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# 6 Design of Workplaces and Hand Tools

## 6.1 LEARNING GOALS

The objective of this chapter is to provide an introduction to basic ergonomic principles of workplace design and evaluation of hand tools. The general process for workplace design will be studied. The student is also provided with sample evaluation tools and a detailed list of potential evaluation tools is also included.

## 6.2 KEY TOPICS

- Workplace design analysis
- Principles of arrangement
- General process for workplace design
- General principles for workplace design
- Designing to fit the moving body
- Designing for the standing operator
- Designing for the sitting operator
- Working in confined and awkward spaces
- Designing for hand and foot operation
- Workplace evaluation tools
- Rapid upper limb assessment (RULA) tools
- Risk factors and risk prediction
- General guidelines for workplace controls and displays

## 6.3 INTRODUCTION AND BACKGROUND

Three hundred years ago, Ramazzini explained the reasons why he believed people who perform work while standing get more easily fatigued than people who have to work while walking. He alleged that in order to maintain an upright position, the muscles must be kept tensed. Also, he affirmed that workers who sit still and look down at their work in a stooped posture often become round shouldered and suffer from numbness in their legs, lameness, and sciatica. Ramazzini strongly believed that all sedentary workers suffered from lumbago (low back pain) and, therefore, recommended that workers should not consistently stand or sit still, but instead engage in dynamic activities to constantly move the body.

The work environment has changed drastically since the Industrial Revolution which began in the United Kingdom and spread to North America, and the rest of the world over 200 years ago. The American Industrial Revolution began in the early

1800s and produced substantial changes in agriculture, manufacturing, mining, transportation, and technology. As a result, the requirement for workers increased as did the need for the design of work environments. The work environment included many physically intensive tasks, and new equipment was designed to support the growing need in all industries, which were flourishing. However, there was not much emphasis on designing the work environment, equipment, or tools for humans. Around 1878, this began to change with work done by Frank and Lillian Gilbreth. As discussed in previous chapters, the Gilbreths' were pioneers in time and motion studies and conducted years of research and analysis to help workers in the industry. The objective of these studies was simplification and industrial efficiency. Much of their efforts improved the workplace for the operators and can be considered the beginning of applied ergonomics research. More than a hundred years later, ergonomists are still adapting to changes in technology and industry to design workplaces to accommodate the human operator. The objective of ergonomics in workplace design is to consider all elements of the physical task, information processing requirements, process, equipment, seating, and tools in order to create an integrated environment that is designed to meet the needs of the worker.

Ergonomically designed tools are more ubiquitous and affect a wider range of users than commonly known. Take the pencil, for example. The Romans were using metal styluses to write in 1300 BC. The earliest styluses, originally made of thin metal, eventually evolved into lead, which could be used to leave a light but readable mark on papyrus, but users did not know it was toxic. In 1564, a large graphite deposit was discovered in England, and graphite replaced lead because it left a darker mark and was nontoxic. However, graphite was so brittle that it needed a holder, so it was prudent to wrap sticks of graphite in string. Finally, a hollowed-out wooden case replaced the string, and by 1662 the first mass-produced wooden pencils were being sold in Nuremberg, Germany. This simple history is an example of how ergonomic problem solving was used to overcome various obstacles and imperfections in order to create a useful tool still used today (Pencil History, 2010).

## 6.4 WORKPLACE DESIGN ANALYSIS

The Occupational Safety and Health Administration (OSHA) states the following about ergonomics in workplace design (OSHA, 1987):

The ergonomic approach to workplace design must be recognized as the most effective and is the first choice for controlling sources of workplace stress.

The reason for this is because the "best fit" is achieved by engineering the problems out at the design stage. In other words, focusing on task design and tool design rather than worker selection or training. With the implementation of the ergonomic approach to job design, prevention of injury is achieved as a result of the worker experiencing improved work postures, reduced forces, fewer repetitions, and reduction in overall exposure to risk factors.

In the design of workplaces, several analysis techniques can be considered (see summary of select analysis tools at the conclusion of this chapter). These investigation techniques can be used to analyze workplace dimensions, to determine human

workplace interface, or to identify ergonomic problems such as injuries, ill health, and productivity. Some of these techniques include workplace evaluation and analysis. Additionally, a variety of technology can be used for the collection, analysis, and interpretation of data to affect job design.

### 6.4.1 PRINCIPLES OF ARRANGEMENT

In the design of a workplace there are several principles that should not generally be included. The principles (OSHA, 1987) should be followed to ensure a safe workplace. The principles are as follows:

- Importance principle—The importance of the design requirements.
- Frequency of use principle—Tasks that are easily accessible, non-stressful, and frequent.
- Functional principle—Groupings of tasks that serve in the task.
- Sequence of use principle—The sequence of task design, design such that the sequence is consistent throughout the sequence.

### 6.4.2 GENERAL PROCESS FOR WORKPLACE DESIGN

To effectively design a workplace, the design process must consider the environment, task requirements, and the human operator. The general approach for workplace design is shown in Figure 6.1.

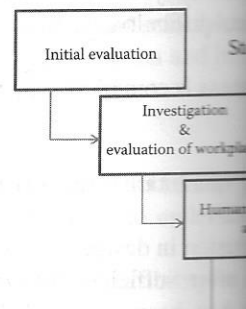


FIGURE 6.1 Five step approach to workplace design.

workplace interface, or to identify workplace factors that may contribute to ergonomic problems such as injuries, illnesses, operator discomfort, and reduced productivity. Some of these techniques include surveys, interviews, observation analysis, workplace evaluation and analysis of tools and equipment used for the job task. Additionally, a variety of technology-based tools are available to support the collection, analysis, and interpretation of workplace or operator-related characteristics that affect job design.

#### 6.4.1 PRINCIPLES OF ARRANGEMENT

In the design of a workplace there are often trade-offs as all desired conditions cannot generally be included. The principles of arrangement (Sanders and McCormick, 1987) should be followed to ensure a functional and well-designed workplace. These principles are as follows:

- Importance principle—The most relevant activities should lead the development of the design requirements.
- Frequency of use principle—Design such that frequently required activities are easily accessible, non-strenuous, and convenient.
- Functional principle—Group components according to the function they serve in the task.
- Sequence of use principle—If sequential patterns or routines are a part of task design, design such that the operator performs smooth transitions throughout the sequence.

#### 6.4.2 GENERAL PROCESS FOR WORKPLACE DESIGN

To effectively design a workplace, ergonomists should have significant details of the environment, task requirements, and anticipated worker population. A five-step approach for workplace design is summarized in the following (Figure 6.1):

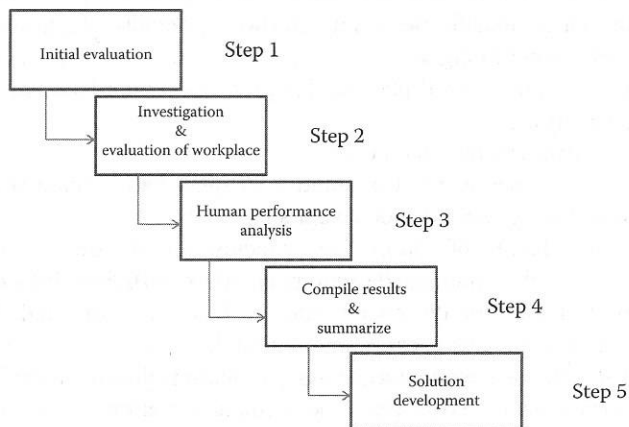


FIGURE 6.1 Five step approach to workplace design.

1. The first step in the workplace design analysis is to perform an initial evaluation.
  - a. A thorough description of the environment and tasks needs to be meticulously studied, as well as any attributes that contribute to the task completion. Components of the analysis should include task and process design, workplace design, design of equipment, and tools.
  - b. It is important to look for any job requirements that exceed the capabilities of the workers.
  - c. Written procedures that workers are to follow should be evaluated for accessibility and ease of use.
  - d. Procedures involving situational or external factors, policies, scheduling, and stress should also be evaluated.
2. The second step includes an investigation and evaluation of the workplace and environmental factors.
  - a. Identify and evaluate all tools and equipment.
  - b. Assess working conditions.
  - c. Identify and evaluate safety.
3. The third step involves an analysis of human performance and physiological responses.
  - a. Performance measures productivity over the shift. This can be measured in terms of total units completed, units produced per hour, idle time, time on arbitrary tasks, interruptions, distractions, and accidents.
  - b. The quality of output is also measured, for instance the number of defects, the number of mistakes, and the number of times instructions must be referenced.
  - c. Physiological measures that are studied during this step consist of direct measurements, such as heart rate, blood pressure, breathing rate, muscle activity (EMG reading), body or skin temperature, and oxygen consumption.
  - d. Psychophysical measures, which are more subjective, are also considered. These include perceived exertion, difficulty, energy expended, and the level of fatigue.
4. The fourth step in the workplace design process is compilation of all results from the analysis.
  - a. Summarize evaluation outcomes.
  - b. Rank outcomes using a qualitative or quantitative scale (i.e., highly acceptable, acceptable, not acceptable).
  - c. Prioritize factors of importance for inclusion in design.
5. The fifth step is solutions development, after sufficient information to develop strategies for design or redesign has been collected. The data should be used to develop ergonomic-based designs.
  - a. It is useful to develop multiple design solutions that are at various levels of sophistication, costs, and time to implementation.
  - b. Thus, it may be helpful to produce three levels of design solutions that include the following:
    - i. Immediate design solutions
    - ii. Interim design solutions
    - iii. Long-term design solutions

Using the steps listed in the preceding text as a broad workplace analysis; however, design should be used as the guide to tailor this approach to the specific workplace to ensure that consideration is given to the design of tools, and equipment. For instance, adjustments to reduce muscle fatigue, minimize awkward postures, and consider adjustments that address multiple aspects of the workplace or tools, such as jigs, clamps, and vises. Such adjustments help hold objects in place and reduce static and repetition of tasks. Efficient use of a workplace eases accessibility of parts, reduces storage space. Lift tables are highly recommended to reduce stooping, crouching, and twisting. A firm support for the legs and feet, and promotes posture are just a few examples of approaches to

## 6.5 GENERAL PRINCIPLES OF WORKPLACE DESIGN

Workplaces should be designed for safety and health. This is done in the engineering design stage. The design approach eliminates problems by design. This offers a resource in the ergonomic workplace design that include hand tools (NIOSH Ergonomics 2010b). Excerpts from the NIOSH Ergonomics 2010b.

In addition to applying ergonomic principles, it is important to apply other principles to the design of the workstation. A brief explanation and basis is provided in the following:

- Maintainability
  - Increase product life.
  - Provide easy to understand units or parts.
  - Consider accessibility or space to work.
  - Identify potential hazards and provide warning labels and interpret, and understand.
  - Follow established standards and color.

- i. Immediate design solutions
- ii. Interim design solutions
- iii. Long-term design solutions

Using the steps listed in the preceding text as a guideline will be useful in producing a broad workplace analysis; however, details of the work environment should be used as the guide to tailor this approach to the workplace needs. This process is designed to ensure that consideration is given to the person, workstation, work tasks, products, tools, and equipment. For instance, adjusting the workstation in order to reduce static muscle fatigue, minimize awkward postures, and improve visual acuity are considerations that address multiple aspects of the workstation. Adjusting work pieces or tools, such as jigs, clamps, and vises, is also an important consideration. These types adjustments help hold objects in place and minimize uncomfortable postures. Such adjustments can also reduce static loading, discomfort, application of force, and repetition of tasks. Efficient use of components and storage bins throughout the workplace eases accessibility of parts, reduces transportation time, distances, and storage space. Lift tables are highly recommended because they reduce lifting tasks, stooping, crouching, and twisting. A foot rest is another product that helps reduce fatigue and back strain, relieves stress on the legs, back, and neck, promotes circulation in the legs and feet, and promotes proper posture and comfortable seating. There are just a few examples of approaches that can be used to address worker needs.

## 6.5 GENERAL PRINCIPLES OF WORKPLACE DESIGN

Workplaces should be designed for safety, efficiency, and productivity. Ideally, this is done in the engineering design stage, prior to any operator exposure, as the engineering approach eliminates problems by designing them out of the environment. OSHA offers a resource in the ergonomic toolbox to provide guidance in varied areas of workplace design that include hand tool design and work station design (OSHA, 2010b). Excerpts from the NIOSH Ergonomic Toolbox are provided in Table 6.1.

In addition to applying ergonomic principles of workplace design, it is equally important to apply other principles to promote a safe, durable, and long-term workstation. A brief explanation and basis for ensuring the use of these principles is provided in the following:

- Maintainability
  - Increase product life.
  - Provide easy to understand instructions and procedures for replacing units or parts.
  - Consider accessibility or space available for the maintenance personnel to work.
  - Identify potential hazards (remove or warn users for hazards).
  - Provide warning labels and place them where they can be perceived, interpreted, and understood.
  - Follow established standards (i.e., ISO standards) for label placement and color.

**TABLE 6.1 (continued)**  
**NIOSH Ergonomic Toolbox: General Workstation Design Principles**

**Tray 9–D. Design Principles for Lifting and Lowering Tasks**

1. Optimize material flow through the workplace by
  - a. Reducing manual lifting of materials to a minimum
  - b. Establishing adequate receiving, storage, and shipping facilities
  - c. Maintaining adequate clearances in aisle and access areas
2. Eliminate the need to lift or lower manually by
  - a. Increasing the weight to a point where it must be mechanically handled
  - b. Palletizing handling of raw materials and products
  - c. Using unit load concept (bulk handling in large bins or containers)
3. Reduce the weight of the object by
  - a. Reducing the weight and capacity of the container
  - b. Reducing the load in the container
  - c. Limiting the quantity per container to suppliers
4. Reduce the hand distance from the body by
  - a. Changing the shape of the object or container so that it can be held closer to the body
  - b. Providing grips or handles for enabling the load to be held closer to the body
5. Convert load lifting, carrying, and lowering movements to a push or pull by providing
  - a. Conveyors
  - b. Ball caster tables
  - c. Hand trucks
  - d. Four-wheel carts

**Tray 9–E. Design Principles for Pushing and Pulling Tasks**

1. Eliminate the need to push or pull by using the following mechanical aids, when applicable:
  - a. Conveyors (powered and non-powered)
  - b. Powered trucks
  - c. Lift tables
  - d. Slides or chutes
2. Reduce the force required to push or pull by
  - a. Reducing side and/or weight of load
  - b. Using four-wheel trucks or dollies
  - c. Using non-powered conveyors
  - d. Requiring that wheels and casters on hand trucks or dollies have (i) periodic lubrication of bearings, (ii) adequate maintenance, and (iii) proper sizing (provide larger diameter wheels and casters)
  - e. Maintaining the floors to eliminate holes and bumps
  - f. Requiring surface treatment of floors to reduce friction
3. Reduce the distance of the push or pull by
  - a. Moving receiving, storage, production, or shipping areas closer to work production areas
  - b. Improving the production process to eliminate unnecessary materials handling steps
4. Optimize the technique of the push or pull by
  - a. Providing variable-height handles so that both short and tall employees can maintain an elbow bend of 80°–100°
  - b. Replacing a pull with a push whenever possible
  - c. Using ramps with a slope of less than 10%

**TABLE 6.1 (continued)**  
**NIOSH Ergonomic Toolbox: General Workstation**

**Tray 9–F. Design Principles for Carrying**

1. Eliminate the need to carry by rearranging the workplace movement and using the following mechanical handling aids:
  - a. Conveyors (all kinds)
  - b. Lift trucks and hand trucks
  - c. Tables or slides between workstations
  - d. Four-wheel carts or dollies
  - e. Air or gravity press ejection systems
2. Reduce the weight that is carried by
  - a. Reducing the weight of the object
  - b. Reducing the weight of the container
  - c. Reducing the load in the container
  - d. Reducing the quantity per container to suppliers
3. Reduce the bulk of the materials that are carried by
  - a. Reducing the size or shape of the object or container
  - b. Providing handles or hand-grips that allow materials to be carried by two or more persons.
  - c. Assigning the job to two or more persons.
4. Reduce the carrying distance by
  - a. Moving receiving, storage, or shipping areas closer to work production areas
  - b. Using powered and non-powered conveyors
5. Convert carry to push or pull by
  - a. Using non-powered conveyors
  - b. Using hand trucks and push carts

Source: Adapted from design checklists developed by NIOSH, pp.19046–3129; DHHS (NIOSH) publication (OSHA) docs/97–117/pdfs/97–117.pdf website, accessed 10/1/2010.

- Safety
  - Safety should be a priority design.
  - Provide guards, fail-safe mechanisms.
  - Safety should not impair productivity.
  - Provide protection against accidents.
- Usability
  - Apply usability principles in design.
  - Increase efficiency and minimize errors.
  - Consider human capabilities, human factors, and anthropometrics.
  - Provide clear, concise documentation.
- Comfort
  - Reduce fatigue, complaints, and injuries.
  - Consider expected use and possible misuse.
  - Promote user acceptance.
  - Prototype testing.

TABLE 6.1 (continued)

## NIOSH Ergonomic Toolbox: General Workstation Design Principles

## Tray 9-F. Design Principles for Carrying Tasks

1. Eliminate the need to carry by rearranging the workplace to eliminate unnecessary materials movement and using the following mechanical handling aids, when applicable:
  - a. Conveyors (all kinds)
  - b. Lift trucks and hand trucks
  - c. Tables or slides between workstations
  - d. Four-wheel carts or dollies
  - e. Air or gravity press ejection systems
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  - d. Reducing the quantity per container to suppliers
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  - c. Assigning the job to two or more persons.
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  - b. Using powered and non-powered conveyors
5. Convert carry to push or pull by
  - a. Using non-powered conveyors
  - b. Using hand trucks and push carts

Source: Adapted from design checklists developed by Ridyard, D., *Appl. Ergon. Technol.*, pp.19046-3129; DHHS (NIOSH) publication number 97-117, <http://www.cdc.gov/hiosh/docs/97-117/pdfs/97-117.pdf> website, accessed April 18, 2011.

- Safety
  - Safety should be a priority design.
  - Provide guards, fail-safe mechanisms, warnings, labels, and alarms.
  - Safety should not impair productivity.
  - Provide protection against accidental activation of control switches.
- Usability
  - Apply usability principles in design.
  - Increase efficiency and minimize errors.
  - Consider human capabilities, human stature dimensions, and population anthropometrics.
  - Provide clear, concise documentations and instructions for users.
- Comfort
  - Reduce fatigue, complaints, and discomfort.
  - Consider expected use and possible misuse by the worker.
  - Promote user acceptance.
  - Prototype testing.

- Reliability
  - Increase use and confidence in workstation.
  - Support quality and scheduling.
- Durability
  - Design to withstand expected factors related to users' expected lifespan.
  - Design with consideration of application environment.

### 6.5.1 DESIGNING TO FIT THE MOVING BODY

Humans are dynamic and function better over extended periods when allowed to vary posture, loading, and work position. The workplace should be designed to accommodate a range of motions that are expected of the operator for task performance. One way to accomplish this is to select the extremes of body positions that are expected and design for the motions between these ranges.

Traditionally, there are three work postures or combinations of these postures including lying down, sitting, and standing. However, there are other positions, for example, kneeling on one or both knees, squatting, and stooping. In order to measure the effects of work postures, both independent and dependent variables need to be considered. Independent variables relate to body movements, postures, and change measurement variables, such as rate of change, range of change, and maximum displacement. Dependent variables fall within a range of disciplines including physiological, for example, oxygen consumption, heart rate, blood pressure, and electromyogram; medical, such as musculoskeletal disorders (MSDs) and cumulative trauma disorders (CTDs); biomechanical, for instance spine disc pressure, x-rays, CAT scans, and force calculations from models; engineering, for example, productivity, forces, and pressures on seat, backrest or floor; and psychophysical, including subjective measures, such as interviews and surveys (Kroemer et al. 1994). Subjective measures consist primarily of subjective pain or discomfort ratings. Subjective measures have been highly correlated with many physiological measures, such as heart rate and psychological rating of perceived exertion. However, these measures are highly dependent on how well the survey is administered and the results can be quite accurate.

Biomechanics is a useful tool to evaluate dynamic task performance, as the field studies the human body in movement. These types of evaluations are used extensively in occupational analysis and to enhance the performance of athletes, particularly in elite athletics such as the Olympics. Biomechanical analysis can include the use of modeling tools video analysis, and mathematical models to predict the loading and impact of a work environment on an operator, indirect and direct measurement tools to assess capabilities in specific postures, or task activities throughout task performance.

### 6.5.2 DESIGNING FOR THE STANDING OPERATOR

Standing is usually used as a working posture if sitting is not possible, because the operator must exert large forces with the hands, the work area requires mobility, or the operator has to cover a large work area. Standing in one place should only

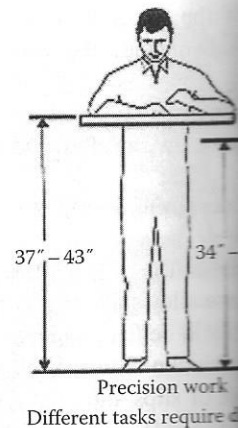


FIGURE 6.2 Standing workstation design

be imposed for a limited time period. The work area is placed high above the floor to justify the cost.

The working height is critically important. Working height depends on the activity and the operator's height (Figure 6.2). The main reference points are generally the strongest hand forces, the elbow and hip heights. If the working height is too high, the operator is frequently lifted, causing discomfort and fatigue. Working heights at or above the elbow height can cause tendonitis or other cumulative trauma disorders. If work is placed too low, the back is strained, potentially leading to long-term discomfort, pain, and injury.

The average elbow height (distal to the elbow) is bent at right angles with the forearm. The recommended working height for men is 1000 mm and 100 mm below the elbow level for women (Grandjean, 1997):

- Delicate work or fine manipulation
  - Support the elbows to minimize fatigue
  - Design to support viewing
  - Design for work surfaces
- Manual work (i.e., light assembly)
  - Allow space for equipment
  - Design for work surfaces
- Exertion of extensive manual force (e.g., assembly or woodworking)

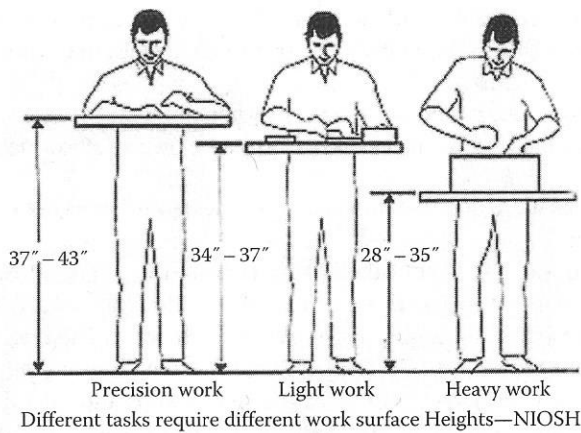


FIGURE 6.2 Standing workstation design dimensions.

be imposed for a limited time period. Forcing someone to stand because the work area is placed high above the floor or outside the sitting reach areas is not a good justification.

The working height is critically important in the design of workplaces, and this height depends on the activity and the size of the object handled such as hand tools (Figure 6.2). The main reference point is the elbow height of the worker, because generally the strongest hand forces and the most useful mobility are between the elbow and hip heights. If the working height is too high, the shoulders must be frequently lifted, causing discomfort and painful cramps in both the neck and shoulders. Working heights at or above shoulder height can also contribute to shoulder tendonitis or other cumulative trauma disorder (CTDs) of the shoulder. Likewise, if work is placed too low, the back must be constantly bent leading to temporary or potentially long-term discomfort, pain, or injury.

The average elbow height (distance from floor to underside of elbow when it is bent at right angles with the upper arm vertical) is almost 1070 mm for men and 1000 mm for women both in North America and Europe. The generally recommended working height for hand work, while standing, is between 50 and 100 mm below the elbow level. The following text lists three recommended height guidelines when performing certain types of standing work (Kroemer and Grandjean, 1997):

- Delicate work or fine manipulation (i.e., drawing)
  - Support the elbows to minimize loading on the back.
  - Design to support viewing requirements.
  - Design for work surfaces 50–100 mm above the elbow height.
- Manual work (i.e., light assembly)
  - Allow space for equipment, hand tools, materials, and containers.
  - Design for work surfaces 100–150 mm below the elbow height.
- Exertion of extensive manual effort or constant use of weight (i.e., heavy assembly or woodworking)

- When constant use of the strength of the upper part of the body is involved (heavy assembly work or woodworking), the working surface needs to be lower.
- Provide forearm and wrist support when possible.
- Design for work surfaces 150–400 mm below the elbow height.

Table 6.1 provides more detailed dimensions for designing standing workstations for men and women.

Sufficient room for the feet of the operator must also be provided, including toe and knee space in a standing workplace. This space allows the worker to move closer to the workspace. The floor at the workstation should be flat and free of obstacles to reduce the risk of tripping. Likewise, sufficient friction between the soles of shoes and floor surfaces is necessary to reduce the risk of slips and falls. Finally, to promote comfort when standing, elastic floor mats and soft soles have been useful for reducing foot, leg, and back discomfort.

To manage the static loading that results from standing workstations, employers will sometimes provide stand seats or semi-seats. These semi-seats should provide a level of support between standing and sitting without interfering with the task performance. Due to variability within a task, this type of seating is often useful for certain job activities without impacting overall task performance. However, it is important to remember to not fully take the weight off the legs using these seats, as they tend to be higher than traditional seating and oftentimes workers cannot fully reach the floor and thus can lead to ischemia (occlusion of blood flow in the legs). Possible disadvantages that come with these seats include stability issues, restriction of the range of motion, and discomfort due to ischemia in the lower limbs.

### 6.5.3 DESIGNING FOR THE SITTING OPERATOR

Sitting down is a much less strenuous working posture than standing. Stabilizing the body while sitting down is easier because fewer muscles need to be contracted and the body benefits from the support of the chair. Sitting allows better control of hand movements, but the seated postures mean the capacity for force exertion with the hands is reduced. Sitting individuals can operate controls with their feet; however, the amount of force that can be applied is considerably less than when standing. When designing a workstation for a sitting operator, it is important to consider the free space required by the legs and feet for movement in all directions. Also, the seat should be designed so that the sitting posture can be changed frequently. An adjustable chair that meets ergonomic design criteria should be considered. An overview of the dimensions of interest for seated workers is shown in Figure 6.3.

Humans are not biomechanically adapted for long-term static postures, whether it is standing or sitting. Therefore, sitting for extended periods of time can lead to lower back pain and foot swelling. Changing postures throughout the shift will reduce continued compression of the spinal column, as well as muscle fatigue. The preferred working area is right in front of the body at about elbow height, with the upper arms hanging. Visual requirements should also be considered when determining work-

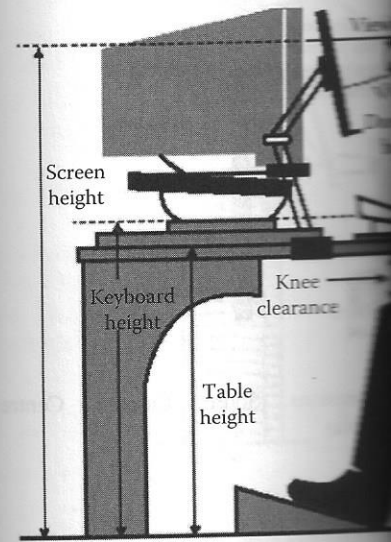


FIGURE 6.3 Seated worker.

area height. Seat heights should range from 14 to 19 inches, and are determined by the design of the seat pan and adjustability.

#### 6.5.3.1 Elements of an Ergonomic Chair

When picking out a chair, it is critical to consider the seat pan, foot rests, and appropriate height level. Poor chair design can produce risk factors for back pain, as the most common complaint of sedentary workers is back pain. Essential elements of workstation design for seated workers include the following:

- Lumbar support
  - Supports the lower region of the back
  - Promotes proper posture
  - Minimizes the load on the lower back
- Chair with a waterfall edge
  - Results in termination of seat pressure on the feet
  - Prevents the obstruction of blood flow
- Armrest
  - Adjustable, compatible with the work surface
- Slightly tilted seat pan
  - Promotes proper posture, particularly for long-term sitting

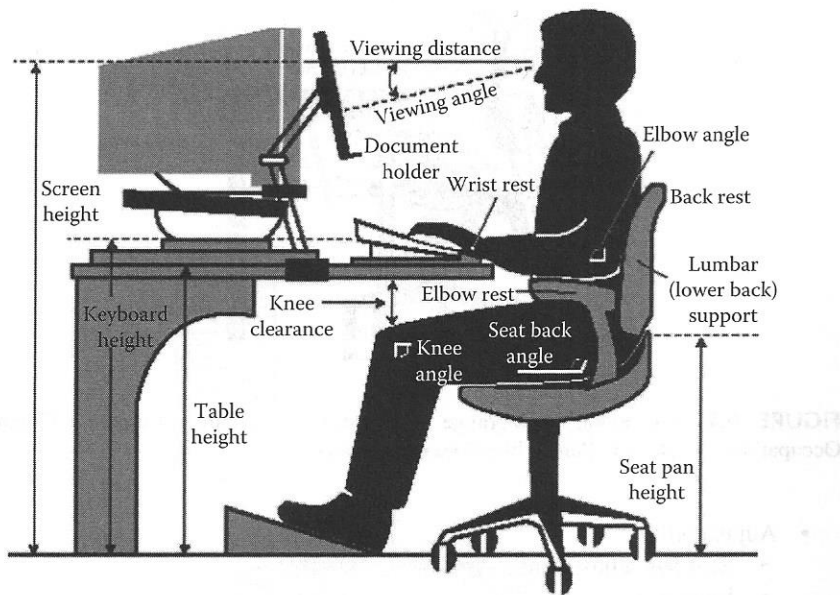


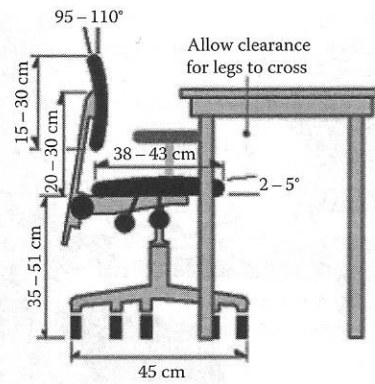
FIGURE 6.3 Seated worker.

area height. Seat heights should range from 35 to 50 cm, and the comfort of the seat is determined by the design of the seat pan, backrest, material that touches the body, and adjustability.

### 6.5.3.1 Elements of an Ergonomic Chair

When picking out a chair, it is critical to consider the type of chair, lumbar support, foot rests, and appropriate height level. Many physical and task requirement factors can produce risk factors for back pain, as evidenced by the fact that the primary complaint of sedentary workers is back problems. According to OSHA, the chair is an essential element of workstation design (OSHA, 2011). Ergonomic seating requirements include the following:

- Lumbar support
  - Supports the lower region of the back
  - Promotes proper posture
  - Minimizes the load on the lower back
- Chair with a waterfall edge
  - Results in termination of seat in back of thigh or lower leg
  - Prevents the obstruction of blood flow to the lower extremities
- Armrest
  - Adjustable, compatible with task performance
- Slightly tilted seat pan
  - Promotes proper posture, particularly in the lower back



**FIGURE 6.4** Ergonomic chair range of dimensions. (Source: Canadian Centre for Occupational Health and Safety, <http://www.ccohs.ca>)

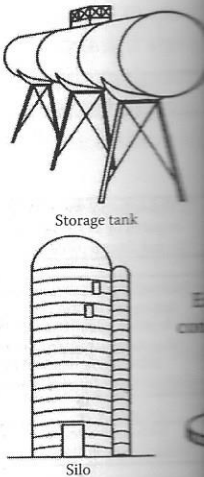
- Adjustability
  - Seat pan adjustment
  - Back rest
  - Height

The qualities of a safe and healthy chair are shown in the OSHA eTools as well as on the Canadian Centre for Occupational Health and Safety (CCOHS) website (Figure 6.4).

The tools contained in the OSHA eTools were developed by the U.S. Federal Government under the direction of a technical editorial board lead by Brett Besser (OSHA eTools, 2011). It is important that we move our bodies frequently at work and avoid static postures for long periods of time. The traditional thinking that everyone should sit completely upright is mistaken. Many different postures can be comfortable, and there is no one “best” posture. Work furniture should be designed to support task requirements and placed for easy variations of postures. Sitting on flat hard surfaces causes the natural lordosis of the spine to become flattened. Therefore, sitting on such surfaces should be avoided. Also, forward declining seats force the hip angle to open and contribute to lordosis. Some of the disadvantages that come with forward declining seats include: hard to sit on, forward slippage, shin pressure, increased fatigue, and uneasy work positions. Comprehensive guidelines for office ergonomics is contained in the OSHA eTools resource (OSHA, 2011).

#### 6.5.4 WORKING IN CONFINED AND AWKWARD SPACES

Confined space operations exist throughout a vast majority of industries and in some cases have resulted in injuries and deaths. Examples of confined work spaces are shown in Figure 6.5. According to the Bureau of Labor Statistics (BLS), from July 1, 1972, to January 2002, 119 workers were injured and 353 were killed in confined spaces (BLS, 2004). John Rekus, a well-known researcher in the area of confined space operations, attributes confined space injuries and deaths to atmospheric

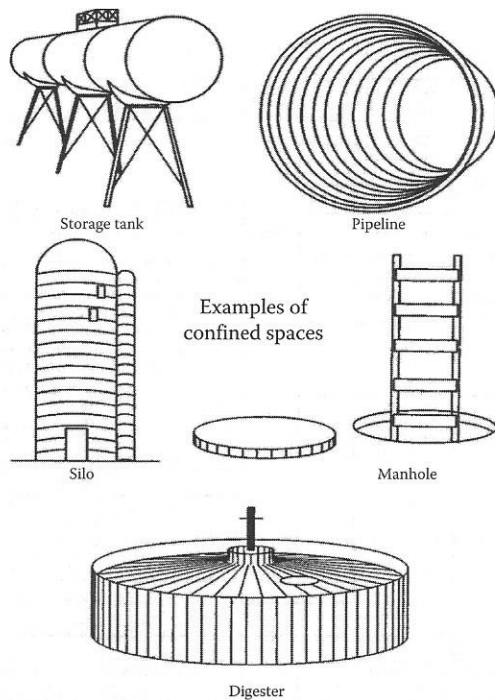


**FIGURE 6.5** Examples of confined work spaces. (Source: *Confined Spaces*, 1987, CDC website: <http://www.cdc.gov/niosh/publications/confinedspaces.html>)

oxygen-deficient environments, explosions, falling objects, being caught or crushed, being struck by moving equipment, temperature extremes, noise vibrations, and other hazards. Risk factors are often a result of task design, inherent task risks, but in some cases a result of unsafe safety practices. While some issues in confined spaces require a combination of ergonomics and safety to support workers in reducing operator risk levels. Confined space operations present unique risk factors, such as claustrophobia, reduced situational and spatial awareness, and limited escape routes, which should be addressed as an aspect of task design.

On January 14, 1993, the U.S. Occupational Safety and Health Administration (OSHA) issued the final rule for Confined Spaces for General Industry (29 CFR 1910.146) with an effective date of April 15, 1993. This rule is part of a comprehensive confined space program that includes permitting, testing, training, emergency rescue, and other safety measures (May 5, 1995) (Figure 6.6).

Although there has been some research on task analysis and habitability pertaining to confined spaces, such as Arctic underwater mining, NASA's

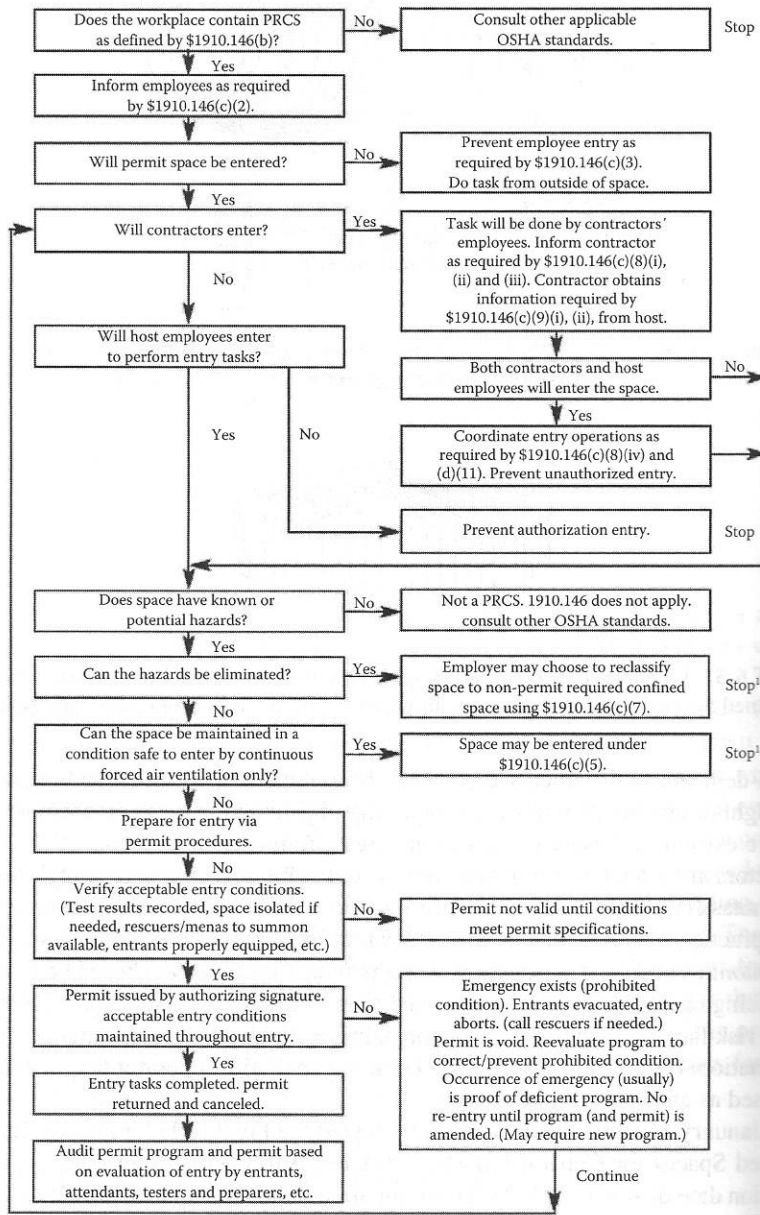


**FIGURE 6.5** Examples of confined work spaces (Source: Pettit and Linn, *A Guide to Safety in Confined Spaces*, 1987, CDC website: <http://www.cdc.gov/niosh/topics/confinedspace/>).

oxygen-deficient environments, explosions, becoming trapped, electrocution, becoming caught or crushed, being struck by falling objects, ingress or egress issues, temperature extremes, noise vibrations, and stress from exertion (Rekus, 1994). These risk factors are often a result of task design constraints (i.e., underground mining) or inherent task risks, but in some cases result from a lack of appropriate ergonomic and safety practices. While some issues in task requirements cannot be changed, the use of ergonomics and safety to support workers in confined spaces should be a priority in reducing operator risk levels. Confined space workers are also subject to psychological risk factors, such as claustrophobia, maintaining appropriate attention levels, and situational and spatial awareness. These psychological operator needs should be addressed as an aspect of task design.

On January 14, 1993, the U.S. OSHA adopted the Final Rule for Permit-Required Confined Spaces for General Industry (29 CFR 1910.146) with an effective implementation date of April 15, 1993. This regulation requires employers to set up a comprehensive confined space program that includes, but is not limited to, identification, permitting, testing, training, emergency response, and rescue (OSHA Directives, May 5, 1995) (Figure 6.6).

Although there has been some research in the areas of work design, workload, task analysis and habitability pertaining to confined environments, including the Arctic underwater mining, NASA studies, and tanking operations, there is a need



<sup>1</sup>Spaces may have to be evacuated and reevaluated if hazards arise during entry. Source: 29 CFR 1910.146 appendix A.

FIGURE 6.6 Permit required confined space decision flow chart.

for further research in order to identify performance in all types of confined space in risk factor matrix, but ultimately in utilizing potential injury to the confined space workers and McCauley-Bell, 2005; Winn et al., 19

### 6.5.5 DESIGNING FOR HAND USE

The human hand is one of the most intricate structures containing over 29 major and minor bones, joints, and ligaments. This network of joints and ligaments allows for a wide range of postures and movements. In the occupational setting, the hand is used extensively in physical task performance and a large variety of required activities. These activities range from fine, precise movements to coarse, forceful movements and task performance (Kroemer et al. as follows (Kroemer et al.

- Fine manipulation of objects, requiring precision, for example, writing, adjusting controls.
- Fast movements toward an object, such as catching a ball, but fairly small exertion.
- Frequent movements between target and source, for example, switching and then operating it.
- Forceful activities with little or no precision, for example, an assembly line worker assembling them.
- Forceful activities with little or no precision, for example, using a hand tool against resistance, such as driving a nail in the wall.
- Forceful activities with large displacement, such as putting a nail in the wall.

The three categories of requirements are precision, strength, and displacement. Fitts' Law was developed to predict human performance in tasks that require precision. Fitts' Law was developed to predict human performance in tasks that require precision. Fitts' Law was developed to predict human performance in tasks that require precision. Fitts' Law was developed to predict human performance in tasks that require precision.

where  
 $MT = a + b \log_2 \left( \frac{A}{W} \right)$   
 $MT$  is the movement time  
 $a$  and  $b$  are empirically determined constants  
 $A$  is the movement amplitude (distance from starting point to target)  
 $W$  is the width of the target

for further research in order to identify the risk factors that affect human performance in all types of confined space industries—not only in developing a formal risk factor matrix, but ultimately in utilizing the identified risk factors in mitigating potential injury to the confined space worker (Brody, 1993; Randolph, 1996; Relvini and McCauley-Bell, 2005; Winn et al., 1996).

### 6.5.5 DESIGNING FOR HAND USE

The human hand is one of the most intricate members of the human anatomy containing over 29 major and minor bones, 29 major joints, 48 nerves, and 123 ligaments. This network of joints and ligaments enable the hand to assume a broad array of postures and movements. In the occupational environment, the hand is used extensively in physical task performance and the human hand is capable of performing a large variety of required activities. These activities range from fine manipulation to coarse, forceful movements and task performance can be categorized according to Kroemer et al. as follows (Kroemer et al., 2010):

- Fine manipulation of objects, requiring little displacement and force, for example, writing, adjusting controls, and assembling small parts
- Fast movements toward an object, requiring moderate accuracy to reach the target but fairly small exertions of force, for example, moving toward a switch and then operating it
- Frequent movements between targets that require higher accuracy but little force, for example, an assembly task that involves taking parts from bins and assembling them
- Forceful activities with little or moderate displacement, for example, turning a hand tool against resistance
- Forceful activities with large displacement, for example, using a hammer to put a nail in the wall

The three categories of requirements when designing tasks for hand use are accuracy, strength, and displacement. *Fitts' Law* (Fitts, 1954) has been used historically as a foundational source for guidance in design for accurate and fast movements. Fitts' Law was developed to predict hand movement time and can be used to promote accuracy in task performance. The premise of this law is that movement time is a direction function of task difficulty, and that task difficulty is directly related to movement distance and inversely related to the size of the target. The following equation describes this relationship:

$$MT = a + b \log_2 \left( \frac{2A}{W} \right) \quad (6.1)$$

where

$MT$  is the movement time

$a$  and  $b$  are empirically determined constants

$A$  is the movement amplitude (distance) from start to centerline of target

$W$  is the width of the target

The term  $\log_2(2A/W)$  is referred to as the index of difficulty and is a measure of the difficulty of the motor task.

This law should be considered in task design involving hand tasks and hand movements particularly for precise activities.

Fitts' Law has also been applied to foot motion (Drury, 1975). This study used a modification of this law to predict movement time for operating foot pedals. Drury defined the index of difficulty as follows:

$$ID = \log_2 \left( \frac{A}{W} + S \right) + 0.05 \quad (6.2)$$

where

$ID$  is the index of difficulty

$A$  is the movement amplitude (distance) from start to centerline of target

$W$  is the width of the target

$S$  is the shoe sole width

This information can be used in design foot controls, pedals, or other foot-activated devices.

Methods-time measurement (MTM) is a well-researched area of occupational ergonomics, laboratory experiments, and process design. This work was originally referred to as scientific management (Luczak, 1997). MTM is a procedure for improving methods and establishing time standards by recognizing, classifying, and describing the motions used or required to perform a given operation and assigning predetermined time standards to these motions (MTM.org, website, 2011). The MTM Association for Standards and Research is a nonprofit organization that has led the way in the development of computerized and manual work measurement systems that recognize, classify, describe, and objectively measure the performance of individuals working at various levels within an organization (MTM.org, website, 2011). Although this area began with one method for time measurement, it has evolved into a dynamic family of systems that can be used in numerous industrial settings. An example of the use of MTM times is shown in Table 6.2 (Maynard, 1948). This table can be used to predict movement time for specific distances given a particular type of movement (Luczak, 1997).

### 6.5.5.1 Hand Tool Design

The design of hand tools is a complicated ergonomic task because several factors must be simultaneously considered. It is essential that hand tools fit the contours of the hand while using strength and energy capabilities required for task performance without overloading the body; likewise tools should be designed so that they can be held securely with a straight wrist and proper arm posture. Numerous disorders are associated with improper use of hand tools when ergonomic principles are violated. Some disorders that have been reported due to non-powered and powered hand tools include (NIOSH, 1995) the following:

TABLE 6.2

Example of a MTM Table of Motion Times

Case	Description	Distance moved (in.)	Methods-Time (min)
A	Reach to object in fixed location or to object in other hand or on which other hand rests	1	6.1
		2	6.5
		3	7.0
		4	7.4
B	Reach to single object in location that may vary slightly from cycle to cycle	5	7.9
		6	8.3
		7	8.7
		8	9.1
C	Reach to object in group	9	10.5
		10	11.0
		12	11.4
		14	11.8
D	Reach to very small object or where accurate grasp is required	16	12.2
		18	12.7
		20	13.1
		22	13.6
E	Reach to indefinite location to get hand in position for body balance or next motion or out of way	24	14.0
		26	14.5
		28	15.0
		30	15.5

Source: Maynard et al. (1948).

- Acute musculoskeletal problems
- Muscle, tendon, or ligament tear, etc.
- Chronic Musculoskeletal Disorders
- Vascular disorders
- Vibration "white finger"
- Hearing impairments
- Respiratory disorders

The types of industries in the United States range from service industries to agriculture experiencing nonfatal occupational injuries listed in Table 6.3 (U.S. Bureau of Labor

**TABLE 6.2**  
**Example of a MTM Table of Motion Times**

		Methods-Time Data						
		Table I-Reach						
		Leveled Time TMUs						
Case	Description	Distance moved (in.)	A STD.	A Hand in Mot.	A with C, D or B	B Hand in Mot.	C or D	E
A	Reach to object in fixed location or to object in other hand or on which other hand rests	1			2.1		3.6	
		2			4.3		5.9	
		3			5.9		7.3	
		4	6.1	4.9	7.1	4.3	8.4	6.8
B	Reach to single object in location that may vary slightly from cycle to cycle	5	6.5	5.3	7.8	5.0	9.4	7.4
		6	7.0	5.7	8.6	5.7	10.1	8.0
		7	7.4	6.1	9.3	6.5	10.8	8.7
		8	7.9	6.5	10.1	7.2	11.5	9.3
C	Reach to object in group	9	8.3	6.9	10.8	7.9	12.2	9.9
		10	8.7	7.3	11.5	8.6	12.9	10.5
		12	9.6	8.1	12.9	10.1	14.2	11.8
		14	10.5	8.9	14.4	11.5	15.6	13.0
D	Reach to very small object or where accurate grasp is required	16	11.4	9.7	15.8	12.9	17.0	14.2
		18	12.3	10.5	17.2	14.4	18.4	15.5
		20	13.1	11.3	18.6		19.8	16.7
		22	14.0	12.1	20.1		21.2	18.0
E	Reach to indefinite location to get hand in position for body balance or next motion or out of way	24	14.9	12.9	21.5		22.5	19.2
		26	15.8	13.7	22.9		23.9	20.4
		28	16.7	14.5	24.4		26.3	21.7
		30	17.5	15.3	25.8		26.7	22.9

Source: Maynard et al. (1948).

- Acute musculoskeletal problems
- Muscle, tendon, or ligament tear, bone fractures
- Chronic Musculoskeletal Disorders (MSDs)
- Vascular disorders
- Vibration "white finger"
- Hearing impairments
- Respiratory disorders

The types of industries in the United States that are prone to occupational injuries range from service industries to agriculture. Some of the primary industry divisions experiencing nonfatal occupational injuries due to hand tools in the United States are listed in Table 6.3 (U.S. Bureau of Labor Statistics, 2002).

**TABLE 6.3**  
**Nonfatal Occupational Injuries Due to Hand Tools in Major U.S. Industry Divisions (2002)**

Industry	Total Number	Due to Hand Tools
All private industry	1,436,194	66,588
Agriculture, forestry, and fishing	31,520	2,185
Mining	11,355	758
Construction	163,641	14,439
Manufacturing	280,005	16,032
Transportation and public utilities	168,632	3,116
Wholesale and retail trade	372,192	19,179
Finance, insurance, and real estate	36,689	1,399
Services	372,159	9,443

*Source:* Kumar, S. (Ed.), *Biomechanics in Ergonomics*, 2nd edn., CRC Press, New York, 2008.

While the actual number of incidents is larger in some industries such as services, the evidence that this is more of an issue in physically intensive industries such as construction, transportation, mining, and agriculture is seen when reviewing the incidence rates. Table 6.4 provides incidence rates for nonfatal occupational industries due to hand tools in the United States.

Given these statistics, an emphasis should be placed on designing safe hand tools, procedures for use, and employing necessary administrative controls to reduce risk of injury in hand tool use.

Hand grip on a tool, also known as tool coupling, is important in defining the amount of force transferred, as well as the precision of transfer. Kroemer identifies ten generally recognized tool couplings as follows (Kroemer, 1986, 2001):

1. Digit touch
  - a. One digit (finger) touches an object
2. Palm to touch
  - a. Some part of the palm or hand touches object
3. Finger palmar grip (hook grip)
  - a. One finger or several fingers hook onto a ridge or handle. This type of finger action is used where thumb counterforce is not needed.
4. Thumb-fingertip grip (tip pinch)
  - a. The thumb tip opposes one fingertip.
5. Thumb-finger palmar grip (pad pinch or plier grip)
  - a. Thumb pad opposes the palmar pad of one finger (or the pads of several fingers) near the tips.
6. Thumb-forefinger side grip (lateral grip or side pinch)
  - a. Thumb opposes the radial side of the forefinger

**TABLE 6.4**  
**Incidence of Nonfatal Occupational Injuries in the United States (2002) Due to Different Types of Non-Powered Hand Tools Classified by Major U.S. Industry Divisions**

Tool Type	Total Number	Agriculture, Forestry, and Fishing			Transportation and Public Utilities			Wholesale Trade		Retail Trade		Finance, Insurance, and Real Estate		Services	
		208.6	198.8	174.5	270.6	175.0	153.6	53.5	133.8	10.8	7.0	3.0	7.0	1.6	2.3
A	162.6	208.6	198.8	174.5	270.6	175.0	153.6	53.5	133.8	10.8	7.0	3.0	7.0	1.6	2.3
B	10.6	16.2	30.6	12.0	12.3	8.0	10.8	3.0	10.8	10.8	10.8	3.0	10.8	1.6	2.3
C	5.1	9.4	13.5	5.8	3.6	3.9	7.9	1.6	7.9	7.9	7.9	1.6	7.9	1.6	2.3
D	0.1	—	0.3	0.1	—	0.1	—	—	—	—	—	—	—	—	0.0
E	2.7	5.2	5.1	2.3	0.7	2.1	6.3	0.8	6.3	6.3	6.3	0.8	6.3	0.8	1.2

**TABLE 6.4**  
**Incidence of Nonfatal Occupational Injuries in the United States (2002) Due to Different Types of Non-Powered Hand Tools Classified by Major U.S. Industry Divisions**

Tool Type	Total Number	Agriculture, Forestry, and Fishing				Mining			Construction		Manufacturing		Transportation and Public Utilities		Wholesale Trade		Retail Trade		Finance, Insurance, and Real Estate		Services
A	162.6	208.6	198.8	276.8	174.5	270.6	175.0	153.6	53.5	133.8											
B	10.6	16.2	15.6	30.6	12.0	12.3	8.0	10.8	3.0	7.0											
C	5.1	9.4	11.9	13.5	5.8	3.6	3.9	7.9	1.6	2.3											
D	0.1	—	0.2	0.3	0.1	—	0.1	—	—	0.0											
E	2.7	5.2	0.5	5.1	2.3	0.7	2.1	6.3	0.8	1.2											
F	0.5	2.0	—	3.0	0.4	0.7	0.2	0.1	0.4	0.3											
G	0.1	—	3.0	0.2	0.3	0.2	—	—	—	0.1											
H	0.1	—	—	—	0.1	0.0	—	0.1	—	0.1											
I	0.5	0.6	2.3	2.6	0.9	0.5	0.5	0.1	0.2	0.1											
J	0.1	—	—	0.2	0.1	—	—	—	—	0.0											
K	0.4	0.6	2.8	0.9	0.9	0.7	0.6	0.2	0.1	0.1											
L	0.6	0.8	2.9	1.1	0.6	0.7	0.3	1.0	0.1	0.4											

Source: Kumar, S. (Ed.), *Biomechanics in Ergonomics*, 2nd edn., CRC Press, New York, 2008.

Note: A, total in all private industries; B, tools, instruments, and equipment; C, non-powered hand tools; D, non-powered boring hand tools; E, non-powered cutting hand tools; F, non-powered digging hand tools; G, non-powered gripping hand tools; H, non-powered measuring hand tools; I, non-powered striking and nailing hand tools; J, non-powered surfacing hand tools; K, non-powered turning hand tools; L, non-powered hand tools such as crowbars, pitchforks, etc.

7. Thumb-two-finger grip (writing grip)
  - a. Thumb and two fingers, often forefinger and middle finger, oppose each other at or near the tip.
8. Thumb-fingering enclosure (disc grip)
  - a. Thumb pad and the pads of three or four fingers oppose each other near the tips (object grasped does not touch the palm). This grip evolves from coupling #7.
9. Finger-palm enclosure (collet enclosure)
  - a. Most, or all, of the inner surface of the hand is in contact with the object while enclosing it. This enclosure evolves easily from coupling #8.
10. Power grasp
  - a. The total inner hand surface is grasping the (often cylindrical) handle that runs parallel to the knuckles and generally protrudes on one or both sides from the hand. This grasp evolves easily from coupling #9.

Although there are often additional risks when using powered hand tools, the use of non-powered hand tools poses definite risks in task performance. These tools can include hammers, crowbars, pitch forks, and digging tools. The incidence rate for nonfatal occupational injuries in the United States due to non-powered hand tools is shown in Table 6.4.

Incidence rates represent the number of injuries and illness per 10,000 full-time workers and are computed as follows:

$$\text{Incidence rate} = \left( \frac{N}{EH} \times 20,000,000 \right) \quad (\text{Figure 6.3})$$

where

$N$  is the number of injuries

$EH$  is the total hours worked by all employees during the calendar year

20,000,000 is the base for 10,000 equivalent full-time workers (working for 40 hours/week, 50 weeks/year).

Hand tools are either manual, power driven, or a combination of both. When using manually driven tools, the operator generates all the energy and is always in full control of the energy exerted, except with percussion tools. A few examples of manually driven tools and tasks are described in the following:

- *Percussive*: swing or hold handle
- *Scraping*: push, pull, or hold handle
- *Rotation or boring*: push, pull, turn, or hold handle
- *Squeezing*: press and hold handle
- *Cutting*: pull or push while holding handle, for example, scissors and knives

When handling power-driven tools, the operator holds places and moves the tool. Energy is generated by an external power source with the exception of the operators' dynamic static load in holding the tool. Sudden resistance can cause injury

and vibrations can lead to overuse disorder. It is important when handling hand tools. The hand should be kept straight to avoid overexertion of the muscles and compression of nerves and blood vessels. Normal force along the forearm axis. It is always better to bend the hand in tools need to be designed so that the handle is not curved. Having a straight and uniform surface. A curved handle can make the grip uncomfortable, however, it is in line with hand anatomy. Friction on surfaces can increase the risk of dropping the tools. The following are guidelines for working with hand tools (Kroemer, 2001):

- Push or pull in the direction of the force of the tool.
- Keep the wrist straight.
- Provide good coupling between hand and tool.
- Avoid pressure spots and pinch points.
- Avoid tools that transmit vibrations.
- Do not operate tools frequently and rest when necessary. Rest is preferable.

When considering existing tools in a new design on the operators' hand should be considered. (2004), on evaluation of non-powered hand tools used in forestry trades. A 16-item checklist was developed for the evaluation (see Figure 6.7).

### 6.5.5.2 Power Hand Tools

In 1994, the Engineering Control Technology Institute for Occupational Safety and Health initiated the development of Power Hand Tools in the Automotive Industry to reduce the incidence of work-related MSDs. According to the Institute, power tools categorizes and evaluates products as follows:

- Tool weight and load distribution
- Tool grip size, shape, and texture
- Torque reaction
- Torque scatter performance
- Vibration

Vibration is a factor that has had substantial effects on workers. Moderate-, and high-frequency vibrations can cause substantial vibration and in some cases can damage the blood vessels and nerves. There is a greater risk of developing a vibration-related injury if the worker is exposed often or for long periods of time. The

and vibrations can lead to overuse disorders or CTDs. Proper posture of the hand is important when handling hand tools. The wrist should never be bent but should be kept straight to avoid overexertion of the muscles and hand tissues, as well as compression of nerves and blood vessels. Normally, the grasp centerline is at about 70° to the forearm axis. It is always better to bend the tool than to bend the wrist. Handles in tools need to be designed so that the handle fits to the form of the hand, instead of having a straight and uniform surface. Bulges and restrictions generate a form fit but can make the grip uncomfortable, however, when used in a manner consistent with hand anatomy. Friction on surfaces can also help improve grip and reduce the risk of dropping the tools. The following rules should be applied when designing or working with hand tools (Kroemer, 2001):

- Push or pull in the direction of the forearm, with the handle directly in front of it.
- Keep the wrist straight.
- Provide good coupling between hand and handle, by shape and friction.
- Avoid pressure spots and pinch points.
- Avoid tools that transmit vibrations to the hand.
- Do not operate tools frequently and forcefully by hand; automated interaction is preferable.

When considering existing tools in a workplace, the ergonomic impact of the design on the operators' hand should be considered. In study by Dababneh et al. (2004), on evaluation of non-powered hand tools, 18 tools were selected to represent typical non-powered hand tools commonly used in the construction and carpentry trades. A 16-item checklist was developed that can be useful in hand tool evaluation (see Figure 6.7).

#### 6.5.5.2 Power Hand Tools

In 1994, the Engineering Control Technology Branch (ECTB) of the National Institute for Occupational Safety and Health initiated a project entitled the "Ergonomic Study of Power Hand Tools in the Automotive Manufacturing Industry" due to a prevalence of work-related MSDs. According to this study, the ergonomic evaluation of power tools categorizes and evaluates properties that include

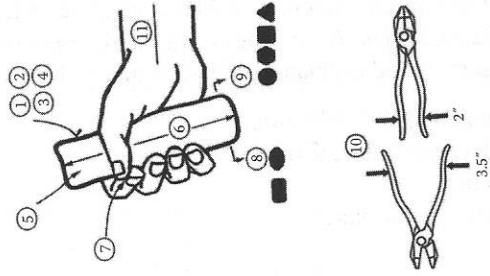
- Tool weight and load distribution
- Tool grip size, shape, and texture
- Torque reaction
- Torque scatter performance
- Vibration

Vibration is a factor that has had substantial impacts on workers. This includes low-, moderate-, and high-frequency vibration. Some hand-held power tools can produce substantial vibration and in some cases tools generate vibration levels so high they can damage the blood vessels and nerves in the operators' hands. Workers are at a greater risk of developing a vibration-related injury if they use vibrating power tools often or for long periods of time. The hand-arm vibration syndrome (HAVS) is the

**Checklist for the Ergonomic Evaluation of Hand Tools**

Considering the job the tool is designed for and the work environment, respond to each item on the checklist by "Yes," "No," or "NA" (not applicable). Place the score that corresponds to your response in the "score" column. Add the scores of all items to get the total score of the tool. Maximum score is 100.  
 (\*Items 7, 8, 9, and 10 are not applicable for all tools.)

First thing first: The tool will do the job with the desired quality and will last as expected.  
 Yes: continue with the checklist;  
 No: reject the tool.



Item	Ergonomic Feature	Yes	NA	No	Score
1	Grip surface is non-slippery.	+10		0	
2	Grip surface does not have sharp edges, undercuts, deep ribs, and/or finger grooves.	+10		0	
3	Grip surface is electrically insulated; tool handle is either made of wood or coated with rubber or soft plastic.	+10		0	
4	Grip surface is thermally insulated; it will not get hot or cold quickly when working in a hot or cold environment.	+2		0	
5	Handle is made of wood, or grip surface is coated with semi-pliable material; not too hard and not too soft, similar to the rubber used in the soles of sport shoes.	+10		0	
6	Grip length is 4 - 6"; handle does not end inside the palm of the hand.	+10		0	
7	For one-handle tools: Size of handle cross section is not too small or too large. The index finger and the thumb are allowed to overlap by 3/8" when gripping (for hammers and hammer-like tools, overlap of 1/2" is acceptable).	+8*	0	0	
8	For one-handle tools other than screwdrivers: Shape of handle cross section is oval or rounded-edge rectangular.	+2*	0	0	
9	For screwdrivers: The basic shape of handle cross section is circular, hexagonal, square, or triangular.	+2*	0	0	
10	For two-handle tools (plier-like): Grip span is greater or equal than 2" when fully closed and less than or equal to 3.5" when fully open.	+10*	0	0	
11	Angle of the handle is formed so that the work can be done keeping a straight wrist.	+10		0	
12	The tool weight is less than 5 lb.	+10		0	
13	The tool can be used with either hand.	+2		0	
14	The tool can be used with the worker's dominant hand.	+10		0	
15	The tool will allow a two-handed operation (using both hands at the same time).	+4		0	
16	The tool and accessories are clearly marked and/or color coded so they are easy to identify; colors are bright and tool contrasts with the surroundings of the work area.	+2		0	

Total score of the tool (100 points possible)



FIGURE 6.7 Checklist for non-powered hand tools

Result of regular use of vibrating pneumatic hand tools. This musculoskeletal condition... Power hand tools generally use electric motor, gas, battery, or power actuated. A few e...

- Drills
- Staple guns
- Pneumatic torque wrenches
- Nail guns
- Portable abrasive wheel tools
- Floor sanders

Operators using power hand tools are often... abrasive and splashing objects; or exposed... hazard. Hazards and ergonomic risk... can be prevented by the following five b... (OSHA, 2011):

- Keep all tools in good condition with
- Use the right tool for the job.
- Examine each tool for damage before
- Operate according to the manufactur
- Provide and use the proper protectio

**6.5.6 DESIGNING FOR FOOT OPERATION**

Compared to hand movements over the... energy, are less accurate, and are slower... be used, because these physical efforts... alone. For a person who sits while at w... complicated, because the seat supports th... The amount of force that can be exert... posture during actuation. Following are c... controls (Helander, 2006):

- Require repeated foot operation
- Design for pushing roughly in the
- Small forces should be applied by
- Perform large forces by pushing
- Do not require fine control, cont... simultaneously.

For the sitting operator of a foot control, the best produced at knee angles of 100

result of regular use of vibrating pneumatic, electric, hydraulic, or gasoline-powered hand tools. This musculoskeletal condition can be permanently disabling.

Power hand tools generally use electric motors but can also be pneumatic, hydraulic, gas, battery, or power actuated. A few examples of power hand tools include

- Drills
- Staple guns
- Pneumatic torque wrenches
- Nail guns
- Portable abrasive wheel tools
- Floor sanders

Operators using power hand tools are often exposed to the hazards of falling, flying, abrasive and splashing objects; or exposed to harmful dusts, fumes, mists, vapors, or gases. The appropriate personal protective equipment is necessary to protect from the hazard. Hazards and ergonomic risk factors involved in the use of power tools can be prevented by the following five basic safety rules (Hand and Power Tools, 2011; OSHA, 2011):

- Keep all tools in good condition with regular maintenance.
- Use the right tool for the job.
- Examine each tool for damage before use.
- Operate according to the manufacturer's instructions.
- Provide and use the proper protective equipment.

#### 6.5.6 DESIGNING FOR FOOT OPERATION

Compared to hand movements over the same distance, foot motions consume more energy, are less accurate, and are slower. However, they are considerably more powerful. If the person stands at work, little force and infrequent use of the foot should be used, because these physical efforts require the operator to stand on the other leg alone. For a person who sits while at work, the operation of foot controls is not as complicated, because the seat supports the body, allowing the feet to move as needed.

The amount of force that can be exerted by the foot depends largely on the body posture during actuation. Following are some rules that are used in the design of foot controls (Helander, 2006):

- Require repeated foot operation only from a seated operator.
- Design for pushing roughly in the direction of the lower leg.
- Small forces should be applied by tilting the foot about the ankle.
- Perform large forces by pushing with the whole leg, if possible with a solid back support from the seat.
- Do not require fine control, continuous operations, and quick movements simultaneously.

For the sitting operator of a foot control, guidelines suggest that light downward forces are best produced at knee angles of 105°–110°, while strong forward forces require

knee angles of  $135^{\circ}$ – $155^{\circ}$ . For the standing operator, the controls and work station should allow the knee to bend comfortably; tasks should not overstress the foot through excessive repetition in actuation, and should be within reach of the foot work envelope.

## 6.6 WORK ENVELOPES

The primary work space (i.e., work surface) should take into account the maximum vertical and horizontal reach of both male and female workers. This space, defined as the work envelope, represents the space where task activities, equipments, and tools should be placed for an individual to perform the task without excessive reach, awkward posture, or discomfort. An example of seated work reach envelopes are provided in Figure 6.8. In the standing work envelope, the individual should not have to bend forward and only the extension of the arm and hand should be considered as the functional work space is designed. The work stations should be designed for the fifth percentile female to reach the work area and the most frequently performed activities should be performed while the individual's elbows are at the sides, thus creating a smaller vertical and horizontal work envelope (Eastman Kodak, 1983). The dimensions used to define the work envelopes should be compatible with the employee population and take into consideration all work, equipment, and tools that

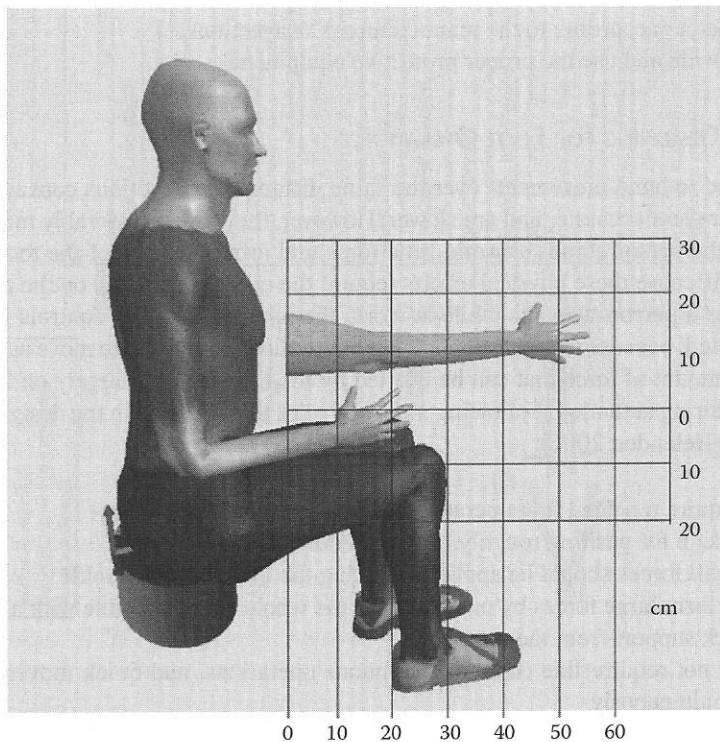


FIGURE 6.8 Example of a worker reaching for envelopes.

are required for task performance. For a

VI, Appendix A of Eastman Kodak (1983)

## 6.7 WORKPLACE EVALUATION

A useful resource to identify applica  
*Ergonomics Handbook* (Marras and  
Bernard in the College of Public Health  
piled an impressive summary of ergonom  
of postural and workplace evaluation to  
analysis. An abbreviated list of some of  
this chapter. Any tool that is used should  
accepted data or norms, and have underg  
(i.e., publication in peer review journals).  
consider the following factors:

- Type of environment being assessed
- Level of expected risks
- Types of risks
- User population
- Compatibility of tool in assessing (primary risk factors)
- Economic resources available to

A job analysis tool designed to provide  
standing of the operator and work env  
Erhebungsverfahren zur Tätigkeitsanaly  
"Ergonomic Job Analysis Technique." T  
ates relevant areas of the following in task

- Work object
- Work resources
- Working environment
- Work task
- Work requirements

Table 6.5 provides details associated with  
using the AET method.

This is a theoretical approach that can be  
(analysis tools) to perform the assessment  
assuring a systematic and comprehensive

JACK ergonomic software is a human  
oped by the Center for Human Model  
Pennsylvania. This product can support  
by providing users with a computer-based  
design and system parameters relevant to

are required for task performance. For a detailed listing of dimensions, see Chapter VI, Appendix A of Eastman Kodak (1983).

## 6.7 WORKPLACE EVALUATION TOOLS

A useful resource to identify applicable ergonomic tools is *The Occupational Ergonomics Handbook* (Marras and Karwowski, 2001). Likewise, Dr. Thomas Bernard in the College of Public Health at the University of South Florida has compiled an impressive summary of ergonomic analysis tools (Bernard, 2011). A number of postural and workplace evaluation tools are available to support an ergonomic analysis. An abbreviated list of some of these tools is provided at the conclusion of this chapter. Any tool that is used should follow sound ergonomic principles, utilize accepted data or norms, and have undergone some form of independent evaluation (i.e., publication in peer review journals). The selection of an evaluation tool should consider the following factors:

- Type of environment being assessed
- Level of expected risks
- Types of risks
- User population
- Compatibility of tool in assessing task risk factors (i.e., can it assess primary risk factors)
- Economic resources available to support the test

A job analysis tool designed to provide a systematic approach to a holistic understanding of the operator and work environment is the "Arbeitswissenschaftliches Erhebungsverfahren zur Tätigkeitsanalyse" or AET method, translated as the "Ergonomic Job Analysis Technique." This technique considers, measures, or evaluates relevant areas of the following in task performance (Luczak, 1997):

- Work object
- Work resources
- Working environment
- Work task
- Work requirements

Table 6.5 provides details associated with each of these aspects of the evaluation using the AET method.

This is a theoretical approach that can be applied utilizing any number of resources (analysis tools) to perform the assessments in each category and can be useful in assuring a systematic and comprehensive evaluation of the work environment.

JACK ergonomic software is a human-centric modeling software system developed by the Center for Human Modeling and Simulation at the University of Pennsylvania. This product can support research, design, and product development by providing users with a computer-based tool that allows the evaluation of various design and system parameters relevant to biomechanics, ergonomics, and physiology.

**TABLE 6.5**  
**Contents of the AET**

<b>Part A—Work System Analysis</b>	
1. Work objects	
1.1. Material work objects (physical condition, special properties of the material, quality of surfaces, manipulation delicacy, form, size, weight, dangerousness)	
1.2. Energy as work object	
1.3. Information as work object	
1.4. Man, animals, plants as work objects	
2. Equipment	
2.1. Working equipment	
2.1.1. Equipment, tools, machinery to change the properties of work objects	
2.1.2. Means of transport	
2.1.3. Controls	
2.2. Other equipment	
2.2.1. Displays, measuring instruments	
2.2.2. Technical aids to support human sense organs	
2.2.3. Work chair, table, room	
3. Work environment	
3.1. Physical environment	
3.1.1. Environmental influences	
3.1.2. Dangerousness of work and risk of occupational diseases	
3.2. Organizational and social environment	
3.2.1. Temporal organization of work	
3.2.2. Position in the organization of work sequence	
3.2.3. Hierarchical position in the organization	
3.2.4. Position in the communication system	
3.3. Principles and methods of remuneration	
3.3.1. Principles of remuneration	
3.3.2. Methods of remuneration	
<b>Part B—Task Analysis</b>	
1. Tasks relating to material work objects	
2. Tasks relating to abstract work objects	
3. Man-related tasks	
4. Number and repetitiveness of tasks	
<b>Part C—Job Demand Analysis</b>	
1. Demands on perception	
1.1. Mode of perception	
1.1.1. Visual	
1.1.2. Auditory	
1.1.3. Tactile	
1.1.4. Olfactory	
1.1.5. Proprioceptive	
1.2. Absolute/relative evaluation of perceived information	
1.3. Accuracy of perception	

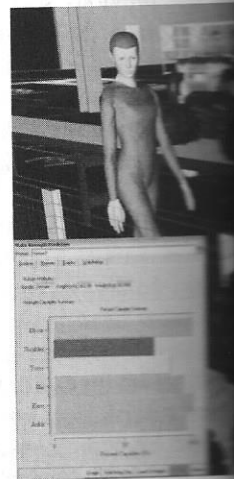
(continued)

**TABLE 6.5 (continued)**  
**Contents of the AET**

<b>Part C—Job Demand Analysis</b>	
2. Demands for decision	
2.1. Complexity of decision	
2.2. Pressure of time	
2.3. Required knowledge	
3. Demands for response/activity	
3.1. Body postures	
3.2. Static work	
3.3. Heavy muscular work	
3.4. Light muscular work, active light work	
3.5. Strenuousness and frequency of movements	

Specifically, this tool allows users to... through the positioning of biomechanical... in virtual environments for evaluation... ports ergonomics and biomechanical... humans perform tasks. In this system... various sizes can be placed in virtual en... performance. A result of the detailed mo... dition for in-depth ergonomic assessment

JACK, or other similar products, can... and workplace tasks by supporting de...



**FIGURE 6.9** Jack Siemens ergonomic...

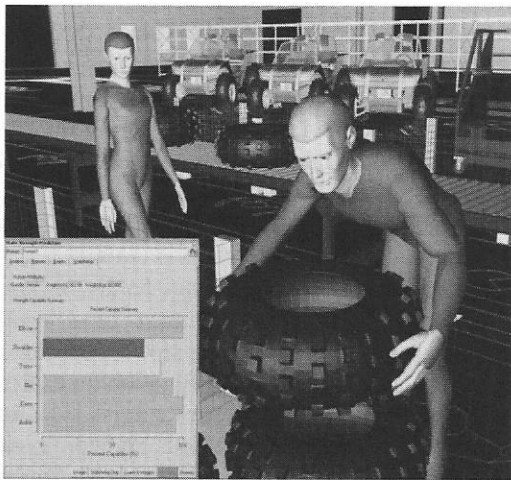
**TABLE 6.5 (continued)**  
**Contents of the AET**

**Part C—Job Demand Analysis**

- 2. Demands for decision
  - 2.1. Complexity of decision
  - 2.2. Pressure of time
  - 2.3. Required knowledge
- 3. Demands for response/activity
  - 3.1. Body postures
  - 3.2. Static work
  - 3.3. Heavy muscular work
  - 3.4. Light muscular work, active light work
  - 3.5. Strenuousness and frequency of movements

Specifically, this tool allows users to improve product design and workplace tasks through the positioning of biomechanically accurate digital humans of various sizes in virtual environments for evaluation. JACK is a human simulation tool that supports ergonomics and biomechanical analysis by creating animations in which digital humans perform tasks. In this system, biomechanically accurate digital humans of various sizes can be placed in virtual environments, assigned tasks, and analyzed for performance. A result of the detailed models available for evaluation is a realistic condition for in-depth ergonomic assessment (Figure 6.9) (Karwowski and Marras, 2003).

JACK, or other similar products, can improve the ergonomics of product designs and workplace tasks by supporting designers and ergonomists in understanding



**FIGURE 6.9** Jack Siemens ergonomic software.



## 6.8 GENERAL GUIDELINES FOR WORKPLACES WITH CONTROLS AND DISPLAYS

The information age has led to the design of individual workstations that have numerous and often complex controls and displays. According to Van Coltt and Kinkade (1972), when designing workplaces, some general guidelines can be applied (Sanders and McCormick, 1987):

- *First priority:* primary visual tasks
- *Second priority:* primary controls that interact with primary visual tasks
- *Third priority:* control–display relationships (put controls near associated displays, compatible movement relationships, etc.)
- *Fourth priority:* arrangement of elements to be used in sequence
- *Fifth priority:* convenient location of elements that are used frequently
- *Sixth priority:* consistency with other layouts within the system or in other systems

A more detailed discussion of controls and display can be found in Chapter 9.

## 6.9 SUMMARY

Workplace design requires the accommodation of employees of different builds and sizes so that everyone is comfortable and can work in the appropriate postures necessary to avoid injury while accessing tools for task performance. Some common principles of workplace design include the provision of comfortable seating, workstation design, equipment selection and environmental factors. An ergonomic approach should be applied to ensure a safe, healthy, and productive workplace.

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### Case Studies

#### *Ergonomics Case Study:*

#### *The Dow Chemical Company's Use of the "Six Sigma" Methodology* May 15, 2004

#### **The Problem: Reducing Musculoskeletal Disorders**

Ergonomics-related injuries, including musculoskeletal disorders (MSDs) caused by repetitive strains, continue to be a serious problem for employers. In 2002, ergonomics-related injuries accounted for a third of all workplace injuries involving missed work time, with an average absence of nine days per injury.<sup>1</sup> The resulting worker injury claims and loss of productivity are estimated to cost \$13 to \$20 million per year for U.S. employers.<sup>2</sup> As computer workstation users spend more and more time at desktops, the risk of MSDs occurring has increased. Yet, as illustrated below, in many companies there are inherent difficulties and concerns associated with addressing this increased ergonomics risk.

For example, Tricia, the Environmental, Health and Safety (EH&S) Leader for the Specialty Chemicals Business of The Dow Chemical Company, wants to reduce MSDs among computer workstation users throughout her business' various divisions and operations. Before she can understand what changes to make in either the workstations or the work practices in those divisions, she must identify the root causes of MSDs among the operators. Although she has some theories, Tricia does not know for sure what factors are causing or contributing to the employees' MSD complaints. Only by knowing the root causes can she implement with confidence controls that would achieve positive results.

Tricia also suspects, but is not sure, that many of the root causes of MSDs are the same across the different operations and divisions in her business. Because of constraints on both her budget and time, Tricia would like to design one basic program that is flexible enough to implement company-wide. She also knows that any reductions achieved under the new program must be sustained over the long term, and she is concerned that over time employees and managers will "backslide" on their commitment to the program and return to their ergonomically risky behaviors.

Fortunately for Tricia, she could refer to a similar project successfully undertaken by the Design and Construction function of The Dow Chemical Company, which is discussed in the case study below. This project, which utilized a problem-solving methodology called "Six Sigma," offered an innovative way to address Tricia's concerns for the development and implementation of a sustainable program to reduce MSDs throughout her business.

## The Solution

### The Dow Chemical Company's Innovative Use of "Six Sigma"<sup>3</sup>

Avoiding ergonomics-related injuries is an important component of The Dow Chemical Company's ("Dow" or "the Company") overall emphasis on safety and health. Dow is a science and technology company that develops, manufactures, and provides various chemical, plastic, and agricultural products and services for customers in over 180 countries. In 1994, Dow adopted a set of voluntary 10-year EH&S goals to dramatically improve the Company's performance by 2005. These goals call for a reduction in the Company's reportable injury and illness rate by 90% to 0.24%.

In 2000, the company identified an opportunity to improve its injury rate within the Dow Design and Construction business unit. Dow Design and Construction ("DDC") is responsible for managing the design and construction of Dow's facilities worldwide. Because DDC's approximately 1250 workers (including employees and contractors) work primarily at desktop workstations, where they spend the majority of their time working at computer keyboards, they were increasingly susceptible to ergonomics injuries. While the rate of ergonomics-related injuries among the DDC workers was low (only three were reported in 1999), the Company chose to make proactive improvements before ergonomic injuries increased in number or severity.

Dow's EH&S function decided to address ergonomic injuries at DDC using the "Six Sigma" problem solving methodology. Six Sigma is a disciplined,

process-oriented approach to problem-solving in manufacturing companies, which emphasizes the reduction of defects in products and services by applying a four-step process. Six Sigma emphasizes sustainable results and is particularly useful for EH&S projects. At Dow Chemical Company, Six Sigma, Dow developed a Six Sigma project to identify contributing factors to MSDs in the workplace and to reduce those factors by 70%. While each step of the project is outlined below, a more detailed description of the project appears at the end of this case study.

### Step 1: Measure

Once the Six Sigma project team developed a project charter, they began by defining the current process. The project team identified events from workstation assignment to workstation use. The next identified a series of key variables that could be measured.

- User attributes (such as daily time available)
- User behaviors (including posture, movement, and speed)
- Environmental factors (such as workstation design, lighting, and noise)

In this phase of the Six Sigma methodology, the project team designed a process for which improvement is desired. The project team identified this process would be the occurrence of MSDs. The project team identified the start of the project that measuring the current process was going to be difficult. Therefore, the project team identified the "defect," and a goal of 70% improvement was set for the project. Scored surveys of the current process were conducted on the variables identified in the list above.

### Step 2: Analyze

Accurately identifying the root causes of a problem is a more effective improvement, is an important part of the Six Sigma methodology. Therefore, the project team used a variety of methods to determine differences in the workstation design, and behavior at the different DDC workstations. The project team used root causes underlying these variables and methodologies, including brain mapping, a process performance matrix, and Antecedent-Consequence analyses. After developing a list of potential root causes, the team used additional Six Sigma tools to identify root causes and validate them. For example, there was a failure of the employee to receive training on workstation compliance to his or her personal well-being. The employee survey, in which many of the employees stated "it won't happen to me."

process-oriented approach to problem solving, adopted by Dow and many other companies, which emphasizes the reduction of defects in processes, products and services by applying a four-step improvement methodology. Because Six Sigma emphasizes sustainable results over short-term fixes, Dow has found it particularly useful for EH&S projects. Following the steps prescribed under Six Sigma, Dow developed a Six Sigma project team, which first defined the primary contributing factors to MSDs in the DDC function, and then sought to reduce those factors by 70%. While each of the four steps of the Six Sigma project are outlined below, a more detailed discussion of the Six Sigma methodology appears at the end of this case study.

### **Step 1: Measure**

Once the Six Sigma project team developed its charter and defined its task, it then began by defining the current process. First, the team outlined the sequence of events from workstation assignment to task performance and potential injury. They next identified a series of key variables affecting the process outcome that included:

- User attributes (such as daily time at workstations)
- User behaviors (including posture, force, and duration of use)
- Environmental factors

In this phase of the Six Sigma method, the “defect”—a measurable outcome of the process for which improvement is desired—is defined. While the true “defect” for this process would be the occurrence of an ergonomic injury, there were so few at the start of the project that measuring a statistically significant improvement was going to be difficult. Therefore, the key process variables identified were taken as the “defect,” and a goal of 70% improvement (reduction) in the baseline level was set for the project. Scored surveys of DDC workstation users were developed and conducted on the variables identified and used to measure the baseline defect level.

### **Step 2: Analyze**

Accurately identifying the root causes of a problem, which in turn leads to more effective improvements, is an essential function of the Six Sigma methodology. Therefore, the project team next analyzed the collected survey data to determine differences in the workstations, work environments, user training, and behavior at the different DDC sites. The team then identified possible root causes underlying these variables using several of the Six Sigma tools and methodologies, including brainstorming, “fishbone” diagramming, a work performance matrix, and Antecedent-Behavior-Consequence and Balance of Consequences analyses. After developing a list of possible root causes, the team used additional Six Sigma tools and methodologies to identify probable root causes and validate them. For example, one possible root cause identified was a failure of the employee to recognize the importance of ergonomics compliance to his or her personal well-being. This root cause was validated by the employee survey, in which many of the employees expressed an attitude of “it won’t happen to me.”

Other key root causes validated through this process were the lack of adjustable furniture at some worksites and a lack of “ownership” in personal safety on the part of the employee. The team also determined that ergonomics was not emphasized by DDC to the same extent as other, more immediate, safety issues such as the use of personal protective equipment in hazardous environments.

### Step 3: Improve

After determining the most significant root causes through analysis and validation, the project team developed a series of improvements to correct the identified root causes, including both work-related and personal risk factors. Workstation deficiencies were easily addressed by implementing a workstation upgrade plan. Elevating workstation ergonomics to the same level of importance as other personal safety and health issues was a more challenging improvement. However, the team elevated the focus on workstation ergonomics by improving awareness on the part of management and employees and by altering employee behavior and work habits through increased accountability.

The project team developed a novel approach to raising employee awareness by collecting a series of personal testimonials from other employees and posting them on the Company’s intranet site. These testimonials were supplemented by more traditional communications, including regular work group safety meetings, training, and increased ergonomics resources. At each facility, the company also designated Ergonomic Focal Points and Ergonomic Contacts, DDC workers who volunteered to receive specialized training and be available as a first point of contact for ergonomic concerns and questions. The team addressed employee behavior by providing feedback to individuals, creating a specific channel for early reporting of discomfort, and developing a health assessment program to address the early warning signs of potential MSDs. Employee personal accountability was addressed by implementing a “Safety First” mentality that stressed ergonomics as a key issue in personal safety and not a separate stand-alone topic.

These improvements are not static, but are a part of an ongoing ergonomics safety and health process. For example, while furniture improvements have been implemented, it is understood that the workstations will continually evolve to meet the employees’ changing needs.

### Step 4: Control

After the immediate improvements were implemented, the project team developed a long-term control plan designed to sustain the achievements. The control plan took the sequence of events which might contribute to an injury, as outlined in the Measure step, and added a series of performance standards, measures, responsibilities, and contingency plans. For example, in the original sequence, an employee was instructed to attend ergonomics training when starting a job, but there was no control measure to ensure this took place. Under the control plan, the employee is now required to attend the training within 30 days of job assignment, and the designated Ergo Contact at the job site is alerted and follows up with the employee if the employee fails to attend within that timeframe. Each

step in the sequence has a similar control measure followed long after the conclusion of the project.

### Results of the Project

DDC made immediate improvements to workstation ergonomics. The number of ergonomic injuries has been reduced 64% since the baseline in 2001. These improvements have been sustained for all. These improvements have been shared with other units, and workers, and employees are producing a better understanding of the personal responsibility like these have been repeated throughout the company. Ergonomics injuries has declined. In 2001, 53% of ergonomic injuries resulted in lost work time or advanced medical care. By 2005, only 30% of ergonomic injuries were lost work time or advanced medical care required only first aid or precautionary measures. This reduction contributed to Dow’s 2005 goal of reducing the ergonomic injury and illness rate by 90% to 0.24%.

Moreover, by virtue of the Six Sigma methodology, the project has developed an ongoing control plan to sustain its immediate results and continue to improve. The project have been shared with other units, leading to similar projects throughout the company.

Dow believes that using Six Sigma methodology encourages employers to develop program improvements based on data analysis, rather than speculation, resulting in a permanent fix that will yield benefits indefinitely. By eliminating error attempts at solutions, the Company has reduced ergonomic injuries with confidence and control through a program in a systematic and sustainable manner.

### Sidebar: Six Sigma Methodology

The Greek letter sigma ( $\sigma$ ) is used in statistics to measure or how much a process varies from its target. In Six Sigma methodology, deficiencies are described in terms of sigma. A score with the score of 6s equal to 3.4 defects per million. The following four-step process known as DMAIC (Define, Measure, Analyze, Improve, Control) to significantly reduce defects in a process.

**Step 1: Measure**—clearly define the process, measure the project, and identify a clear goal.

**Step 2: Analyze**—determine the root cause of the problem.

**Step 3: Improve**—develop solutions to address the root cause and implement improvement.

**Step 4: Control**—implement a long-term control plan to ensure improvements are sustained.

step in the sequence has a similar control, ensuring that the improved process is followed long after the conclusion of the project.

### Results of the Project

DDC made immediate improvements in the identified risk factors, which have been reduced 64% since the baseline measurement and by more than 45% overall. These improvements have been well received by the DDC's management and workers, and employees are proactive in addressing discomfort and have a better understanding of the personal benefits of ergonomics. As improvements like these have been repeated throughout the Company, the severity of ergonomics injuries has declined. In 2001, 53% of the Company's ergonomic injuries resulted in lost work time or advanced medical treatment. However, in 2003, only 30% of ergonomic injuries were this severe; the remaining 70% of cases required only first aid or precautionary measures. This result, in turn, has contributed to Dow's 2005 goal of reducing the Company's reportable injury and illness rate by 90% to 0.24%.

Moreover, by virtue of the Six Sigma Methodology's emphasis on long-term control, the project has developed an ongoing process that will help the DDC sustain its immediate results and continue to improve. The positive results of this project have been shared with Tricia and other EH&S managers at other business units, leading to similar projects throughout the company.

Dow believes that using Six Sigma for EH&S projects such as these enables employers to develop program improvements based on measurement and analysis, rather than speculation, resulting in a more cost-efficient and sustainable fix that will yield benefits indefinitely. Rather than undertaking costly trial and error attempts at solutions, the Company was able to identify the root causes of ergonomic injuries with confidence and make improvements to the ergonomics program in a systematic and sustainable way.

### Sidebar: Six Sigma Methodology

The Greek letter sigma ( $\sigma$ ) is used in mathematics to represent standard deviation, or how much a process varies from its average value. Under the Six Sigma methodology, deficiencies are described in terms of "defects" per million opportunities, with the score of 6s equal to 3.4 defects per million opportunities. Six Sigma uses the following four-step process known as MAIC (Measure, Analyze, Improve, Control) to significantly reduce defects in processes, products, and/or services:

*Step 1: Measure*—clearly define the process to be improved and the "defect" for the project, and identify a clear and appropriate measure for the "defect."

*Step 2: Analyze*—determine the root causes of the defect.

*Step 3: Improve*—develop solutions to address the root causes and validate process improvement.

*Step 4: Control*—implement a long-term strategy to ensure that the improvements are sustained.

The methodology can be applied to any process that allows the measurement of benefits and improvements in defect reduction, whether in the manufacture of a product, the delivery of a service, the control of costs, or the management of injuries and illnesses.

Dow has adopted the Six Sigma methodology to accelerate the company's improvement in quality and productivity. Dow has expanded the use of the Six Sigma approach to help manage aspects of the Company's operations beyond production and quality, including the safety and health of its workforce. Some of the projects to which Dow has applied the Six Sigma methodology include:

- Reduction of repetitive stress injuries
- Reduction of motor vehicle accidents
- Improved safety for visitors (especially contractors)
- Site logistics risk reduction
- Off-the-job safety process improvement

These projects have been key components of Dow's 2005 Environmental, Health and Safety Goals, which include reducing Dow's reportable injury and illness rate by 90% to 0.24%.

As the example in our case study illustrates, Dow's Environmental Health and Safety (EHS) function has found the Six Sigma methodology particularly useful in identifying and validating root causes that are hard to discern because of their subjectivity, and in focusing improvements to an ergonomics program in ways that caused measurable improvements. Moreover, since the Six Sigma process includes implementation of controls to ensure that achievements are sustained over a long-term period, the Company expects to realize the benefits of its efforts for years to come.

### CASE STUDY REFERENCES

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2. "A Critical Review of Epidemiologic Evidence for Work-Related Musculoskeletal Disorders of the Neck, Upper Extremity, and Low Back," The National Institute for Occupational Safety and Health.
3. Dow Chemical Company: Case study was developed from information provided by Karen Kearns, Industrial Hygiene Specialist, and Mark Spence, Manager, North American Health and Safety Regulatory Affairs, The Dow Chemical Company.

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### EXERCISES

- 6.1 Explain the history of MTM and how it is used.
- 6.2 What is the OSHA perspective on hand tool design?
- 6.3 Explain Fitts' Law and its application to hand tool design.
- 6.4 Discuss the principles for good hand tool design.
- 6.5 Use the AET approach to design a hand tool for a specific manufacturing task.

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