WORKPLACE, EQUIPMENT, AND TOOL DESIGN

IENG 301

FUNDAMENTALS OF WORK STUDY AND ERGONOMICS

Ergonomics

- Designing the workplace, tools, equipment and work environment to fit the human operator is called *ergonomics*.

Principles of Work Design

- Increased production and efficiency of the operation,
- Decreased injury rates for the human operator.

Anthropometry and Design

- The primary guideline is to design the workplace to accomodate most individuals with regard to structural size of the human body

- The science of measuring the human body is termed anthropometry.

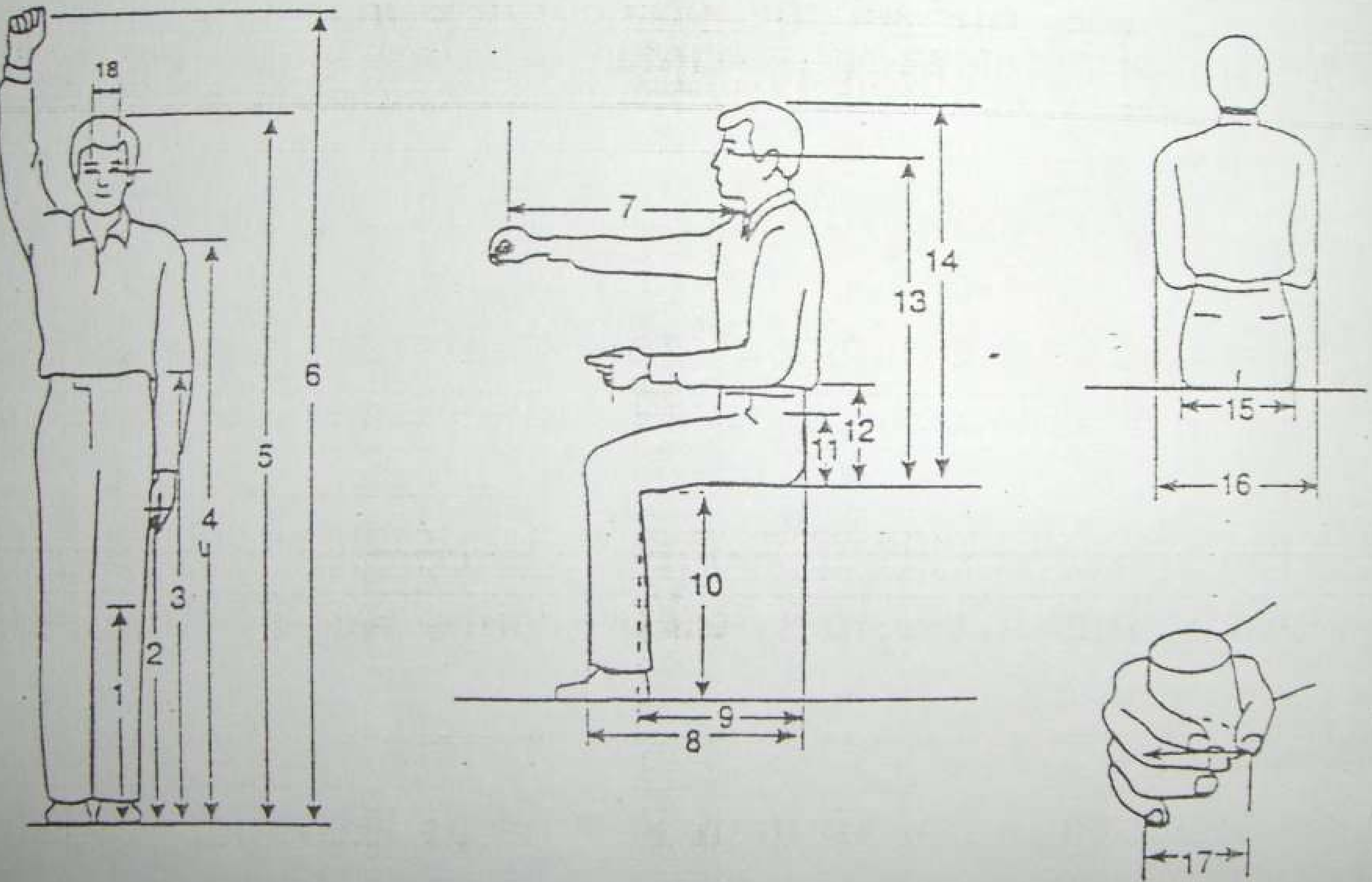


Figure 3.4 Illustration of the anthropometric measures given in Table 3.2

	Female 5th	Female 50th	Female 95th	Male 5th	Male 50th	Male 95th
Standing						
1. Tibial height	38.1	42.0	46.0	41.0	45.6	50.2
2. Knuckle height	64.3	70.2	75.9	69.8	75.4	80.4
3. Elbow height	93.6	101.9	108.8	100.0	109.9	119.0
4. Shoulder (acromion) height	121.1	131.1	141.9	132.3	142.8	152.4
5. Stature	149.5	160.5	171.3	161.8	173.6	184.4
6. Functional overhead reach	185.0	199.2	213.4	195.6	209.6	223.6
Sitting						
7. Functional forward reach	64.0	71.0	79.0	76.3	82.5	88.3
8. Buttock–knee depth	51.8	56.9	62.5	54.0	59.4	64.2
9. Buttock–popliteal depth	43.0	48.1	53.5	44.2	49.5	54.8
10. Popliteal height	35.5	39.8	44.3	39.2	44.2	48.8
11. Thigh clearance	10.6	13.7	17.5	11.4	14.4	17.7
12. Sitting elbow height	18.1	23.3	28.1	19.0	24.3	29.4
13. Sitting eye height	67.5	73.7	78.5	72.6	78.6	84.4
14. Sitting height	78.2	85.0	90.7	84.2	90.6	96.7
15. Hip breadth	31.2	36.4	43.7	30.8	35.4	40.6
16. Elbow-to-elbow breadth	31.5	38.4	49.1	35.0	41.7	50.6
Other dimensions						
17. Grip breadth, inside diameter	4.0	4.3	4.6	4.2	4.8	5.2
18. Interpupillary distance	5.1	5.8	6.5	5.5	6.2	6.8

1 in. = 2.54 cm.

Probability Distributions and Percentiles

A *kth percentile* is defined as a value such that k percent of the data values (plotted in ascending order) are at or below this value and $100 - k$ percent of the data values are at or above this value. A histogram plot of U.S. adult male statures shows a bell-shaped curve, termed a *normal distribution*, with a median value of 68.3 inches (see Figure 5–1). This is also the 50th percentile value, for example, half of all males are shorter than 68.3 inches, while half are taller. The 5th percentile male is only 63.7 inches tall, while a 95th percentile male is 72.6 inches tall. The proof is as follows.

Typically, in a statistical approach, the approximately bell-shaped curve is normalized by the transformation:

$$z = (x - \mu)/\sigma$$

where: μ = Mean.
σ = Standard deviation (measure of dispersion).

to form a standard normal distribution (also termed a z distribution; see Figure 5–2).

Once normalized, any approximately bell-shaped population distribution will have the same statistical properties. This allows easy calculation of any percentile value desired, using the appropriate k and z values, as follows:

k^{th} percentile	10 or 90	5 or 95	2.5 or 97.5	1 or 99
z value	± 1.28	± 1.645	± 1.96	± 2.33

$$k^{th} \text{ percentile} = \mu \pm z\sigma$$

Given that the mean stature for males in the United States is 68.3 inches (173.6 cm), while the standard deviation is 2.71 inches (6.9 cm) (Webb Associates, 1978), the 95th percentile male stature is calculated as:

$$68.3 + 1.645\ (2.71) = 72.76 \text{ inches}$$

while the 5th percentile male stature is calculated as:

$$68.3 - 1.645\ (2.71) = 63.84 \text{ inches}$$

(continued)

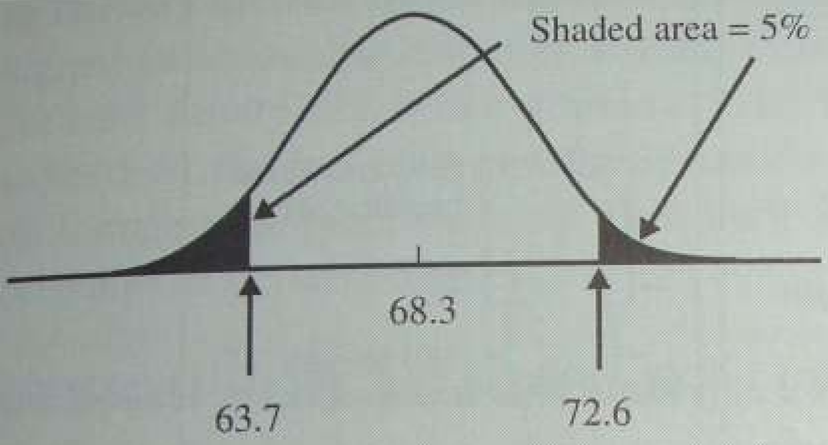


Figure 5–1 | Normal distribution of U.S. adult male statures.

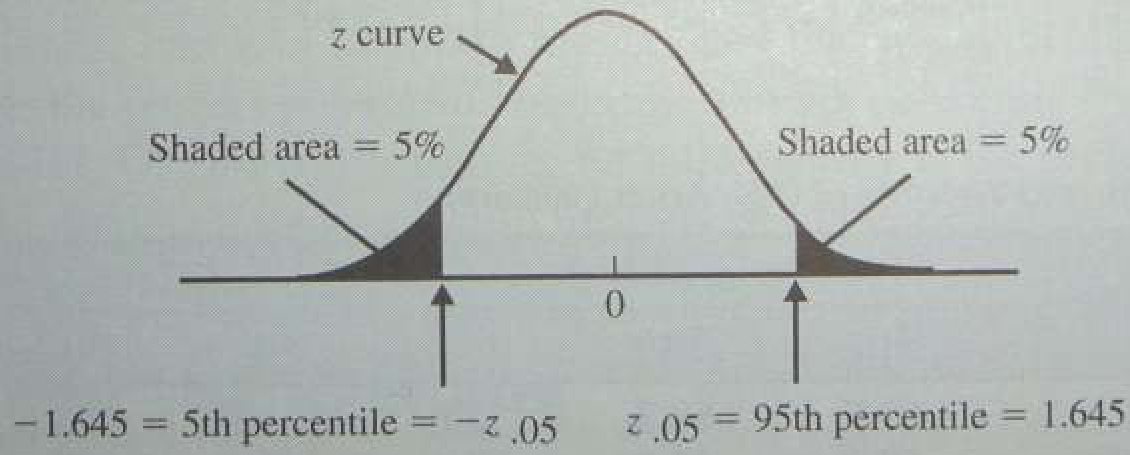


Figure 5–2 | Standard normal distribution of male weights.

Design

- Designing for most individuals is an approach that involves the use of one of three different specific design principles, as determined by the type of design problem.
  - Design for Extremes
  - Design for Adjustability
  - Design for the Average

Design fo Extremes

- Implies that a specific desing feature is a limiting factor in determining either the maximum or minimum value of population variable that will be accomodated.

  e.g. Clearances, such as doorway or opening into a storage tank should be designed for the maximum individual, that is, a 95 percent of all males and almost all females will be able to enter the opening.

  Added space in military aircraft or submarines is expensive, therefore designed to accomodate only a certain (smaller) range of individuals.

Design for Adjustability

- is typically used for equipment or facilities that can be adjusted rto fit a wider range of individuals.

  e.g. Chairs, tables, desks, vehicle seats, steering columns, and tool supports
  (ranging from 5^{th} percentile females to 95^{th} percentile males)

- It is the preferred method of design, but there is a trade-off with the cost implementation.

Design for the Average

- is the cheapest but least preferred approach.
- Eventhough there is no individual with all average dimensions, there are certain situations where it would be impractical ot roo costly to include adjustability for all features.

  e.g. Most industrial machine tools are too large and too heavy to include height adjustability for the operator.

- Designing operating height at the 50th percentile of the elbow height for the combined female and male populations means that most individuals will not be excessively inconvinienced.

Seating design in a large training room

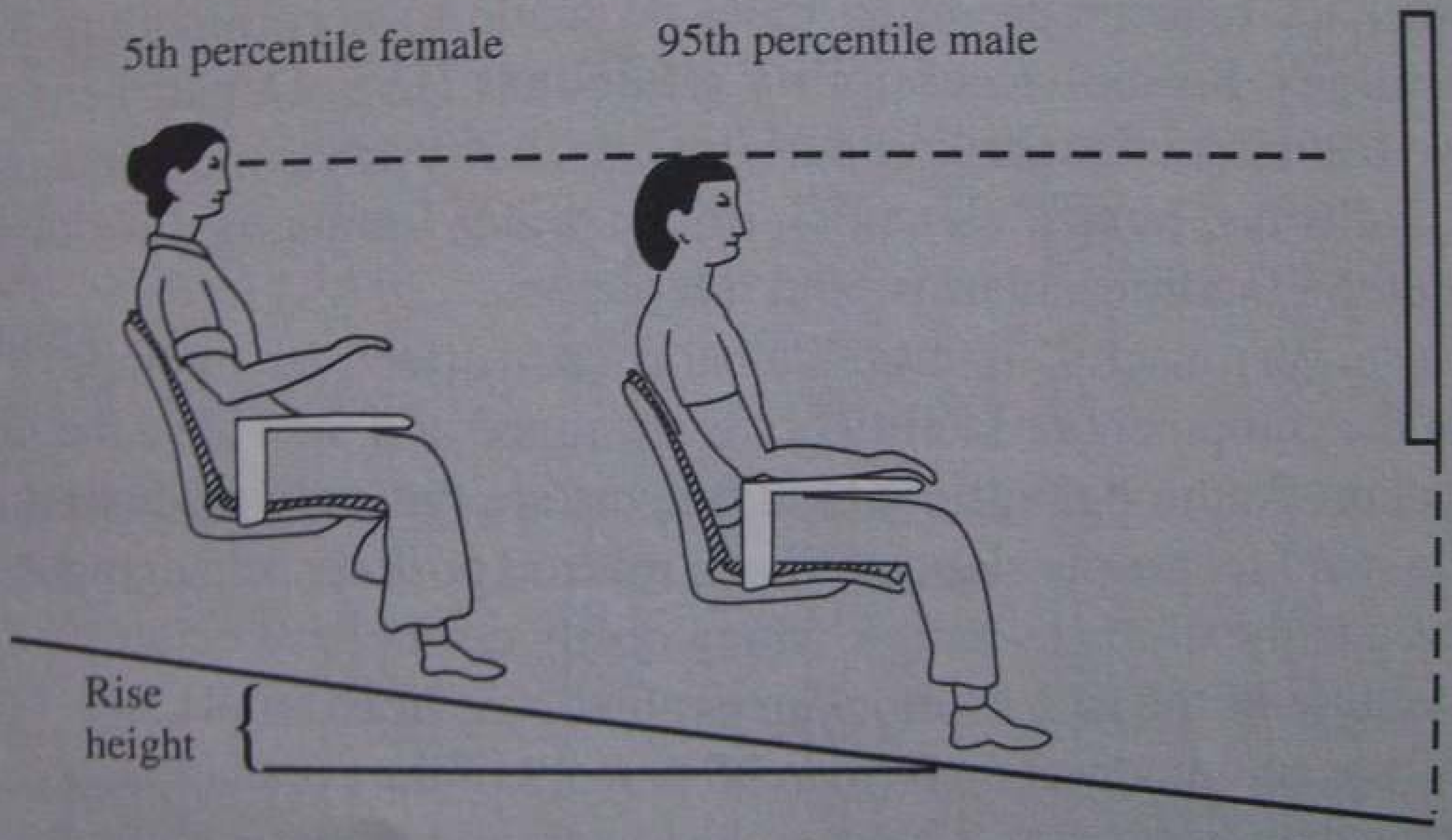


Figure 5–3 | Seating design in a large training room.

Principles of Work Design: The Workplace

- Determine the work surface height by elbow height
  - The work surface height (seated/standing) should be determined by a comfortable working posture for the operator.
  - This means that the upper arms are hanging down naturally and the elbows are flexed at 90 degrees so that the forearms are parallel to teh ground.

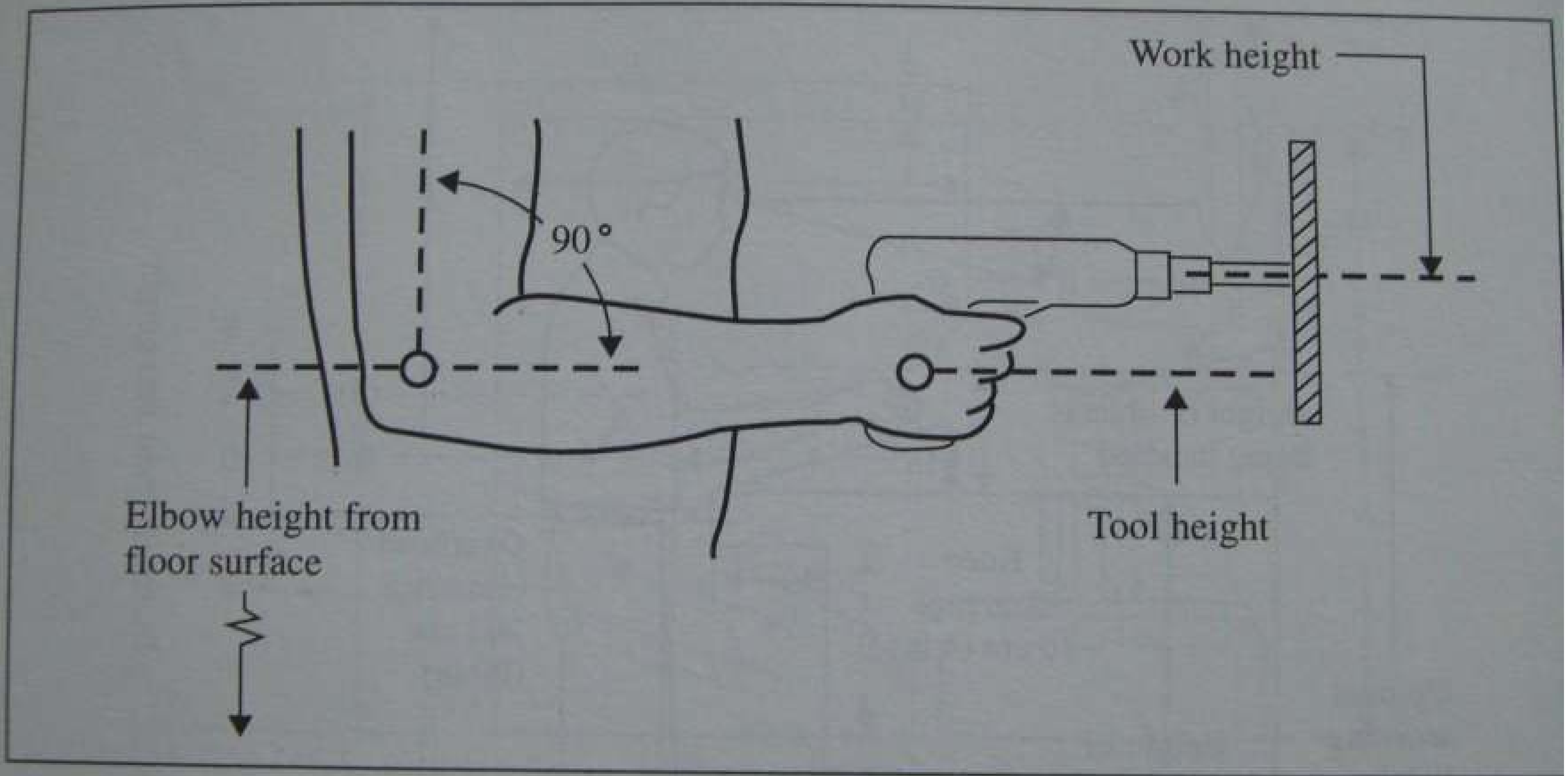


Figure 5–4 | Graphic aid for determining correct worksurface height.
(*From:* Putz-Anderson, 1988)

Principles of Work Design: The Workplace

- Adjust the work surface height based on the task being performed
    - For rough assembly involving the lifting of heavy parts, it is more advantageous to lower the work surface by 20 cm to take the advantage of the stronger trunk muscles,
    - For fine assmebly involving minute visual details, it is more advantageous to raise the work surface up to 20 cm to bring the details closer to the optimum line of sight of 15 degrees,
    - Another, perhaps better, alternative is to slant the work surface approximately 15 degrees to satisfy both principles.

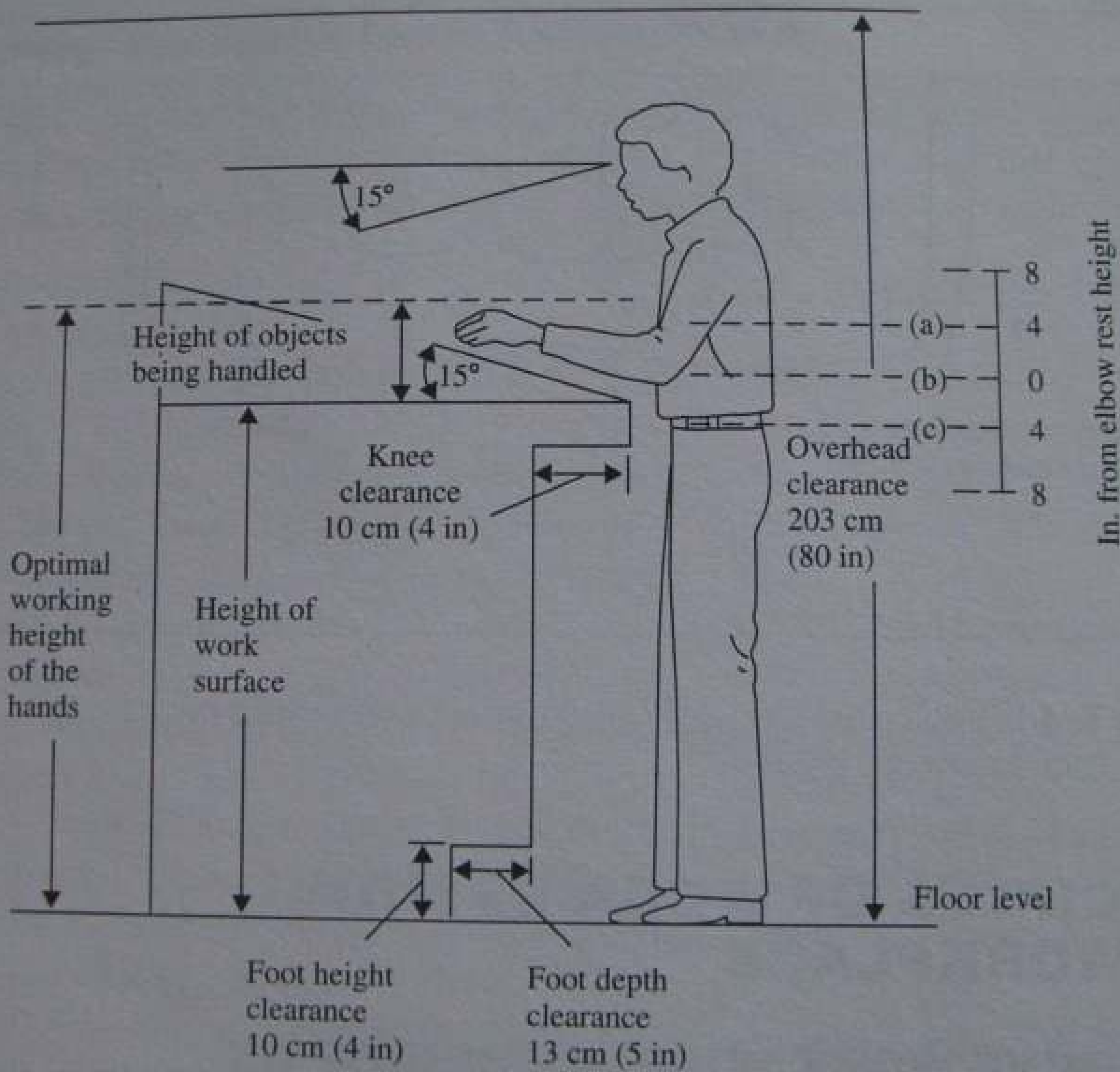


Figure 5–5 | Recommended standing workplace dimensions. (a) For precision work with arm rest, (b) for light assembly, (c) for heavy work.

Principles of Work Design: The Workplace

- Adjust the work surface height based on the task being performed
  - These principles also apply to a seated workstation.
  - A majority of tasks, such as writing or light assembly are best performed at the resting-elbow height.
  - Seated workstations should be provided with adjustable chairs and adjustable footrests.

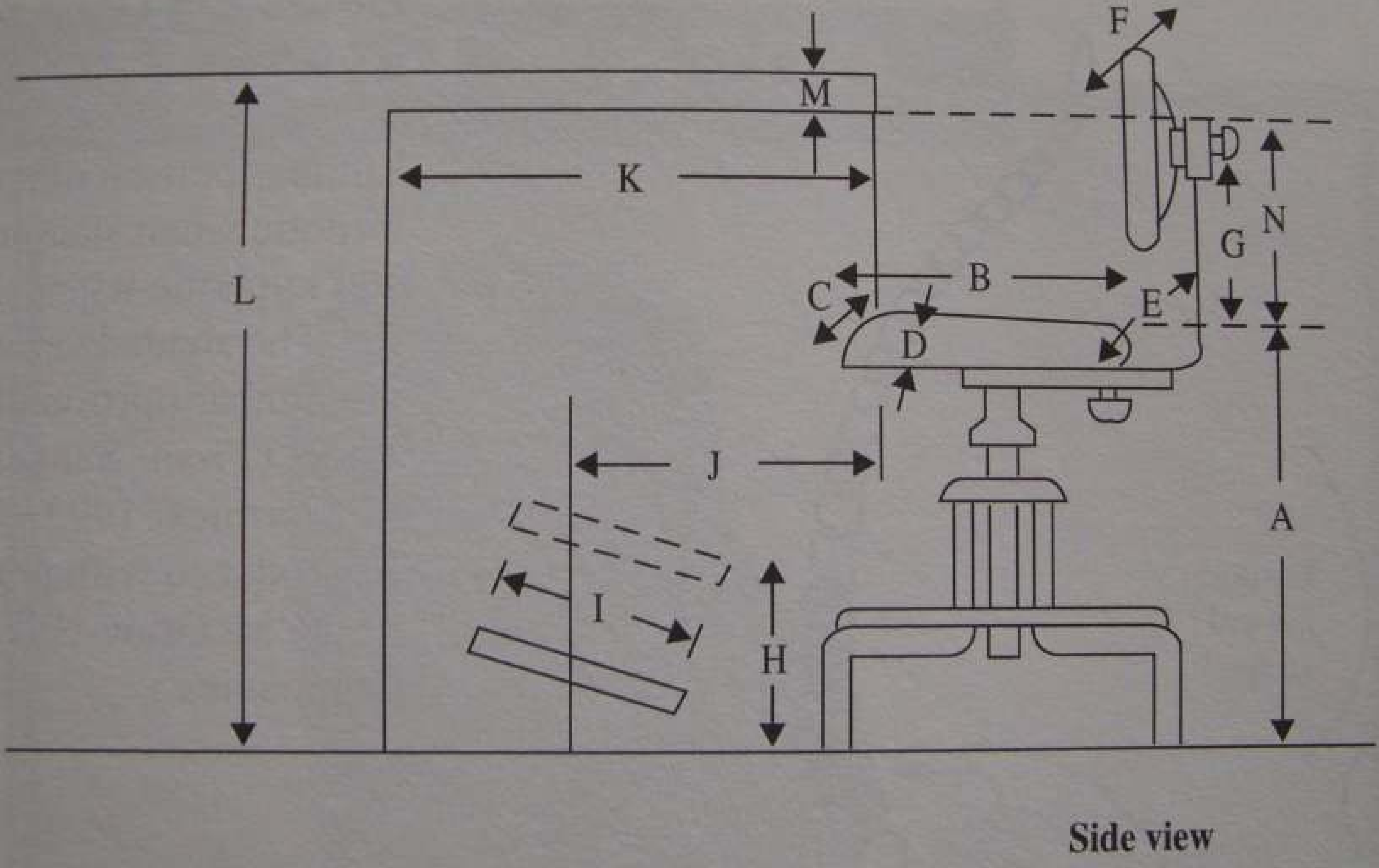


Figure 5–6 | Adjustable chair (specific seat parameter values found in Table 5–2).

Principles of Work Design: The Workplace

- Provide a comfortable chair for the seated operator
  - It is very important to privde *lumbar support* in the form of an outward bulge in the seat back, or even a simple lumbar pad placed at the belt level

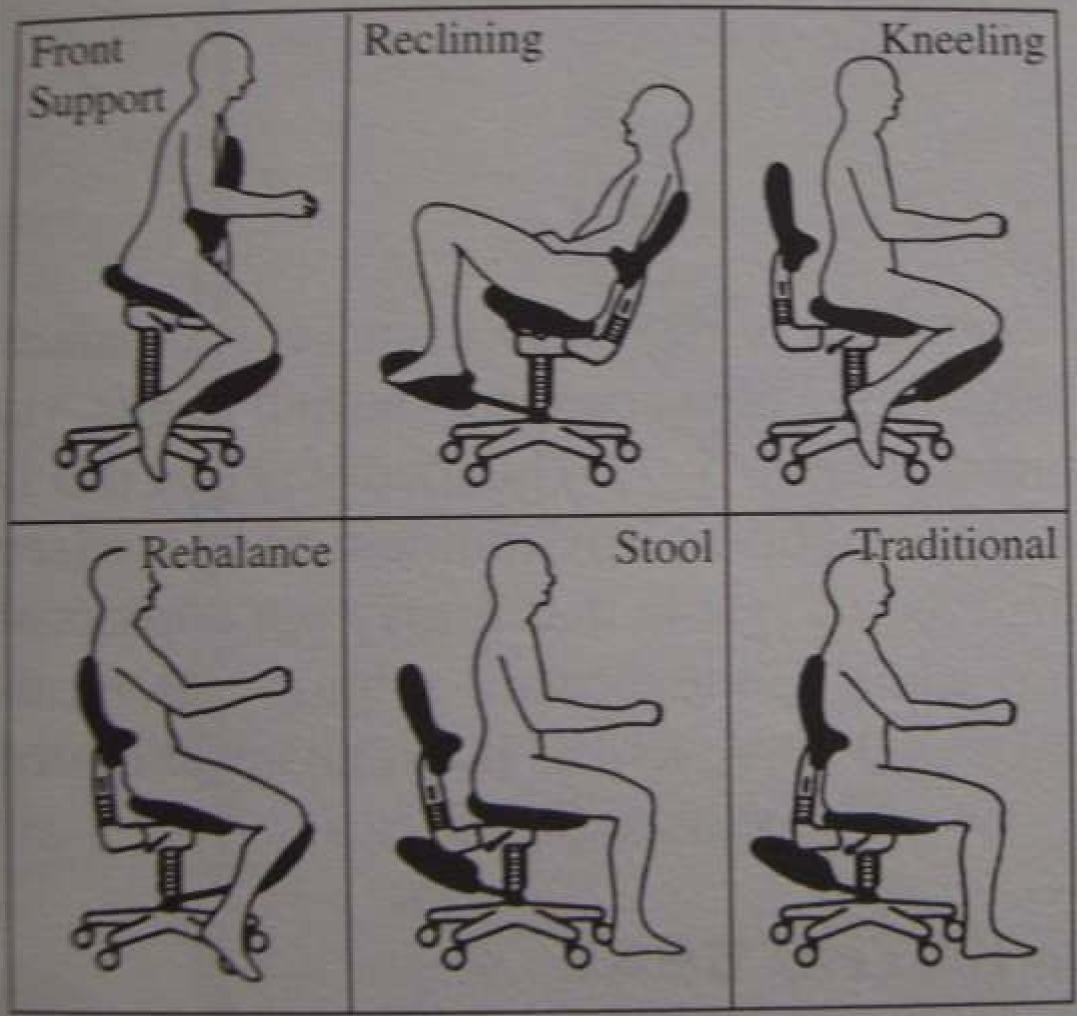


Figure 5–7 | Six basic seating postures.
(*From:* Serber, 1990. Reprinted with permission of the Human Factors and Ergonomics Societ All rights reserved.)

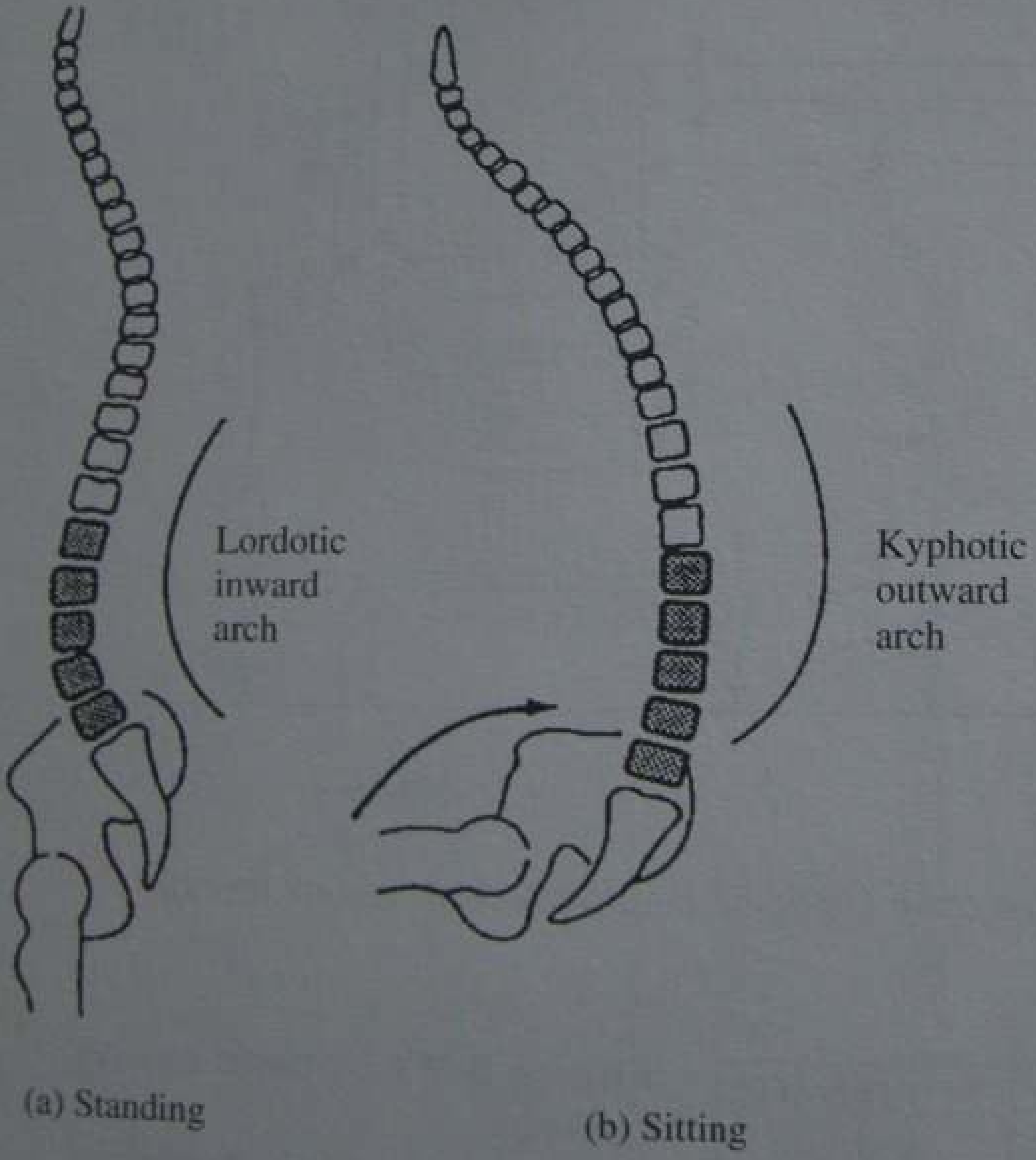


Figure 5–8 | Posture of the spine when standing and sitting.
Lumbar portion of spine is lordotic when standing (a) and kyphotic when sitting (b). The shaded vertebrae are the lumbar portion of the spine. (*From:* Sanders and McCormick, 1993. Reproduced with permission of the McGraw-Hill Companies.)

Principles of Work Design: The Workplace

- Provide adjustability in the seat
  - A second cinsideration is the reduction of disk pressure, which can increase considerably with a forward tilt of the trunk.
  - Seat height is most critical, with ideal heihgt being determined by the person's popliteal height.
  - Armrests for shoulder and arm support and footrests for shorter individuals are recommended.

Table 5–2 | Recommended Seat Adjustment Ranges

Seat parameter	Design Value [in inches (cm) unless specified]	Comments
A–Seat height	16–20.5 (40–52)	Too high—compresses thighs; too low—disk pressure increases
B–Seat depth	15–17 (38–43)	Too long—cuts popliteal region, use waterfall contour
C–Seat width	≥18.2 (≥46.2)	Wider seats recommended for heavy individuals
D–Seat pan angle	−10°–+10°	Downward tilting requires more friction in the fabric
E–Seat back to pan angle	>90°	>105° preferred, but requires workstation modifications
F–Seat back width	>12 (>30.5)	Measured in the lumbar region
G–Lumbar support	6–9 (15–23)	Vertical height from seat pan to center of lumbar support
H–Footrest height	1–9 (2.5–23)	
I–Foot rest depth	12 (30.5)	
J–Footrest distance	16.5 (42)	
K–Leg clearance	26 (66)	
L–Work surface height	~32 (~81)	Determined by elbow rest height
M–Work surface thickness	<2 (<5)	Maximum value
N–Thigh clearance	>8 (>20)	Minimum value

Note: A–G from ANSI (1988); H–M from Eastman Kodak (1983).

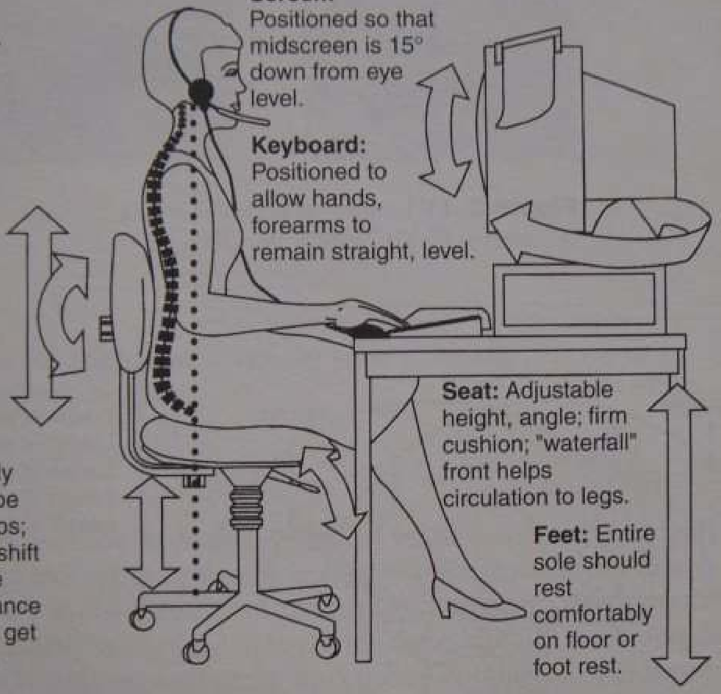
Arms: When operator's hands are on keyboard, upper arm and forearm should form right angle; hands should be lined up with forearm; if hands are angled up from the wrist, try lowering or downward tilting the keyboard; optional arm rests should be adjustable.

Telephone: Cradling telephone receiver between head and shoulder can cause muscle strain; headset allows head, neck to remain straight while keeping hands free.

Document holder: Same height and distance from user as the screen, so eyes can remain focused as they look from one to the other.

Backrest: Adjustable for occasional variations; shape should match contour of lower back, providing even pressure and support.

Posture: Sit all the way back into chair for proper back support; back, neck should be comfortably erect; knees should be slightly lower than hips; do not cross legs or shift weight one side; give joints, muscles a chance to relax; periodically, get up and walk around.



Desk: Thin work surface to allow leg room and posture adjustments; adjustable surface height preferable; table should be large enough for books, files, telephone while permitting different positions of screen, keyboard, mouse pad.

Avoiding eye strain:
1. Get glasses that improve focus on screen; measure distance before visiting eye doctor.
2. Try to position screen or lamps so that lighting is indirect; do not have light shining directly at screen or into eyes.
3. Use a glare-reducing screen.
4. Periodically rest eyes by looking into the distance.

Figure 5–10 | Properly adjusted workstation.

Principles of Work Design: The Workplace

- Encourage postural flexibility
  - The workstation height should be adjustable so that work can be performed efficiently either standing or sitting.

- Provide antifatigue mats for a standing operator
  - Standing for extended periods of time on a cement floor is fatiguing.
  - The mats allow smal muscle contractions in the legs, forcing the blood to move and keeping it from tending to pool in the lower extremities.

Principles of Work Design: The Workplace

- Locate all tools and materials within the normal working area
  - The greater the distance, the larger the muscular effort, control and time
  - Therefore, it is important to minimize the distances

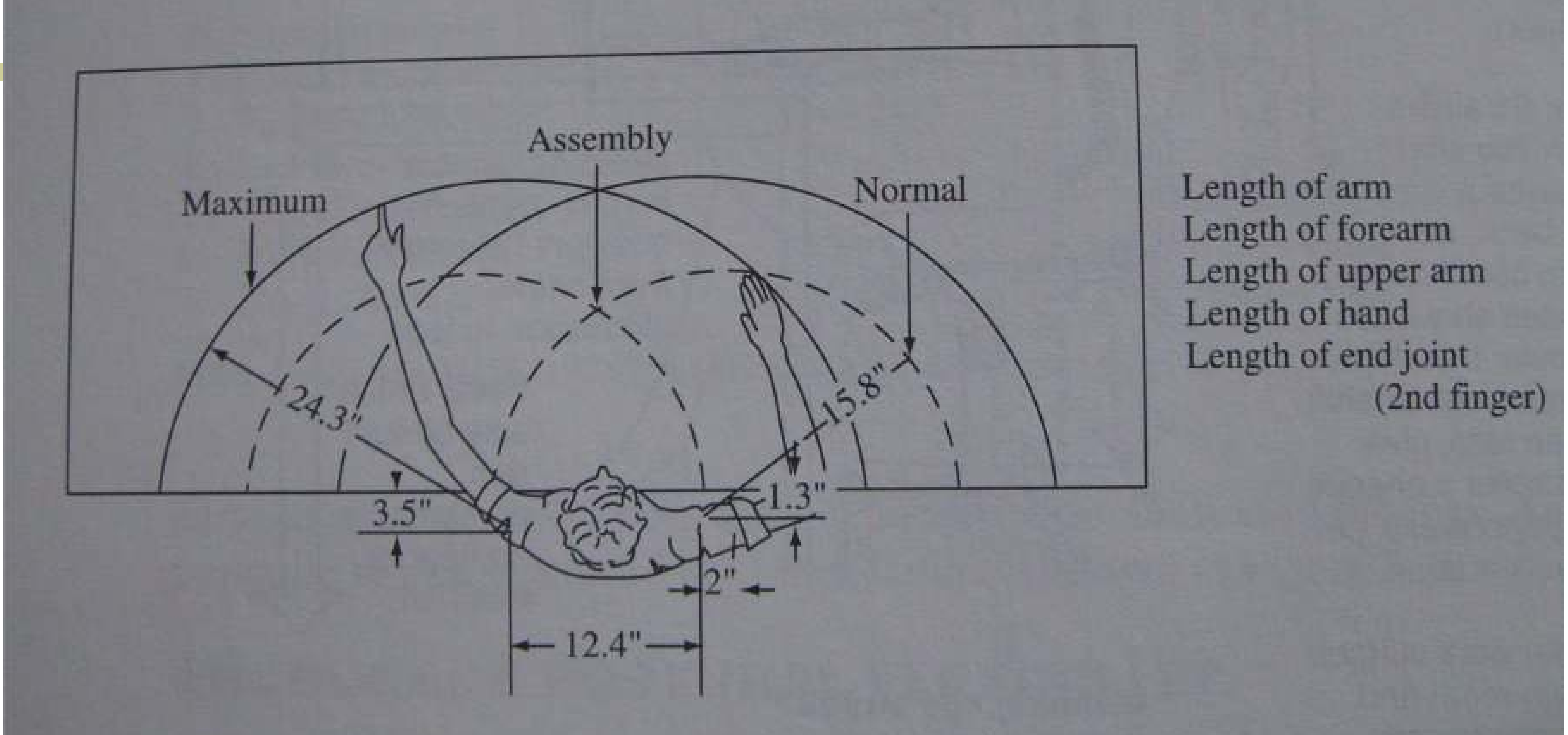


Figure 5–12 | Normal and maximum working areas in the horizontal plane for women (for men, multiply by 1.09).

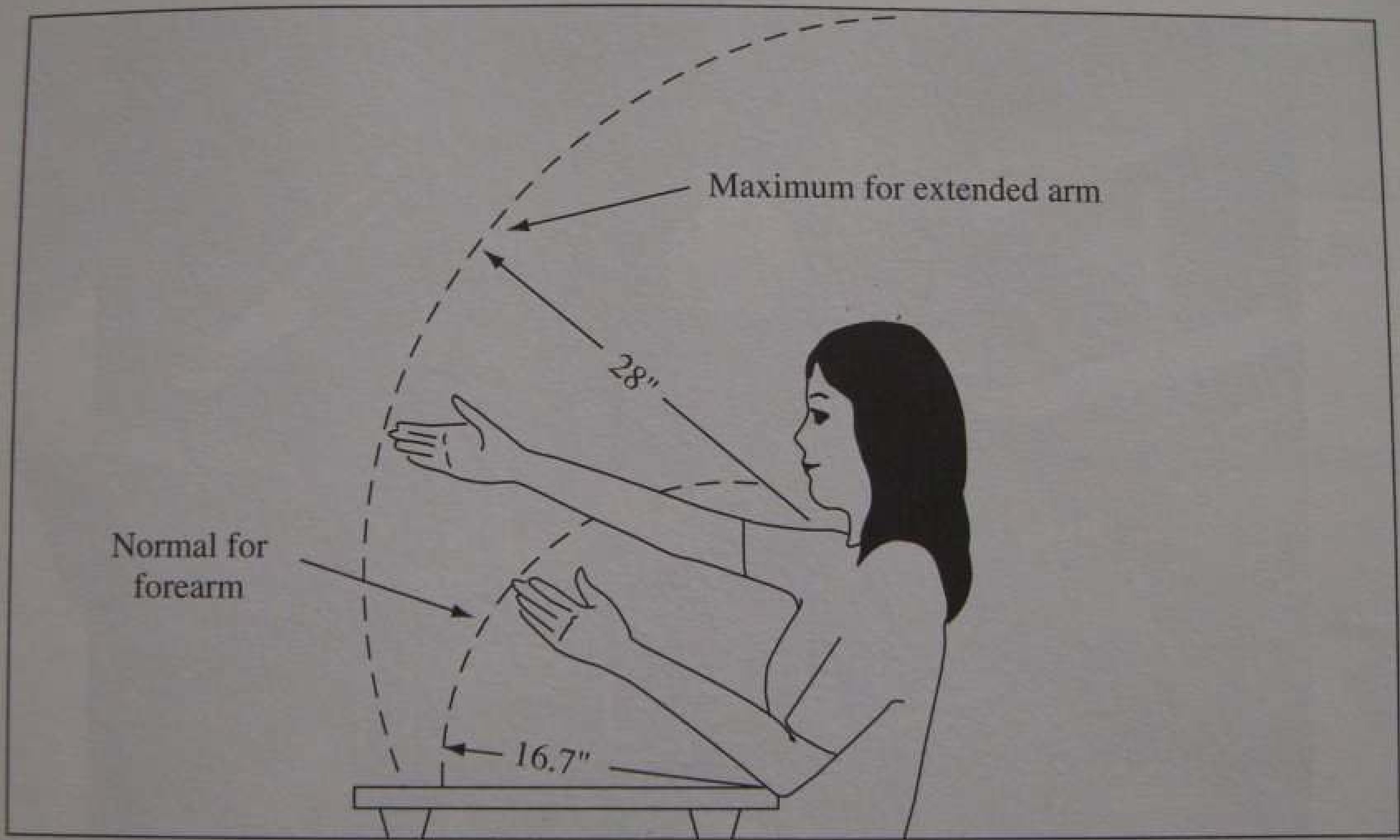


Figure 5–13 | Normal and maximum working areas in the vertical plane for women (for men, multiply by 1.09).

Principles of Work Design: The Workplace

- Fix locations for all tools and materials to permit the best sequence
  - In driving an automobile, the break pedal is in a fixed location, no time is required to decide where the brake is located.

- Use gravity bins and drop delivery to reduce reach and move times
  - The time required to perform both of the transport therbligs "reach" and "move" is directly proportional to the distance that the hands must move in performing these therbligs.

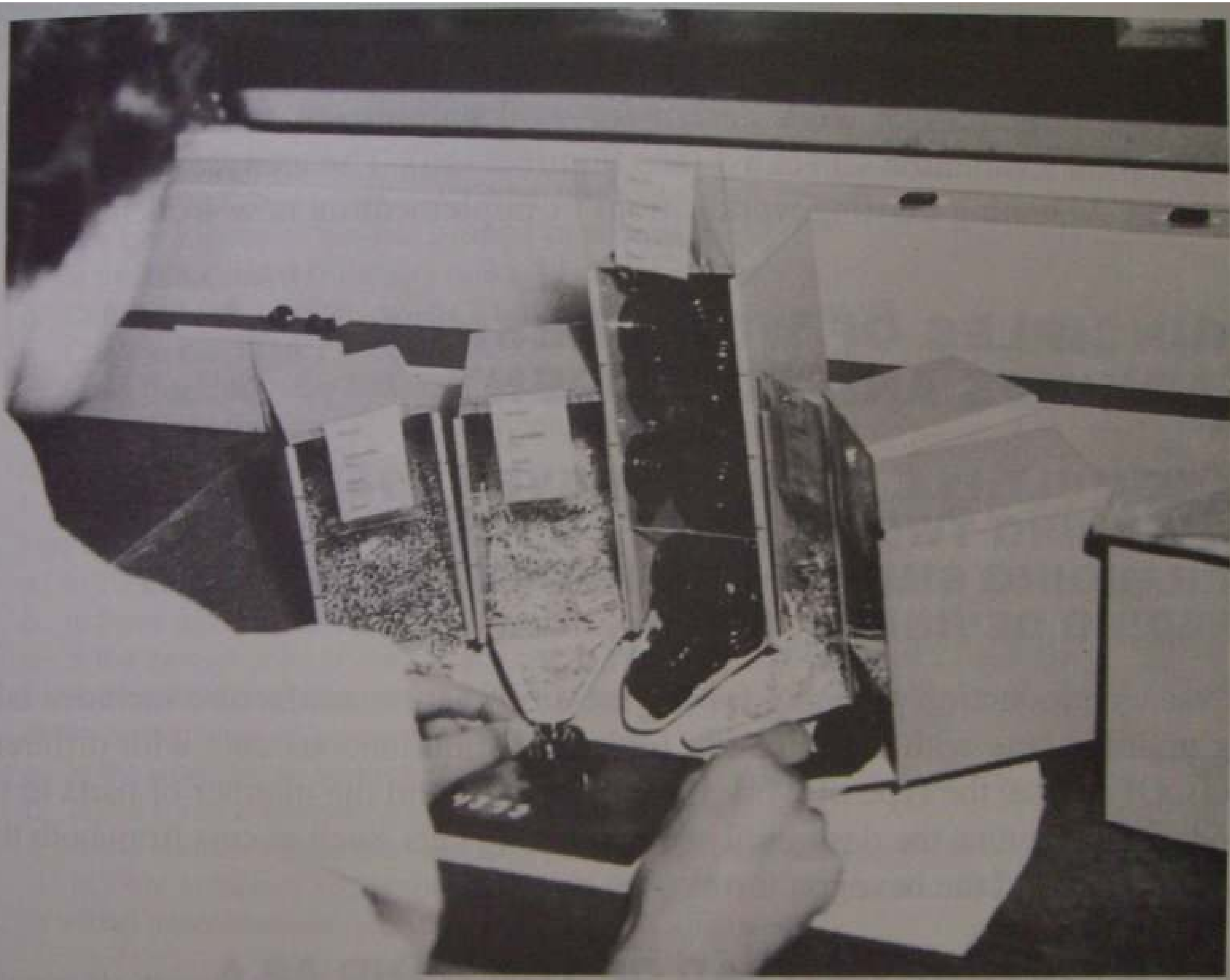


Figure 5–15 | A workstation utilizing gravity bins and a belt conveyor to reduce reach and move times.

Principles of Work Design: The Workplace

- Arrange tool, controls, and other components optimally to minimize motions
  - The most important or most frequently used components should be placed in the most convinient locations

  e.g. Emergency stop button should be placed in a readily visible, reachable, or convinient position

Sitting Workstation	**Yes**	**No**
1. Is the chair easily adjustable according to the following features:	❑	❑
a. Is the seat height adjustable from 15 to 22 inches?	❑	❑
b. Is the seat width a minimum of 18 inches?	❑	❑
c. Is the seat depth 15 to 16 inches?	❑	❑
d. Can the seat be sloped ± 10° from horizontal?	❑	❑
e. Is a back rest with lumbar support provided?	❑	❑
f. Is the back rest a minimum of 8 x 12 inches in size?	❑	❑
g. Can the back rest be moved 7 to 10 inches above the seat?	❑	❑
h. Can the back rest be moved 12 to 17 inches from the front of the seat?	❑	❑
i. Does the chair have five legs for support?	❑	❑
j. Are casters and swivel capability provided for mobile tasks?	❑	❑
k. Is the chair covering breathable?	❑	❑
l. Is a footrest (large, stable, and adjustable in height and slope) provided?	❑	❑
2. Has the chair been adjusted properly?	❑	❑
a. Is the seat height adjusted to the popliteal height with the feet flat on the floor?	❑	❑
b. Is there approximately a 90° angle between the trunk and thigh?	❑	❑
c. Is the lumbar area of the back support in the small of the back (~ belt line)?	❑	❑
d. Is there sufficient legroom (i.e., to the back of the workstation)?	❑	❑
3. Is the workstation surface adjustable?	❑	❑
a. Is the workstation surface roughly at elbow rest height?	❑	❑
b. Is the surface lowered 2 to 4 inches for heavy assembly?	❑	❑
c. Is the surface raised 2 to 4 inches (or tilted) for detailed assembly or visually intensive tasks?	❑	❑
d. Is there sufficient thigh room (i.e., from the bottom of the worksurface)?	❑	❑
4. Is sitting alternated with standing or walking?	❑	❑

Computer Workstation	**Yes**	**N**
1. Has the chair been adjusted first, then keyboard and mouse, finally the monitor?	❑	❑
2. Is the keyboard as low as possible (without hitting the legs)?	❑	❑

d. Is there sufficient thigh room (i.e., from the bottom of the worksurface)?	❑	❑
4. Is sitting alternated with standing or walking?	❑	❑

Computer Workstation

	Yes	No
1. Has the chair been adjusted first, then keyboard and mouse, finally the monitor?	❑	❑
2. Is the keyboard as low as possible (without hitting the legs)?	❑	❑
a. Are the shoulders relaxed, upper arms hanging down comfortably, and forearms below horizontal (i.e., elbow angle >90°)?	❑	❑
b. Is a keyboard shelf utilized (i.e., lower than a normal 28-inch writing surface)?	❑	❑
c. Is the keyboard sloped downward so as to maintain a neutral wrist position?	❑	❑
d. Is the mouse positioned next to the keyboard at the same height?	❑	❑
e. Are armrests (adjustable in height at least 5 inches) provided?	❑	❑
f. If no armrest, are wrist rests provided?	❑	❑
3. Is the monitor positioned 16 to 30 inches (roughly arm's length) from the eyes?	❑	❑
a. Is the top of the screen slightly below eye level?	❑	❑
b. Is the bottom of the screen roughly 30° down from horizontal eye level?	❑	❑
c. Is the monitor positioned at a 90° angle to windows to minimize glare?	❑	❑
d. Can the windows be covered with curtains or blinds to reduce bright light?	❑	❑
e. Is the monitor tilted to minimize ceiling light reflections?	❑	❑
f. If glare still exists, is an antiglare filter utilized?	❑	❑
g. Is a document holder utilized for data transfer from papers?	❑	❑
h. Is the main visual task (monitor or documents) placed directly in front?	❑	❑

Standing Workstation

	Yes	No
1. Is the workstation surface adjustable?	❑	❑
a. Is the workstation surface roughly at elbow rest height?	❑	❑
b. Is the surface lowered 4 to 8 inches for heavy assembly?	❑	❑
c. Is the surface raised 4 to 8 inches (or tilted) for detailed assembly or visually intensive tasks?	❑	❑
2. Is there sufficient legroom?	❑	❑
3. Is a sit/stand stool (adjustable in height) provided?	❑	❑
4. Is standing alternated with sitting?	❑	❑

Figure 5–16 | Workstation evaluation checklist.

Principles of Work Design: Machines and Equipment

- Take multiple cuts whenever possible by combining two or more tools in one, or by arranging simultaneous cuts from both feeding devices

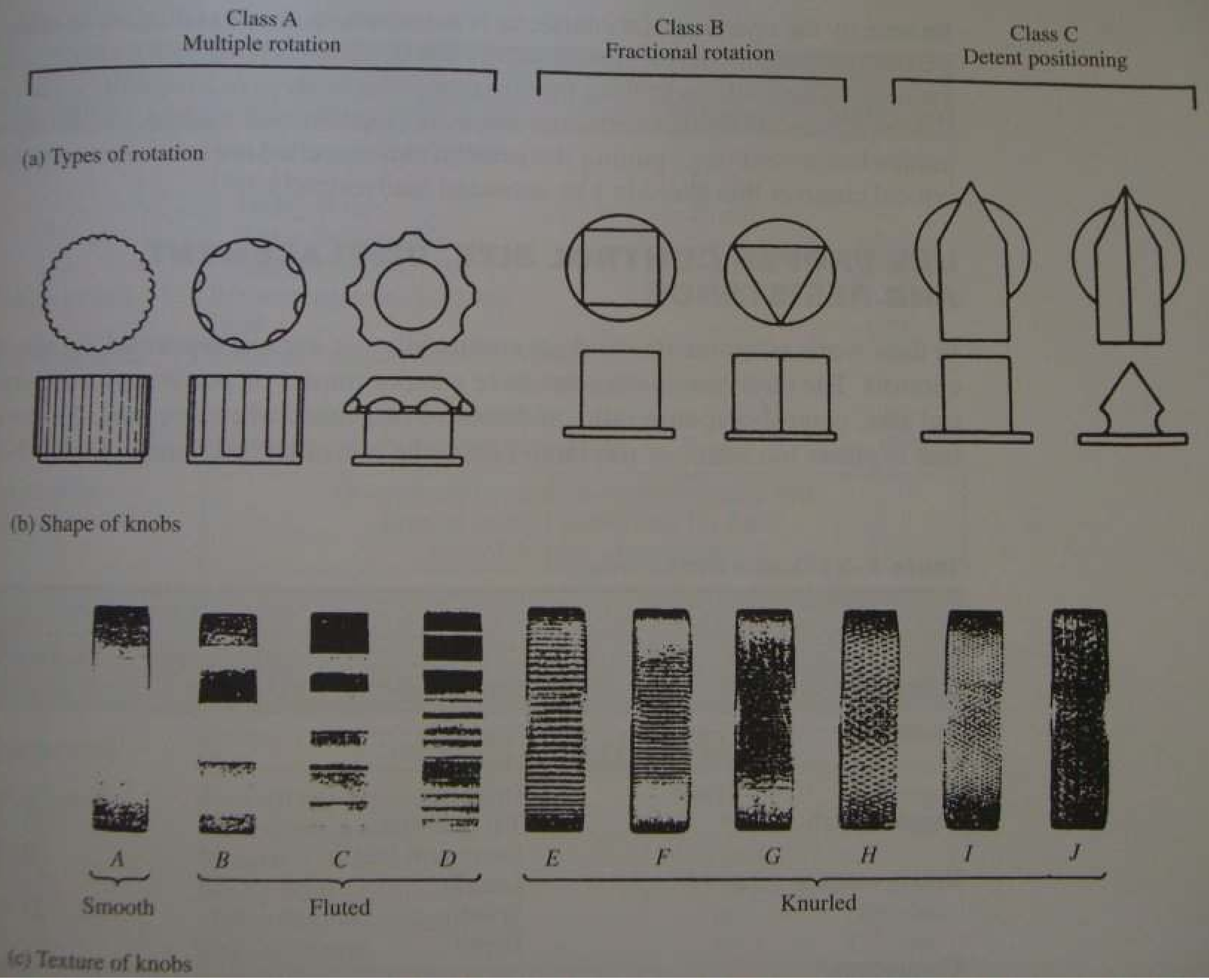
- Use a fixture instead of the hand as a holding device

Principles of Work Design: Machines and Equipment

- Locate all controldevices for best operator accessibility and strength capability
  - Handwheels, cranks and levers should be of such a size and placed in such positions that operators can manipulate them with maximum proficiency and minimum fatigue.
  - Frequently used controls should be positioned between elbow and shoulder height.
  - Seated operators can apply maximum force to levers located at elbow level, standing operators, to levers located at shoulder height

Principles of Work Design: Machines and Equipment

- Use shape, tecture and size coding for controls
  - Shape coding, using two or three dimensional geometric configurations, permits both tactual and visual identification.



Class A
Multiple rotation
Class B
Fractional rotation
Class C
Detent positioning
(a) Types of rotation
(b) Shape of knobs
A
B
C
D
E
F
G
H
I
J
Smooth
Fluted
Knurled
(c) Texture of knobs

Principles of Work Design: Machines and Equipment

- Use proper control size, displacement and resistance
- Insure proper compatibility between controls and displays

Cumulative Trauma Disorders (CTD)

- CTD (repetitive motion injuries or work-related musculoskeletal diorders) are injuries to the musculoskeletal system that develop gradually as a result of repeated microtrauma due to poor design and the excessive use of hand tools and other equipment.

Cumulative Trauma Disorders (CTD)

- National Safety Council (USA) suggest that 15-20% of workers in key industries (meatpacking, poultry processing, auto assembly, garment manufacturing) are at potential risk for CTD.
- 61% of all occupational illnesses are associated with repetitive motions.

Cumulative Trauma Disorders (CTD)

- Four major work-related facors lead to the development of CTD;
  1. Excessive force
  2. Awkward or extreme joint motions
  3. High repetition
  4. Duration of work

Cumulative Trauma Disorders (CTD)

- Tenosynovitis: inflammation of the tendon sheaths due to overuse or unaccustomed use of improperly designed tools
- Tendinitis: if the inflamations spreads to the tendons
- Carpal Tunnel Syndrome: a disorder of the hand caused by injury of the median nerve inside the wrist

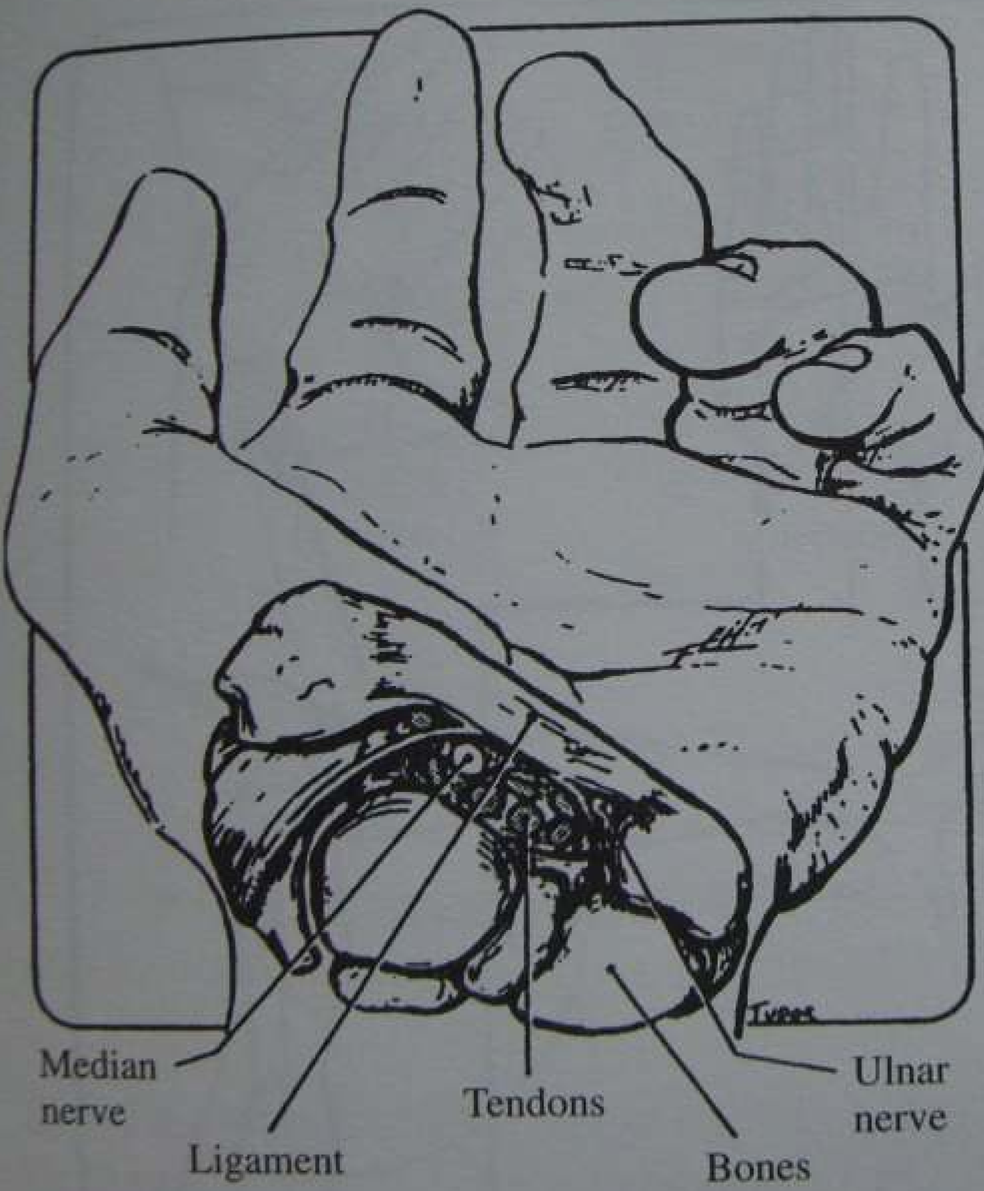


Figure 5–22 | A pictorial view of the carpal tunnel
(*From:* Putz-Anderson, 1988)

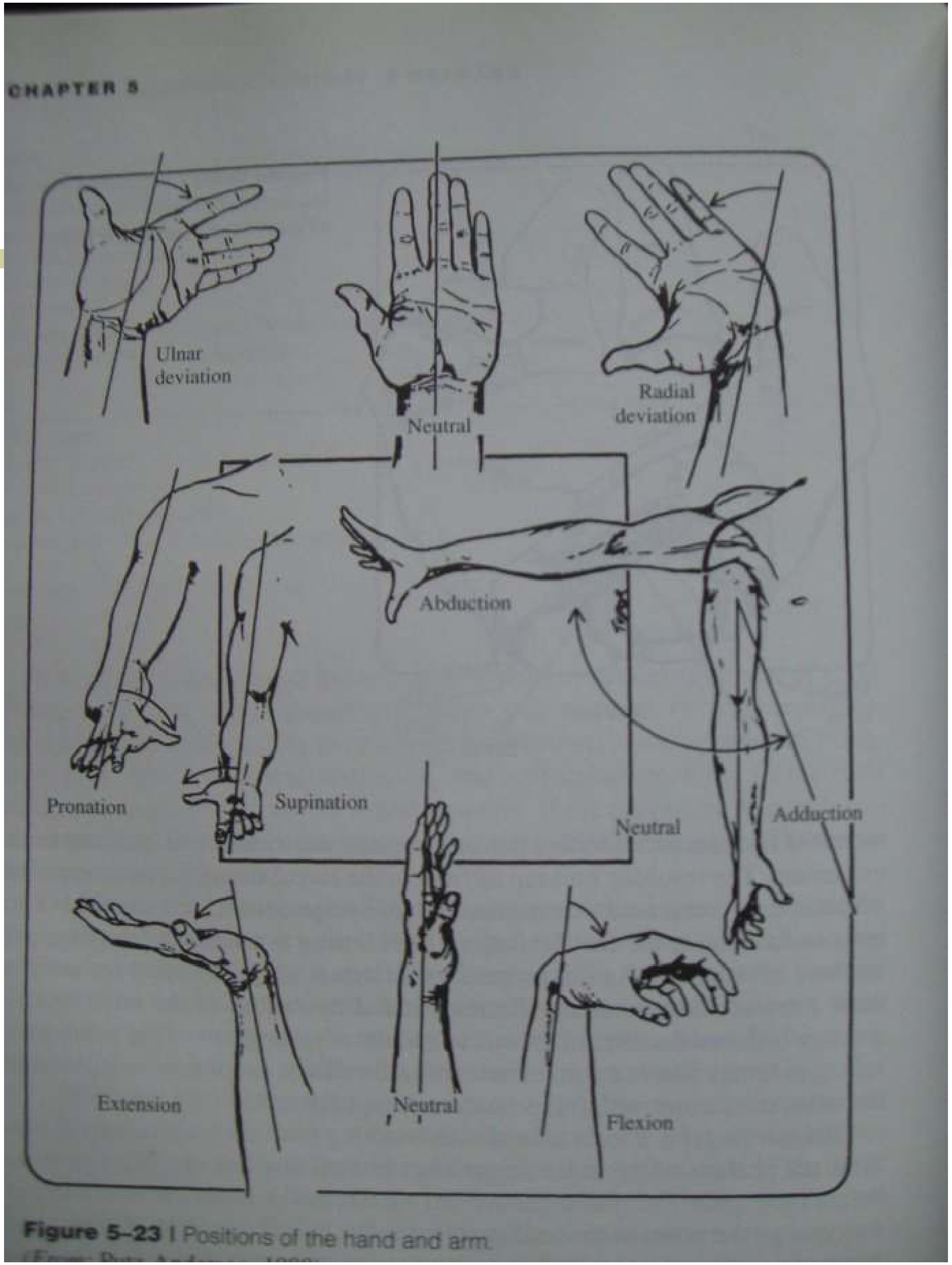
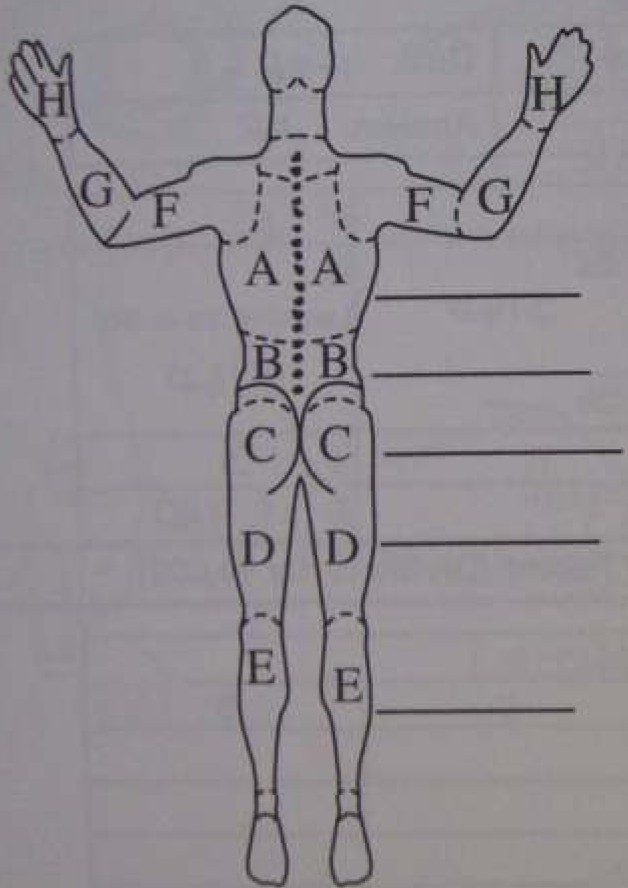


Figure 5–23 | Positions of the hand and arm.



0	Nothing at all	
.5	Extremely weak	(just noticeable)
1	Very weak	
2	Weak	(light)
3	Moderate	
4		
5	Strong	(heavy)
6		
7	Very strong	
8		
9		
10	Extremely strong	(almost max)
•	Maximal	

Figure 5–24 | Body discomfort chart.
(Adapted from Corlett and Bishop, 1976)

Principles of Work Design: Tools

- Use a power grip for tasks requiring force and pinch grips for tasks reqiring precision

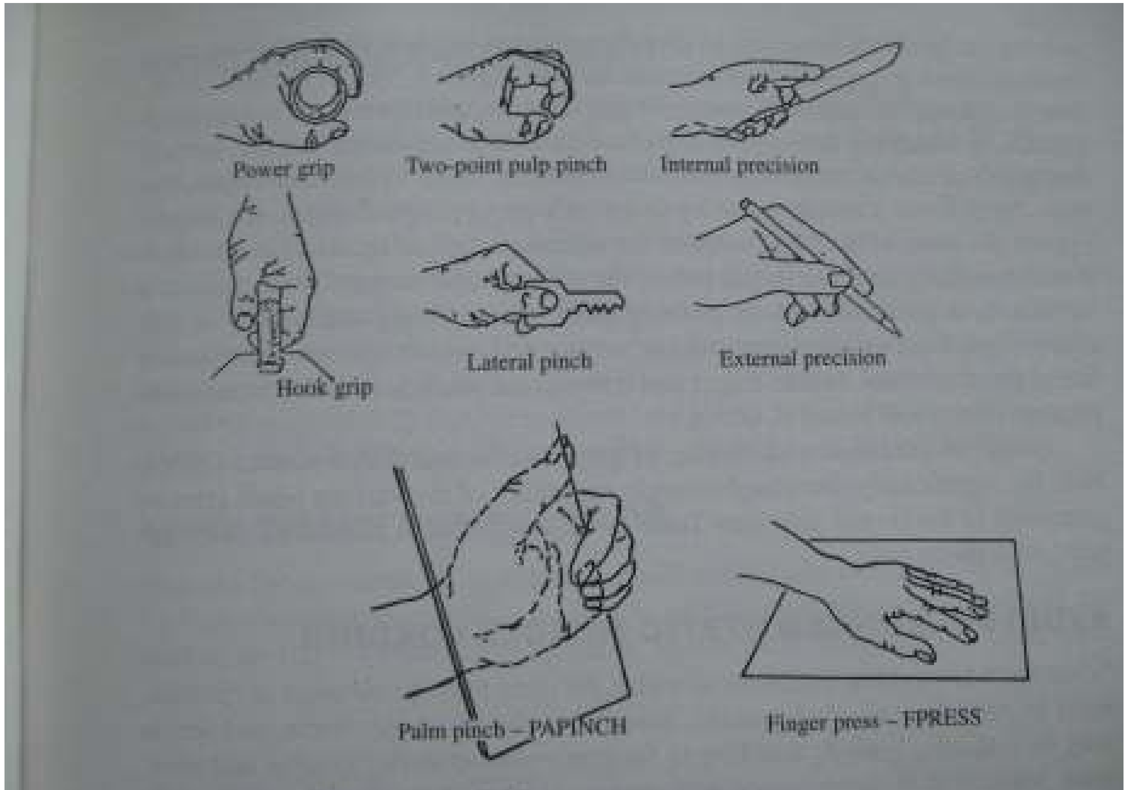


Figure 5–26 | Types of grip.

Principles of Work Design: Tools

- Avoid prolongeed static muslce loading
- Perform twisting motiıns with elbows bent
- Maintain a straight wrist
- Avoid tissue compression

Principles of Work Design: Tools

- Design tools so that they can be used by either hanf and by most individuals
- Avoid repetitive finger action
- Use the strongest working fingers: the middle finger and the thumb

Principles of Work Design: Tools

- Design 1.5 inch handle diameters for power grips
- Design handle lengths to be a minimum of 4 inches
- Design a 3-inch grip span for two-handled tools

Principles of Work Design: Tools

- Design appropriately shaped handles
- Design grip surface to be compressible and nonconductive
- Keep the weight of the tool below 5 pounds
- Use gloves judiciously

Principles of Work Design: Tools

- Use power tools such as nut and screwdrivers instead of manual tools

- Use the proper configuration and orientation of power tools

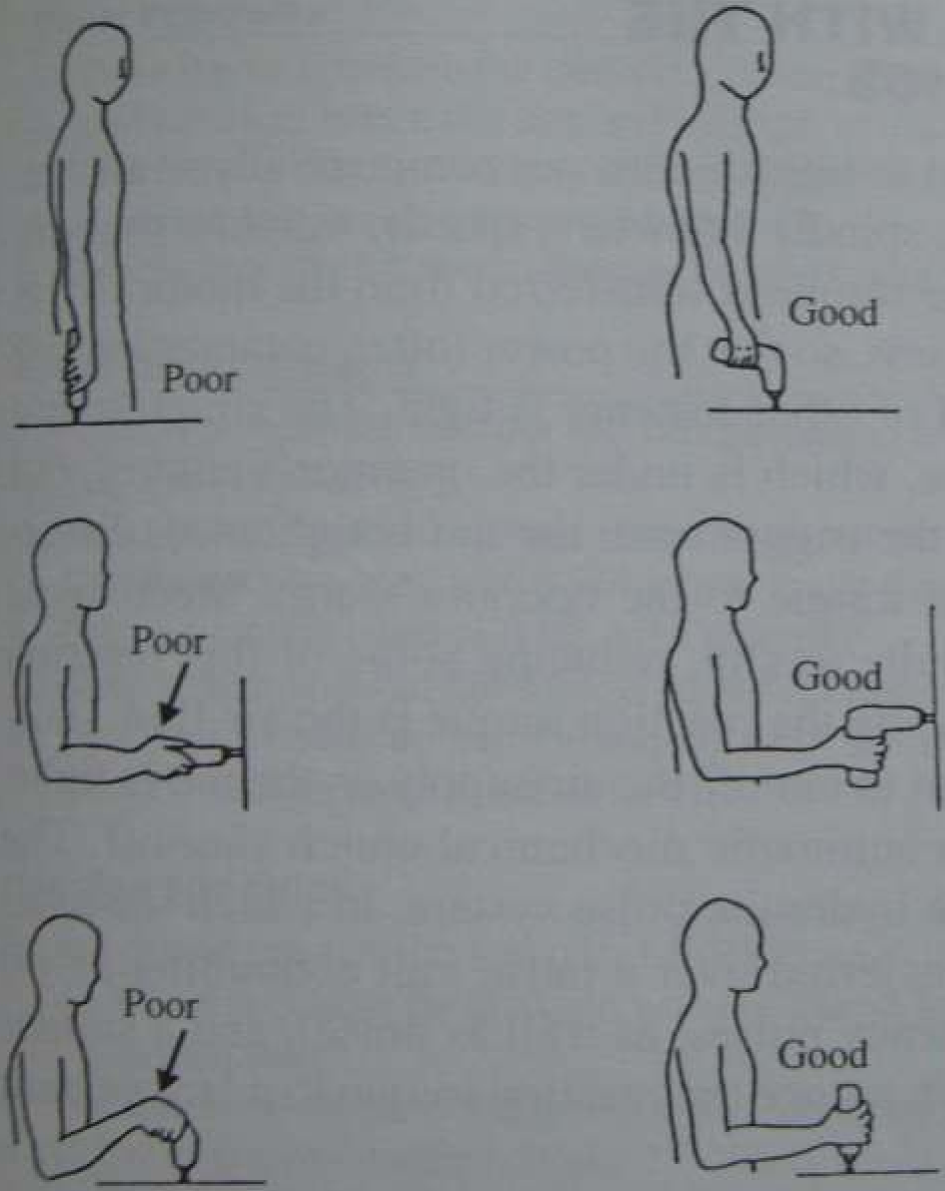


Figure 5–33 | Proper orientation of power tools in the workplace. (*From:* Armstrong, 1993)

Principles of Work Design: Tools

- Choose a power tool with the proper characteristics

- Use reaction bars and tool balancers for power tools