]	64	26	10	-21	-37	-53	-69	-100	-132	-3.3	-12.2	-29.4	-38.3	-47.2	-56.1	-73.3	-91.1
ve 40 mph km/hr) e is little tional t.		LITTLE DANGER In < 1 hr with dry skin. Maximum danger of false sense of security.			INCREASING DANGER Danger from freezing of exposed flesh within 1 minute.			GREAT DANGER Exposed flesh may freeze within 30 seconds.		LITTLE DANGER In < 1 hr with dry skin. Maximum danger of false sense of security.			INCREASING DANGER Danger from freezing of exposed flesh within 1 minute.			GREAT DANGER Exposed flesh may freeze within 30 seconds.	

e: U.S. Army Research Institute, 1989[9]

V. Anthropometry

Anthropometry is the study of human body measurements. Tables 9.11 and 9.12 show some measurements for females and males, respectively. Figure 9.4 shows measurement definitions. U.S. civilian's measurements were used when available. Anthropometric data can be used for workstation design, such as the height of storage shelves for equipment or parts, and tool and equipment selection, such as the length of shovel handles or the span of hand-held tools (e.g., pliers).

Table 9.11 — Anthropometric Measurements of U.S. Women (inches or pounds)[10]

Measurement	*Source*	*Mean (s.d.)*	Percentile of Population		
			5th%	*50th%*	*95th%*
Crotch height	1	29.3 (1.6)	26.8	29.3	32.0
Elbow height, standing	2	40.19 (1.5)	38.6	41.1	43.6
Elbow rest height, sitting	3	9.40 (1.2)	7.1	9.2	11.1
Elbow to elbow breath	3	15.3 (2.1)	12.4	15.1	19.3
Eye height, sitting	1	29.02 (1.2)	27.1	29.0	31.0
Hand breath	1	2.97 (0.2)	2.72	2.99	3.23
Knee height, sitting	3	19.56 (1.1)	17.8	19.6	21.5
Popliteal height, sitting	3	15.63 (1.1)	14.0	15.7	17.4
Sitting height	3	33.34 (1.4)	30.9	33.5	35.7
Stature	3	63.10 (2.6)	58.9	63.2	67.4
Thigh clearance	3	5.40 (0.7)	4.2	5.4	6.9
Thumb-tip reach	1	29.19 (1.5)	26.7	29.2	31.6
Waist Depth	1	7.01 (0.7)	5.8	6.6	8.0
Weight	1	140.44 (30.5)	101.9	134.7	198.2

Sources: 1. U.S. Air Force women; 2. airline stewardesses; 3. National Health Exam Survey of U.S. civilian women

Table 9.12 — Anthropometric Measurements of U.S. Men (inches or pounds)[10]

Measurement	*Source*	*Mean (s.d.)*	Percentile of Population		
			5th%	*50th%*	*95th%*
Crotch height	1	32.68 (1.8)	29.8	32.7	35.6
Elbow height, standing	1	43.24 (1.9)	40.1	43.2	46.5
Elbow rest height, sitting	2	9.50 (1.2)	7.5	9.6	11.6
Elbow to elbow breath	2	16.53 (1.8)	13.8	16.4	19.9
Eye height, sitting	1	31.39 (1.3)	29.2	31.4	33.5
Hand breath	1	3.49 (0.2)	3.2	3.5	3.8
Knee height, sitting	2	21.3 (1.1)	19.4	21.4	23.3
Popliteal height, sitting	2	17.31 (1.1)	15.4	17.4	19.2
Sitting height	2	35.61 (1.4)	33.1	35.7	38.1
Stature	2	68.20 (2.7)	63.7	68.3	72.6
Thigh clearance	2	5.63 (0.7)	4.5	5.7	7.0
Thumb-tip reach	1	31.05 (1.7)	28.4	31.0	33.9
Waist depth	1	8.33 (1.0)	7.0	8.1	10.2
Weight	2	165.13 (27.8)	123.9	163.2	214.1

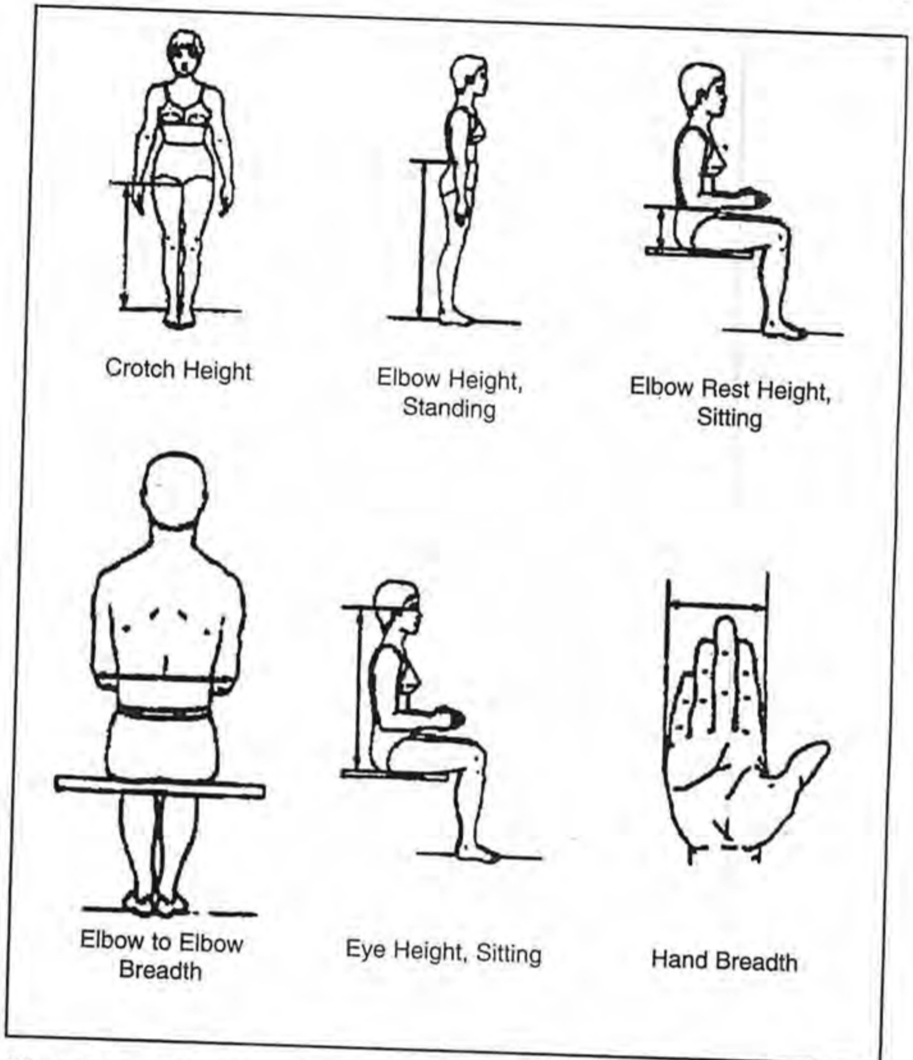

Figure 9.4 — Anthropometric measurements. [Reprinted from NASA, 1978[10]]

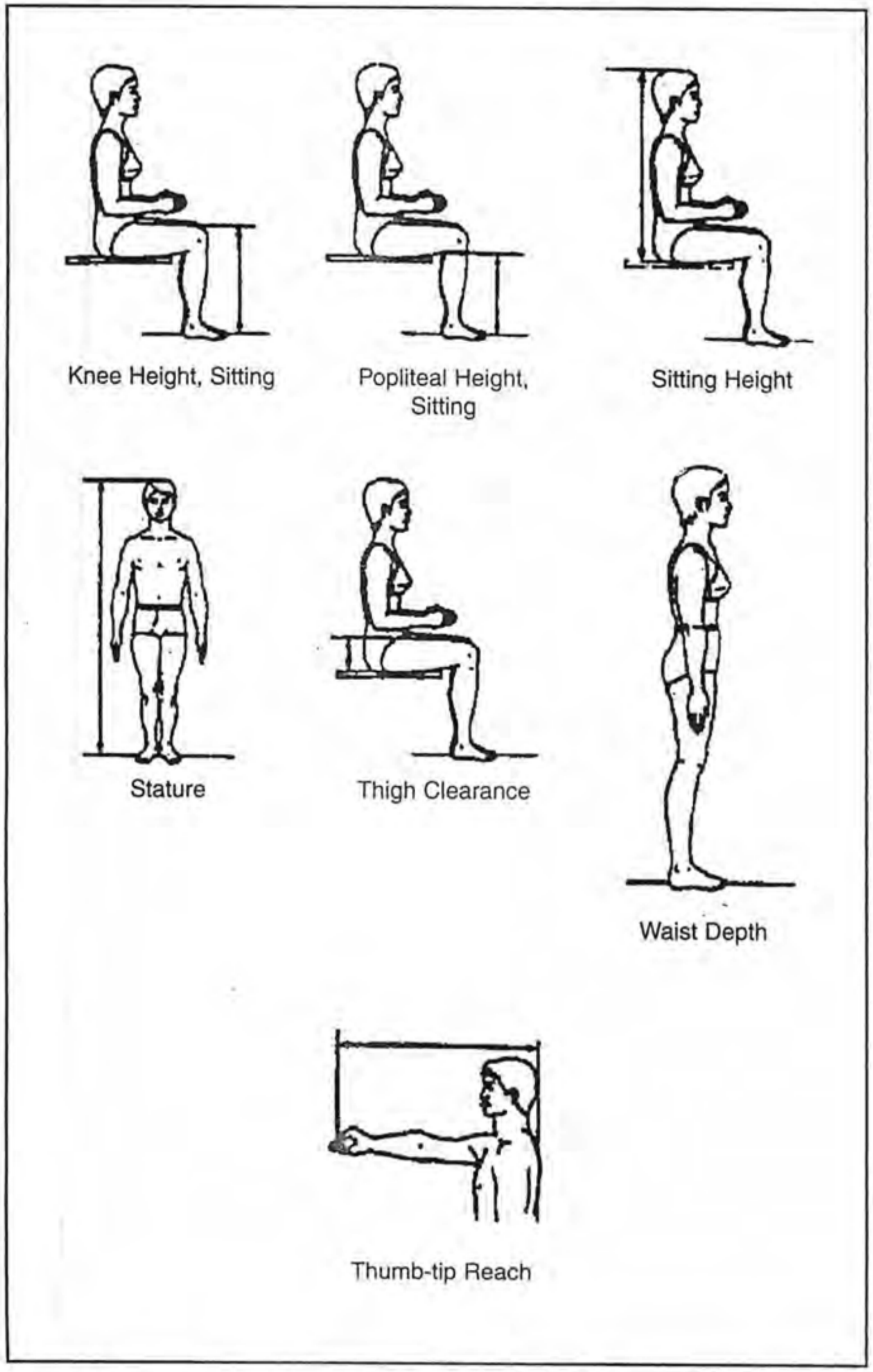

Figure 9.4 — Anthropometric measurements (continued). [Reprinted from NASA, 1998[10]]

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AIHA Engineering Committee

Edited by

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and David L. Johnson, Ph.D., PE, CIH

American Industrial Hygiene Association
Fairfax, Virginia

This manual was developed by experts with background, training, and experience in various aspects of industrial hygiene and occupational and environmental health and safety, working with information and conditions existing at the time of publication. The American Industrial Hygiene Association (AIHA), as publisher, and the authors have been diligent in ensuring that the material and methods addressed in this book reflect prevailing industrial hygiene and OHS&E practices. It is possible, however, that certain procedures discussed will require modification because of changing federal, state, local, or international regulations.

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