ERGONOMICS GUIDES

An ergonomics guide to carpal tunnel syndrome

THOMAS J. ARMSTRONG, Ph.D.
Associate Professor, Department of Environmental and Industrial Health, The University of Michigan, Ann Arbor, MI 48109

introduction

This guide is concerned with carpal tunnel syndrome — what it is, what causes it, and what can be done about it. Carpal tunnel syndrome is a disorder of the hand caused by injury of the median nerve inside the wrist.[1-14] The median nerve is one of three major nerves of the upper extremity that contains motor, sensory, and autonomic fibers. Injury of the median nerve results in impaired or lost nervous function in the first three and one-half digits and the thenar eminance at the base of the thumb which are shown in Figure 1. Motor nerve impairment results in reduced muscle control and ultimately muscle atrophy; "thenar atrophy" is a common symptom in advanced cases of carpal tunnel syndrome. Sensory nerve impairment results in sensations of numbness, tingling, and pain, and in loss of sensory feedback from the hand, an important factor of the ability to grasp, hold and manipulate objects. Persons suffering from carpal tunnel syndrome often complain that they cannot tell hot from cold, that they do not feel they have much strength, and that they have trouble performing simple manipulations, such tasks as tying their shoes. The term "nocturnal numbness" is used to describe symptoms that often awaken people during bed rest. Autonomic nerve impairment often results in loss of sweat function; the areas of the hand innervated by the median nerve often are reported to be dry and shiny in persons suffering from carpal tunnel syndrome. The moistness of the hand is an important factor of friction and affects the ability to grasp and manipulate objects. It is common to moisten a fingertip when turning the page of a book. Clumbsiness is a common symptom of carpal tunnel syndrome. In summary, carpal tunnel syndrome is manifested as a specific pattern of neurological deficits that result in discomfort and impaired use of the hand.

Carpal tunnel syndrome is one of a family of "occupational illnesses" of the upper extremity that includes disorders such as tendinitis, bursitis, synovitis, tenosynovitis, De Quervain's disease, trigger finger and tennis elbow that are referred to as "repetitive trauma disorders".[15,16] Although carpal tunnel syndrome and certain tendon disorders both may occur in workers performing repetitive hand work, the term "carpal tunnel syndrome" should not be confused with other repetitive trauma illnesses.[16-19] The overall incidence rate and prevalence of carpal tunnel syndrome in the work force is not yet known. Although the available data vary considerably from site to site and job to job, they show that carpal tunnel syndrome and related illnesses are a major problem in some settings.

In a retrospective study of carpal tunnel syndrome occurring in an automobile unholstery plant, Wehrle reported a plant-wide incidence rate of 2.0 cases per 200,000 work hours.[20] The incidence rate on some jobs was as high as 25.6. In a retrospective study of personal and occupational factors of carpal tunnel syndrome, Cannon, Bernacki, and Walter reported 30 cases from June, 1977 to July, 1978 in a population of 20,000 hourly workers.[21] Sixteen of these cases were identified from records of persons receiving workers compensation. The rest of the cases were not compensated, and were identified from other medical department records. In another study in an athletic products plant, the plant-wide incidence of all compensable cumulative trauma disorders from 1976 and 1977 was found to be 35.8 cases per 200,000 hours; the plant-wide incidence of carpal tunnel syndrome was 1.7.[22] On some jobs, the incidence rate of all cumulative trauma disorders was as high as 44.1; the incidence rate of carpal tunnel syndrome was 3.4 In general, carpal tunnel syndrome probably is

Copyright 1983, by American Industrial Hygiene Association

under reported because workers may not associate their symptoms with their job, especially when the symptoms occur at night after work. They may not report symptoms for fear losing their job or being placed in another area if they complain. Also, a worker may elect to see a personal physician rather than a plant physician. In either situation, the case is not recorded as an occupational disease.

nonoccupational causes of carpal tunnel syndrome

Frequently reported nonoccupational factors of carpal tunnel syndrome include: 1) systemic diseases, 2) congenital defects, 3) wrist size, 4) acute trauma, 5) pregnancy, 6) oral contraceptives, and 7) gynocological surgery. Systemic diseases such as rheumatoid arthritis, acromegaly, gout, diabetes, myxoedema, ganglion formation, and certain forms of cancer all can contribute to carpal tunnel syndrome.[6,10,23-26] Congenital defects include bony protrusions into the carpal tunnel, anomalous muscles extending into or originating in the carpal tunnel, and the shape of the median nerve. Recent studies of carpal tunnel patients made with the use of computerized CAT scanners suggest that there is an association between a very small carpal tunnel and idiopathic carpal tunnel syndrome.[27,28] In a study of personal factors, Armstrong and Chaffin were unable to find any association between hand and wrist size and occupational carpal tunnel syndrome.[28] Median nerve injury inside the carpal tunnel can be produced by a blow to the wrist, laceration, burn or other acute wrist trauma.[30-38] Such injuries

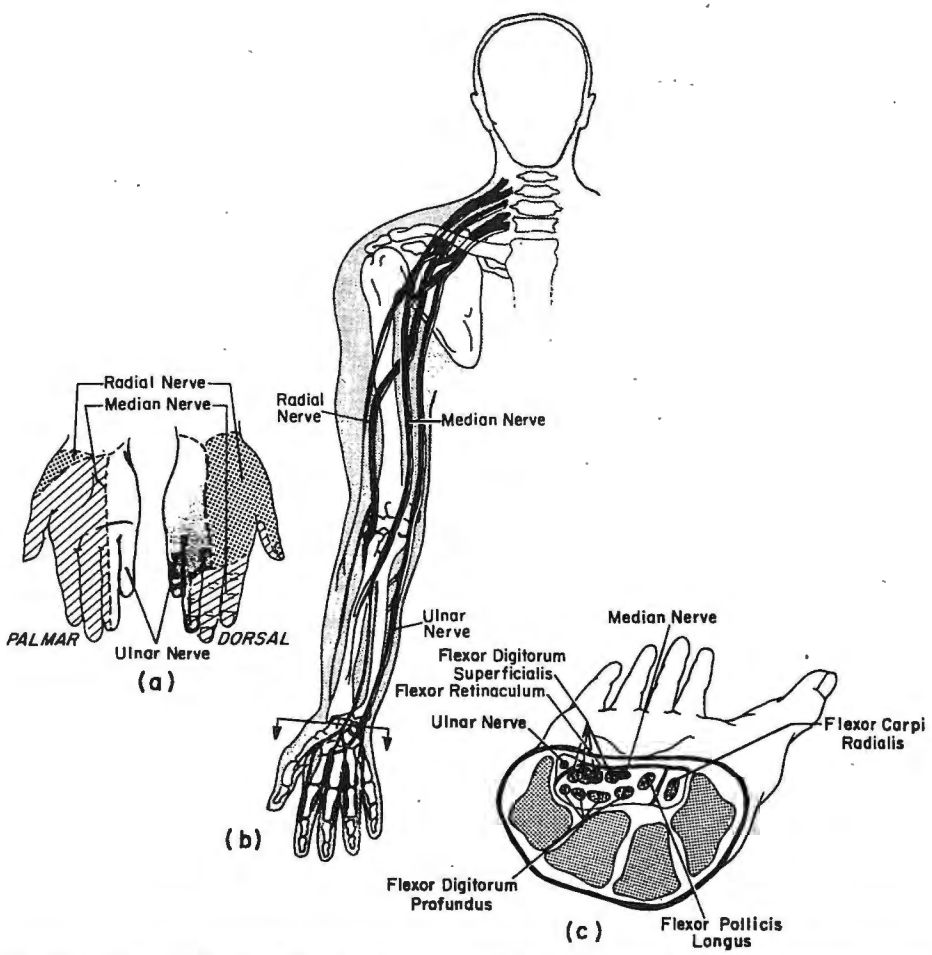

Figure 1 — The median nerve is one of three major nerves that innervate the upper extremity and provide motor, sensory and autonomic function, a. The median nerve generally provides sensory function in the first three and one half digits and over the base of the thumb, b. The median nerve passes through the carpal tunnel with the finger flexor tendons, c.

could produce symptoms of carpal tunnel syndrome. The use of oral contraceptives, menopause, pregnancy, and gynecological surgery are all reported as factors of carpal tunnel syndrome. Since all are uniquely female problems, they may, in some cases, contribute to a disproportionately high incidence rate of the syndrome in females.[34,35] Nonoccupational factors may suggest the need for medical screening, but so far there are no reliable preemployment indicators of worker predisposition to carpal tunnel syndrome. As a practical matter, employers probably will find it easier to exercise control over the design of jobs than over the selection of workers. This guide is concerned primarily with prevention of carpal tunnel syndrome through control of occupational factors.

occupational factors of carpal tunnel syndrome

Occupational factors include physical exertions with certain hand postures or against certain objects, and exposures to vibration or cold temperatures. Explanation of these factors requires consideration of the unique anatomy of the wrist. The carpal tunnel is a structure inside the wrist formed on three sides by irregularly shaped bones and on the fourth by a tough ligament called the flexor retinaculum (see Figure 1). The carpal tunnel is the pathway between the forearm and hand for the median nerve and the finger flexor tendons (see Figure 2). The flexor tendons transmit forces from the finger flexor muscles in the medial side of the forearm to the fingers and are the major source of strength during forceful exertions of the hand. Synovial membranes lubricate movements of the tendons back and forth through the carpal tunnel. Finger movements with a flexed or extended wrist cause the tendons to be displaced past and against the adjacent walls of the carpal tunnel much like a belt sliding over a pulley (see Figure 2). Contact forces between the tendons and adjacent surfaces cause irritation of the synovial membranes or "synovitis".[13,36] Synovitis results in thickening of the synovial membrane which in turn causes compression of the median nerve inside the stiff boney-ligamentous walls of the carpal tunnel.[6,7] In addition, flexing the wrist causes acute median nerve compression between the flexor tendons and the flexor retinaculum (see Figure 1). It is widely recognized that flexing the wrist often precipitates acute symptoms in carpal tunnel syndrome patients.[7,8,12] Thus, repeated exertions with a flexed wrist contributes to occupational carpal tunnel syndrome. It follows from the pulley-belt analogy, that extension of the wrist will cause the median nerve to be stretched around the outside radius of the pulley; thus, repeated exertions with a fully extended wrist also contributes to occupational carpal tunnel syndrome.[1,37]

Deviations of the wrist from side to side will displace the tendons against the inside of the carpal tunnel; however, it is doubtful that there is sufficient range of motion to produce significantly more stress than when the wrist is straight. It has been shown that deviation of the wrist may be stressful to tendons outside of the carpal tunnel and may be a factor of disorders such as De Quervain's disease.[19,36] As a general rule, tools and tasks should be designed so that they can be used and performed without causing wrist deviations from side to side or causing the wrist to be

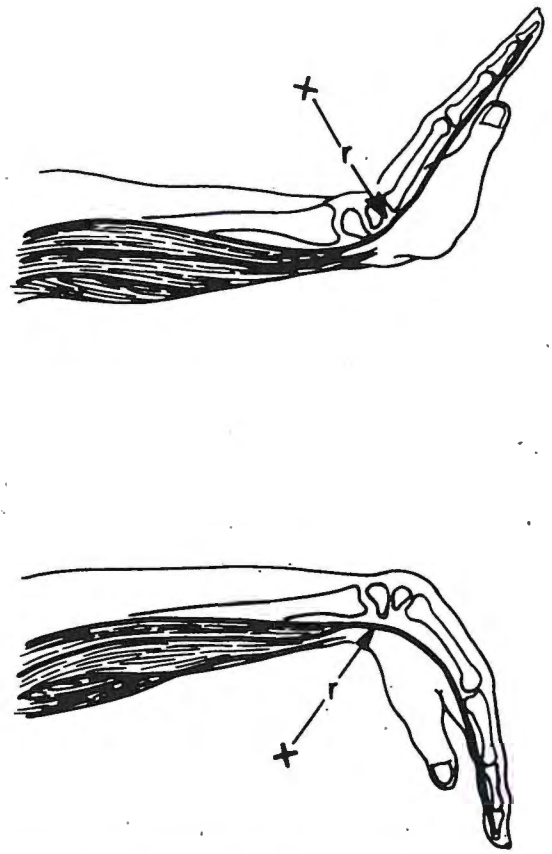

Figure 2 — Bending the wrist causes the finger flexor tendons to rub on adjacent surfaces of the carpal tunnel.

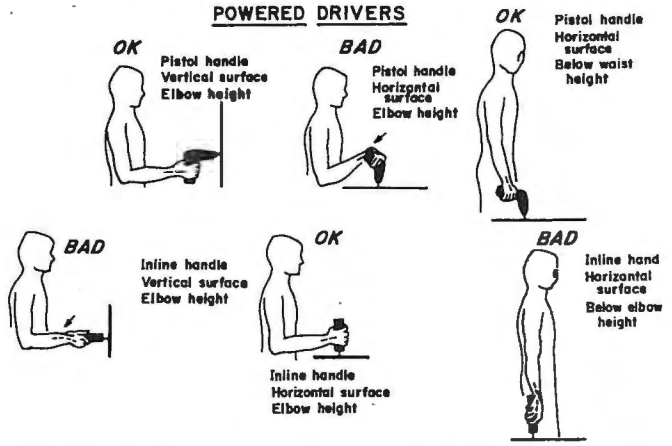

Figure 3 — Wrist posture is determined by the elevation and orientation of the work surface with respect to the workers and the shape of the tool.

flexed or highly extended. The wrist should be maintained in the same position as though the arm were hanging relaxed at the worker's side. Some examples of good and bad work station designs for inline and pistol shaped screw drivers are shown in Figure 3.

Regardless of the wrist position, stresses on the finger flexor tendons will be related to the mangitude of the exertion and the posture of the hand.[13,37] It is well known that the hand is four to five times stronger in a grip posture than in a pinch posture.[38,39] This means that roughly four to five times as much muscle strength and tendon force is required to pinch something than to grip it.[13] This stress on the tendons can be minimized by designing handles that maximize the strength of the hand. Some examples of good and bad handles designs are shown in Figure 4.

Median nerve compression also can be caused by tasks that require a sustained or repeated stress over the base of the palm.[4] Tapping on the base of the palm is commonly used to precipitate acute symptoms of carpal tunnel syndrome as a diagnostic test.[10,28] Examples of tasks that often produce pressure on the base of the palm include the use of screwdrivers, scrapers, paint brushes, and buffers. Such tasks should be designed so that the grip stresses are distributed over the muscular eminances at the base of the thumb and little finger and not in the center of the palm. Some examples of good and bad handle design are shown in Figure 5.

Vibration is a recognized factor of peripheral neuropathies including carpal tunnel syndrome, although the mechanism is not yet understood.[21,40,41] Vibration exposure may result

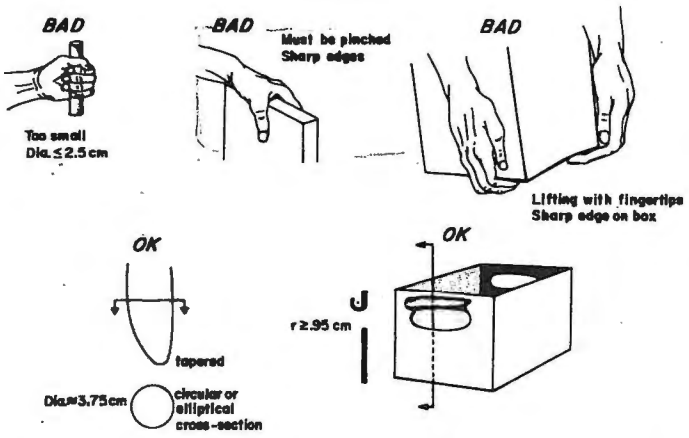

Figure 4 — The strength requirements of a task are affected by the size and shape of the handles.

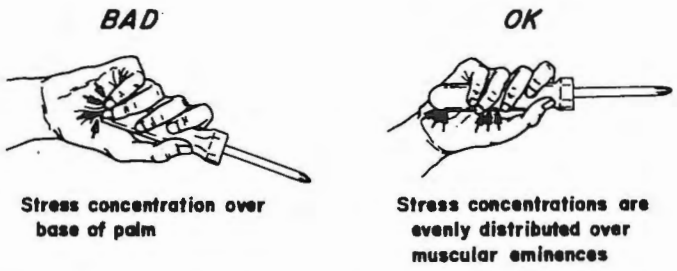

Figure 5 — Objects should be designed to distribute forces over the large fleshy areas at the base of the thumb and little finger to avoid stress concentrations over the base of the palm.

from air or motor powered drills, drivers, saws, grinders, sanders or buffers. It may result from gripping the wheel of a motor vehicle or holding a part against a buffing wheel. Isolation of the hand from vibration is desirable but a discussion of how this can be achieved is beyond the scope of this guide and the reader is referred to the works of Harris and Crede[42] and Miwa.[43]

The force exerted to hold and manipulate things is related to sensory feedback from the finger tips.[44] Therefore, steps should be taken to maximize and preserve sensory feedback. Use of textured surfaces will maximize sensory feedback. Sustained gripping and hard surfaces should be avoided to minimize sensory fatigue. The hand should be insulated to prevent cooling and sensory inhibition. This can be achieved by thorough control of room air temperature, careful location of exhaust parts on air powered tools, and the use of handle materials with a low thermal conductivity. Gloves may also be used, but with care. It has been shown that gloves may themselves inhibit sensory feedback.[45] Also, gloves will attenuate worker strength, thus increasing the strength requirements of a task.[46] The problem may be further aggravated if gloves fit poorly. Unfortunately, the limited range of glove sizes poorly accommodates the broad anthropometric variations in workers' hands. Employers would do well to maintain some inventory of sizes and styles so that workers can select the ones that best fit their hands and needs.

Although it has not been formally studied, repetitiveness is believed to be an important factor of carpal tunnel syndrome. In some cases repetitiveness can be controlled through work content or rotation. Work content can be increased so that a worker does more tasks fewer times, but care must be exercised to make sure that the additional tasks are compatible with the tools and work station used for the first. Depending on the availability of other jobs and on labor agreements, worker rotations sometimes can be used to reduce worker exposure to stressful tasks that cannot be controlled through tool and work station design.

evaluation and control of occupational carpal tunnel syndrome

Evaluation of carpal tunnel syndrome and related cumulative trauma illnesses includes analysis of health data to identify jobs in which there is an elevated incidence of carpal tunnel syndrome and analysis of work methods to identify the risk factors described above. Sources of health data include first aid logs, medical visit logs, medical reports, worker compensation reports, and OSHA logs. It is suggested that these records be reviewed for carpal tunnel syndrome and all other related illnesses such as tendonitis and strains. Experience has shown that these other illnesses sometimes give way to carpal tunnel syndrome and they are often a result of the same kinds of stresses as is carpal tunnel syndrome. Incidence rates should be computed for each job classification or department to identify those areas where the risk of developing repetitive trauma disorders is considered unacceptable. While only one case may be considered unacceptable, it is doubtful that all cases can be prevented. The incidence rates in job groups without hand intensive work, such as supervisors and managers, can be used as a reasonable goal for hand intensive jobs.

TABLE I
Work Elements Proposed by Gilbreth for Analysis of Manual Work Activities[16,17]

Element	Description
Search	Looking for something with the eyes or hand.
Select	Locate one object that is mixed with others.
Grasp	Touching or gripping an object with the hand.
Reach	Movement of the hand to some object or location.
Move	Movement of some object from one location to another.
Hold	To exert force to hold an object on a fixed location.
Position	Movement of an object in a desired orientation.
Inspect	Examine an object by sight, sound, touch, smell or taste.
Assemble	The jointing together of two or more objects.
Disassemble	The separation of two or more objects.
Use	Manipulation of a tool or device with the hand.
Unavoidable delay	An interruption in work activity due to some factor beyond the worker's control.
Avoidable delay	An interruption in work activity due to some factor under the worker's control.
Plan	A mental process that preceeds movement.
Rest to overcome fatigue	An interruption in work activity required to overcome the effects of repeated exertions or movements.

Once the problem areas have been identified, the jobs should be systematically analyzed for occupational factors of carpal tunnel syndrome. Traditional time and motion study procedures in which a job is divided into a sequence of acts or "elements" for the right and left hand can be used to describe what the worker does.[47,48] A list of fundamental elements or "Therbligs" is shown in Table I.

After the job has been described, each element should be reviewed for the factors, described above, that can contribute to carpal tunnel syndrome. These included posture, strength, stress concentrations over the base of the palm, vibration, cold temperature, and gloves. The posture of the hand and wrist must be recorded for each element. This may be done by direct observation or from films that are replayed in slow motion.[48,50] Strength can, in some cases be estimated from weight of the object or knowledge of the task, such as how well two objects fit together.

In other cases the force of exertion may be estimated from measurements of the electrical potentials produced by contracting muscles, electromyography, or EMG, The EMG produced on the medial surface of the forearm are related to the amount of force produced by the finger flexor muscles. By simultaneously recording force and EMG for given hand postures, the EMG can be used to estimate the force exerted to perform a manual task. Care should be exercised to calibrate the EMG-force relationship for each subject before and after each test.

Stress concentrations can be identified from the shape of the objects the worker must hold and from direct observations. Vibration is suggested by the use of powered equipment such as penumatic powered drills and sanders, and buffing wheels. Quantification of vibration requires the use of accelerometers and spectral analyzers.[42] Cold temperatures may be associated with the ambient air or with the materials that are being handled. The use of gloves can be determined from observation and interviews of workers and supervisors.

As an example consider the job shown in Figure 6 in which a worker takes parts out of a container and places them on a moving conveyor. Although hypothetical, this example is typical of many industrial jobs in which small parts are assembled on a production line. This job requires only one hand so the non-dominant hand is at rest throughout the work cycle. The elements from Table I required to perform this job, reach, grasp, move, position, assemble and release, are listed along with corresponding hand postures in Table II.

It can be seen that reaching into the parts box to grasp the part requires wrist flexion in combi-

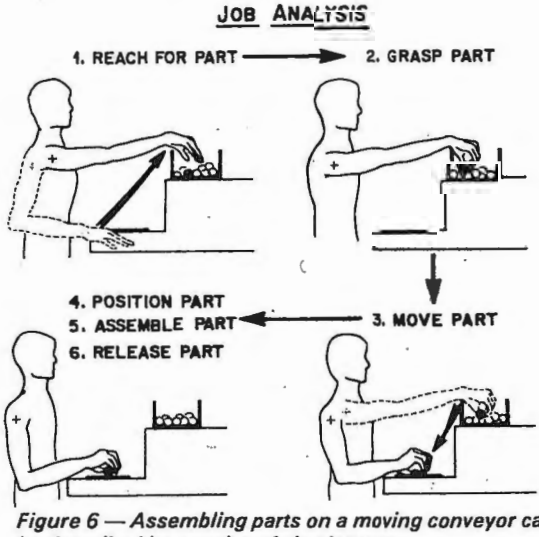

Figure 6 — Assembling parts on a moving conveyor can be described by a series of six elements.

TABLE II
Job Analysis[A]

Element	Posture[B] Wrist	Hand	Comments
1. Reach for part	Flexed	Relaxed	
2. Grasp part	Flexed	Pinch	Sharp edge of carton rubs on wrist.
3. Move part	Extended	Pinch	
4. Position part	Extended	Pinch	Sharp edge of conveyor.
5. Assemble part	Extended	Forceful pinching	Sharp edge of conveyor.
6. Release part	Extended	Relaxed	Sharp edge of conveyor.

[A]Each work element should be reviewed for potential risk factors of carpal tunnel syndrome: strength, postures, stress concentrations, vibration, cold temperatures, and gloves.

[B]Posture at end of element.

nation with pinching. Assembling the part in the jib requires forceful pinching. It also can be seen that reaching and grasping the parts causes the wrist to rub on the sharp edge of the box. The worker has some tendency to rub his or her forearm on the edge of the work bench while positioning the part. While this probably will not contribute to carpal tunnel syndrome, it could cause a nerve injury in the forearm and it is uncomfortable. There is not a problem with cold exposure, gloves, or vibration in this situation.

After the job analysis has been completed, alternative work stations, tool, and methods can be considered to reduce stress on the hand and wrist. For example, the container should be designed and positioned so that the worker does not have to flex his or her wrist and it should not have a sharp edge. Some examples of good and bad container design are shown in Figure 7. The job should be positioned on the work surface so that it can be reached without resting the arm on the sharp edge of the work bench. Some examples of good and bag jig design are shown in Figure 8.

summary

Carpal tunnel syndrome is a disabling condition of the hand that can be caused, precipitated or aggravated by certain work activities. Activities include exertions with a flexed or hyperextended wrist — especially in combination with forceful exertions, use of tools that produce stress on the base of the palm, exposure to fibration and cold, and the use of some gloves. Stressful work activities can be identified through analysis of health records, work methods, and postures. Examples of how jobs can be redesigned for control of stressful exertions are given.

acknowledgement

This guide was made possible by a contract from the National Institute for Occupational Safety and Health (PO 81-3000). The author wishes to acknowledge Mr. Dan Habes, the NIOSH Pro-

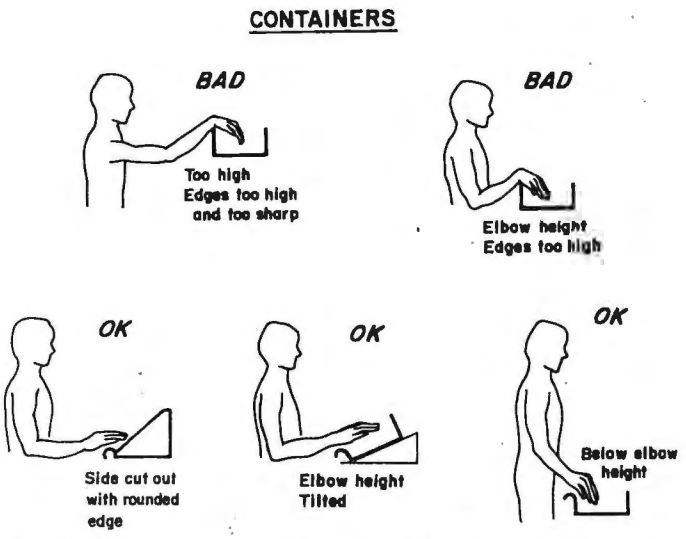

Figure 7 — Containers should be designed so that workers can reach all locations without flexing their wrist. All edges that come into contact with the worker should be well rounded.

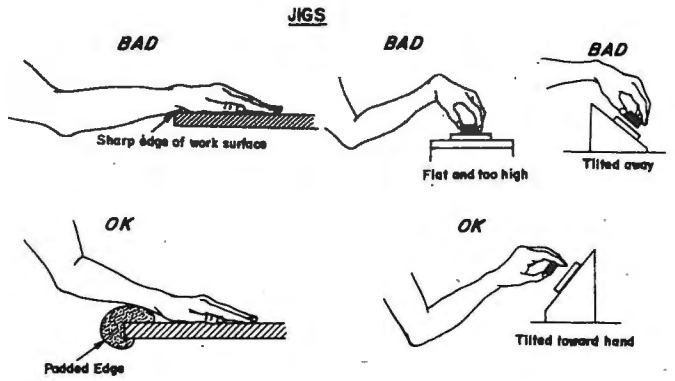

Figure 8 — Jigs should be located and oriented so that parts can be assembled without flexing the wrist.

ject Director, and Dr. Roger Stephens, OSHA, the AIHA Ergonomics Guide editor for their helpful advice.

references

1. **Brain, W., A. Wright and M. Wilkinson:** Spontaneous Compression of Both Median Nerves in the Carpal Tunnel. *Lancet 1*:277-282 (1947).
2. **Phalen, G., W. Gardner and A. LaLonde:** Neuropathy of Median Nerve Due to Compression Beneath the Transverse Carpal Ligament. *J. Bone Joint Surg. 32A*:109-112 (1950).
3. **Tanzer, R.:** The Carpal Tunnel Syndrome. *J. Bone Joint Surg. 41A*:626-634 (1959).
4. **Kendall, D.:** Aetiology, Diagnosis, and Treatment of Paraesthesiae in the Hands. *Br. Med. J. 2*:1633-1640 (1960).
5. **Robbins, H.:** Anatomical Study of the Median Nerve in the Carpal Tunnel and the Etiologies of Carpal Tunnel Syndrome. *J. Bone Joint Surg. 45A*:953-966 (1963).
6. **Yamaguchi, D., P. Lipscomb and E. Soule:** Carpal Tunnel Syndrome. *Minn. Med.* 22-31 (Jan. 1965).
7. **Phalen, G.:** The Carpal Tunnel Syndrome. *J. Bone Joint Surg. 48A*:211-228 (1966).
8. **Phalen, G.:** The Carpal Tunnel Syndrome. *Clin. Orthop. 83*:29-40 (1972).
9. **Neary, D., J. Ochoa and R. Gilliatt:** Subclinical Entrapment Neuropathy in Man. *J. Neurological Sciences 24*:283-293 (1974).
10. **Posch, J. and D. Marcotte:** Carpal Tunnel Syndrome, an Analysis of 1,201 Cases. *Orthop. Rev. 5*:25-35 (1976).
11. **Sunderland, S.:** The Nerve Lesion in the Carpal Tunnel Syndrome. *J. Neurology, Neurosurgery, Psychiatry 39*:615-626 (1976).
12. **Smith, E., D. Sonstegard and W. Anderson:** Contribution of Flexor Tendons to the Carpal Tunnel Syndrome. *Arch. Phys. Med. Rehabil.* (Sept. 1977).
13. **Armstrong, T. and D. Chaffin:** Some Biomechanical Aspects of the Carpal Tunnel. *J. Biomech. 12*:567-570 (1979).
14. **Gelberman, R., P. Hergenroeder, A. Hargens, G. Lunborg and W. Akeson:** The Carpal Tunnel Syndrome. A Study of Carpal Canel Pressures. *J. Bone Joint Surg. 63A(3)*:380-383 (March, 1981).
15. **U.S. Dept. of Labor, Occupational Safety and Health Administration:** *Recordkeeping Requirements Under the Occupational Safety and Health Act of 1970.* 1977 0-251-096. U.S. Government Printing Office, Washington, DC (1978).
16. **Hadler, N.:** Industrial Rheumatology. *Arth. Rheum. 20*:1019-1025 (1977).
17. **Wisseman, C. and D. Badger:** *Hazard Evaluation and Technical Assistance,* Report # TA 76-93. U.S. Dept. of HEW Center for Disease Control, NIOSH, Cincinnati, OH (1977).
18. **Armstrong, T., J. Foulke, S. Goldstein and B. Joseph:** *Analysis of Cumulative Trauma Disorders and Work Methods,* NIOSH Technical Report. Cincinnati, OH (1981) (in press).
19. **Tichauer, E.** Biomechanics Sustains Occupational Safety and Health. *Ind. Engineering Magazine* 46-56 (Feb. 1976).
20. **Wehrle, J.:** *Chronic Wrist Injuries Associated with Repetitive Hand Motions in Industry,* Occupational Health and Safety Technical Report. Dept. of Industrial and Operations Engineering, The University of Michigan, Ann Arbor, MI (1976).
21. **Cannon, L., E. Bernacki and S. Walter:** Personal and Occupational Factors Associated with Carpal Tunnel Syndrome. *J. Occ. Med. 23*:255-258 (1981).
22. **Armstrong, T. and G. Langolf:** Ergonomics and Occupational Safety and Health. In *Environmental and Occupational Health,* W. Rom, ed. Little, Brown, and Company, Boston, MA (1982).
23. **Robbins, H.:** Anatomical Study of the Median Nerve in the Carpal Tunnel and Etiologies of the Carpal Tunnel Syndrome. *J. Bone Joint Surg. 45A*:953-966 (1963).
24. **Barnes, C. and H. Currey:** Carpal Tunnel Syndrome on Rheumatoid Arthritis, A Clinical and Electrodiagnostic Survey. *Ann. Rheum. Dis. 26*:226-233 (1967).

25. **Phillips, R.:** Carpal Tunnel Syndrome as a Manifestation of Systemic Disease. *Ann. Rheum. Dis. 26*:59-63 (1967).
26. **Herbison, G., C. Teng, J. Martin and J. Ditunno:** Carpal Tunnel Syndrome in Rheumatoid Arthritis. *Am. J. Phys. Med. 52*:63-74 (1973).
27. **Herndon, J., R. Eaton and J. Littler:** Carpal Tunnel Syndrome, an Unusual Presentation of Osteoid-Osteoma of the Capitate. *J. Bone Joint Surg. 56A*:1715-1718 (1974).
28. **Dekel, S., T. Papaioannou, G. Rushworth and R. Coates:** Idiopathic Carpal Tunnel Syndrome Caused by Carpal Stenosis. *Br. Med. J. 280*:1297-1299 (1980).
29. **Gelmers, H.:** Primary Carpal Tunnel Stenosis as a Cause of Entrapment of the Median Nerve. *Acta. Neurochir. 55*:317-320 (1981).
30. **Armstrong, T. and D. Chaffin:** Carpal Tunnel Syndrome and Selected Personal Attributes. *J. Occ. Med. 21*:481-486 (1979).
31. **Kendell, D.:** Non-penetrating Injuries of the Median Nerve at the Wrist. *Brain 73*:84-95 (1950).
32. **Omer, G.:** Injuries to Nerves of the Upper Extremity. *J. Bone Joint Surg. 56A*:1615-1624 (1974).
33. **Browne, E. and C. Synder:** Carpal Tunnel Syndrome Caused by Hand Injuries. *Plas. Recons. Surg. 56*:41-43 (1975).
34. **McGrath, M. and I. Polayes:** Post Traumatic Median Neuroma: A Cause of Carpal Tunnel Syndrome. *Ann. Plast. Surg. 3*:227-230 (1979).
35. **Sabour, M. and H. Fadel:** The Carpal Tunnel Syndrome: A New Complication Ascribed to the "Pill". *Am. Obstet. Gynecol. 107*:1265-1267 (1970).
36. **Tichauer, E.:** Some Aspects of Stresses on the Forearm and Hand in Industry. *J. Occ. Med. 8*:67-71 (1966).
37. **Chao, E., J. Opgrande and F. Axmear:** Three Dimensional Force Analysis of Finger Joints in Selected Isometric Hand Functions. *J. Biomech. 9*:387-396 (1976).
38. **Taylor, C.:** The Biomechanics of Normal and the Amputated Upper Extremity. In *Human Limbs and Their Substitute,* P.E. Klopsteg and P.D.D. Wilson, eds. McGraw Hill, New York, NY (1954).
39. **Swansen, A., I. Matev and G. Groot:** The Strength of the Hand. *Bulletin of Prosthetics Research* 145-153 (1970).
40. **Lucas, E.:** Lesion of the Peripheral Nervous System Due to Vibration. *Work Env. - Health 7*:67-79 (1970).
41. **Rothfleisch, S. and D. Sherman:** Carpal Tunnel Syndrome, Biomechanical Aspects of Occupational Occurrence and Implications Regarding Surgical Management. *Orthop. Rev. 7*:107-109 (1978).
42. **Harris, C. and C. Crede:** *Shock and Vibration Handbook.* McGraw-Hill Book Company, New York, NY (1976).
43. **Miwa, T., Y. Yonekawa, A. Nara, K. Kanada and K. Baba:** Vibration Isolators for Portable Vibrating Tools Part I. A Grinder. *Ind. Health (Japan) 17*:85-101 (1979).
44. **Flatt, A.:** Kinesiology of the Hand. In *American Academy of Orthopaedic Surgeons Instructional Course Lectures,* Vol. 50, pp. 902-913. C.V. Mosby, St. Louis, MO (1961).
45. **Roebuck, J., K. Kroemer and W. Thompson:** *Engineering Anthropometry Methods.* John Wiley and Sons, New York, NY (1975).
46. **Hertzberg, T.** Some Contributions of Applied Physical Anthropology to Human Engineering. *Annals of the New York Academy of Sciences 63(4)*:616-629.
47. **Barnes, R.:** *Motion and Time Study, Design and Measurement of Work.* John Wiley and Sons, Inc., New York, NY (1968).
48. **Niebel, B.:** *Motion and Time Study.* Richard D. Irwin, Inc., Homewood, IL (1972).
49. **Armstrong, T., D. Chaffin and J. Foulke:** A Methodology for Documenting Hand Positions and Forces During Manual Work. *J. Biomech. 12*:131-133 (1979).
50. **Armstrong, T., J. Foulke, B. Joseph and S. Goldstein:** Investigation of Cumulative Trauma Disorders in a Poultry Processing Plant. *Am. Ind. Hyg. Assoc. J. 43*:103-116 (1982).