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Ergonomics

The Ergonomic Use of Hand Tools: Guidelines for the Practitioner

Scott Schneider, Column Editor

Reported by Awwad Dababneh and Thomas Waters

This paper is the first step of a project currently in process at the National Institute for Occupational Safety and Health (NIOSH). The objective of this project is to establish guidelines for the selection and use of hand tools. We hope that readers of this paper will comment on its form and content which will help us plan the next step for a guideline that is comprehensive and easy to use. Comments and questions may be mailed to Dr. Awwad Dababneh, DBBS, 4676 Columbia Parkway, C24, Cincinnati, OH 45226-1998, or by e-mail to abd7@cdc.gov. This work was performed while Dr. Dababneh held a National Research Council-NIOSH Research Associateship.

Introduction

Hand tools are associated with acute (instantaneous) hazards such as tripping, falling, and injuries like cuts, strains, sprains, burns, and lacerations. Hand tools are also associated with disorders that happen over a period of time. These have many names and are often referred to collectively as "cumulative trauma disorders (CTDs)," "repetitive motion injuries (RMIs)," "repetitive strain injuries (RSIs)," "overuse syndrome," or, simply, musculoskeletal disorders (MSD).[1,35] This type of disorder can affect the hands, arms, shoulders, back, or any part of the body. The primary conditions that may contribute to the development of such disorders are called risk factors. The most common risk factors are:[7,4,17,40]

- Exerting high muscle force when performing a task;
- High level of repetition of a task;
- Awkward posture, such as working with the hands held too high or too low or bent wrists;
- Working in cold, hot, and/or high noise places;
- Vibration; and
- Unbalanced work-rest cycle or inadequate recovery from fatigue before the next work period.

The basic principles for the ergonomic use of hand tools call for minimizing the risk of injuries by controlling the above mentioned risk factors.[4] If possible, workers' exposure to risk factors should be prevented, or otherwise reduced to an acceptable level.

Worker-Tool-Target System

Work with hand tools may be modeled as a three-part system—the worker, the tool, and the work piece or the target. The hand tool represents the center of the model or the linkage between the worker and the work piece. All hand tools consist of two basic parts, the handle and the end effect. The design of the handle is crucial because it is the point of interaction between the worker and the rest of the system. Though a good design of a tool handle is important, it is not enough to guarantee the comfort and productivity of the worker. An ergonomically sound worker-tool-target system requires a good fit among all three elements. Important characteristics of a target may include type of work surface (horizontal, inclined, or vertical), elevation of work surface, and type of fittings (type of screw, nuts, etc.). The objective of an ergonomic design is to fit the work to the worker, which implies that the tool and/or the target should be designed to accommodate the individual's capabilities.

Task Requirements and Grip Type

There are three basic task requirements when using hand tools: force needed, number of cycles, and precision. Tasks that involve fine fittings, such as clockwork, require high precision and low force. In contrast, using a framing hammer requires less precision and a relatively higher force. Task requirements not only influence the choice of tool, but also the type of hand grip the operator uses. There are two major types of hand grips: a power grip for exerting high forces, and a pinch-like grip for precision. The power grip is a closed fist grip and is formed with the entire hand (four fingers forming one jaw, thumb the other). The precision grip is formed between the tips of the thumb and fingers. The tips of the thumb and fingers have more nerve-end concentration than the palm of the hand. The operator uses tactile sensation from the tips of the fingers as a feedback signal for the control of force and movement. Precision work may also require high visual demands which may require the operator to look closely at the work piece. This may put the worker in an awkward posture, which may lead to discomfort and rapid fatiguing. In general, visual acuity should be checked and corrected if necessary on a periodical basis.

Limitations of Human Capabilities

The human body has limited physical capabilities. For example, there are limitations on how high one can exert

a force whether in pushing, pulling, or lifting. The human body is also limited in its range of motion, that is, how far or high one can reach. The force one can exert depends on the posture of the body. The human body is strongest when the body joints are in a neutral position. In general, for the use of hand tools, the strongest posture a worker could assume is standing, feet apart, torso and neck upright, elbows at around 90 degrees, straight wrists, and using a power grip (closed fist grip like a pistol grip). In general, to minimize the worker's exertion level when working with hand tools, the worker should work from the strongest posture. Figure 1, shows two operators working from the strongest posture. Note that a pistol grip is used to work on the vertical surface, and an in-line tool is used to work on the horizontal surface to allow the work to be done from the strongest posture.

It may be infeasible to do all of the job from a strong posture at all times. It is best to design the job to allow the worker to assume the strongest posture when the demand of force is highest. For repetitive tasks, it is important to design the task to allow the worker to work from a strong posture most of the cycle time.

The human body is not suitable for repetitive actions. The frequency of a task determines the number of muscle exertions needed to perform the task.[8] Repeated muscle exertions without adequate recovery can lead to fatigue and may cause muscle disorders. To assess risk of repeated muscle loading, the frequency of a task may be classified as high, medium, or low. Fifteen or less cycles per minute is considered to be

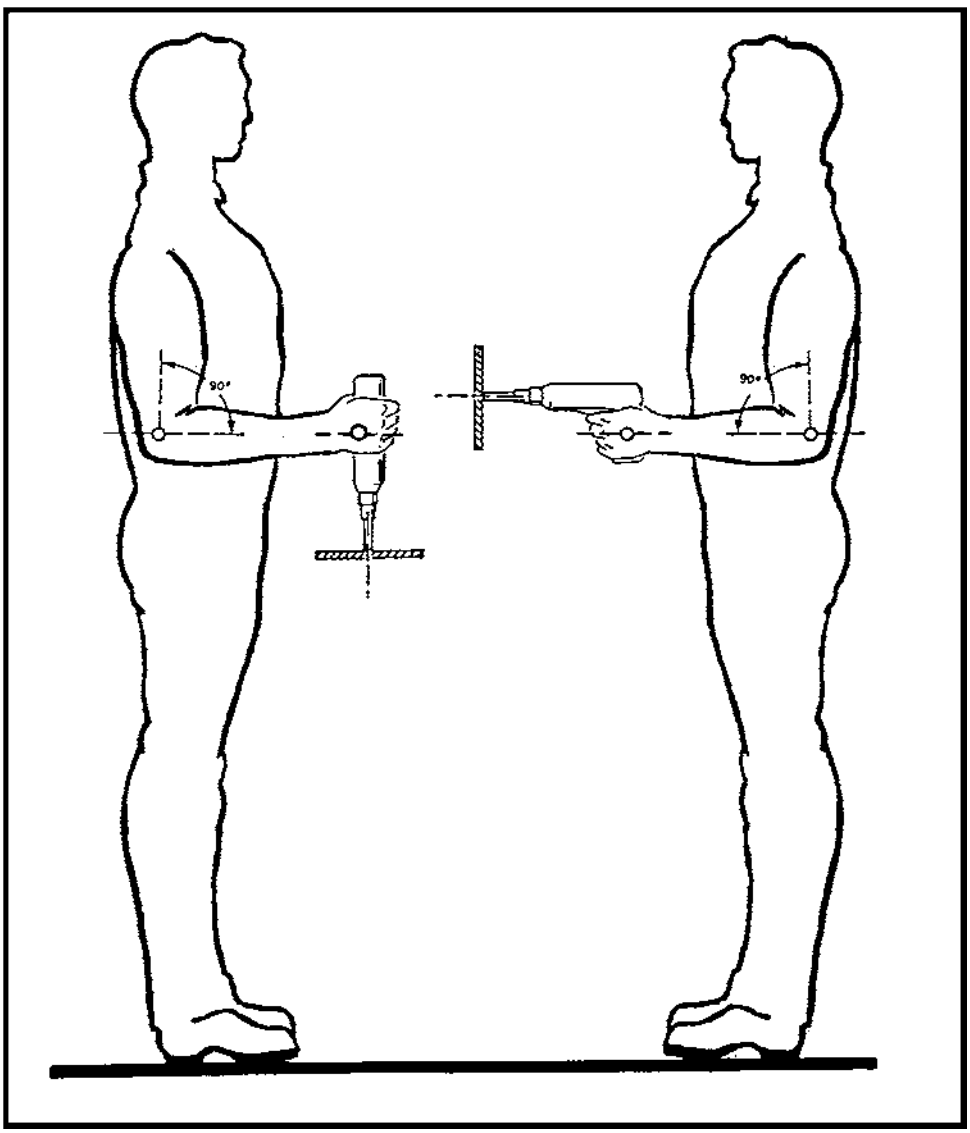

FIGURE 1
Tool-target configurations should be designed to enable the operator of a hand tool to work from the strongest posture.

low, and 50 or above is considered to be high.[31] Moderate or high-task frequencies, if coupled with demands of high forces, may put the worker at risk of musculoskeletal disorders.

Conflicting Goals

A hand tool functions as a force magnifier; it magnifies and concentrates muscle forces in a way that will allow the operator to cut steel or secure a nut using only small forces over a number of movements. For example, when using a hand saw, the worker pushes on the saw in a reciprocating movement for a number of strokes. Hand saws could be designed to reduce the operating force or to minimize the number of strokes needed to cut a piece of wood. An aggressive tooth design will reduce the number of strokes needed, but at the same time it will require a larger push force than a less aggressive saw. On the other hand, the less aggressive tooth design will require more strokes. It is not possible to design manual hand tools in a way that would minimize both the operating force and the number of repetitions needed to finish the task. This creates conflicting goals for the designers of hand tools. For many tasks, using power tools may be the solution; unfortunately, there are still many tasks that can only be done with manual hand tools.

Use Proper Tools

Proper fit between the tool end effect and the target is a major consideration for the ergonomic use of hand tools. Tools should be selected to do the work for which they are designed. For example, the proper use of a screw driver is to drive screws in or out, but not for use as a chisel. Also, the size of the tool end effect should fit the target. Working with unfit tool sizes may cause safety problems in two ways. First, tools may slip off the target, putting the worker at risk of injury. Second, it may require the worker to exert more effort on balancing the tool, keeping it coupled with the target, and doing the work,[15,39] which will cause faster fatigue and may lead to a higher risk of musculoskeletal disorders.

General Guidelines for Selection of Tools

Evaluation of the use of hand tools should consider the worker, the work piece or the target, and the tool itself.[14,19,20,23,32] There are certain design features that would make one tool better to use than another. For example, in using a plier or plier-like tool, using a light spring to re-open the plier is a recommended feature. The human hand is stronger when closing the plier than when opening it. A light spring will not put considerable pressure against the hand when closing the plier, and saves the worker from continuously re-opening the plier. Table I is a list of guidelines that can be used to select a good tool. This table lists general features of hand tools and evaluation criteria, what to look for and what to avoid in a tool.

Power Tools

Using power hand tools enables workers to do the task with less force and greater speed. However, power tools may cause harm to workers because of certain risk factors that are unique to them:[30,33,35]

- Power tools have a higher potential for serious instantaneous injuries because they involve more power;
- They may involve vibration;
- Exhaust air from pneumatic tools, which is usually cold, could cause vascular constriction in the hand and may lead to discomfort and/or injuries to the muscles (white finger syndrome);
- They have higher noise level; and
- They have high torque reactions on the hands of the worker.

In general, power hand tools are heavier than manual hand tools, and may involve long electrical wires, air or hydraulic hoses, or heavy batteries. Heavier hand tools require more effort to handle, which may cause the worker to fatigue faster. If the effective weight of the tool (that is, the weight of the power hand tool and accessories) is heavier than 5 lbs, the tool should be suspended on a balancer.

Trigger Design

All power tools have some kind of a trigger for operational control. Triggers can be operated with the index finger, middle and index fingers, or the thumb. There is no one ideal trigger design, but there are certain features that a good design should have. It is better to have the trigger designed with the option of being used with one or two fingers or with the thumb.[34] This implies that the trigger should be long enough to allow the use of two fingers, but should not exceed 2 inches. A good trigger would be placed within the grip, so the worker could use the middle part of the finger(s) and not the tip of the finger(s). Triggers should not have grooves for the fingers, but, in pistol-like tools, a small extension at the top of the trigger would prevent the rubbing of the top side of the index finger against the body of the tool. Triggers should be easy to operate and hold, and the required operating force should not exceed 2.2 lb.[21] The travel distance of the trigger when pressed should not exceed 3/4″ and is best if kept to 1/4″. When fully pressed the trigger should not protrude more than 1/4″ and is best if recessed so that it is flush with the handle.

Personal Protective Equipment (PPE)

The most popular PPE when using hand tools are gloves. Although good gloves may enhance tool gripping and protect worker's hands, using gloves is associated with over-gripping.[24] Poorly designed gloves may affect the dexterity of the hands and make the worker exert more force than needed to grip the tool, which may lead to rapid fatigue. Gloves with a special lining may be used for protection from vibration. Special care should be taken when selecting gloves; there is no "one size fits all."

TABLE I
General guidelines for the selection of hand tools

Tool feature	Ergonomic goal	Select	Avoid	Rationale
Grip surface[18,25,10,27,22,41]	• Non-slip • Electrically insulated • Thermally insulated • Compressible	• Finely textured surfaces. • Coated surfaces with rubber or soft plastic. Note: Wooden handles are good, too.	• Polished metal, smooth, or slippery surfaces. • Deep ribs or grooves • Fluid or oil absorbent coating materials.	• Finely textured grip surfaces provide better non-slip grip because of their higher friction characteristics. • Grip surfaces that are coated with semi-pliable (not too hard and not too soft) material provide better grip fit, more even distribution of contact pressure, and isolation of vibration. • Deep ribs and grooves on grip surfaces create pressure concentration points on the hand which may lead to discomfort or rapid fatigue. • Cold grip surfaces would reduce blood circulation in the hand which may lead to discomfort and may cause more complications if the hand is exposed frequently to a cold environment.
Shape of handle cross-section[26,13,15,10,25]	• Good fit between hand and tool. • Preventing handle from rotating inside the hand, and giving the worker a sense of the direction the tool is pointing.	• For tools other than screwdrivers select handles with oval or rounded-edge rectangular cross-sections. • For screwdrivers, select circular, and rounded-edge hexagonal and triangular cross-sections of handles.	• Handles with cross-sections that have sharp edges. • Handles with ridges that separate the fingers.	• Sharp or non-rounded edges on handles should be avoided because they create pressure concentration in the hand which may lead to discomfort and rapid fatiguing. • Handles with oval cross-sections are more comfortable to us because they fit inside the grip better than round shapes, will not allow the handle to rotate inside the grip, and provide a sense of tool orientation. • There is no definite optimum cross-section of a tool handle. The workers' choice should consider the "select" and "avoid" criteria in the previous columns and chose handles for maximum comfort.
Grip length[10,22,27,41]	• Grip length should be long enough to allow the worker to use a closed fist grip that is formed with all fingers and thumb (power grip).	• Grip length should be longer than the width of the hand across the palm. • Use 5–6″ long. Note: Gloved hands require 0.5″ longer handles.	• Short handles that end in the palm of the hand, creating a pressure point that may cause discomfort and rapid fatiguing.	• Power grip is the strongest grip the worker can use. Using power grip will allow the worker to exert higher force, or use the necessary force to do the job with the least effort and minimum discomfort. • Handles that end in the middle of the hand may cause pressure on nerves and blood vessels which may lead to discomfort or injury.

(Continued on next page)

TABLE I
General guidelines for the selection of hand tools *(Continued)*

Tool feature	Ergonomic goal	Select	Avoid	Rationale
Size of handle cross-section[26,10,12,13,15,22,27,41]	• Minimize gripping effort needed to do the task.	• For one-handle tools, for example, hammers and saws, the index finger and the thumb should be allowed to overlap by 3/8″.	• Too small or too large handles.	• Excessive gripping forces are exerted when using handles too small or too big in relation to the size of the worker's hand.
Grip span for two-handle (plier-like) tools.	• Minimize gripping effort needed to do the task.	• For two-handle tools, for example, pliers and cutters, select tools with grip span that are not less than 2″ when fully closed and less than 3.5″ when fully opened.	• Too small or too large grip span.	• Excessive gripping forces are exerted when using a grip span that is too small or too big in relation to the size of the worker's hand. • Maximum grip strength occurs with a grip span range of 2–3.5″.
Angle of the handle.[3,39,37,38]	• Keeping a straight wrist and upper arms and elbows close to the body.	• Select pistol grip or in-line tools that will minimize wrist deviation from straight when performing the task...	• Avoid combinations of tool-work situation that will force the worker to work with deviated wrists, elevated shoulders, and/or extended elbows.	• Keeping a straight wrist and upper arms and elbows close to the body are important features of the strongest position (neutral posture) the worker can assume when carrying out a task. • Working from the strongest posture will reduce the effort needed to exert the required forces to do the task, which will increase comfort level and decrease the chances of injury.
Tool weight[40,41,22,27,10]	• Minimize effort of carrying the tool. • Minimize required effort to push down the tool.	• For tools that do not require a push down force, the lighter the tool the better. • For tools that require a push down force, a heavier tool will reduce the needed push down force, but should be easy to move around. • For hammers and hammer-like tools choose the hammer weight that is most comfortable for the individual worker for the specific task.	• The use of heavy tools for long periods of time.	• In general, tools are carried for a longer time than they are operated. The effort of carrying the tool is reduced by choosing a lighter tool. • If the work situation requires the worker to push down on the tool, the weight of a heavier tool would reduce the needed push down force to do the task. One should be careful when selecting a heavy tool and consider the whole work cycle. Heavy tools may reduce the required push down force but may be harder to move around. • A heavy hammer would do a task (driving in a nail) in a number of hits that are less than when a lighter hammer is used, but at the same time a heavy hammer may produce higher reaction forces at the hand and wrist which may lead to discomfort and rapid fatiguing.

		• Total weight of tool and accessories should be less than 5 lbs. Tools that weigh more than 5 lbs. are considered heavy and should be used with extra caution and more frequent rest breaks.		
Handedness[1,6,36]	• Use proper tool design that fits the worker's dominant hand. • If possible, reduce the demand on the dominant hand by switching to the other hand for part of time.	• Select tools that can be used by either hand. • If not possible, select left-handed tool design for left-handed workers and right-handed tool design for right-handed workers.	• Avoid tools with provisions to be used by one hand and not the other.	• Unsymmetrical designs of tools may be easier to use in one hand than the other. This could be caused by a certain feature in the handle shape, the location of the center of gravity, and/or the line of vision of the end-effect of the tool. • It is best to chose tools that can be used by both hands, but if this is not possible the tool should be matched to the user's preference.
Two-handed[36,41]	• Reduce the effort by sharing the load between the two hands.	• Select tools that will allow a two-hand operation when applicable.	• Avoid tools that do not have enough space to place the other hand for a two-hand operation.	• Two hands are stronger than one hand, thus it is more comfortable to have a two-hand operation.
Color	• Easier to identify and locate.	• Select bright colors (orange, yellow, etc.), that are contrasted with the surroundings at the workplace. • Select tools with clear size markings, or tools that are color-coded.	• Avoid polished and shiny surfaces.	• Color is the least important ergonomic feature of a tool. It does not affect the force required to do the task or the number of cycles need to complete a task. • Colored and clearly marked tools are easier to find and may require less visual effort to identify.

The most important PPE a worker should have when using hand tools is safety glasses. The eyes are critical body organs, very sensitive and easily injured. Unlike gloves, wearing safety glasses does not directly interfere with using hand tools, but they should fit the worker's face and be comfortable.

Other important PPE include work shoes, hard hat, knee pads, ear plugs, and respirator. A proper respirator should be used when operating hand tools like sanders, or whenever dust is a by-product. Workers are often reluctant to use respirators because they can be uncomfortable, especially in a hot environment.

Rest Breaks

One may think that taking a rest break is intuitive, in other words, a worker would take a break when he or she feels tired, but this may not be the safest policy. For a healthy and productive workplace, rest breaks should be taken to prevent fatigue, rather than to recuperate from it. Usually, in self-paced work, workers tend not to take a break until they feel tired. Also, they tend to end their break and restart work before they are fully recovered from fatigue. It is best to design the work to allow the workers to take short, frequent breaks. The optimum rest break schedule may depend on the type of work. For light/medium repetitive work, which may be the case when using hand tools, it may be best to have 6–10 minutes of rest every 50–60 minutes of work. In the case of highly demanding tasks, longer and more frequent breaks would be needed. Frequent breaks should be used in addition to the usual lunch, midday, and mid-afternoon breaks. During break time, workers should be encouraged to relax and not to think about work.[5,43] Rest breaks should be used for resting and not for catching up on work.

Conclusion

All tools should be safe to use, and ergonomics is only one issue of safety. Forcefulness, repetition, awkward postures, hot and cold environment, noise, vibration, and an unbalanced work-rest cycle are factors that may contribute to the unsafe use of hand tools. Ergonomic use of hand tools requires a good match among the worker, the tool, and the target or the task. The tool-target combination should be modified to fit the individual worker, allowing him or her to work from the strongest posture. Although one should look beyond the tool and consider all factors that affect the ergonomic use of hand tools, there are general design features of hand tools that are considered ergonomic features. One should keep in mind that there is no single tool that can be used properly in all work situations.

Readers are encouraged to express their opinions and thoughts on this paper by writing to the authors. Feedback from workers, foremen, and supervisors is very important for the future planning and further development of comprehensive and easy to understand guidelines for the use and selection of proper hand tools.

REFERENCES

1. Aghazadeh, F.; Mital, A.: Injuries Due to Handtools. Appl Ergon (December 1987).
2. Ayoub, M.: The Determination of an Optimal Size Cylindrical Handle by Use of Electromyography. Ergonomics 14(4):509–518 (1971).
3. Bobjer, O.: Ergonomic Knives. In: Advances in Industrial Ergonomics and Safety I, pp. 291–298. Anil Mital, Ed. Taylor & Francis, Philadelphia (1989).
4. Bullinger, H.; Lorenz, D.; Muntzinger: Survey About the Analysis and Reduction of Stress Factors for Hand-Held Power Tools. In: Advances in Industrial Ergonomics and Safety I. Anil Mital, Ed. Taylor & Francis, Philadelphia (1989).
5. Cederqvist, T.; Lindberg, M.; Ortengern, R.; Magnusson, B.: Workload in Lower Arm and Shoulder When Using Manual and Powered Screwdrivers at Different Working Heights. Int J Ind Ergon 8:225–235 (1991).
6. Cederqvist, T.; Lindberg, M.: Screwdrivers and Their Use from a Swedish Construction Industry Perspective. Appl Ergon 24(3):148–157 (1993).
7. Cobb, T.; Cooney, W.; An, K.: Aetiology of Work-Related Carpel Tunnel Syndrome: The Role of Lumbrical Muscles and Tool Size on Carpal Tunnel Pressures. Ergonomics 39(1):103–107 (1996).
8. Dahalan, J.; Fernandez, J.: Psychophysical Frequency for a Gripping Task. Int J Ind Ergon 12:219–230 (1993).
9. Drury, C.: Handles for Manual Materials Handling. Appl Ergon 11(1):35–42 (1980).
10. Fransson, C.; Winkel, J.: Hand Strength, the Influence of Grip Span and Grip Type. Ergonomics 34(7):881–892 (1991).
11. Fraser, T.: Ergonomics Principles in the Design of Hand Tools. International Labour Organization, Geneva (1980).
12. Grant, K.; Habes, D.; Steward, L.: The Influence of Handle Diameter on Manual Effort in a Simulated Assembly Task. In: Advances in Industrial Ergonomics and Safety I, pp. 797–804. Anil Mital, Ed. Taylor & Francis, Philadelphia (1992).
13. Grant, K.; Habes, D.: Effectiveness of a Handle Flange for Reducing Manual Effort During Hand Tool Use. Int J Ind Ergon 12:199–207 (1993).
14. Grant, K.; Habes, D.: An Electromyographic Study of Strength and Upper Extremity Muscle Activity in Simulated Meat Cutting Tasks. Appl Ergon 28:129–137 (1993).
15. Grant, K.; Habes, D.; Putz-Anderson, V.: Psychophysical and EMG Correlates of Force Exertion in Manual Work. Int J Ind Ergon 13:31–39 (1994).
16. Grant, K.; Johnson, P.; Galinsky, T.: Evaluation of an Accelerometric Activity Monitor as an Exposure Assessment Tool in Ergonomic Studies. Appl Occup Environ Hyg 10(5):461–466 (1995).
17. Hoozemans, M.; et al.: Pushing and Pulling in Relation to Musculoskeletal Disorders: A Review of Risk Factors. Ergonomics 41(6):757–781 (1998).
18. Kadefors, R.; et al.: An Approach to Ergonomics Evaluation of Hand Tools. Appl Ergon 24(3):203–211 (1993).
19. Mital, A.: Effect of Body Posture and Common Hand Tools on Peak Torque Exertion Capabilities. Appl Ergon June 87–96 (1986).

20. Mital, A.; Channaveeraiah, Ch.: Peak Volitional for Wrenches and Screwdrivers. Int J Appl Ergon 3:41–64 (1988).
21. Mital, A.; Kilborn, A.: Design, Selection and Use Of Hand Tools to Alleviate Trauma of the Upper Extremities: Part I—Guidelines for the Practitioner. Int J Appl Ergon 10:1–5 (1992).
22. Mital, A.; Kilbom, A.: Design, Selection and Use Of Hand Tools to Alleviate Trauma of the Upper Extremities: Part II—The Scientific Basis (Knowledge Base) for the Guide. Int J Appl Ergon 10:7–21 (1992).
23. Mital, A.; Sanghavi, N.: Comparison of Maximum Volitional Torque Exertion Capabilities of Males and Females Using Common Hand Tools. Hum Fact 28(3):283–294 (1986).
24. Mital, A.; Kuo, T.; Faard, H.: A Quantitative Evaluation of Gloves Used with Non-Powered Hand Tools in Routine Maintenance Tasks. Ergonomics 37(2):333–343 (1994).
25. Petrosfky, J.; et al.: The Effect of Handgrip Span on Isometric Exercise Performance. Ergonomics 23(12):1129–1135 (1980).
26. Pheasant, S.; O'Neill, D.: Performance in Gripping and Turning—A Study in Hand/Handle Effectiveness. Ergonomics 6(4):205–208 (1975).
27. Radwin, R.; Haney, J.: An Ergonomics Guide to Hand Tools. American Industrial Hygiene Association, Fairfax, VA (1995).
28. Radwin, R.; Masters, G.; Lupton, F.: A Linear Force-Summing Hand Dynamometer Independent of Point of Application. Appl Ergon 22(5):339–345 (1991).
29. Radwin, R.; Seoungyen, Oh.; Fronczak, F.: Mechanical Model of Hand Force in Power Hand Tools Operation. Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting (1995).
30. Radwin, R.; Seoungyen, Oh.; Biomechanical Aspects of Hand Tools. In: Musculoskeletal Disorders in the Workplace: Principles and Practice, chap. 37. Mosby, Boston (1997).
31. Rodgers, S.: Measuring and Setting Ergonomic Standards—Issues and Perspectives, In: Advances in Occupational Ergonomics and Safety I, pp. 884–890. (1996).
32. Seoungyen, Oh.; Radwin, R.: Dynamics of Power Hand Tools on Operator Hand and Arm Stability. Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting (1994).
33. Seoungyen, Oh.; Radwin, R.: The Effect of Power Hand Tools Dynamics and Workstation Design on Handle Kinematics and Muscle Activity. Int J Ind Ergon 20:59–74 (1997).
34. Seoungyeon, Oh.; Radwin, R.: Pistol Grip Power Tool Handle and Trigger Size Effects on Grip Exertions and Operator Preference. Hum Fact 35(3):551–569 (1993).
35. Schlegel, R.; Willcoxon, R.: An Evaluation of Powered Hand Tools Use in Automobile Assembly. In: Advances in Industrial Ergonomics and Safety I, A. Mital, Ed. Taylor & Francis, Philadelphia (1989).
36. Schmauder, M.; Eckret, R.; Schindhelm, R.: Forces in the Hand-Arm System: Investigation of the Problem of Left-Handedness. Int J Ind Ergon 12:231–237 (1992).
37. Schoenmarklin, R.; Marras, W.: Effects of Handle Angle and Work Orientation on Hammering: II. Muscle Fatigue and Subjective Ratings of Body Discomfort. Hum Fact 31(4):413–420 (1989).
38. Schoenmarklin, R.; Marras, W.: Effects of Handle Angle and Work Orientation on Hammering: I. Wrist Motion and Hammering Performance. Hum Fact 31(4):397–411 (1989).
39. Strasser, H.; Wang, B.; Hoffmann, A.: Electromyographic and Subjective Evaluation of Hand Tools: The Example of Masons' Trowels. Int J Ind Ergon 18:91–106 (1996).
40. Tanka, Sh.; McGlothin, J.: A Conceptual Model to Assess Musculoskeletal Stress of Manual Work for Establishment of Quantitative Guidelines to Prevent Hand and Wrist Cumulative Trauma Disorders (CTDs). In: Advances in Industrial Ergonomics and Safety I.A. Mital, Ed. Taylor & Francis, Philadelphia (1989).
41. Tichauer, E.R.: Ergonomic Principles Basic to Hand Tool Design. Am Ind Hyg Assoc J 38(11):622–634 (1977).
42. Zimmerman, R.L.; Shaull, J.E.: Hand Tool Ergonomics, the Operator's Story. In: Advances in Industrial Ergonomics and Safety I, pp. 257–265. A. Mital, Ed. Taylor & Francis, Philadelphia (1989).
43. Dababneh, A.: Ph.D. dissertation at the University of Cincinnati/College of Engineering, unpublished (1997).