

Design-In Ergonomics Guidelines*



*Formerly titled *Manufacturing Engineering Ergonomics Guidelines (MEEG)*.

Disclaimer

Data and information provided in these guidelines are for use during the design of new products or processes. In all cases where design requirements indicate use of this data is inappropriate, you should contact the appropriate Delphi Divisional Industrial Engineering or Ergonomics Representative. Improper use of the data in this book may result in bodily harm, and / or property damage.

When designing equipment for any country outside the United States and Canada, you may need to modify portions of these guidelines by using the appropriate anthropometric data for the country for which the equipment is intended. Failure to do so can result in bodily harm and / or property damage. A computer program, Anthro07.xls, contains anthropometric data for specific regions throughout the world and can be found by accessing Delphi's intranet at:

<http://apollo.delphiauto.net/ergonomics/design-in.htm>

This document contains general guidelines relating to the design of equipment, tools, jobs and other workplace processes which may be useful in improving the overall level of physical comfort experienced by employees in relation to their working environment and, by doing so, may improve individual and collective efficiency and productivity. However, because workplace situations and individual tolerance for various levels of activity are unique and variable, these guidelines alone are not intended to and cannot be used to specifically predict or prevent the occurrence of cumulative trauma or other forms of muscular skeletal disorders. These guidelines are intended to assist in the development of new products and processes and consequently must be integrated with other factors, such as feasibility and design requirements.

Because these general guidelines are not intended to inhibit the development or application of new technology, Delphi requests all industrial equipment builders to call to the attention of the purchasing division / plant, any section of this document which, in their opinion, may inhibit the application of new technology. This would allow an opportunity for any new technology proposal to be evaluated as to the overall merits of its application.

While Delphi believes that the requirements described within provide a basis for implementing sound ergonomic design into industrial tools, machinery and equipment within Delphi, these standards should not be relied upon for use at non-Delphi operations. Delphi specifically disclaims any liability should these standards be used for equipment, operations, processes and facilities outside their intended purpose.

Preface

Participants in the development and preparation of the Design-In Ergonomics Guidelines (DEG) consist of members of the Delphi Ergonomics Council (DEC). An updated listing of DEC representatives can be found by accessing Delphi's Ergonomics website at:

http://apollo.delphiauto.net/ergonomics/div_ergo_info.htm.

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September, 2009

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Foreword

The DEG is a requirement of the Delphi Business System (DBS) and supports Delphi's "lean initiatives" through integrated requirements defined in the Product Development Process (PDP).

Objective of Manual:

Support Delphi's design-in engineering teams by providing an easy to use database containing ergonomic guidelines for the safe and efficient design of new products, equipment, processes, hand tools, packaging and material handling.

Scope of Manual:

These guidelines are the standardized ergonomics guidelines for use by all Delphi divisions, globally and by all design-responsible engineers as the basis for any new design. In addition, these guidelines are to be used in conjunction with the Design-in & Ergonomics Integration Requirements documents as documented in DBS, PDP, and as defined in the Advanced Development Process (ADP).

Support:

The Manufacturing Engineering Task Team (METT), Engineering Task Team (ETT), and the Manufacturing Task Team (MTT) support design-in ergonomics activity and these guidelines. The emphasis that is placed on ergonomics relative to employee safety and optimizing performance are key elements of a successful manufacturing and engineering organization.

DELPHI Design-in & Ergonomics Integration Requirements

An Overview

PLAN
& DESIGN

DESIGN
VALIDATION

PROCESS
VALIDATION

PRODUCTION
& CONTINUOUS
IMPROVEMENT

Purpose: Ensure adherence to corporate ergonomic guidelines for optimal performance and little to no risk of injury by evaluating all features of the product and the manufacturing system which include layout, operator workplace design, equipment design, operator methods, parts presentation, containerization, and material storage and handling for ergonomic issues.

- Review existing documentation (Lessons-Learned, Illness/Injury Data, Safety Incident Reports, Quality reports, etc.) on this or on a similar product and/or operation to identify potential improvements.
 - Contact plant/site ergonomics representative for lessons-learned.
 - Contact plant medical for injury/illness data.
 - Contact H&S for Safety Incident Reports.
 - Contact Quality for PR&R's, sort/rework/scrap issues.
- Complete Design-In Ergonomics Checklist.
 - Step 1 – Information Gathering
 - Step 2 – Product Design
 - Step 3 – Equipment Design
 - Step 4 – Hand Tool Design
 - Step 5 – Operator Material Handling
 - Step 6 – Overall Process Design
 - Step 7 – Containers/Packaging
- Design out or modify unacceptable conditions found in items that include: product, equipment, process, containers, dunnage, hand tools, assist devices, material handling routes & operator activity.
- Plant/site ergonomics representatives are members of the design-in team and participate in the design review meetings.

- Update the Design-In Ergonomics Checklist and Container Design worksheet as necessary and make changes to design when needed.
 - Utilize mock-ups to validate product/equipment/process design as well as material flow and containerization.
 - Provide opportunity for input from experienced operators and skilled trades who are familiar with product/process.
- Ergonomic assessment of equipment, tools and gages during validation prior to shipment to manufacturing site. Complete a Risk Factor Checklist (RFC2) and utilize Secondary Analysis Tools as needed.
 - Redesign based on ergonomic guidelines.
- Ergonomic assessment of packaging/containerization of incoming and outbound products.

- Update the RFC2 for ergonomic risk assessment.
- Identify improvement opportunities, implement corrective action.
- Solicit input from all shifts involved, include operators, skilled trades & indirect employees.

ERGONOMIC TOOLS:

Go to <http://apella.delphiauto.mcl/ergonomics/>

- Design-in & Ergonomics Integration Requirements, document
- Design-In Ergonomics Guidelines
- Design-In Ergonomics Checklist
- Risk Factor Checklist (RFC2) & Secondary Analysis Tools
- Ergonomics Worksheet for Container Design
- Supermarket/Material Handling Guidelines, booklet

RESPONSIBILITY

The industrial engineer is the team's resource to assist with ergonomics analyses and is responsible for the correct application of the tools. It is, however, the responsibility of the design engineers to complete the Design-in Ergonomics Checklist for items they design and to implement changes or other corrective action when necessary.

CHANGE PROCESS

As the system changes, ergonomics evaluation of existing jobs should be conducted using the RFC2.

Table of Contents

1	Introduction.....	7
1.1	Ergonomics Goals and Benefits	7
1.2	Flow Charting Ergonomics in New Designs	8
1.3	Design-In Ergonomics Checklist.....	9
1.4	Risk Factor Checklist.....	10
2	Environment.....	11
2.1	Light.....	11
2.1.1	Recommended Light Levels	11
2.1.2	Glare.....	12
2.1.3	Lighting for Color Rendering	13
2.2	Noise.....	13
2.3	Visual Aids / Labels / Signs	14
2.3.1	Legibility.....	14
2.3.2	Color Combinations	15
2.3.3	Readability.....	15
3	Operator Interface	16
3.1	Repetitive Motion	16
3.1.1	Quantifying Repetition – Operator Cycle Time	16
3.1.2	Repetition, Force and Injury.....	17
3.1.3	Guidelines for the Design of Jobs with Repetitive Activity	17
3.2	Forces.....	18
3.2.1	General Guidelines	18
3.2.2	Occasional and Repetitive Force Exertions	19
3.2.3	Electrical Connectors	21
3.3	Posture.....	22
3.4	Hand Tool Design Factors	24
3.4.1	General Guidelines for Hand Tools:.....	24
3.4.2	Power Tool Guidelines.....	25
3.4.3	Torque Guidelines	25
3.4.4	Manual Tool w/ Power Grip Guidelines	26
3.4.5	Manual Tool w/ Precision Grip Guidelines	26
3.4.6	Two Handle Grip Tool Guidelines	26
3.5	Static Muscle Loading	27
3.6	Motion and Memory Economy.....	28
3.6.1	Alphanumeric Coding	28
3.7	Temperature.....	29
3.7.1	Heat vs. Pain Threshold	29
4	Equipment / Workplace Design.....	30
4.1	General Guidelines	30
4.2	Stand Only Workstation	31
4.3	Sit or Stand Workstation.....	32
4.4	Sit Workplace	33
4.5	Reach Envelope for Stand Only or Sit/Stand Workplace.....	34
4.5.1	General Guidelines	34
4.6	Displays.....	34
4.6.1	General Guidelines	35
4.6.2	Dial Indicator Guidelines	36
4.6.3	Selection.....	37
4.6.4	Video Display Terminal (Monitors)	38
4.7	Controls.....	39
4.7.1	General Guidelines	39

4.7.2 Movement Stereotypes, Controls	40
4.7.3 Control Design.....	40
4.7.4 Spacing.....	42
4.8 Access Ports Clearances	43
5 Product Design.....	44
5.1 Principles of Design For Assembly (DFA)	45
5.2 Part Handling Characteristics	48
6 Supermarkets.....	49
7 Analysis Tools - Material Handling & Energy Expenditure	52
7.1 One Handed Lifts (Biomechanical Analysis 3-D SSPP).....	52
7.2 Two Handed Lifts (NIOSH Programs).....	53
7.3 Push, Pull, Carry Program (Snook Tables).....	54
7.4 Energy Expenditure	55
Appendix A - Anthropometric Data, United States and Canada Population.....	56
Appendix B – Body Segment Dimension Definitions.....	57
Appendix C – Forward Reach Values (Equipment/Workplace Design)	61
Appendix D – Vertical Hand Height (Equipment/Workplace Design)	62
Appendix E – Vertical Hand Height (Material Handling, Racks/Shelves).....	63
Appendix F - Cumulative Trauma Disorders (CTD).....	64
Appendix G - Bibliography	66

1 Introduction

1.1 Ergonomics Goals and Benefits

Ergonomics is the body of knowledge to support design of product, process and environment. Ergonomics is the application of science that bridges the gap between man and machine which supports lean manufacturing goals by reducing waste in the manufacturing environment and reducing the risk of injury.

Goals:

Thorough and accurate application of ergonomics guidelines can accomplish the following two goals:

1. Provide an injury-free workplace for employees by minimizing ergonomic stressors, such as:
 - Awkward Postures
 - Forceful Exertions
 - Mechanical Stress
 - Static Muscle Loading
 - Vibration
 - Repetition (multiplier of stressors listed above)
 - Duration (multiplier of stressors listed above)
 - Environmental Stressors

2. Optimize production performance by:
 - Reducing non-value added movements, operator motion
 - Minimizing time spent with set-up, changeover, diagnostics & repair and preventive maintenance
 - Optimizing environmental conditions
 - Optimizing workplace design/organization

Goals:

1. Injury-free Environment
2. Optimize Performance

Benefits:

Benefits, as a result of meeting the ergonomic goals, are:

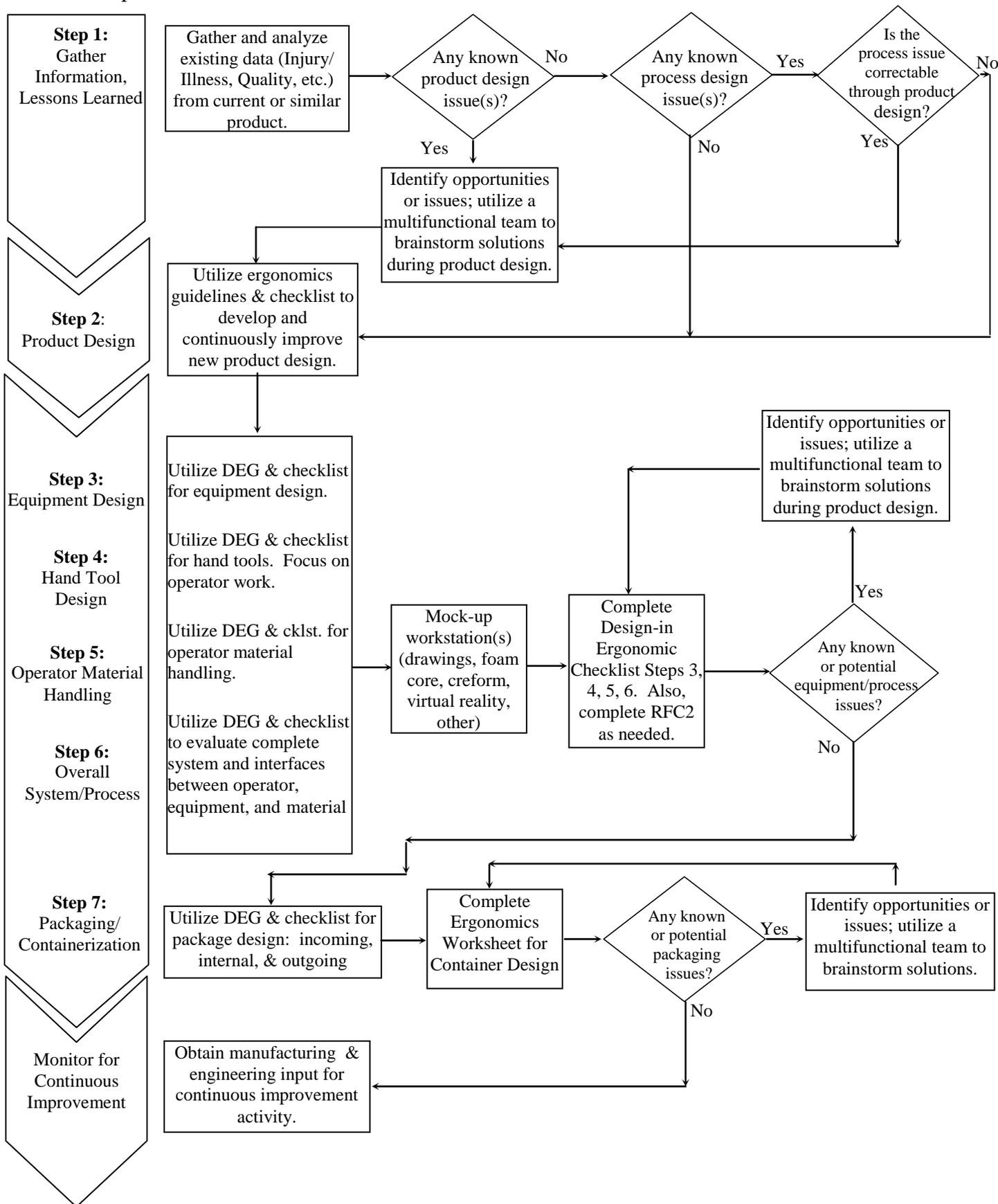
1. Reduced injury/illness and associated costs
2. Minimal cost associated with retrofitting equipment
3. Increased machine availability (performing PM and changeovers quicker)
4. Improved operator efficiency (eliminate excessive reaches, forceful exertions and awkward postures)
5. Improved quality
6. Improved employee morale

Benefits:

1. Improved Morale
2. Increased Productivity
3. Improved Quality
4. \$\$ Saved

1.2 Flow Charting Ergonomics in New Designs

The following is a simplified flow diagram that illustrates where ergonomic planning and evaluation should be performed.



1.3 Design-In Ergonomics Checklist

The Design-In Ergonomics Checklist is a tool for identifying ergonomic elements that are to be considered during design-in activity. To obtain copies of the checklist, go to the *Design-In* tab of the ergonomics website on Delphi's intranet at <http://apollo.delphiauto.net/ergonomics/design-in.htm>.

Description:

The Design-In Ergonomics Checklist is to be used by design engineers at the earliest possible time during the design-in process. The checklist is available in Microsoft Excel format and can be completed electronically, or it can be printed out and manually completed. Also, there are two variations of the checklist, the long version, that contains illustrations and values/scales, or the short version, that contains only the checklist items.

This checklist consists of seven steps, each of which focuses on the performance and injury factors to be considered during design-in.

- Step 1 - Information Gathering
- Step 2 - Product Design
- Step 3 - Equipment Design
- Step 4 - Hand Tools
- Step 5 - Operator Material Handling
- Step 6 - Overall Process Design
- Step 7 - Containers/Packaging

Purpose:

The purpose of the Design-In Ergonomics Checklist is to standardize and simplify the process of gathering lessons learned and then integrating those lessons along with known ergonomics guidelines into new designs. The engineer's focus should be to identify any item that could lead to high level of risk of injury and/or suboptimal performance. This is accomplished by listing ergonomics concepts and discrete data relative to products, equipment, manufacturing processes, hand tools and packaging/container design.

Checklist Limitations:

The checklist will not identify every risk factor but does direct the user to identify areas for further consideration. Also, since most ergonomics issues are multi-factorial, such as high force, poor postures and high repetition, users should apply their ergonomics knowledge or seek the assistance of industrial engineering, plant ergonomics representative or divisional ergonomics manager. This screening tool should be used with a basic understanding of ergonomic concepts. The benefit of the checklist is limited to the experience and effort invested by the individuals performing the analysis.

DELPHI Design-In Ergonomics Checklist			Step 1: Gather Information
Global Application			
Program: _____		Product Description: _____	
Department #: _____		Analyst: _____ Date: _____	
Further information can be found on page 2, 3, 4 of the Delphi Ergonomics Checklist (DEEC). Click on the links in the orange boxes in the table below.			
	Reference:	Date obtained	Area
1 Medical Data			
1.1.1	Last Workday Career	For the design of a new or re-design of an existing product, request medical records for the department of a product that is similar. Look for the injury types that have occurred and determine if the product design could have contributed to the injury--make design changes where feasible.	
1.1.2	Recordable injury		
1.1.3	Non-recordable injury		
1.1.4	Ergonomic errors, manufacturing operator input	Place ergonomic representative on production line during process of final product. Altering product design can minimize prevent process related injury.	
1 Quality Data			
1.2.1	Labeling errors	Altering product design can reduce quality related errors. Understanding what type of errors occurred and provide insight into what the product design has been optimized. Factors can include product label size, location, color, legibility, orientation, etc.	
1.2.2	Inspection due to quality issue		
1.2.3	Missing, wrong, damaged, recovered		
1 Manufacturing Issues - Contact for input			
1.3.1	Plant ergonomic representative	Are there "lessons learned" from a similar, existing product that should be applied to a new/improved design? Look for specialized tools to assist operators in assembly, who have common requests. For equipment, consider the design of the equipment for repair and preventive.	
1.3.2	Operation		
1.3.3	Skilled Trade and Setup		
1 Packaging Issues, relative to Product Design as well as Process Design			
1.4.1	Incoming, supplier packaging	Does product design feature dictate orientation of product for packaging? Orientation of the product in the packaging should be identical to that needed for re-assembly. Consider: does clearances, alignment, is the container right size; is the container too heavy; are hand holds provided; is there anything that needs to be cut off?	
1.4.2	In-house, user in process		
1.4.3	Outgoing, customer packaging		

Ergonomics Container Design Checklist

Delphi Ergonomics Worksheet for Container Design

I. Part Name: _____
 Program: _____ Model Yr: _____
 Date of Analysis: _____ Analyst: _____
 Part Number: _____
 Container Number: _____
 Container Dimensions: L: _____ in. W: _____ in. H: _____ in.
 Part Wt: _____ lb.
 Durrage: removable Q contained Q movable Q
 O = Original Condition; R = Revised Condition

DURRAGE (D1-D3)

D1. Durrage Weight/Force (include swing arms)

	O	R
• < 1 lb.	0	0
• 1 - 10 lb.	1	1
• 10 - 25 lb.	2	2
• > 25 lb.	3	3

Comments: _____

D2. Removable Durrage Size (length + width + height)

	O	R
• < 1 ft.	0	0
• 1 - 5 ft.	1	1
• > 5 - 10 ft.	2	2
• > 10 ft.	3	3

Comments: _____

D3. Durrage Work Envelope Matrix. Indices: 0=poor/unsafe/reduce use or redesign; 1=ok; 2=good; 3=excellent

Hor. Dist. (in) measured from edge of job (i.e. operator belt buckle) to the center of hand grip.

	National Distance		
	5-10	10-15	15-20
Vertical	0-10	10-20	20-30
• 0-10	3	3	3
• 10-20	2	2	2
• 20-30	1	1	1
• 30-40	0	0	0
• 40-50	0	0	0
• 50-60	0	0	0
• 60-70	0	0	0
• 70-80	0	0	0
• 80-90	0	0	0
• 90-100	0	0	0
• 100-110	0	0	0
• 110-120	0	0	0
• 120-130	0	0	0
• 130-140	0	0	0
• 140-150	0	0	0
• 150-160	0	0	0
• 160-170	0	0	0
• 170-180	0	0	0
• 180-190	0	0	0
• 190-200	0	0	0
• 200-210	0	0	0
• 210-220	0	0	0
• 220-230	0	0	0
• 230-240	0	0	0
• 240-250	0	0	0
• 250-260	0	0	0
• 260-270	0	0	0
• 270-280	0	0	0
• 280-290	0	0	0
• 290-300	0	0	0
• 300-310	0	0	0
• 310-320	0	0	0
• 320-330	0	0	0
• 330-340	0	0	0
• 340-350	0	0	0
• 350-360	0	0	0
• 360-370	0	0	0
• 370-380	0	0	0
• 380-390	0	0	0
• 390-400	0	0	0
• 400-410	0	0	0
• 410-420	0	0	0
• 420-430	0	0	0
• 430-440	0	0	0
• 440-450	0	0	0
• 450-460	0	0	0
• 460-470	0	0	0
• 470-480	0	0	0
• 480-490	0	0	0
• 490-500	0	0	0
• 500-510	0	0	0
• 510-520	0	0	0
• 520-530	0	0	0
• 530-540	0	0	0
• 540-550	0	0	0
• 550-560	0	0	0
• 560-570	0	0	0
• 570-580	0	0	0
• 580-590	0	0	0
• 590-600	0	0	0
• 600-610	0	0	0
• 610-620	0	0	0
• 620-630	0	0	0
• 630-640	0	0	0
• 640-650	0	0	0
• 650-660	0	0	0
• 660-670	0	0	0
• 670-680	0	0	0
• 680-690	0	0	0
• 690-700	0	0	0
• 700-710	0	0	0
• 710-720	0	0	0
• 720-730	0	0	0
• 730-740	0	0	0
• 740-750	0	0	0
• 750-760	0	0	0
• 760-770	0	0	0
• 770-780	0	0	0
• 780-790	0	0	0
• 790-800	0	0	0
• 800-810	0	0	0
• 810-820	0	0	0
• 820-830	0	0	0
• 830-840	0	0	0
• 840-850	0	0	0
• 850-860	0	0	0
• 860-870	0	0	0
• 870-880	0	0	0
• 880-890	0	0	0
• 890-900	0	0	0
• 900-910	0	0	0
• 910-920	0	0	0
• 920-930	0	0	0
• 930-940	0	0	0
• 940-950	0	0	0
• 950-960	0	0	0
• 960-970	0	0	0
• 970-980	0	0	0
• 980-990	0	0	0
• 990-1000	0	0	0

Vertical Height (in) measured from floor to hands
 Original Score: _____
 Revised Score: _____
 Comments: _____

P1. Hand Clearance for loading/unloading part (exclude stacked parts)

	O	R
• 16 in.	0	0
• 17 in.	1	1
• 18 in.	2	2
• 19 in.	3	3

Comments: _____

P2. Part Placement

	O	R
• Self align or non critical	0	0
• Guide/rough locators	1	1
• Critical operator judgement	3	3

Comments: _____

P3. Part Rotation, Flipping or Obstructions (2-handed loading)

	O	R
• No rotation; smooth continuous motion	0	0
• No rotation; move direction adjustment	1	1
• Rotate < 90° or flip < 120°	2	2
• Rotate 90°/flip 120°; regrasp	3	3

Comments: _____

P4. Part Load/Unload Work Envelope Matrix. Indices: 0=poor/unsafe/reduce use or redesign; 1=ok; 2=good; 3=excellent

	National Distance		
	5-10	10-15	15-20
Vertical	0-10	10-20	20-30
• 0-10	3	3	3
• 10-20	2	2	2
• 20-30	1	1	1
• 30-40	0	0	0
• 40-50	0	0	0
• 50-60	0	0	0
• 60-70	0	0	0
• 70-80	0	0	0
• 80-90	0	0	0
• 90-100	0	0	0
• 100-110	0	0	0
• 110-120	0	0	0
• 120-130	0	0	0
• 130-140	0	0	0
• 140-150	0	0	0
• 150-160	0	0	0
• 160-170	0	0	0
• 170-180	0	0	0
• 180-190	0	0	0
• 190-200	0	0	0
• 200-210	0	0	0
• 210-220	0	0	0
• 220-230	0	0	0
• 230-240	0	0	0
• 240-250	0	0	0
• 250-260	0	0	0
• 260-270	0	0	0
• 270-280	0	0	0
• 280-290	0	0	0
• 290-300	0	0	0
• 300-310	0	0	0
• 310-320	0	0	0
• 320-330	0	0	0
• 330-340	0	0	0
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• 350-360	0	0	0
• 360-370	0	0	0
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• 400-410	0	0	0
• 410-420	0	0	0
• 420-430	0	0	0
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• 450-460	0	0	0
• 460-470	0	0	0
• 470-480	0	0	0
• 480-490	0	0	0
• 490-500	0	0	0
• 500-510	0	0	0
• 510-520	0	0	0
• 520-530	0	0	0
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• 560-570	0	0	0
• 570-580	0	0	0
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• 590-600	0	0	0
• 600-610	0	0	0
• 610-620	0	0	0
• 620-630	0	0	0
• 630-640	0	0	0
• 640-650	0	0	0
• 650-660	0	0	0
• 660-670	0	0	0
• 670-680	0	0	0
• 680-690	0	0	0
• 690-700	0	0	0
• 700-710	0	0	0
• 710-720	0	0	0
• 720-730	0	0	0
• 730-740	0	0	0
• 740-750	0	0	0
• 750-760	0	0	0
• 760-770	0	0	0
• 770-780	0	0	0
• 780-790	0	0	0
• 790-800	0	0	0
• 800-810	0	0	0
• 810-820	0	0	0
• 820-830	0	0	0
• 830-840	0	0	0
• 840-850	0	0	0
• 850-860	0	0	0
• 860-870	0	0	0
• 870-880	0	0	0
• 880-890	0	0	0
• 890-900	0	0	0
• 900-910	0	0	0
• 910-920	0	0	0
• 920-930	0	0	0
• 930-940	0	0	0
• 940-950	0	0	0
• 950-960	0	0	0
• 960-970	0	0	0
• 970-980	0	0	0
• 980-990	0	0	0
• 990-1000	0	0	0

Original Score: _____
 Revised Score: _____
 Comments: _____

2 Environment

2.1 Light

Numerous studies have examined the relationship between the amount of illumination and productivity. Most have shown some increase in productivity as illumination increases (but the amount of the increase is task-dependent).

Proper selection and placement of lighting sources are the two important elements for a good visual environment process.

2.1.1 Recommended Light Levels

Recommendations for illumination levels in the following table are shown as ranges of luminance for specific types of activities. These guidelines take into account the worker's age (use upper end of range for older workers and difficult tasks), the importance of speed and accuracy, and the reflectance of the task background.

Contact your divisional industrial hygiene representative for further information regarding illumination guidelines and measurement techniques.

Recommended Light Levels		
Type of Activity or Area	Range of Luminance	
	Foot-candles (fc)	LUX
Performance of visual tasks of high contrast or large size: reading printed material, typed originals, handwriting in ink, good xerography; rough bench and machine work; ordinary inspection; rough assembly.	19-46	200-500
Performance of visual tasks of medium contrast or small size: reading pencil handwriting, poorly printed or reproduced material; medium bench and machine work; difficult inspection; medium assembly	46-93	500-1000
Performance of visual tasks of low contrast or very small size: reading handwriting in hard pencil on poor-quality paper, very poorly reproduced material; very difficult inspection	93-186	1000-2000
Performance of visual tasks of low contrast and very small size over a prolonged period: fine assembly, highly difficult inspection, fine bench and machine work	186-464	2000-5000

Perspective on illumination:

- 9 fc (100 lux) = Earth on a cloudy day
- 93 fc (1000 lux) = Earth on a sunny day
- 929 fc (10,000 lux) = White paper on a sunny day

Note: For increasing illumination at a workplace above 93 fc (1000 lux) local task lighting is preferable.

2.1.2 Glare

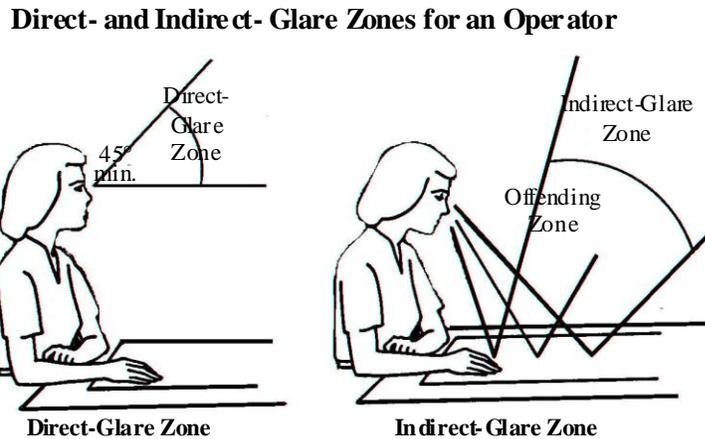
Inadequate lights or improper placement of lights can be sources of glare that could make viewing difficult and uncomfortable. A person's performance varies depending on the location of the light source relative to their line of sight. Glare is classified into two different categories:

Direct Glare

This is caused when a source of light in the visual field is much brighter than the task materials at the workplace.

Indirect Glare

This is caused by light reflected from the work surface.



Examples of ways to control direct glare and indirect glare at the workplace are given below.

To Control Direct Glare	To Control Indirect Glare
Position lights perpendicular to the operator's line of sight.	Avoid placing lights in the indirect-glare offending zone.
Use several low-intensity lights instead of one bright one.	Use lights with diffusing or polarizing lenses.
Position workers so that the highest light levels come from the sides, not front and back.	Use surfaces that diffuse light, such as flat paint, non-gloss paper and textured finishes.
Use diffuse light to provide the best working environment. This may include use of lights with louvers or prismatic lenses.	Change the orientation of a workplace, task, viewing angle or viewing direction until maximum visibility is achieved.
Use more lamps, each of lower power, rather than using few high-powered luminaries.	Avoid flickering light sources.
Use light shields, hoods and visors at the workplace if other methods are impractical.	

2.1.3 Lighting for Color Rendering

Color rendering is a measure of how colors appear under artificial light compared to their color under natural light. The following table summarizes the types of lighting compared to the resultant quality of color rendering.

Color Rendering for Different Light Sources	
Type	Color Rendering
Incandescent	Incandescent lights are commonly used for good color rendering but they are the least energy efficient. Although lamp cost is low, lamp life is typically less than 1 year.
Fluorescent	Fluorescent lights provide fair to good color rendering with a lamp life of 5 – 8 years. However, after one year the illumination is reduced by 50%.
Mercury	Each of these types of lights provide only fair color rendering however, may be acceptable for infrequently used areas.
Metal Halide	
High Pressure Sodium	
Low Pressure Sodium	These lights are the most energy efficient but provide poor color rendering. They are mainly used for warehouse lighting.

2.2 Noise

It is important to consider noise in the design of new or rebuilt equipment. Some studies have suggested that noise can contribute to the variability of quality. Also, tasks that directly involve verbal transmission of information may be degraded if noise affects speech. The noise features that contribute to performance degradation include:

- Variability in level or content
- Intermittence
- High-level repeated noises
- Frequencies above approximately 2000 Hz
- Any combination of the above

Refer to the Delphi Sound Level Specification SL 1.0 – Purchase of New, Rebuilt and Relocated Machinery, Power Tools and Equipment. This document can be obtained by accessing the Industrial Hygiene webpage located on Apollo at: <http://apollo.delphiauto.net/industrialhygiene/ihpp.htm> Contact your divisional industrial hygiene representative for specific information regarding noise level guidelines and measurement techniques.

2.3 Visual Aids / Labels / Signs

2.3.1 Legibility

Use the following guidelines to improve the legibility of messages on labels, signs and other printed communication forms.

- Keep fonts simple.
- For easier and faster reading, type using both upper case and lower case letters.

When a printed label or message must be read quickly and easily, it is important to choose a plain and simple design of type font. There are some slightly more complex designs that can be easily read because they are familiar from wide use. **USE OF ALL UPPER CASE LETTERS REDUCES LEGIBILITY. LESS FAMILIAR DESIGNS MAY RESULT IN ERRORS ESPECIALLY IF THEY ARE READ IN HASTE.** FONTS DESIGNED PRIMARILY FOR AESTHETIC REASONS ARE VERY POOR CHOICES. **OBVIOUSLY EXTREMES LIKE OLD ENGLISH SHOULD NEVER BE USED. AVOID COMPLEX FONTS Keep It Simple.**

- Text should be sized according to the maximum distance the label / sign must be read from. Use height, width and stroke width formulas shown below to perform calculations.
- To convert character height to a font size (point) for computer generated text use:
1 point = 1/72 inch = .353mm

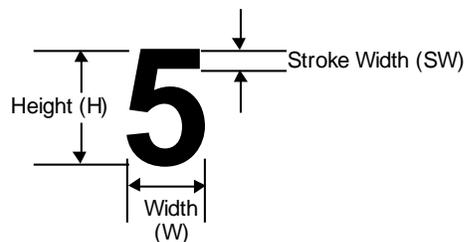
$$\text{Height (in or mm)} = \frac{\text{Viewing Distance (in or mm)}}{200}$$

$$\text{Stroke Width} = \left(\frac{1}{6}\right) H$$

$$\text{Width} = \left(\frac{2}{3}\right) H$$

$$\text{Distance apart of letters: } \left(\frac{1}{5}\right) H$$

$$\text{Distance between words and figures: } \left(\frac{2}{3}\right) H$$



- Letter sizes for some common viewing distances, using the formula above, and assuming illumination (>10 fc or 108 lx), are shown in table below:

Viewing Distance	Minimum Label Height
28 in (0.7 m)	.14 in (3.5 mm)
3 ft (0.9 m)	.18 in (4.5 mm)
6 ft (1.8 m)	.35 in (9 mm)
20 ft (6.1 m)	1.2 in (30.5 mm)

Note: If the sign or label is more than 79 in. (200 cm) above the floor, the character dimensions should be enlarged for better legibility.

2.3.2 Color Combinations

It is best to avoid the use of colored print. If, however, colored letters or numbers must be used, legibility may be reduced and operator reaction time increased. Color combination should be tested in the environment to assess their legibility. Use table below for scaling color combinations versus legibility.

Color Combinations Chart	
Legibility	Color Combination
Very Good	Black characters on a white background Black on yellow
Good	Yellow on black White on black Dark blue on white Green on white
Fair	Red on white Red on yellow
Poor	Green on red Red on green Orange on black Orange on white Pink on purple
Very Poor	Black on blue or Yellow on white

2.3.3 Readability

Readability is the ease of reading words or numbers, assuming the individual characters are legible. The following guidelines give ways to improve readability of labels and signs:

- Use capital letters for headings or messages of a few words only. Use lowercase letters for longer messages. Do not use italics except when needed for emphasizing specific words or short phrases. Underlining is a better alternative method for adding emphasis.
- Avoid abbreviations. Use standard ones if they must be used.
- Use a border to improve readability of a single block of numbers or letters.
- If several labels or messages are clustered in the same area, put distinctive borders around the critical ones only.

When space is limited and the character size is critical, fill most of the space within the border.	2093	Preferred over	2093
When space is not critical, a larger surrounding border contributes to even better readability.	5487	Preferred over	5487

- Make signs and labels accessible, easy to change and maintain. Protect them for ease of cleaning and durability.

3 Operator Interface

3.1 Repetitive Motion

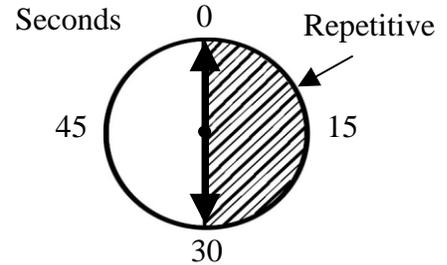
3.1.1 Quantifying Repetition – Operator Cycle Time

This method of evaluating repetition is accomplished by measuring the cycle time of the operator. A task is considered highly repetitive if...

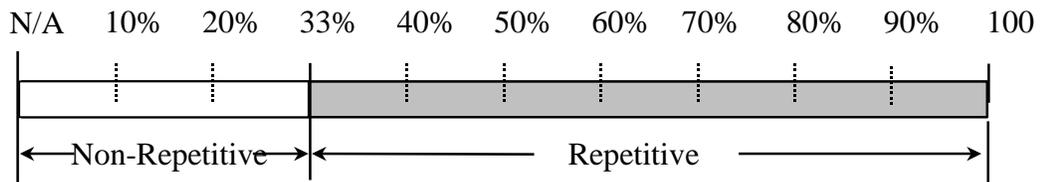
- a. The operator's cycle time is less than 30 seconds

or

- b. The operator cycle time is greater than 30 seconds and the motion is repeated or sustained for more than

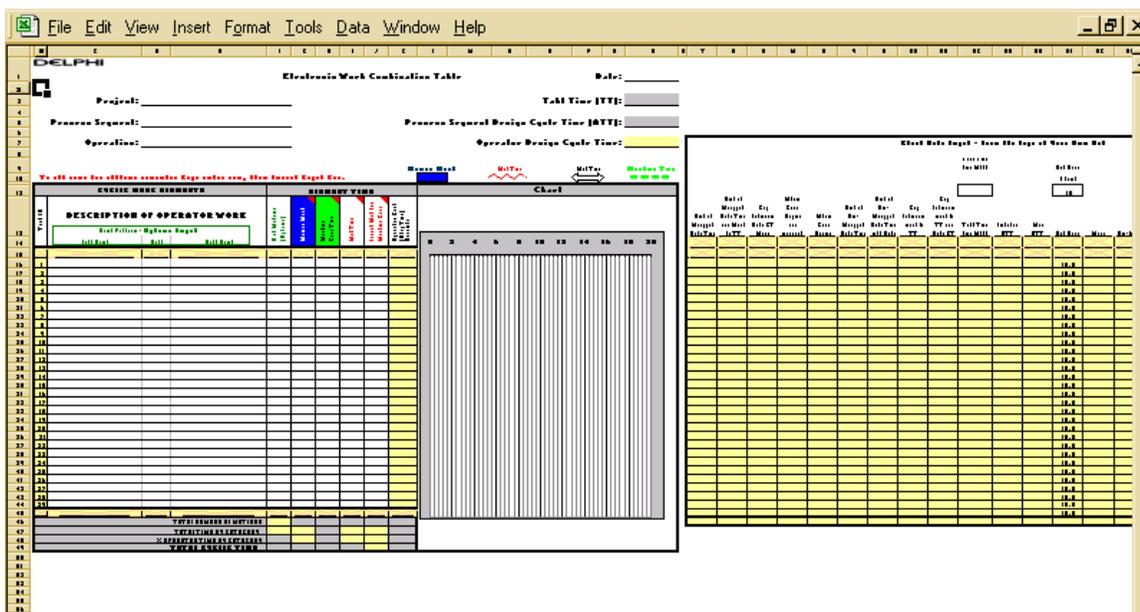


Percent of cycle time:



$\frac{1}{3}$ of the cycle.

Work Combination Tables (WCT) should be used in determining the operator's cycle time. Copies of the WCT sheet along with directions for completion can be obtained by visiting Delphi's intranet at http://apollo.delphiauto.net/lean_coe/m_msd.htm.



3.1.2 Repetition, Force and Injury

Under certain circumstances where repetitive motion cannot be easily changed or controlled, ergonomic risk factors must be minimized.

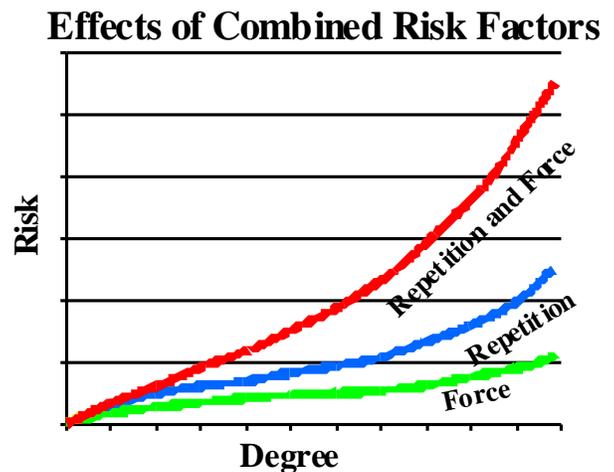
These risk factors include:

1. Awkward Postures
2. Forceful Exertions
3. Mechanical Stress
4. Static Muscle Loading

The graph shown illustrates the risk of Carpal Tunnel Syndrome (CTS) and Tendonitis as a function of force and repetition. It is important to note that posture also interacts with force with regard to risk of injury.

The significance of the graph is:

1. Both repetition and force can cause injury.
2. Repetition poses a greater risk of injury than does force.
3. When repetition is coupled with force, the risk of injury dramatically increases.



3.1.3 Guidelines for the Design of Jobs with Repetitive Activity

The following general guidelines are given for the prevention and management of repetitive motion disorders in the workplace.

- Spread the load over as many muscle groups as possible to avoid overloading the smaller muscle groups, see Forces, Section 3.2.
- Design tasks to permit gripping with the fingers and palm instead of pinching, see Forces, Section 3.2.
- Keep forces low during rotation or flexion of the joint. Use power assists if forces are high. Avoid repetitive gripping actions, see Forces, Section 3.2
- Avoid extreme wrist deviation (see Posture, Section 3.3).
- Design work surface heights, orientations, and reach length to permit the joints to remain as close to the body as possible, see Equipment/Workplace Design, Section 4.
- Provide fixtures to hold parts during assembly so that awkward holding postures can be minimized.
- Engineer products to allow machinery to do highly repetitive tasks. Leave more variable tasks to humans.
- Provide a variety of tasks over a work shift, if possible.

3.2 Forces

It is difficult to provide general guidelines for force exertions because postural and frequency requirements differ in each workplace. (Posture determines both muscle length and joint and body angles, which determine the total force that can be developed during pushing or pulling.)

In addition to variable workplace situations, it is difficult to provide general guidelines for force exertion because the muscle strength data on industrial populations are limited and lack close agreement. Attempts to standardize strength measurements should improve the reliability and validity of these measurements in the future.

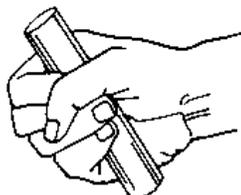
As such, it should not be inferred that forces greater than the ones shown put people at high risk of injury. However, new products or processes, where the realized force is greater than the forces listed, should either be reengineered or designed with an effective and efficient method of applying force or ideally, minimize the force required. **These guidelines are most appropriately used for the design of new jobs than for the evaluation of the risk for injury in existing ones.**

Note: The general force guidelines listed in Section 3.2.2 do not apply to the product design or assembly of conventional and mechanical assist (lever and slide-lock) electrical connectors and connector position assurance (CPA's). For such product or assembly processes, see Section 3.2.3 of DEG and the SAE/USCAR-25 guidelines located at: <http://apollo.delphiauto.net/ergonomics/design-in.htm>

3.2.1 General Guidelines

- Design tasks to permit gripping with the hand and palm instead of pinching.

Power Grip



Pinch Grip



- If forces required are high, possible ways to reduce force are:
 - Improve the direction of force application
 - Provide a power assist
 - Use stronger muscle groups
 - Distribute force over larger area
- The amount of force a person is capable of exerting with their wrist(s) in a deviated posture is approximately 50% of when a neutral wrist posture is used. When reviewing the force guidelines in section 3.2.2, the amount of force that is allowed with a deviated wrist is 1/2 of that allowed for forces with a neutral wrist.
- Improperly fitted gloves can reduce dexterity and increase the force required to maintain control when operating hand tools. Whenever possible, use tape for fingers, fingerless gloves, or fitted surgeon's gloves to minimize loss of sensory feedback.



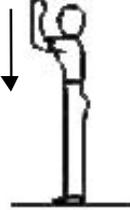
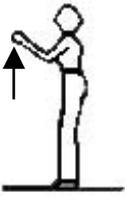
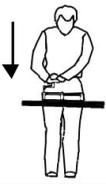
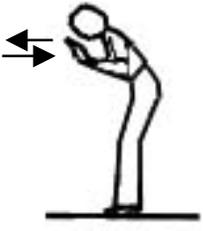
Poorly Fitted



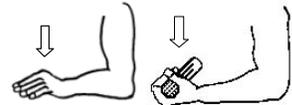
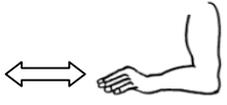
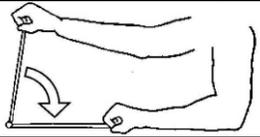
Well Fitted

3.2.2 Occasional and Repetitive Force Exertions

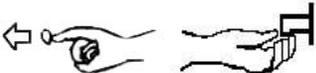
Note: All Forces listed are based on a mixed gender population in a standing position. Seated force values are approximately 85 percent of the standing values shown.

One Hand with Body	Description	Non-Repetitive	Repetitive
	One Hand Push Up Primarily arm muscles involved: Elbow Height	13 lbs. (57.8 N)	4 lbs. (18 N)
	Shoulder Height	9 lbs. (40 N)	3 lbs. (13 N)
	One Hand Lateral – Left/Right Arms fully extended	15 lbs. (66.7 N)	5 lbs. (22 N)
Two Hands			
	Two Hands Pull Down (Vertical) Above head height	45 lbs. (200 N)	15 lbs. (66.7 N)
	Shoulder level	70 lbs. (311 N)	23 lbs. (102 N)
	Two Hands Pull Up (Vertical) Elbow Height	33 lbs. (146.7 N)	11 lbs. (48.9 N)
	Shoulder Height	17 lbs. (75 N)	6 lbs. (26 N)
	Two Hands Push Down (Vertical) Elbow Height	64 lbs. (284 N)	21 lbs. (93 N)
	Two Hands Pull In/Push Out (Horizontal) Primarily arm muscles involved Arms fully extended	24 lbs. (106.7 N)	8 lbs. (35 N)
	Assuming whole body involved	50 lbs. (222 N)	17 lbs. (75 N)
	Two Hand Push Up Shoulder Height Assuming whole body involved	45 lbs. (200 N)	15 lbs. (66.7 N)

Forces (continued)

One Hand	Description	Non- Repetitive	Repetitive w/Neutral Wrist	Repetitive w/Deviated Wrist
	Palm Squeeze	6 lbs. (26 N)	4 lbs. (18 N)	2 lbs. (8.8 N)
	One Hand Pull Up (Palm Up or Down)	18 lbs. (80 N)	6 lbs. (26 N)	3 lbs. (13 N)
	One Hand Pull Down (Palm Up or Down)	18 lbs. (80 N)	6 lbs. (26 N)	3 lbs. (13 N)
	One Hand Push/Pull Horizontal Primarily arm muscles involved & elbow height	18 lbs. (80 N)	6 lbs. (26 N)	3 lbs. (13 N)
	One Hand with Arm, Arbor Press Motion	30 lbs. (133 N)	10 lbs. (44 N)	5 lbs. (22N)
	Forearm Rotation	18 lbs. (80 N)	6 lbs. (26 N)	3 lbs. (13 N)

Forces (continued)

Finger Forces	Description	Non-Repetitive	Repetitive w/Neutral Wrist	Repetitive w/Deviated Wrist
	Finger Push/Pull	10 lbs. (44 N)	2 lbs. (8.8 N)	1 lb. (4 N)
	Key Grip	10 lbs. (44 N)	2 lbs. (8.8 N)	1 lb. (4 N)
	Pinch Grip	10 lbs. (44 N)	2 lbs. (8.8 N)	1 lb. (4 N)
	Pulp/Lateral Pinch	10 lbs. (44 N)	2 lbs. (8.8 N)	1 lb. (4 N)
	Thumb Front Push or Palm Push	10 lbs. (44 N)	2 lbs. (8.8 N)	1 lb. (4 N)
	Finger or thumb twist torque	27 lbf.in. (3Nm)	9 lbf.in. (1Nm)	4.5 lbf.in. (.5Nm)

3.2.3 Electrical Connectors

The force guidelines listed above in Section 3.2.2, do not apply to the product design or assembly of conventional and mechanical assist (lever and slide-lock) electrical connectors and connector position assurance (CPA's). For these items, the document co-authored by the Society of Automotive Engineers and the United States Council for Automotive Research entitled *Electrical Connector Assembly Ergonomic Design Criteria* should be used (also known as: SAE/USCAR-25). These guidelines are located at: <http://apollo.delphiauto.net/ergonomics/design-in.htm>

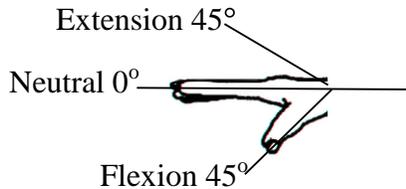
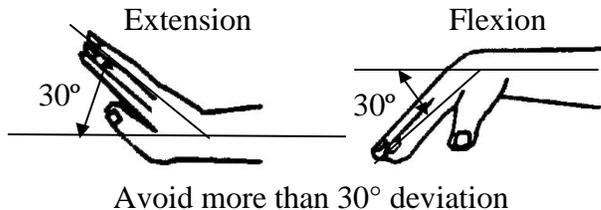
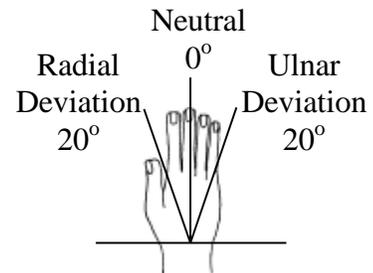
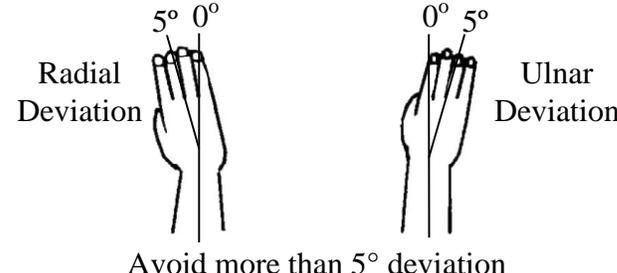
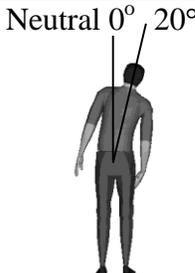
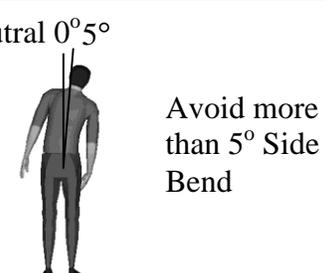
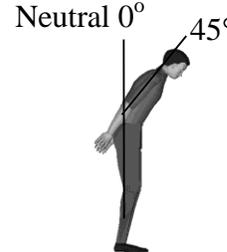
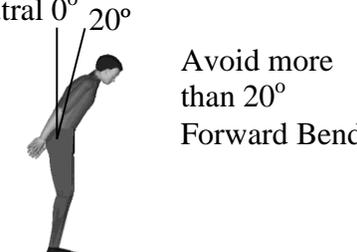
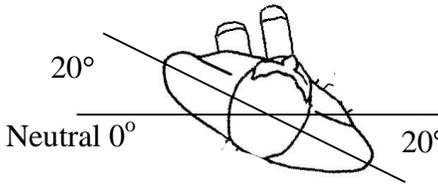
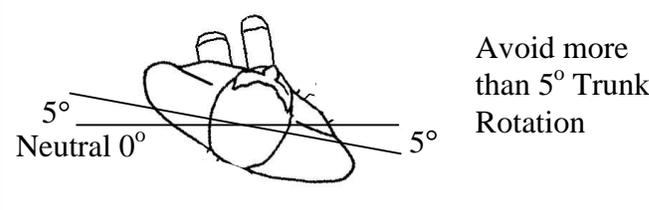
Please note that assembly forces should always be as low as possible. If new, innovative designs are created that exceed the currently accepted injury risk guidelines (SAE/USCAR-25), then that information should be documented and shared for the benefit of other Delphi locations.

Also note that SAE/USCAR-25 does take repetition into account in the guidelines, so they do apply for both occasional and repetitive fore exertions. However, they do not account for situations such as obstructed access, limited visibility, or awkward or non-neutral postures (such as wrist deviation) when assembling electrical connectors. Please contact your ergonomics representative for support if one of these situations is present or for assistance in interpreting the SAE/USCAR-25 guidelines.

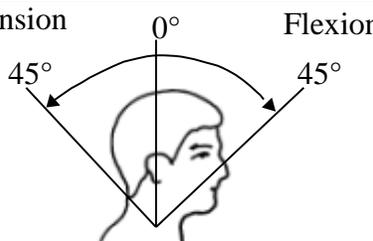
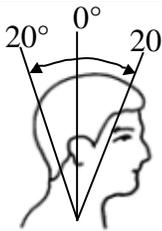
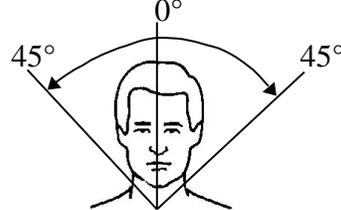
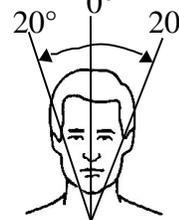
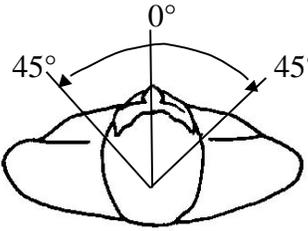
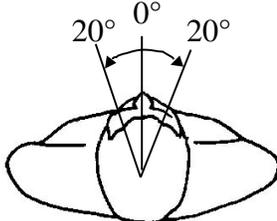
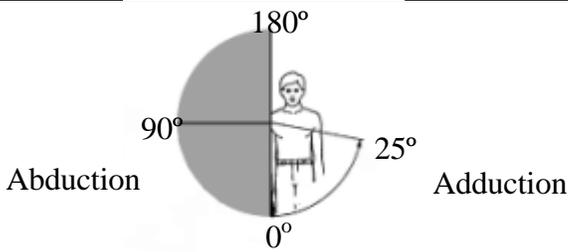
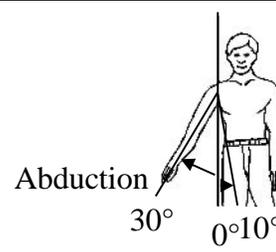
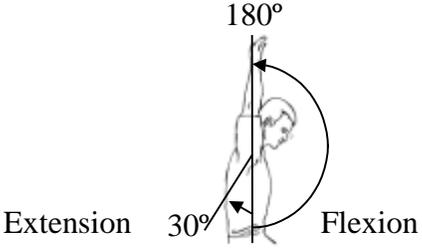
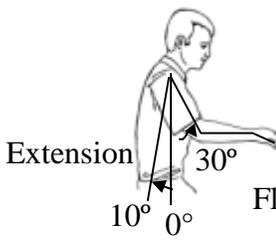
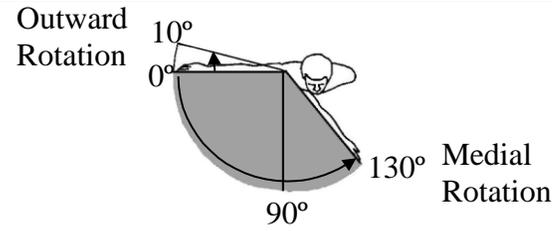
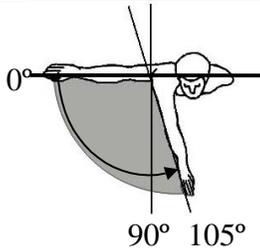
3.3 Posture

The workplace and operator work method should be engineered so that all materials, displays and controls are positioned to control unnatural head positions and shoulder, body, head and wrist deviations.

For specific circumstances that require operating outside the given postural ranges, contact Industrial Engineering or Ergonomics Representative.

Hand and Wrist	
Non-Repetitive Deviation	Repetitive Deviation
 <p>Extension 45° Neutral 0° Flexion 45°</p>	 <p>Extension 30° Flexion 30° Avoid more than 30° deviation</p>
 <p>Radial Deviation 20° Neutral 0° Ulnar Deviation 20°</p>	 <p>Radial Deviation 5° Ulnar Deviation 5° Avoid more than 5° deviation</p>
Back	
 <p>Neutral 0° 20°</p>	 <p>Neutral 0° 5° Avoid more than 5° Side Bend</p>
 <p>Neutral 0° 45°</p>	 <p>Neutral 0° 20° Avoid more than 20° Forward Bend</p>
 <p>Neutral 0° 20°</p>	 <p>Neutral 0° 5° 5° Avoid more than 5° Trunk Rotation</p>

Posture (continued)

Head	
Non-Repetitive Deviation	Repetitive Deviation
<p>Extension 0° Flexion</p> 	 <p>Avoid more than 20° Neck Bend (Forward or Back)</p>
	 <p>Avoid more than 20° Lateral Bend</p>
	 <p>Avoid more than 20° Neck Rotation</p>
Shoulder	
 <p>Abduction 25° Adduction</p>	 <p>Abduction 30° Adduction 10°</p> <p>Avoid more than 10° Adduction and/or 30° Abduction</p>
 <p>Extension 30° Flexion</p>	 <p>Extension 10° Flexion 30°</p> <p>Avoid more than 30° Flexion and/or 10° Extension of the Shoulder</p>
 <p>Outward Rotation 10° Medial Rotation 130°</p>	 <p>90° 105°</p> <p>Avoid Hyperextension of shoulder and/or greater than 105° of medial rotation</p>

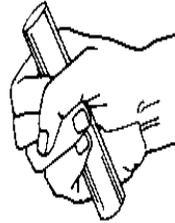
3.4 Hand Tool Design Factors

The shape and size of hand tools directly affect a user's performance capability (especially grip strength) and biomechanical stress on the upper extremity.

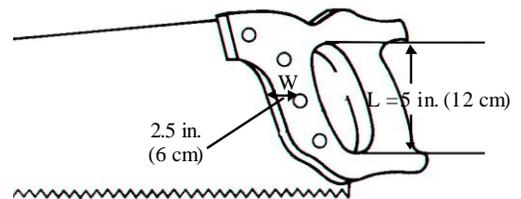
3.4.1 General Guidelines for Hand Tools:

- Distribute the grip forces over as wide an area as possible. The grip force should not be concentrated on one or two fingers or in the center of the palm. Handles and handgrips should generally be designed for a power grip, in which the hand wraps around the handle.
- Choose tools with handles that span the hand and extend beyond the palm.
- When using tools that require putting hands / fingers inside the handle(s), provide sufficient clearance for glove thickness. See saw example on right.
- The tool handle should not exert forces on the sides of the fingers and the hand should not be exposed to sharp edges or corners.
- There should be no finger grooves in the handles of the tools.
- Handles should be covered with smooth, non-slip compressible material. Be sure, however, the coating is not so soft that debris could become embedded.
- Choose a tool that can be used by both the right and left hands.
- Choose a tool that will allow the elbows to be held close to the body.
- Bend the tools, not the wrist. Align the handle axis with the operator's arm to allow the elbows to be held close to the body.

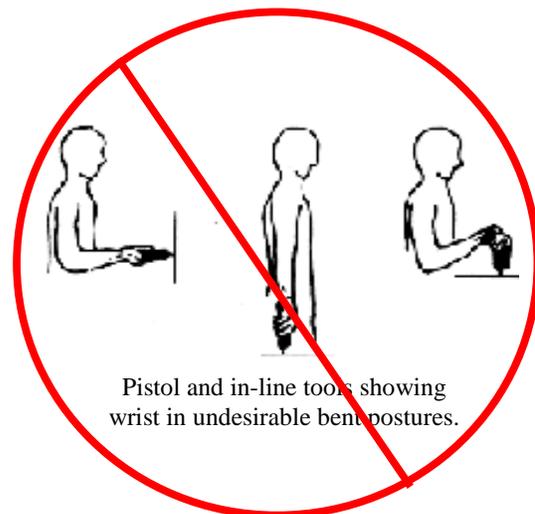
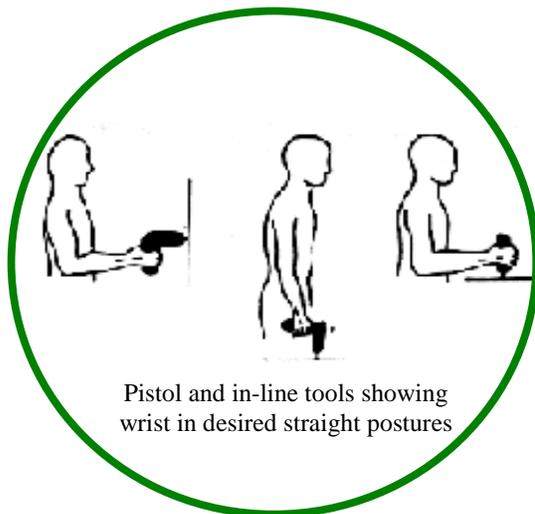
Power Grip



Pinch Grip



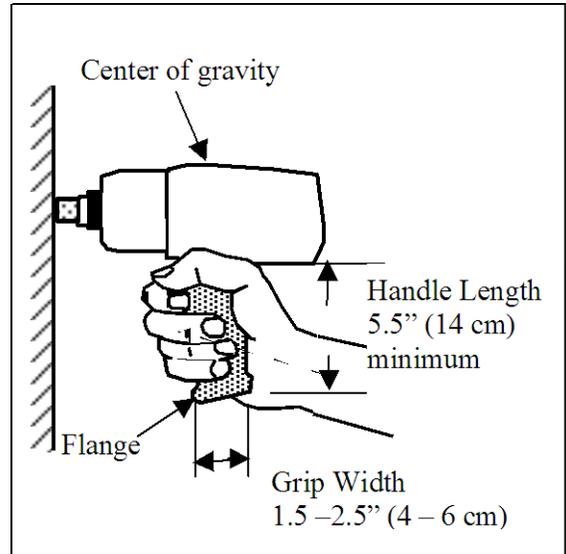
Sized for Gloved Thickness



3.4.2 Power Tool Guidelines

General

- There should be no finger grooves.
- The handle should be located near the tool's center of gravity.
- Handle grip length should accommodate all fingers on the grip.
- Handles should be designed to avoid undue stress on the palm or fingers.
- All power and air cords should be very flexible and should not interfere with the operation and handling of the tool.
- Direct air exhaust away from operator.
- Push-to-start activation should be used whenever feasible. If not, use strip triggers for tools that are balanced on a suspended tool system or single button trigger for tools that are not (activation pressure should be less than 2 lbs., 0.9 kg, or 22 psi).
- If large downward forces are required, select a tool with a flange at the base of the handle.



Assist Mechanisms

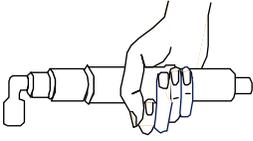
- Use overhead balancer if the tool is greater than 6 lbs. (26 N), if multiple tools are used at the workstation, or if the tool is held for sustained periods of time.
- Assist mechanisms should present the tools in the proper orientation for the user.

Vibration

- Tools should be equipped with vibration dampening characteristics to minimize the transmission of vibration to the hand. Specific guidelines are to:
 - Use vibration isolators in handles.
 - Avoid tools with low frequency/high amplitude vibration.
 - Make sure that tools are properly maintained.
 - Use compressible housing on tool handles.

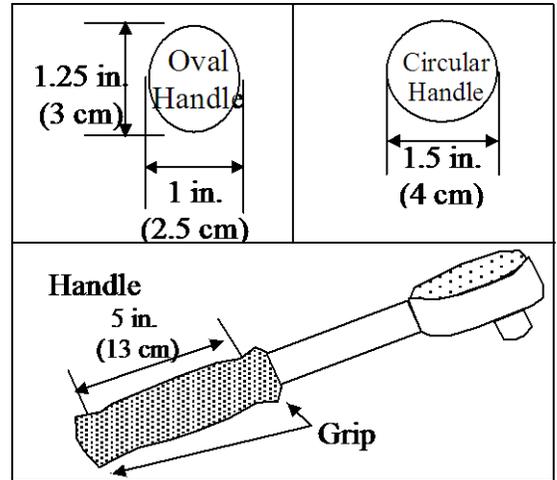
3.4.3 Torque Guidelines

- Select tools with torque control settings wherever applicable.
- Use torque reaction devices if the measured torque exceeds values shown below:

<u>Clutch Device</u>	<u>Right Angle Grip</u>	<u>Pistol Grip</u>	<u>In Line Grip</u>
Almost any power tool can have a clutch device to minimize torque reaction.			
15 ft. lbs. (20 Nm)	7.5 ft. lb. (10 Nm)	1.5 ft. lb. (2 Nm)	.75 ft. lb. (1 Nm)

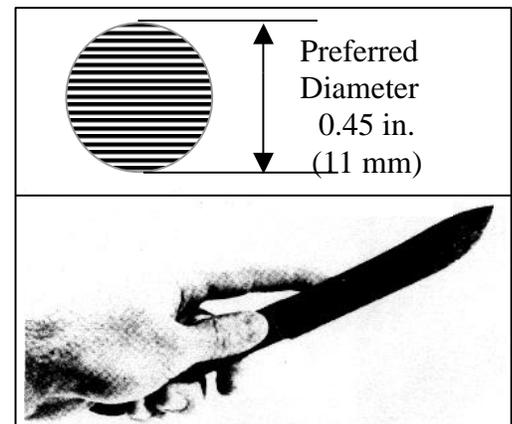
3.4.4 Manual Tool w/ Power Grip Guidelines

- The tool should be designed with an oval shaped handle of 1.25 inches (3 cm) by 1.0 inches (2.5 cm). Otherwise, a circular handle with a diameter between 1.25 to 1.5 inches (3 – 4 cm) for power grips is acceptable, with 1.5 inches (4 cm) preferred.
- The minimum handle length for most operations is 4 inches (10 cm). A 5-inch (13 cm) handle is preferable. Or use 95th percentile male hand breadth + 1 in. (2.5 cm).
- For tools that are used with gloves, add 0.5 inches (1.3 cm) to the handle length.
- A power tool is preferred over a non-powered tool when high forces are required.



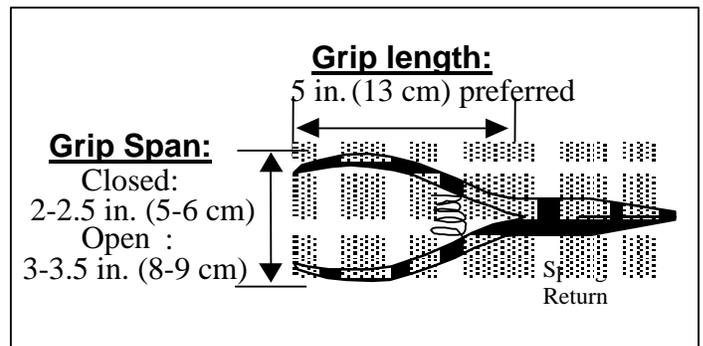
3.4.5 Manual Tool w/ Precision Grip Guidelines

- For precision operations (knife, blade razor, pencil), tool handles may require significantly smaller handling surfaces to allow for fingertip control.
- The recommended diameter is 0.45 inches (11 mm). A range from 0.3 to 0.6 inches (8 to 16 mm) is acceptable.
- For tools with cutting blades, the use of guards may improve thrust capability and reduce accidents.



3.4.6 Two Handle Grip Tool Guidelines

- For tools with two handles (pliers, scissors, clippers, pop riveters), the handle grip span should be between 3 to 3.5 inches (8 to 9 cm) when open and 2 to 2.5 inches (5 to 6 cm) when closed.
- The handle length should be at least 4 inches (10 cm), with 5 inches (13 cm) preferred.
- A spring return is preferred.
- There should be no finger grooves.
- Handle curvature of no more than .5 inches (13 mm) over its entire length; handles should be almost straight with a slight curve. The high points of the curves should rest on the base of the thumb and against the middle of the fingers.
- Each handle of the tool should be a mirror image of the other handle.
- For cutting tools, select a tool with a high quality blade.



3.5 Static Muscle Loading

Maintaining a particular posture for a period of time, even for a short duration, is called static muscle loading. Static muscle loading may result in local muscle fatigue and should be avoided for the design of new processes, see guidelines below:

Upper Extremities

- To minimize static muscle loading, follow the specific design guidelines for:
 - Displays, Section 4.5
 - Hand Heights, Sections 4.2
 - Forward Reaches, Section 4.4
- Reduce force requirements on controls that have to be operated rapidly (> 10 times per minute) or held for periods in excess of 30 seconds.
- Provide aids for carrying tasks taking more than one minute and involving objects weighing more than 15 lbs. (7 kg).
- Use jigs and fixtures to reduce the requirement for holding in assembly tasks.
- Provide handles or handholds on objects, such as containers, to be lifted or carried.

Lower Extremities

Depending on the work situation the following options exist regarding standing/walking:

- Avoid pressure on the feet from static standing (non-movement of the legs while standing) by allowing for a combination of standing, sitting and walking.
- Standing, without walking, results in more discomfort than “active” standing (walking 2-4 minutes every 15 minutes).
- A softer standing surface, such as wood floors or hard surfaces over which a mat has been laid, reduces pain, fatigue and discomfort.
- Chairs can alleviate static muscle loading in the lower extremities. Chair usage must be evaluated on a case-by-case basis. Factors involved include weight of part, reaches and leg/knee clearances, and whether or not the operator must move to several workstations.
- Foot pedals should not be used while standing. Nor should constant pressure or force be required to activate a foot pedal during an assembly operation.



3.6 Motion and Memory Economy

In designing a workstation, consider the following the general principles of motion economy for optimum human capability.

- Rearrange the workplace layout to minimize eye-directed movements, complicated or blind reaches and awkward work/postures. Keep hand movements within peripheral vision.
- Do not design precise movements or fine control immediately after heavy work. Precise movements should only require low force.
- Provide a holding device, such as a fixture, that is easy to load and unload and have positive location of parts with locators.
- Motions should begin and end with both hands simultaneously.
- Simpler, shorter motions (motions with less articulation of joints) are better.
- Design the work sequence so that the hands move symmetrically and simultaneously to and from the center of the body.
- Design so the operator uses continuous curved motions (i.e., pivoting around a joint rather than sudden and sharp changes in direction).
- Optimize the commonly used Methods-Time Measurements (MTM) motions by remembering that they are primarily a function of distance traveled (i.e. hands, eyes, body) and exerted forces (i.e. part weight, torque, exerted force).

3.6.1 Alphanumeric Coding

To optimize memory capacity and reduce errors, the following guidelines are offered.

- An all-numeric code should not exceed four to five digits in length.
- Where longer codes are necessary, the digits should be grouped in threes and fours and separated by a space or a hyphen.
- Alphanumeric codes should have the letters grouped together rather than interspersed throughout the code.
- The letters B, D, I, O, Q and Z and the numbers 0, 1, and 8 should be avoided.
- For long alphanumeric codes, numbers should be used in the last few positions.

Sample Pull Card

Part Number 22152297 	Supplying Location AA24-A-G13 (Dept. 162)	Receiving Location AC13-C-12 (Dept. 164)
Part Description Cylinder Tube		
Standard Quantity 50 	Engineering Change A	
1/1/	If found, return to Supplying Location	

3.7 Temperature

3.7.1 Heat vs. Pain Threshold

Ideally products should be designed where excessive thermal conditions are not required for production. When the product design option is not feasible, the machinery and equipment should be designed to protect the operator from exposure to excessive thermal conditions (hot or cold).

The guidelines given below for touching hot surfaces are based on very short (1-sec) contacts. Therefore, lower surface temperatures must be used for longer contact periods.

If the manufacturing process requires operators to wear gloves or be exposed to the risk of a burn, the table below may be used to reference maximum temperatures for materials often found in the workplace. Because people may contact the workplace surface for more than 1 second, and may also have injured areas on the skin that result in higher heat transfer to underlying cells, these values should be considered **maximum values; designs should not exceed them.**

1 Second Contact of Hot Surfaces with Finger, Maximum Temperatures		
Material	Temperature Threshold, Maximum	
	Pain Threshold, ° F (°C)	First-Degree Burn Threshold, ° F (°C)
Polystyrene GP	171 (77)	281 (138)
Wood (average)	169 (76)	275 (135)
ABS Resins	166 (74)	268 (131)
Phenolics (average)	141 (60)	210 (99)
Brick	138 (59)	202 (95)
Heat-resistant Glass	129 (54)	180 (82)
Water	127 (53)	176 (80)
Concrete	122 (50)	164 (73)
Steel	113 (45)	143 (62)
Aluminum	112 (45)	141 (60)

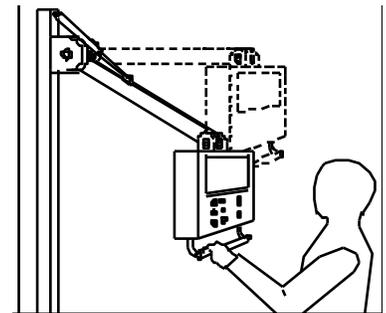
NOTE: Refer to your divisional industrial hygiene representative or the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) – Fundamentals 1997 for determining employee comfort zone effective temperature.

4 Equipment / Workplace Design

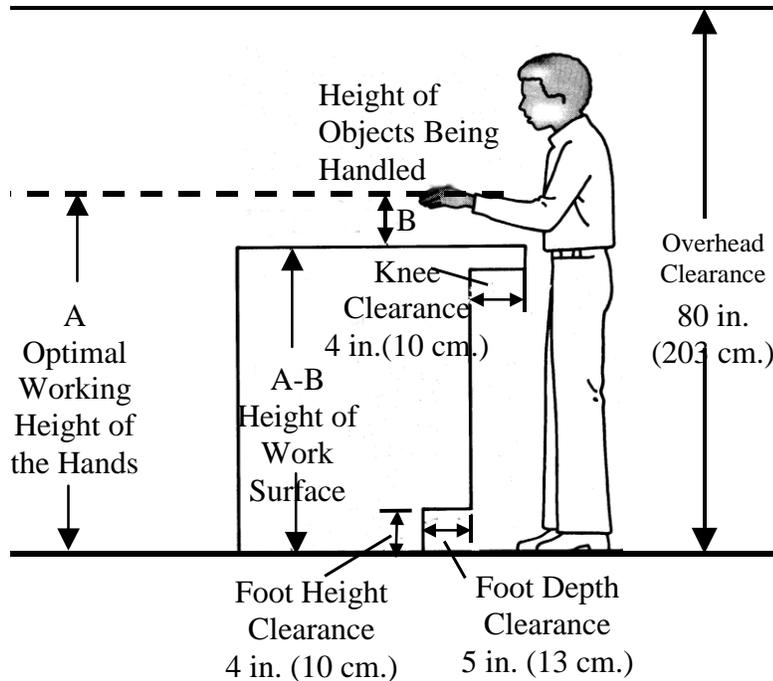
4.1 General Guidelines

Some general ergonomic characteristics of workplaces are summarized below. For further information on equipment design, see Delphi's Lean Equipment Design Manual, by first going to http://apollo.delphiauto.net/lean_coe/, then clicking on the button labeled *Lean Equipment Design*.

- Design equipment to meet anthropometric requirements for the region designated to use the equipment. Anthropometry tables are available in an Excel spreadsheet found at <http://apollo.delphiauto.net/ergonomics/design-in.htm#anthro> by clicking on *Global Anthropometry* link.
- Designing for an adjustable range is the preferred method where practical.
 - Workstations that are adjustable can accommodate both short and tall stature operators. Set the work height to where ergonomic stressors are minimized if adjustability is not possible.
 - Adjustable control/display panels accommodate varying statures and can be moved in varying directions: vertically, horizontally, tilting up/down, or any/all of the above. This is a performance factor that aids in decreasing set-up, changeover, preventive maintenance, and diagnostic/repair time.
- The material flow plan, how material will be delivered and removed from the workstation, should be incorporated into the design of new equipment. See Delphi Manufacturing Systems (DMS) guidelines.
- Design equipment for ease and speed to perform preventive maintenance tasks which include:
 - Easily removable guarding panels or covers.
 - Clearances for hands / tools, see Access Port Clearances, Section 4.8.
 - Unobstructed view of components.
 - Hand tool clearances in and around equipment.
 - Fittings and valves in a convenient place.
 - Clearly mark all items that require adjusting.
- To optimize operator response, utilize audio controls in addition to visual displays to indicate events such as downtime, operating outside parameters or other.
- Keep equipment noise to the minimum level possible; see Delphi's Sound Level Specification SL 1.0 Purchase of New, Rebuilt and Relocated Machinery, Power-tools, and Equipment at <http://apollo.delphiauto.net/industrialhygiene/ihpp.htm>.
- An equipment layout plan that requires operators to turn 180 degrees on a repetitive basis should be avoided, other layout options that provide a more suitable walk pattern for operators should be considered.
- Design equipment so that the operator does not have to bend, stoop, or otherwise alter their posture in order to load fixture or operate equipment.

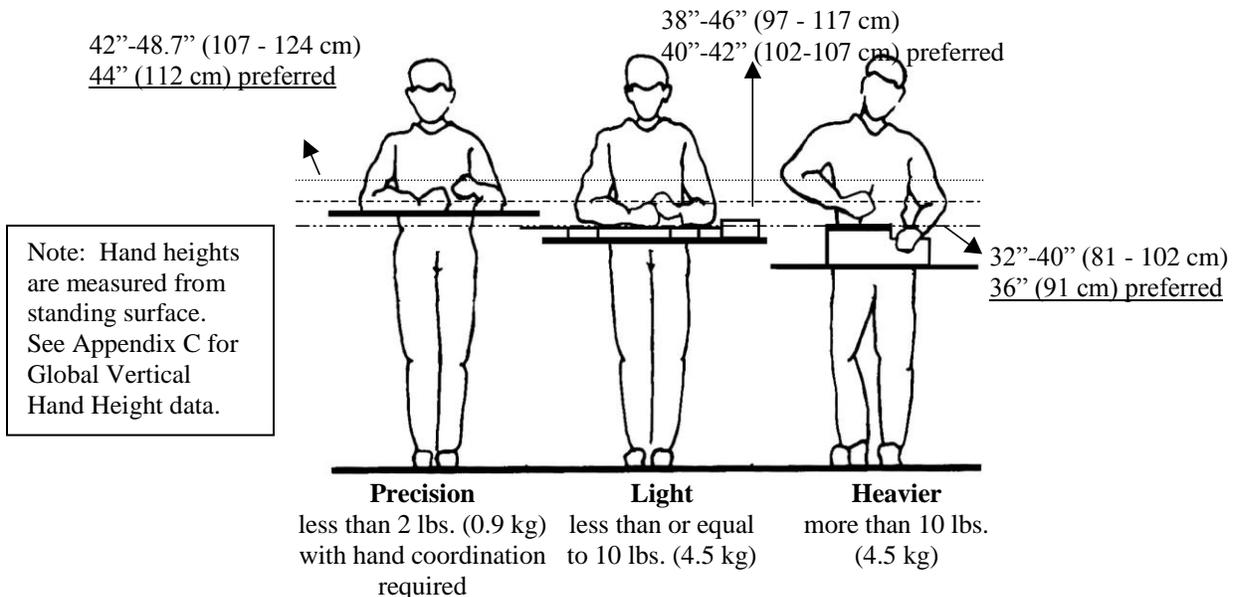


4.2 Stand Only Workstation

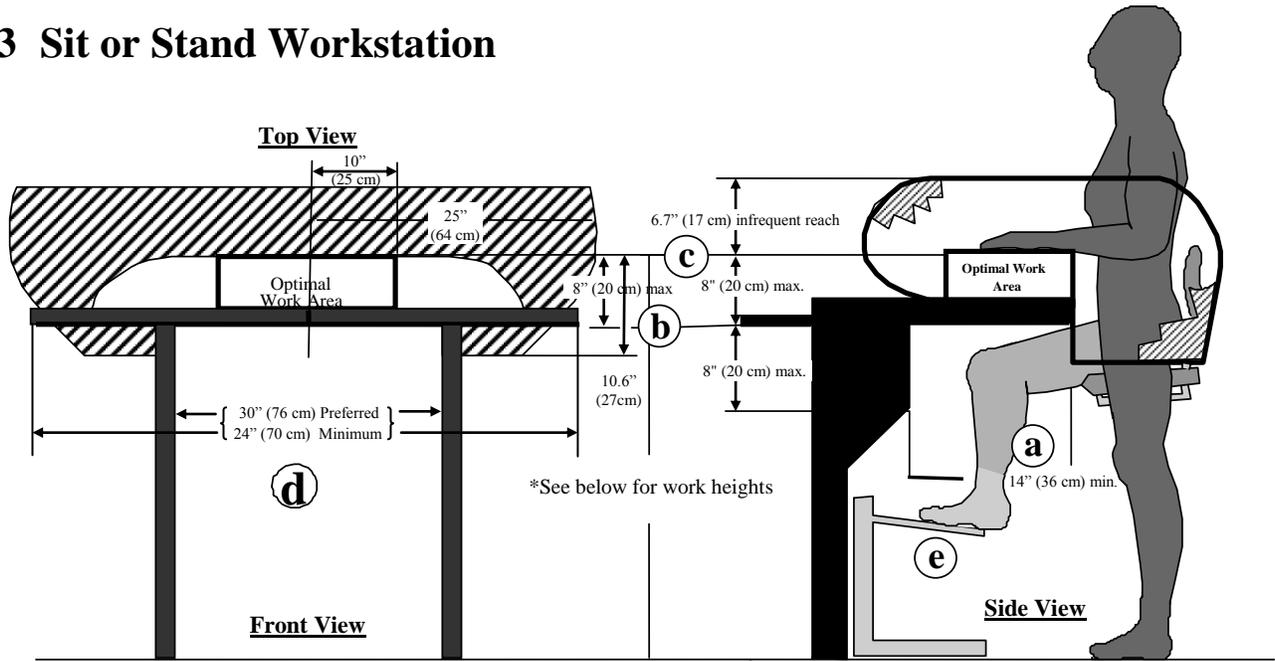


The key items to remember when designing a stand-only workstation are:

- Clearances for feet and knees, see above diagram.
- Static muscle loading. If an operator's workstation is designed to be a stand-only station, there must be regularly occurring walking as part of the job cycle to alleviate static muscle loading, see Static Muscle Loading, Section 3.5.
- For appropriate hand heights if adjustability is not possible, see below. If items of different heights must be worked on at the same workplace, either an adjustable-height workbench should be used or the height of the work surface should be based on the most frequently used items. See Appendix C for Global Vertical Hand Height data.
- For tasks that consist primarily of precision work, a seated or sit-or-stand workstation is preferred.
- Foot pedals should not be used while standing. Nor should constant pressure or force be required to activate a foot pedal during an assembly operation.

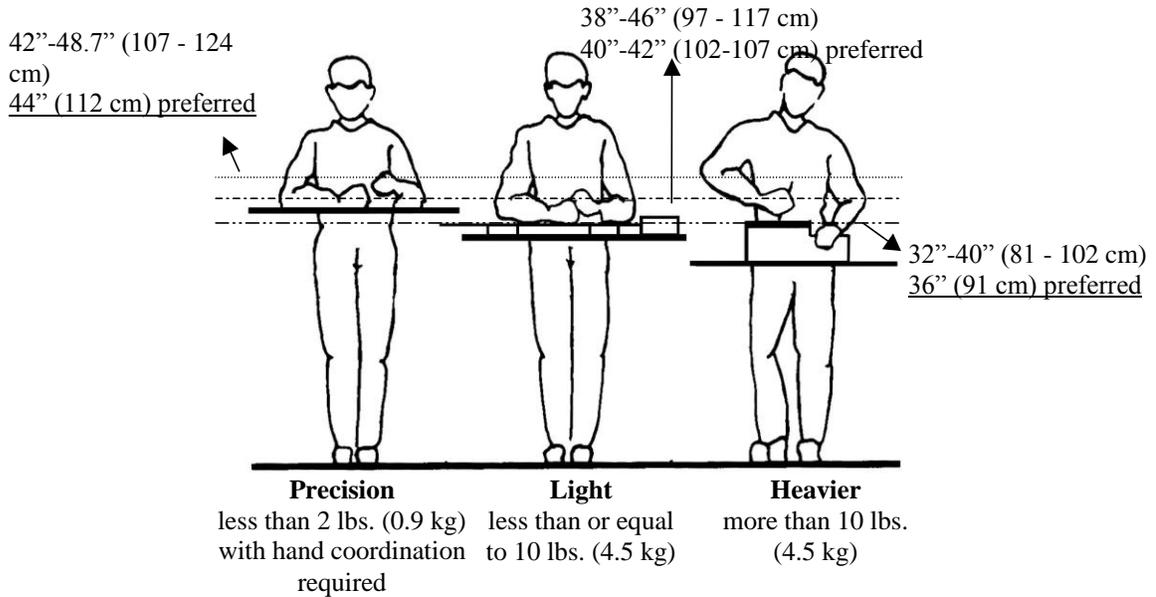


4.3 Sit or Stand Workstation

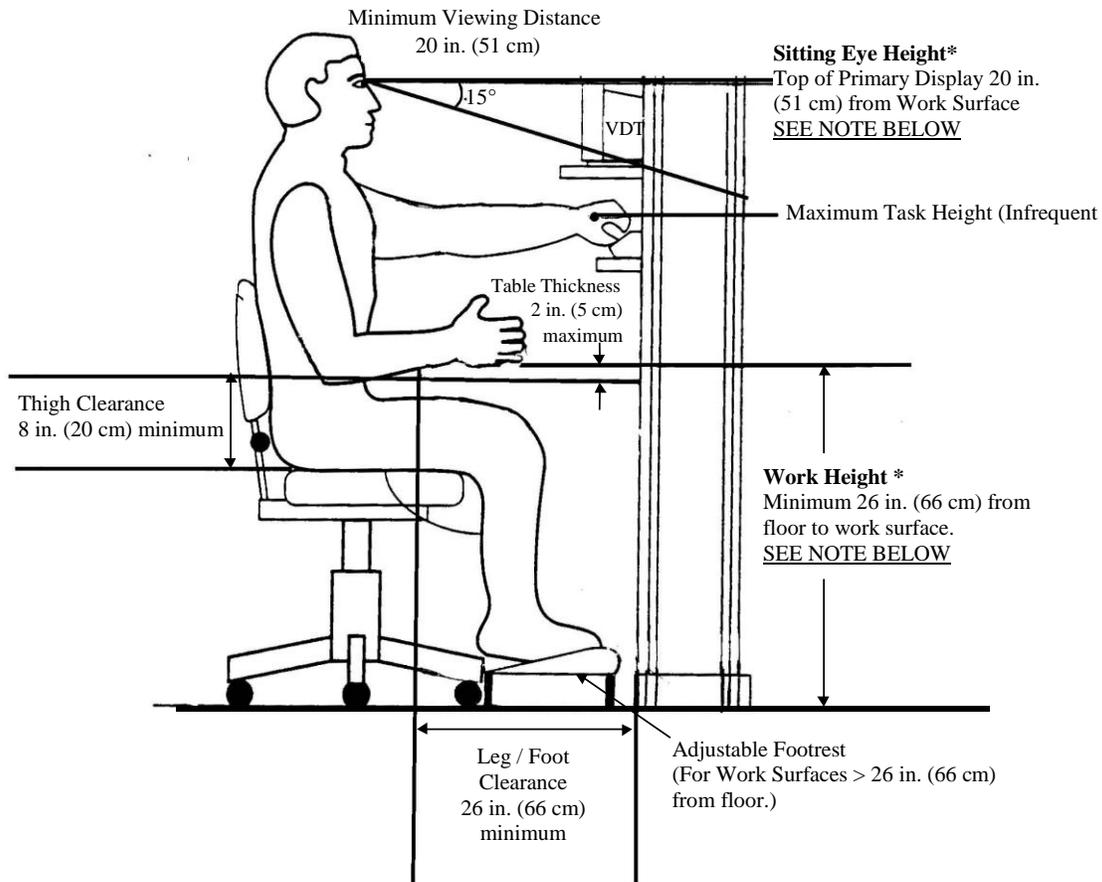


- a Forward knee room minimum 14" (36 cm).
- b Reference is the bottom edge of the nearest object in front of the operator. (stock trays, table, guarding, etc.)
- c Highest hand reach from the floor during the cycle.
- d Operator side knee room clearance. Either leg/thigh width or shoulder width will be the dimension to accommodate. Measure inside table leg clearance if table top is not cantilevered.
- e Adjustable footrest.

Infrequent Reaches Only	
Optimal work area for Repetitive and Infrequent Reaches	



4.4 Sit Workplace



- Flexibility is compromised when a sit-only station is designed.
- The seat should be equipped with adjustability in height to accommodate specific tasks.

Global anthropometry:

*Sitting Eye Height

- If adjustability not practical/feasible, design for the 50th percentile female, measuring sitting surface to the top of the viewing area of screen.

*Work Height

- To design the work-height, you must add the distance of the 95th percentile *Male Seated Elbow Height*, measuring from chair seat to elbow, PLUS, the 95th percentile *Male Lower Leg*, measuring from the floor to the chair seat.

4.5 Reach Envelope for Stand Only or Sit/Stand Workplace

4.5.1 General Guidelines

- Use the regional anthropometric data for the equipment being designed (5th percentile female for optimal reach envelope). To find the reach optimal and infrequent reach dimensions for a specific region of the world, see Appendix C. For actual anthropometry data for a specific region, visit the Ergonomics website on Apollo to retrieve an Excel based program [Anthro07.xls](http://apollo.delphiauto.net/ergonomics/design-in.htm), <http://apollo.delphiauto.net/ergonomics/design-in.htm>
- Any object to be frequently grasped should be located within 6-14 inches (15-36 cm) of the front of the work surface.
- Large or heavy objects (greater than 6 lbs, 2.7kg, per hand) need to be located close to the front of the workplace.
- It is permissible to have an operator occasionally (a few times an hour) reach to procure something outside the work area, but such reaches should not be made a regularly occurring part of a brief work cycle.
- Design material locations to be within appropriate operator reach envelopes.
- Operators should not reach behind their body repetitively, and no more than 10° infrequently, see Posture, Section 3.3.

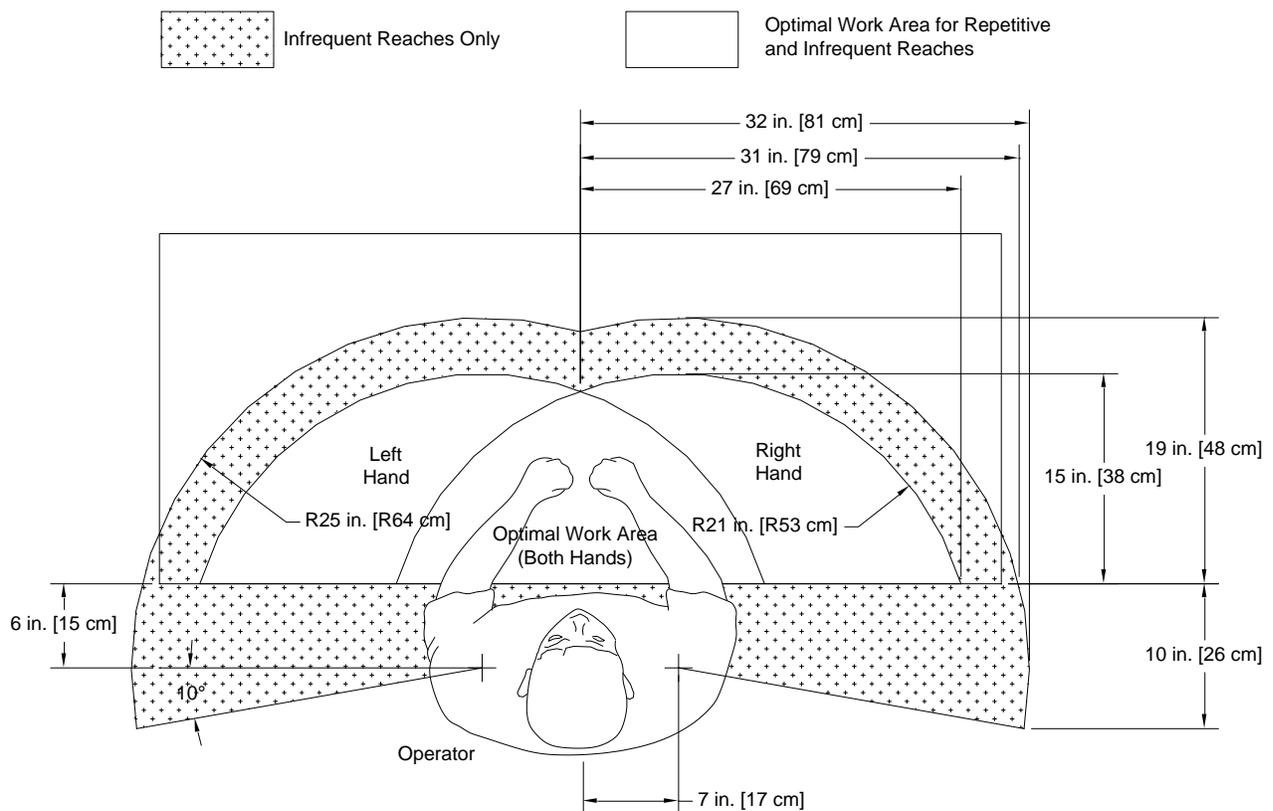
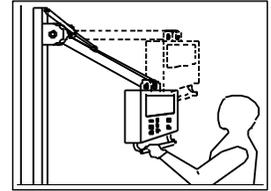


Diagram not to scale. Dimensions are for US and Canada population. See Appendix C for other global populations. Assumes 90° shoulder flexion for infrequent reach and 30° shoulder flexion for repetitive reach.

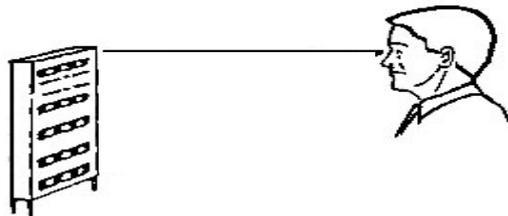
4.6 Displays

The design, selection and installation of a visual display will affect the performance of the operator of a production system. Factors, such as the distance an operator is from a display when it is read, the number of displays on a single console, the readability of the dials and the ambient illumination should be considered when designing, selecting and installing.

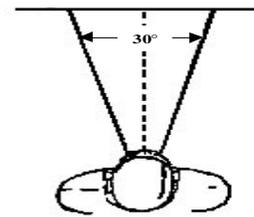


4.5.2 General Guidelines

- Select the type of display (i.e., dial indicator, digital counter, annunciator lights, audio signal) that best and simply displays the required information; see Display Selection, Section 4.6.3.
- Monitors should be mounted on a frame that can be adjusted vertically, horizontally, or tilt forward/back to accommodate varying operator heights and to assist those who have bi-focal lenses. If adjustability is not feasible, see dimensions below.
- All displays should be clearly labeled, see Visual Aids / Labels / Signs; Section 2.1.3.
- Provide adequate levels of lighting; see Lighting, Section 2.1.1.
- Avoid optical distortion from the glass cover plate and glare from light sources; see Glare, Section 2.1.2.
- Avoid shadows on the display face from adjacent protrusions or from the bezel (cover rim) of an inset indicator
- For monitors in a fixed location, measure to top of display or screen (if video display terminal).



Side View.



Top View, Lateral Viewing Angles

For fixed monitor heights - Standing:

U.S. and Canada Populations:

- Preferred standing eye height (zero line) is 62 inches (157 cm), measured from standing surface to top of screen's viewing area. Minimum height = 58 inches (147 cm). Maximum height = 65 inches (165 cm).

Non-U.S. Populations:

- Preferred standing eye height is the 75th percentile Female value found on the Anthropometry Data tables. Maximum height is 95th percentile Male standing eye height. Minimum is 25th percentile female eye height. Measured from standing surface to top of screen's viewing area.

For fixed monitor heights – Seated, All Populations:

- Seated eyesight (zero line) is 30 inches (76 cm), measured from seat pan to top of screen's viewing area.

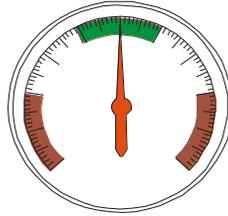
Indicators

- Indicators (not monitors) that are frequently used should be located at standing height between 42 and 62 inches (107 and 157 cm) from the floor, but as close to 62 inches (157 cm) as possible with a 65 inch (165 cm) maximum. Less frequently read indicators can be above or below this height range. For seated workplaces, locate the primary displays no higher than 20 inches (50 cm) above the work surface.

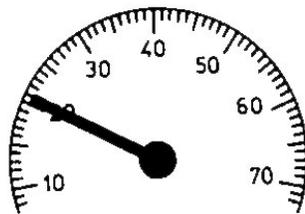
4.5.3 Dial Indicator Guidelines

The following guidelines relate to factors in the display environment that should be controlled:

- Select dials with target zone markings to permit more rapid reading.



- The tip of the pointer should be only as broad as one of the scales lines, and it should not obscure the number, see example below.



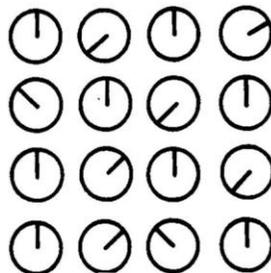
Poor



Good

- Choose indicators with as many gradational marks as are needed for the degree of precision. A maximum number of 9 markings between numbers are allowed.
- Make numbers progress by 1's, 2's, or 5's.
- Orient numbers in an upright position, not radially.
- Align a group of dials uniformly when check reading is required so that all pointers are in the same position for the normal conditions.
- Orient indicators so that they are perpendicular to the operator's line of sight. This design should reduce parallax errors when pointers are read.

Nonaligned



Poor

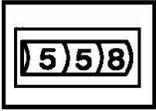
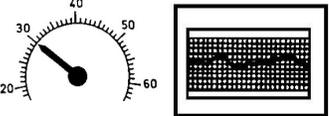
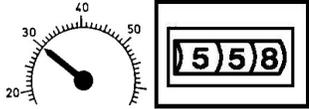
Aligned



Good

4.5.4 Selection

The following table illustrates appropriate ways to display different types of information:

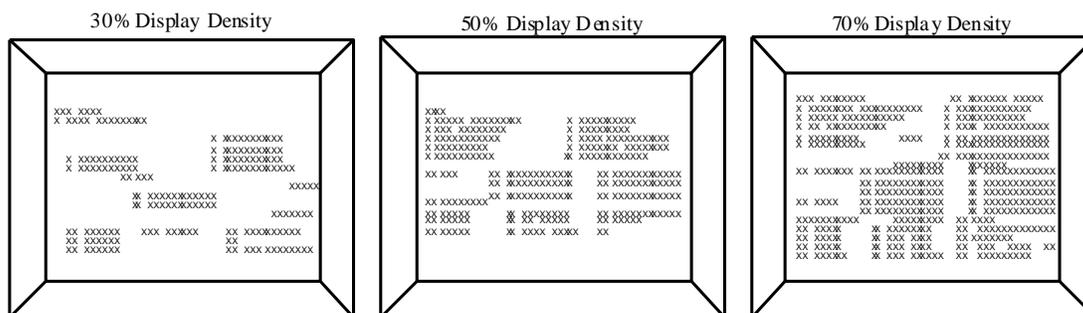
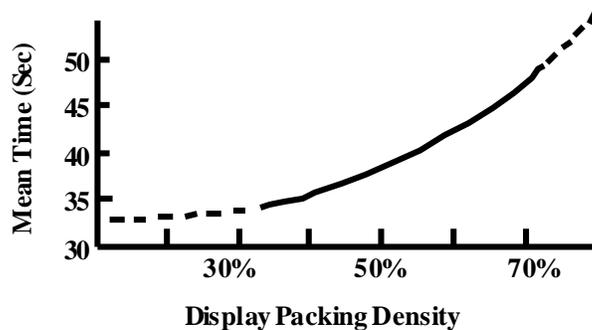
Information Type	Preferred Display	Comments	Uses in Industry	Examples
Quantitative Reading	Digital readout or counter	Minimum reading time, Minimum error potential	Numbers of pieces produced on a production machine	
Qualitative Reading	Moving pointer or graph	Position easy to detect, trends apparent	Temperature changes in an oven	
Check Reading	Moving pointer	Deviation from normal easily detected	Pressure gauges on a utilities console	
Adjustment	Moving pointer or digital readout	Direct relation between pointer movement and motion of control, accuracy	Calibration charts on test equipment	
Status Reading	Lights	Color-coded, indication of status (e.g., "on")	Consoles in production lines	
Operating Instructions	Annunciator lights or computer monitor screens	For infrequent task requiring immediate action	Manufacturing lines in major production systems	

4.5.5 Video Display Terminal (Monitors)

Screen Guidelines

- Locate information of a critical nature near the center of the screen.
- Display status information at the top of the screen, toward the right side. The location of this information will vary according to the type of operations performed, but it should be found in the same general part of the screen across all terminals in a manufacturing system.
- Locate error messages near the bottom of the screen, they should blink at about 3Hz.
- Focus on what information is **required** and make it readable.
- Readability of status information or other text drops off rapidly at screen-packing densities (the amount of space filled with characters) are greater than 50% (see below).

Operator Response Time to Locate Information



4.6 Controls

Safety:

The following controls guidelines do not supersede the Delphi Health & Safety guidelines that are mandated for safety purposes. For more information on controls and safety, visit http://apollo.delphiauto.net/health_safety/ or talk to your health & safety representative.

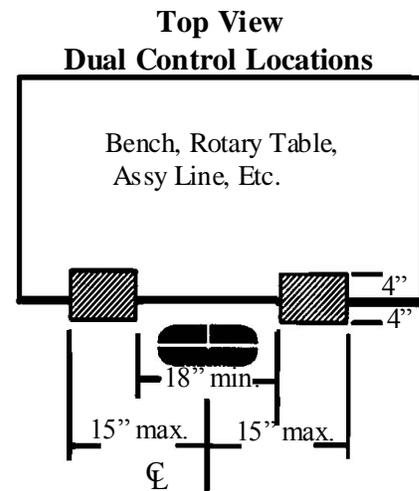
Selection:

Refer to Delphi Guarding/Cycle Initiate Methodology for more information on the different types of guarding, this includes a table of 'pros' and 'cons' as well as a decision tree and is located at: http://apollo.delphiauto.net/lean_coe/m_lean.htm.

4.6.1 General Guidelines

The most frequently used controls should be within easy reach. All controls should be placed or guarded so that they will not be accidentally activated. The following guidelines give some specific recommendations for the location of controls:

- Keep the number of controls to a minimum. The movements required to activate them should be as simple and easy to perform as possible, except where resistance should be incorporated to prevent accidental activation.
- Identification labels should be placed above the control and identical labels above the display.
- If one hand must operate several controls in sequence, arrange the controls to allow for continuous movement through an arc (if this arrangement does not violate any of the basic rules of workstation maximum reaches).
- Assign controls to the hands if they require precision or high-speed operation. When there is only one major control that, at times, must be operated by either hand or both hands, place it in front of the operator, midway between the hands.
- Handedness is important only if a task requires skill or dexterity. If the control requires a precision movement, place it on the right, since 90% of the population is right handed.
- Distinguish between emergency controls and displays and those that are required for normal operations by using the following techniques: separation, color-coding, clear labeling or guarding.
- Emergency controls should be easily accessible and within 30° horizontally of the operator's normal line of sight.
- Controls for set-up, supplemental activities and/or maintenance should be vertically located between 35-65 inches (89-165 cm) above the standing surface.
- Single controls (wobble sticks, whisker switches) should be placed at approximately the same height as where the operator performs work.
- Dual controls for cyclical operator use in a standing position should be vertically located between 36 to 42 inches (91 to 107 cm) above standing surface.
- Horizontal placement of dual controls should follow the diagram as shown to the right.



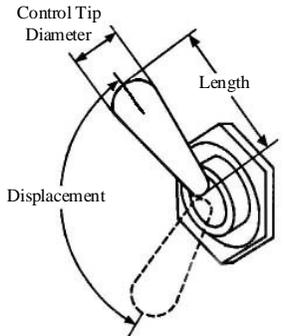
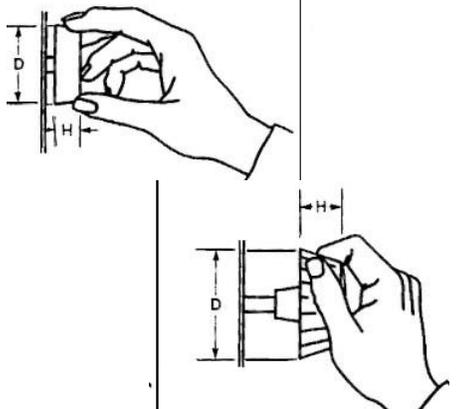
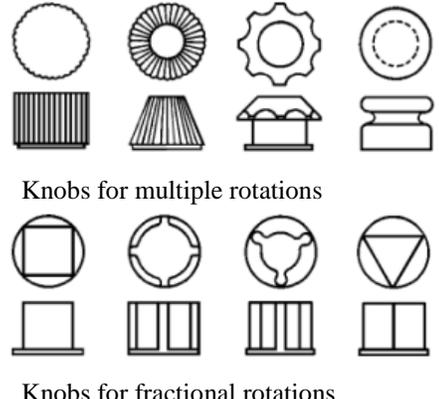
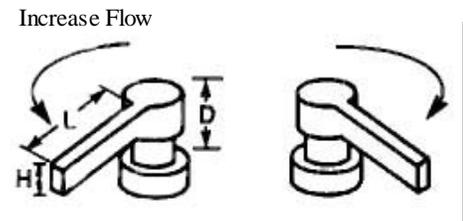
4.6.2 Movement Stereotypes, Controls

Motions required to activate the controls should be simple as possible and should follow established direction of movement stereotypes. The stereotypes listed below are accepted in the United States and Canada but may vary in different countries.

Direction Of Motion		
Up/Right/In	Down/Left/Out	
On	Off	
High	Low	
Raise	Lower	
Open	Close	
Start	Stop	
Fast	Slow	
Increase	Decrease	
Accelerate	Decelerate	

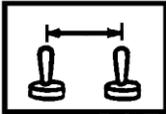
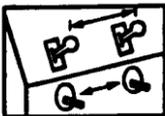
4.6.3 Control Design

Rotary Selector Switches	
	<p>Rotary selector switches are useful for applications where from 3 to 24 values must be selected and where accuracy is needed. With a preset detent for each value, the selections can be made accurately and quickly. Rotary switches require more space to operate than toggle switches since room must be made for the fingers. The selector may be either a bar or a round knob, the former being preferred on panel boards with a large number of similar controls so that the values are easily seen.</p>
	<p>Ease of Use:</p> <ul style="list-style-type: none"> • Size the control to minimize the amount of movement (displacement or rotation). • Identification labels should be placed above the control and identical labels above the display
Push Buttons	
	<p>Push buttons are frequently used to enter information into a piece of equipment where each button represents a separate response, as in selecting a beverage from a vending machine or entering data from a computer keyboard. Push buttons are not a recommended control for repetitive use.</p>

<p>Toggle Switches</p>	
 <p>The diagram shows a toggle switch with a cylindrical control tip. Labels indicate 'Control Tip Diameter' for the width of the tip, 'Length' for the length of the tip, and 'Displacement' for the distance the tip moves from its rest position to its active position.</p>	<p>Toggle switches are most commonly used when an operation has only two options (on or off) and when control panel space is limited. Three-position toggle switches are available (e.g., off, low and high) but can not be operated with as much speed as those with only two positions.</p>
<p>Knobs</p>	
 <p>The diagrams illustrate a hand grasping a knob. The top diagram shows the hand from the side, with 'D' representing the diameter of the knob and 'H' representing the height of the knob. The bottom diagram shows the hand from a different angle, also with 'D' and 'H' labels.</p>	<p>Knobs extend the range of rotary selector switches since they can be rotated through more than 360° and can be moved through a continuous, rather than discrete, series of settings. They should be designed so that the fingers do not obscure the scale, and they should be mounted on the control panel with adequate clearance to allow proper grasping. Adequate clearance is particularly necessary for knobs where forces to activate them are near the maximum values.</p>
 <p>The grid shows various knob shapes. The top row is labeled 'Knobs for multiple rotations' and includes a plain circle, a circle with radial lines, a gear-like circle, and a circle with a dashed outer edge. The bottom row is labeled 'Knobs for fractional rotations' and includes a square, a circle with a square hole, a circle with a triangular hole, a circle with a triangular hole, a square with a circle inside, a square with vertical lines, a square with vertical lines, and a square with a circle inside.</p>	<p>Varying the shape, size and type of controls on a complex control panel may assist the operator in identifying a specific control quickly and can reduce the potential for error. Shape coding is desirable in areas of reduced illumination where vision is blocked, for example, by parts of production equipment or when job requirements force the operator to look elsewhere.</p>
<p>Levers</p>	
 <p>The diagram shows a lever-type valve handle. Labels indicate 'Increase Flow' with an arrow pointing to the right, 'L' for the length of the lever, 'D' for the diameter of the handle, and 'H' for the height of the handle. Below the diagram is the text 'Lever-Type Valve Handle'.</p>	<p>The selection of lever length depends on the task to be done. Long levers require less force in operation than short ones and permit more linear arm motion. Levers should be somewhat to one side of the operator, not directly in front. A minimum force of 2.2-lbs (10N) is recommended to reduce the opportunity for accidental activation of a lever that is activated with a palmer grasp.</p>

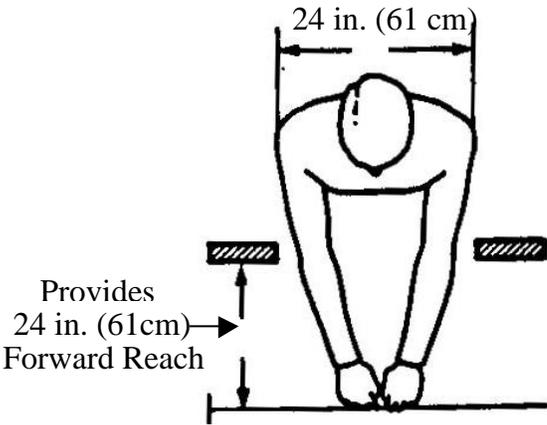
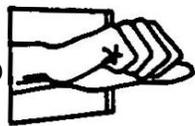
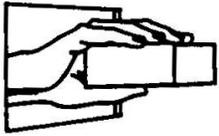
4.6.4 Spacing

Controls should be designed to fit the hands, fingers and thumbs. Also, consider what personal equipment, such as gloves, that might hinder control manipulation. See the table below for spacing specifications.

Control	Type of Use	Measurement of Separation	Recommended Separation			
			<u>Minimum</u>		<u>Desirable</u>	
			in	mm	in.	mm
Push Button	One Finger (Randomly)		1/2	12	2	51
	One Finger (Sequentially)		1/4	6	1	25
	Different Fingers (Randomly or Sequentially)		1/2	12	1/2	12
Toggle Switch	One Finger (Randomly)		3/4	20	2	51
	One Finger (Sequentially)		1/2	12	2	51
	Different Fingers (Randomly or Sequentially)		5/8	16	3/4	20
Crank and Lever	One Hand (Randomly)		2	51	4	100
	Two Hands (Simultaneously)		3	76	5	127
Knob	One Hand (Randomly)		1	25	2	51
	Two Hands (Simultaneously)		3	76	5	127

4.7 Access Ports Clearances

The minimum dimensions for access ports in equipment that will permit the hand, arm or both arms to enter are given.

<p>Body</p>	<p>Both Arms, One Opening</p>  <p>24 in. (61 cm)</p> <p>Provides 24 in. (61 cm) Forward Reach</p>	
<p>Arm</p>	<p>Arm to Elbow</p>  <p>4.5 in. (11 cm) Diameter:</p>	<p>Arm to shoulder</p>  <p>5 in. (13 cm) Diameter:</p> <p>Add 3 in (8 cm) for Winter Clothing</p>
<p>Hand*</p>	<p>Empty (Flat)</p>  <p>4 in. (10 cm)</p> <p>2 in. (5 cm)</p>	<p>Empty (Clenched)</p>  <p>5 in. (13 cm)</p> <p>4 in. (10 cm)</p>
<p>Holding Small Object</p>  <p>4 in. (10 cm)</p> <p>4 in. (10 cm)</p>		<p>Holding Larger Object</p>  <p>1.75 in. (4.5 cm) Clearance Around Object</p>

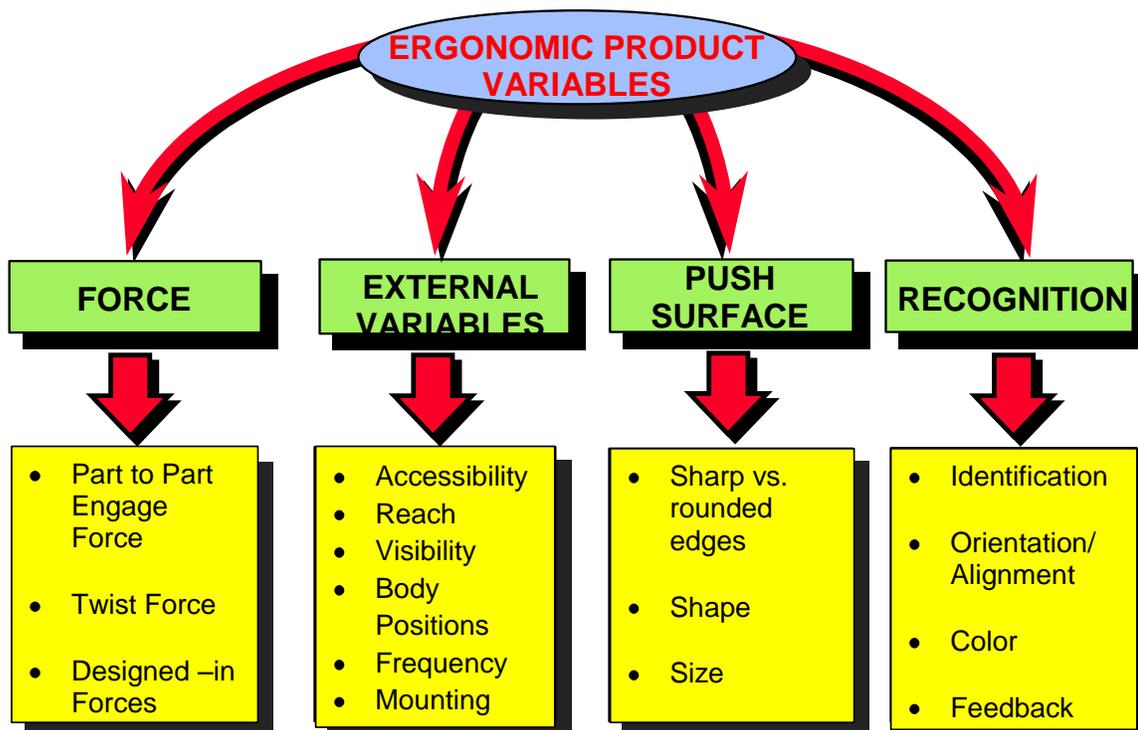
*Add 0.75 in. (2 cm) for gloves.

5 Product Design

The following section is intended to be a “thought starter” for designing products that are simplified and easy to assemble.

Again, one of the goals of ergonomics is to enhance performance. When product design considers capabilities and limitations of the human body and designs the product to optimize those capabilities, performance is enhanced.

Consider the ergonomic variables in the following chart when designing new products:



5.1 Principles of Design For Assembly (DFA)

This section features some highlights from the Boothroyd-Dewhurst Design for Assembly methodology (DFA).

Reduce

Minimize the number of parts. Potential for part count reduction is based on subjecting each part to these three questions:

1. During operation of the product, does the part move relative to all other parts already assembled? (e.g., a piston in a cylinder)
2. Must the part be different material than or be isolated from all other parts already assembled? (e.g., contact pins in an electrical connector)
3. Must the part be separate from all other parts already assembled in order to allow assembly or disassembly of those parts? (e.g., cover plate on a gear box)

When the answer is “no” to all three questions, the designer should treat each such part as a candidate for elimination or combination with another part.

Reduce the number of part numbers – part number proliferation increases the opportunity for error.

Layering

Design the product with a base part as the foundation and fixture for other parts. The assembly process should proceed in a layer assembly sequence from above. This aids operators (and machines) in terms of effort required and simplicity of handling and insertion functions... not to mention gaining the help of gravity. If the parts or fasteners cannot be loaded from above, design so that they can be loaded from front.

Obstructions, Access and Visual

Part handling problems arise when design features, other parts or fixtures obstruct access to locations. The problem really becomes acute when visual obstructions are present and it becomes necessary to find locations and insert parts by touch.

Loading a fixture from the top or front is preferable because it requires less operator time. When loading from under or bottom, like the upper mandrel of an arbor press, the load is blind and requires additional time for alignment and placing. Another efficiency factor is the design of the fixture. Positive or self-aligning fixtures are preferred to prevent the operators from having to make assessments on proper part placement. Design equipment and locate fixtures so operators do not have to bend their neck or back in order to load, see, activate, or unload. An awkward posture is an injury risk factor.

Symmetry

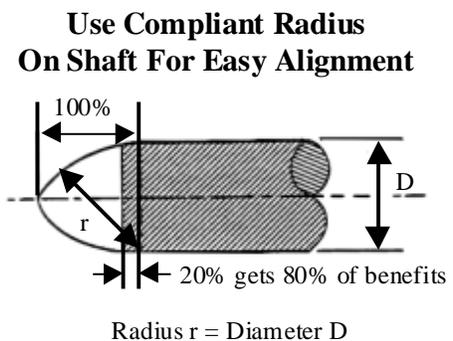
Symmetrical parts simplify orientation for manual assembly. For parts that must be non-symmetrical, exaggerate asymmetrical features.

Compliant Radius

This design idea may be the most efficient means to facilitate insertion of cylindrical parts (i.e., pins, shafts) into mating holes without jamming and with minimal alignment difficulty.

Hand Tools

Avoid designs that require assist tools to assemble.



Minimal Force and Force Direction

Mating parts should be designed with minimal force required to engage. Use fasteners with low engage forces (e.g. rosebud and fir tree/Christmas tree clips). For manual assemblies, follow the force guidelines detailed in Section 3.2.

Push forces are preferred over pull or lateral force exertions.

For heavier parts that require mechanical assistance to move, include in the product design: hooks, handles and/or sufficient finger clearances to facilitate handling.

Hand Grip Clearances

Design the part so that the operator's grip span does not exceed 3.5 inches (9 cm). Consider how a part is to be moved into/out of any fixture and dunnage/packaging.

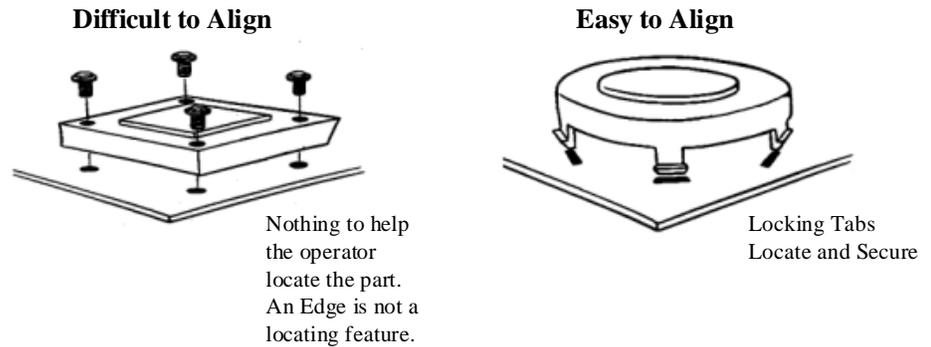
Design products so that sufficient clearance for hands and fingers are provided during assembly.

Feedback

Design parts that produce good visual, audible and/or tactile feedback during product assembly.

Error Proofing

Design product components so they cannot be assembled incorrectly. Try to "commonize" similar parts or if they must be different, make them obviously different.

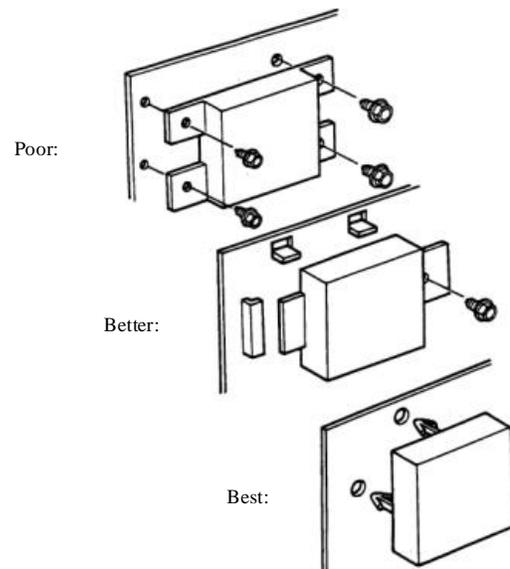


Positive / Self Locating

Positive or self-locating features on parts minimize the difficulties associated with the alignment and positioning of objects. Well-designed chamfers, guide pins and locating stops are examples that simplify the part loading activity.

Threaded Fasteners

Look for other attachment means before resorting to threaded fasteners. When threaded fasteners are required and the number has been reduced by elimination, commonize to minimize operator error, tooling changes and inventory.



Make it easy for the Customer's Assembly

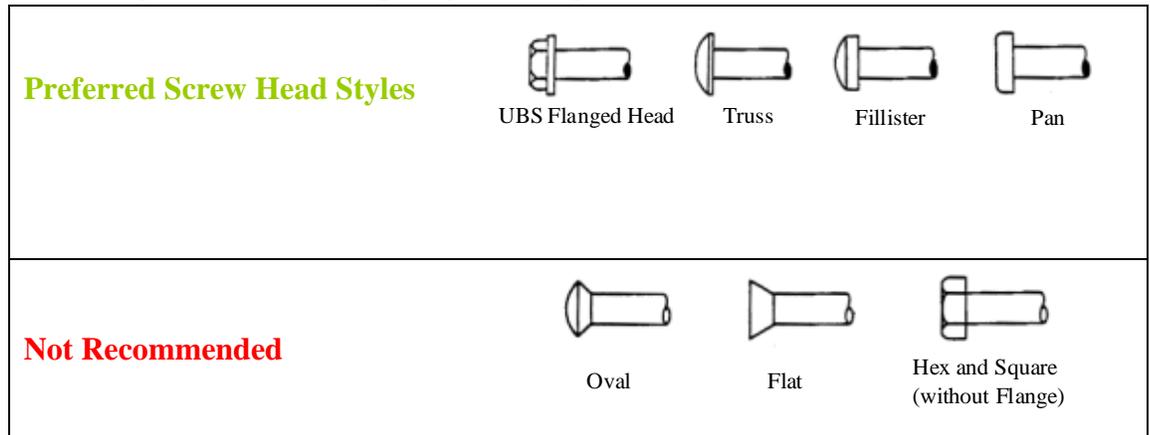
Evaluate fastening and insertion forces for Delphi product into the customer's assembly by following the force guidelines in section 3.2.

Evaluate product characteristics that could affect packaging design such as part orientation, accessibility, and ease to remove the Delphi assembly from container.

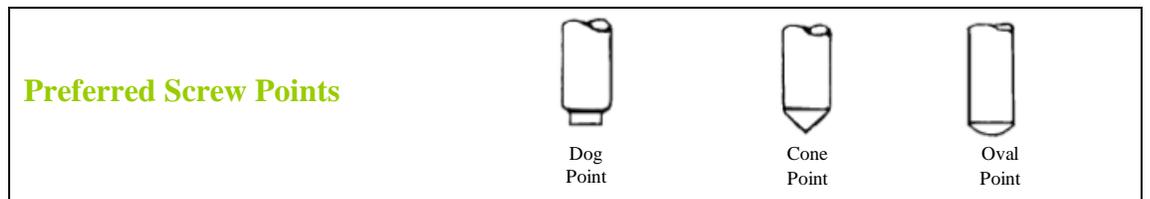
Fastener Types

If threaded fasteners must be used, they should have:

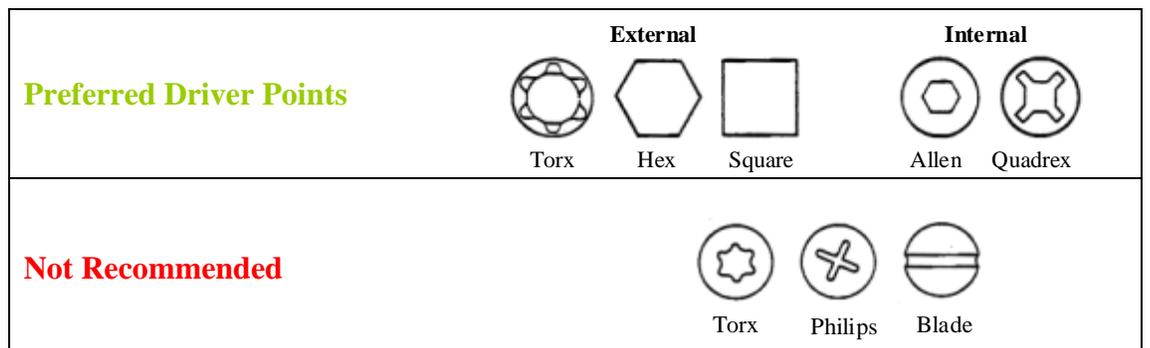
- Oil-free finishes with flanged style heads to eliminate washers.
- Good shank length to head diameter ratios (at least 1.5 to 1).
- Head designs, which ensure quality fastening. Flat head screws are the worst choice.



- Use “dog”, “cone” or “oval” point ends.



- Driver points provide accurate torque monitoring and good retention of fastener.



5.2 Part Handling Characteristics

The operator should be able to retrieve one part with one hand and prepare it for insertion. Component characteristics that can make this impossible are defined, thus highlighting the part handling problems.

1. Nest and Tangle (Mild); One hand can shake to release tangled parts.
2. Nest and Tangle (Severe); Two hands required to free parts from each other.
3. Flexible; Will not hold shape under own weight.
4. Stick to Each Other; Self-adhesive or greasy parts.
5. Slippery; Short conical parts or oily ball bearings.
6. Heavy; 10 lbs. or more.
7. Sharp; Die cut parts with burrs.
8. Fragile; Parts easily broken, damaged, or scratched.
9. Small; Manually handled parts such as washers.

6 Supermarkets

Central Material Area Quick Guide

This section addresses material handling activities intended for material handlers and supermarket attendants. For complete guidelines, see Engineering Design Ergonomics Guidelines for CMA and Supermarket Material Handling Operations (Small Lot Delivery) written by Bob Fox and posted at <http://apollo.delphiauto.net/ergonomics/design-in.htm#sprmkt>

To obtain a copy of the Delphi Ergonomics Container Worksheet and/or instructions for use, visit the ergonomics website, in the *Design-In* page, <http://apollo.delphiauto.net/ergonomics/design-in.htm#checklist> See Step 7, Container Design.

Definitions

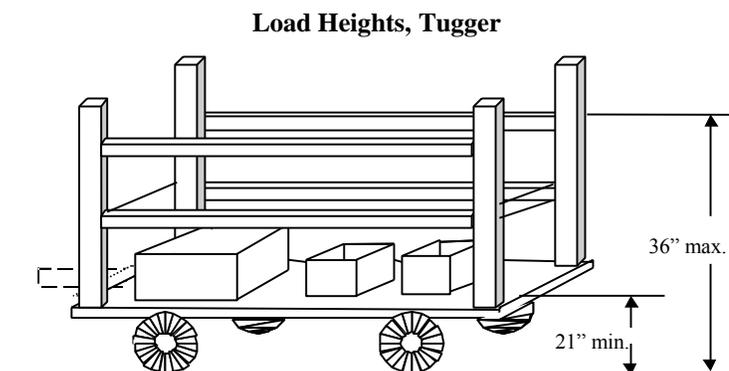
Mall, Supermarket and Central Material Area (CMA) all refer to material marshalling areas used as part of a material pull system where small lots of material are delivered to the assembly lines via tugger transport and manual handling.

Coupled operations involve the route driver both loading the tugger in the CMA and delivering to the user locations on the line. The typical time for a load and deliver cycle is one hour.

Decoupled operations involve the loading of a tugger by an attendant in the CMA and the delivery by the route driver. The typical cycle time is 30 minutes for a delivery.

Tugger Design Features

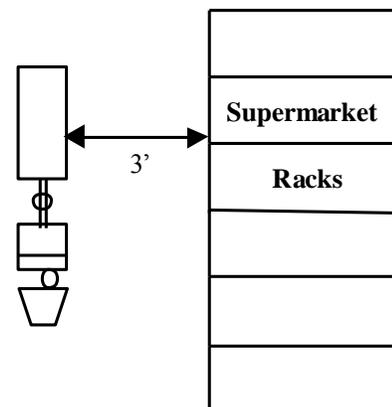
- The size and power of the tugger should be appropriate for plant conditions. The size and number of trailers should be sufficient for the load carried.
- Vertical height of loaded surfaces on tugger and trailer should be at least 21 inches (53 cm), if material is stacked, and no more than 36 inches (91 cm), if stacking is minimal.



Aisle Width Top View

CMA Layout and Equipment Design

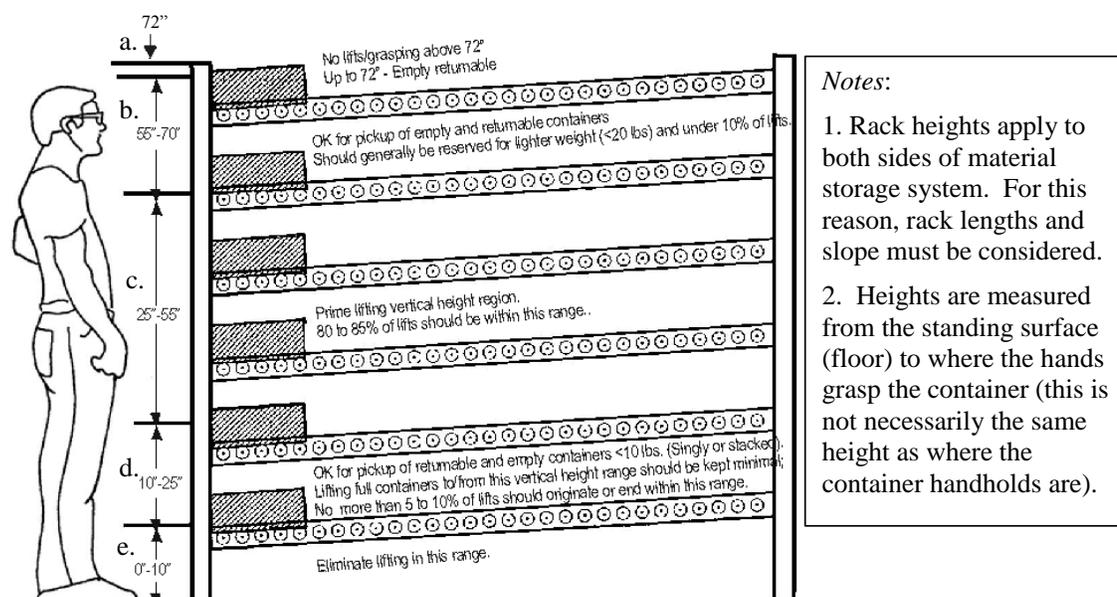
- Sufficient aisle space should be provided in the CMA area to allow the route driver or CMA attendant to take at least one step (about 3 ft. or 1 m.) between the tugger or trailer and the racks when loading. It is preferable to take a step and turn the feet rather than twist the back when handling loads.



Rack/Shelf Heights

- Rack and Shelf Design Features

- Provide adequate clearance between and around items on shelves to allow sufficient grasp space and clearance for the hands and fingers. About 3 in. (7.5 cm) between containers and between the top of a container and the bottom of the next shelf level will be sufficient.
- Shelf slope should be in range of 3.5 to 5 degrees, equating to a 0.75 - 1 inch (2 – 2.5 cm) drop for every 12 inches (30 cm) of shelf length from the load to the pull end of the shelf.
- The number of roller elements in the shelf should be sufficient to contain the size and weight of cartons and containers placed on them.
- Features such as roller bars or wheels on the lip of the pull end of the shelf may help reduce the pulling effort involved to extract containers.



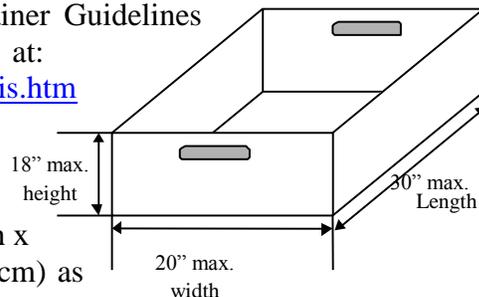
Rack heights for various global populations are available, see Appendix E or calculate them using the formulas provided below. Find the X value for a desired population by using the Global Anthropometry Data located at <http://apollo.delphiauto.net/ergonomics/design-in.htm>.

$X = 5^{\text{th}}$ percentile, Female, Standing Overhead Reach

Item	Formula	Vertical Height Range Description:
a.	X	No lifting or grasping above height X.
b.	(X-17)" to (X-2)"	Ok for pick up of empty and returnable containers. Should generally be reserved for lighter weights (<20 lbs.) and fewer than 10% of lifts.
c.	(X-47)" to (X-17)"	Prime lifting vertical height region. 80 to 85% of lifts should be within this range.
d.	(X-62)" to (X-47)"	OK for pick up of returnable & empty containers <10 lbs. (singly or stacked). Lifting full containers to/from this vertical height range should be kept minimized. Not more than 5 to 10% of lifts should originate or end in this range.
e.	0 to (X-62)"	Eliminate lifting in this range.

Standard Sized Containers – Manually Handled

- Weight
 - The weight of manually handled containers should be evaluated on a case by case basis. For standard (non-oversized) containers, the weight should not exceed 35 lbs. (15.9 kg). Follow the Delphi Ergonomics Container Guidelines and apply the NIOSH lifting guidelines found at: http://apollo.delphiauto.net/ergonomics/risk_analysis.htm
- Size
 - Maximum container size of a standard (non-oversized) manually handled containers is 30 length x 20 width x 18 height inches (76 l x 50 w x 46 h cm) as shown.



Over-Sized Containers – Manually Handled

- Containers that exceed the above dimensions for a standard container are considered oversized. Handling of over-sized containers should be acceptable if:
 - Weights is 30 lb. (13.6 kg) or less
 - They are lifted /lowered to/from vertical heights under about 48 in. (122 cm);
 - Two of the three dimensions are within the standard container size limits;
 - The container has well-designed and well-located handholds
 - The over-sized containers are a minority of containers handled (30% or less).

Repacks

- Items repacked within the plant should also conform to the size and weight limits given above. Repacked items should be packed in containers of an appropriate size with a balanced load and a stable center of mass. Items with sharp edges should not protrude from the container.

Special Situations - Pallets Set on Roller Racks:

- Ensure that pallet rack height and height of containers on pallet present containers at acceptable heights.
- Use the smallest pallet size possible/practical to provide shorter and easier reaches.
- Minimize forces required to slide cartons or containers at the far end of a tier on a pallet. Common lids and appropriate dunnage may help.

In general, the material handler routes should be acceptable if the following conditions exist:

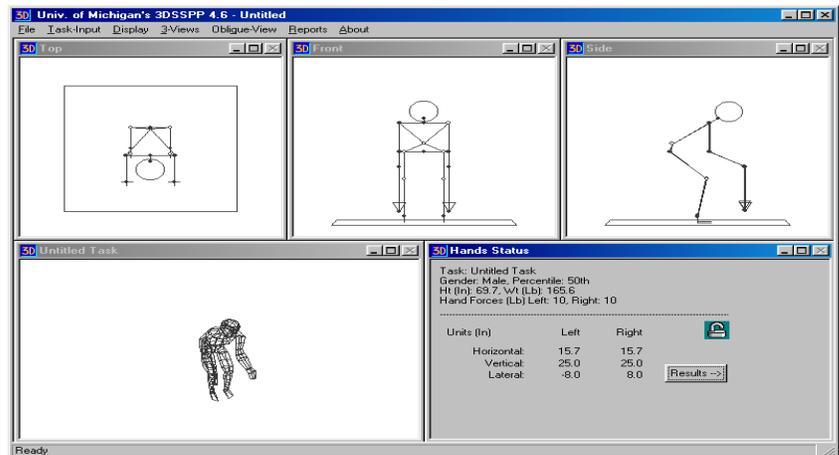
- 80 to 85% of the lifts are within the recommended lift range of 25 - 55 inches (64 – 140 cm);
- The load **weighted average** is within the range of 28 to 32 lbs. (12.7 to 14.5 kg);
- The horizontal distances (per NIOSH definition) average under 16 inches (41 cm);
- Numbers of cartons / containers delivered are within the range of 55 to 65 per hour (coupled) or per 30 minutes (decoupled).

Note: For more information on Delphi's Global Supplier Packaging Specifications or Delphi's Standard Container Menu, visit <http://apollo.delphiauto.net/packaging/>.

7 Analysis Tools - Material Handling & Energy Expenditure

7.1 One Handed Lifts (Biomechanical Analysis 3-D Static Strength Posture Predictions)

For one-handed lifting, use the 3-D Static Strength Posture Prediction model as the analysis tool. The program calculates an estimation of low-back compressive force, for both male and female populations as well as the static strength capability percentages based on the generated moments around the joints. The 3D model also allows a three dimensional human study that is capable of



analyzing a greater range of body postures, including cross-body movements and forces in varying directions. A simplified version of 3D-SSPP is the *Force Exertion Screening* tool that analyzes one-handed force exertions, found at: http://apollo.delphiauto.net/ergonomics/risk_analysis.htm.

Biomechanical Analysis may also be of concern if the worker:

- Two handed handling of loads or exerted forces that are greater than 10 lbs.
- One handed handling loads or exerted forces greater than 5 lbs. per hand.
- Must reach out, stoop, squat, lean, twist, bend or work above shoulder height while handling the load or exerting the force.
- Must handle a large or bulky object.

The program is most applicable in the analysis of the 'slow' movement used in heavy material handling tasks. Such tasks can best be analyzed by describing the activity as a sequence of static postures.

Advantages:

- May be used on an existing job or on a planned job, given estimated weights and distances.
- Allows a relatively quick assessment of the biomechanical impact of postures and loads.
- Good for making comparisons between alternative methods and for evaluating improvements.

Disadvantages:

- Does not take into account dynamic actions or consequences of twisting.
- The effects of acceleration and momentum must be negligible.
- Evaluates the consequences of a single lift and not the effects of repetition or prolonged performance.

7.2 Two Handed Lifts (NIOSH Programs)

When lifting with two hands and designing for a new product, use the 1991 NIOSH lifting equations that is available as an Excel based program on the Ergonomics website at http://apollo.delphiauto.net/ergonomics/risk_analysis.htm.

1981 vs. 1991 NIOSH Lift Equation

The NIOSH equation attempts to integrate the biomechanical, physiological and psychophysical aspects of lifting tasks to produce an overall assessment of the risk of injury of the task. Horizontal distance, vertical location of the hands at the beginning of the lift, range of lift, frequency of lift and job duration are part of the 1981 equation. The 1981 equation computes a weight value for a task designated as an Action Limit (AL), which is protective of about 99% of the male population and 75 % of the female population.

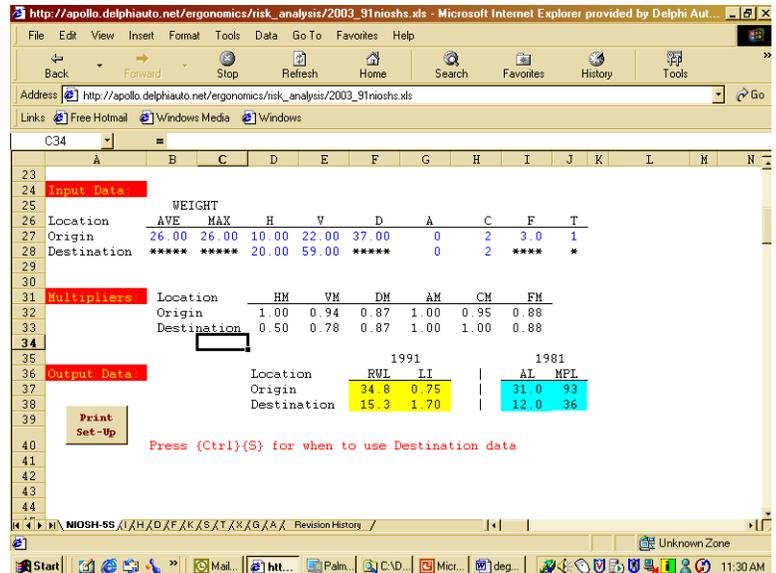
The 1991 equation adds coupling, asymmetry and expands the job duration categories and has been designated as appropriate for use with future product lines. The 1991 equation computes a Recommended Weight Limit (RWL) and Lift Index (LI), which compare the recommended weight to the actual weight. The RWL is designed to be protective of 99% of the male population and 90% of the female population.

Performing lifting tasks from a seated posture can result in greater lower back forces than those measured while standing with a flexed trunk (due to the forward bending moment around the lower vertebrae of the back). For this reason, performing lifting tasks greater than 10 lbs (or 5 lbs. per hand), while in a seated position, should be analyzed using the 3D Static Strength Posture Prediction model.

Conditions

The following conditions must exist in order to apply the 1981 or 1991 NIOSH Lifting Guidelines:

1. Standing Operation
2. 2 Handed Lift
3. Weight > 10 lbs.
4. Asymmetry < 30° (trunk twisting)
5. Vertical distance traveled by part >10 inches (25 cm)
6. Object width 30 in. (76cm) or less
7. Object easy to grasp
8. Smooth lifting



7.3 Push, Pull, Carry Program (Snook Tables)

To analyze pushing, pulling or carrying activities, use the psychophysical tables (a.k.a. Snook Tables and a.k.a. Manual Material Handling program), now available as Excel based computer programs that can be found on the Ergonomics website on Delphi's internet at: http://apollo.delphiauto.net/ergonomics/risk_analysis.htm, the file names are:

MMH_e_02.xls (English units) or MMH_m_02.xls (Metric units)

This manual material-handling program for push, pulls or carries, calculates the maximum weights for carrying and the maximum initial and sustained forces for push and pull activities. The program provides values for men and women separately.

Snook Tables represent:

- Interaction between physical and mental processes
- Quantifies a person's perceived tolerance of manual material handling stress

Limitations:

- Models using this approach tend to over-predict the amount of weight people can carry at high frequencies and for extended periods of time.
- Limited input variables such as distances traveled, handle height for push / pull, etc.

	1st Scenario	2nd Scenario	3rd Scenario
Percent Capable	90	75	50
Handle Height	35.0 (in)	35.0 (in)	35.0 (in)
Pushing Distance	6 (ft)	6 (ft)	6 (ft)
Frequency of Push	10 per min	10 per min	10 per min
Initial Force:	31 (lbf)	37 (lbf)	44 (lbf)
Sustained Force:	11 (lbf)	15 (lbf)	20 (lbf)

Task Description: Push a cart 6 feet down an aisle, 10 times per minute.

7.4 Energy Expenditure

Energy expenditure is the amount of energy required to perform a task and is expressed in kilocalories per minute (kcal/min). The human body is constantly expending energy, to what extent depends on the activity performed, see table on right.

Activity	Energy Expenditure kcal/min	Total Time (min.) to Burn 145 kcal for a 170 lb. Male
Sleeping	1.2	120
Sitting	1.6	90
Standing	2.3	60
Walking	4.0	36
Cycling	5.2	27
Sawing wood	6.6	22
Skating	10	14
Running	13	11
Climbing stairs	14	10

Energy Expenditure may be of concern if the worker:

- Walk, carries, pushes or pulls objects more than 100 feet in a one-minute period and carrying more than 5 lbs.
- Lifts or exerts forces of at least 10 lbs. four or more times per minute.
- Must squat, stoop or otherwise move his / her center of gravity vertically four or more times per minute, a distance of eight vertical feet.

and

- Does the above activity for a sustained period of time (achieves and maintains a physiological steady state) for at least ten minutes per hour, several times per day.

Energy expenditure for a specific job can be predicted by analyzing the job elements. A computer program is available, *Gmenergy.xls* and can be found on the Ergonomics homepage on Delphi's internet at http://apollo.delphiauto.net/ergonomics/risk_analysis.htm.

Advantages: Easy to use, may be used with a task description of an actual or planned job.

Disadvantages: Has a limited number of task elements that may be entered, assumes a cyclical, repetitive activity, difficult to use for irregular activities. Does not consider biomechanical impact of load handling or force exertion.

The screenshot shows the Microsoft Excel interface for the Gmenergy program. The main window displays the 'METABOLIC CALCULATION WORKSHEET SUMMARY' with the following data:

- Gender: 1 (Male)
- Job Title: Assemble Part
- Job Number: 456877
- Analyst: [Blank]
- Date: [Blank]
- 100% of Posture Accounted For
- Body Weight (lbs): 170
- % Time Sitting: 0
- % Time Standing: 100
- % Time Standing Best: 0
- Job Cycle Time (min): 0.75
- Total Energy Expenditure (kcal): 1.60
- Energy Expenditure Rate (kcal/min): 2.13

Below the summary is a 'Worksheet' section with a table of task elements:

Number	Type of Task	Task Description	Freq	Avg Push/Pull Force (lbs.)	Grade of Floor (%)	Start Hgt (in)	End Hgt (in)	Wgt of Load (lbs.)	Walk Dist. (ft)	Horiz. Dist. Mov. (in)	Time in Min.	KCal per Task
50	Lift-arm	Lift part from container	1.0			33	40	5			0.02	1
51	Lower-arm	Lower part into fixture	1.0			40	39	5			0.02	1
52	Hand-light	Place component on part	1.0								0.50	0.10
53	Walking	Walk to next operation	1.0			0			5		0.02	0.08

Appendix A - Anthropometric Data, United States and Canada Population

Segment	Males			Females		
	Population Percentiles in inches			Population Percentiles in inches		
	5th	50th	95th	5th	50th	95th
1. Forward Functional Reach	30.0	32.5	34.8	25.2	28.0	31.1
2. Elbow Height	41.4	45.3	48.9	38.9	41.8	44.8
3. Knuckle Height	28.5	30.7	32.7	26.3	28.6	30.9
4. Shoulder Height	53.1	57.2	61.0	48.7	52.6	56.9
5. Eye Height	61.5	65.9	70.0	56.4	60.6	64.7
6. Stature	65.7	70.3	74.6	60.9	65.2	69.4
7. Standing Overhead Reach ***	78.1	83.5	88.9	72.5	77.0	81.5
8. Thigh Clearance	5.4	5.7	7.0	4.2	5.4	6.9
9. Eye Height	28.6	30.9	33.2	26.6	28.9	30.9
10. Sitting Height	33.1	35.7	38.1	30.9	33.5	35.7
11. Elbow to Finger Tip	17.4	18.9	20.2	15.2	16.6	18.1
12. Knee Height	21.4	23.4	25.3	19.8	21.6	23.5
13. Seat Height	16.4	18.4	20.2	15.0	16.7	18.4
14. Seat Length	17.4	19.5	21.6	16.9	18.9	21.1
15. Upper Leg Length	21.3	23.4	25.3	20.4	22.4	24.6
16. Sit Overhead Reach ***	52.7	56.4	60.3	48.6	52.2	55.8
17. Hip Breadth ***	12.9	14.4	16.2	13.5	15.1	17.0
18. Shoulder Height	20.7	23.4	25.9	19.4	21.9	24.3
19. Elbow Height	7.5	9.6	11.6	7.1	9.2	11.1
20. Elbow Breadth	13.8	16.4	19.9	12.4	15.1	19.3
21. Hand Length	6.9	7.5	8.1	6.5	7.1	7.8
22. Hand Breadth	3.2	3.5	3.9	2.8	3.0	3.3
23. Hand Thickness	0.9	1.1	1.2	1.0	1.1	1.2
24. Foot Length	9.8	10.6	11.4	8.8	9.5	10.3
25. Foot Breadth	3.5	3.9	4.2	3.2	3.5	3.8
26. Arm Span **	65.2	70.0	75.8	58.7	63.2	67.9
27. Elbow Span **	34.1	37.2	40.2	30.7	33.5	36.2

One (1) inch has been added to all vertical dimensions to account for shoes.

** Data from S. Pheasant, *Bodyspace, Anthropometry, Ergonomics, and Design*, 1986

*** Data from the UAW-GM Ergonomics Pilot Project

NOTE:

Upper Limit = 5th percentile Female shoulder height.

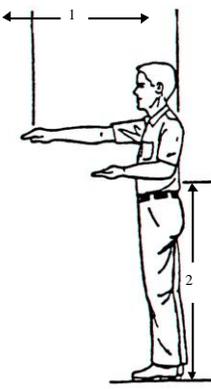
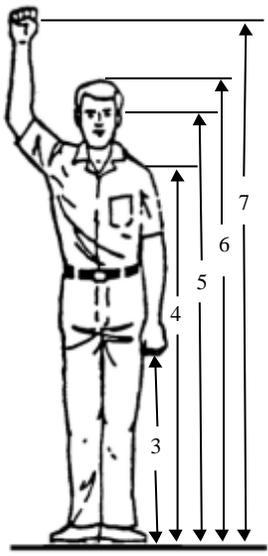
Forward Limit = 5th percentile Female Forward Functional Reach.

Outer Limit = 5th percentile Female Elbow Span.

Lower Limit = 95th percentile Male Knuckle Height.

Appendix B – Body Segment Dimension Definitions

When evaluating or designing a workstation, you will use the specific body dimension information related to the work tasks being performed. The following list provides a definition of each body dimension and also gives a possible application for that dimension. The definition number corresponds directly to the body dimension number on the chart.

Side View Standing		
	1. Forward Functional Reach	The distance from the shoulder joint to the knuckles of the hand, measured with the arm extended in front of the body. This dimension may be used in determining the maximum reach distance to objects located in front of the body in standing or seated workstation. (Note: minimal force should be required at this location).
	2. Elbow Height	The distance from the floor to the elbow measured while standing with the arm at the side of the body. This dimension may be used in determining the height of a workbench in a standing workstation.
Front View Standing		
	3. Knuckle Height	The distance from the floor to the knuckles of the hand, measured while standing with the arm at the side of the body. This dimension may be used in determining the best location for heavy objects that need to be lifted.
	4. Shoulder Height	The distance from the floor to the top of the shoulder, measured while standing with the arm at the side of the body. This dimension may be used in determining the upper height limit for pushing or pulling tasks.
	5. Eye Height	The distance from the floor to the eyes, measured while standing. This dimension may be used in determining the location of displays and visual information needed to perform tasks in a standing workstation.
	6. Stature	The distance from the floor to the top of the head, measured while standing. This dimension may be used in determining the height necessary for overhead clearances.
	7. Standing Overhead Reach	The distance from the floor to the knuckles of the hand, measured while standing with the arm extended upright over the head. This dimension may be used in determining the maximum height for infrequent overhead reaches while performing tasks in a standing workstation.

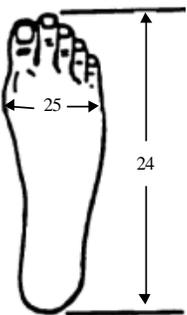
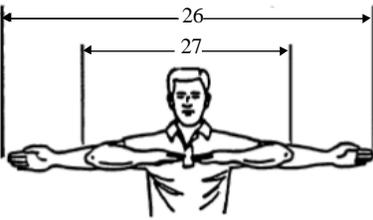
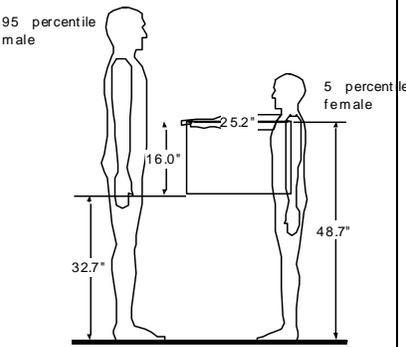
Appendix B, Continued

Side View Seated		
	8. Thigh Clearance	The distance from the chair seat to the top of the thigh, measured while seated. This dimension may be used in determining the clearance needed between a chair seat and the underside of a workbench in a seated workstation.
	9. Eye Height	The distance from the chair seat to the eyes, measured while seated. This dimension may be helpful in determining the location of displays and visual information needed to perform tasks in a seated workstation.
	10. Sitting Height	The distance from the chair seat to the top of the head, measured while sitting. This dimension may be used in determining the height necessary for clearances of overhead structures on machinery or equipment.
	11. Elbow to Finger Tip	The distance from the elbow to the tip of the middle finger. This dimension may be used in determining the proper location of parts or tools on a workbench that need to be used frequently while performing a task in a standing or seated workstation.
	12. Knee Height	The distance from the floor to the top of the knee, measured while seated. This dimension may be used in determining the clearance needed between the underside of a workbench and the floor in a seated workstation.
	13. Seat Height	The distance from the floor to the bottom of the thigh, measured while sitting. This dimension may be used in determining the distance from the floor to the top of a chair seat in a seated workstation.
	14. Seat Length	The distance from the lower back to the rear of the knee, measured while seated. This dimension may be used in determining the depth of chair seats.
	15. Upper Leg Length	The distance from the lower back to the front of the knee, measured while seated. This dimension may be used in determining the forward clearance needed under a workbench in a seated workstation.
16. Seated Overhead Reach	The distance from the chair seat to the knuckles of the hand, measured while seated with the arm extended upright over the head. This dimension may be used in determining the maximum height for infrequent overhead reaches while performing tasks in a seated workstation.	

Appendix B, Continued

Rear View Seated		
	17. Hip Breadth	The distance from the outside of one leg at the hip to the outside of the other leg at the hip. This dimension may be used in determining the width of chair seats.
	18. Shoulder Height	The distance from the chair seat to the top of the shoulder, measured while seated. This dimension may be used in determining the upper height limit for locating parts or tools that must be used frequently while performing tasks in a seated workstation.
	19. Elbow Height	The distance from the chair seat to the elbow, measured while seated. This dimension may be used in determining the lower height limit for locating parts or tools that must be used frequently while performing tasks in a seated workstation.
	20. Elbow Breadth	The distance between the two outer elbow (epicondyles) bones with the elbows resting at the side.
Hand		
	21. Hand Length	The distance from the wrist to the fingertips. This dimension may be used in determining the length of gloves and the diameter of tool handles.
	22. Hand Breadth	The distance from one side of the hand to the other side, measured across the palm above the thumb joint. This dimension may help in matching the length of tool handles to hand size.
	23. Hand Thickness	The distance from the palm of the hand to the back of the hand, measured below the base of the middle finger. This dimension may help in determining the clearance needed for hand access openings in containers or equipment.

Appendix B, Continued

Rear View Seated		
	24. Foot Length	The distance from the rear of the foot to the tip of the toes. This dimension may be used in determining the toe clearance needed under a workbench in a standing workstation.
	25. Foot Breadth	The distance from one side of the foot to the other side, measured at the ball of the foot. This dimension may be used in determining the width of foot-operated controls.
Rear View Seated		
	26. Arm Span	The distance from the fingertips of one hand to the fingertips of the other hand, measured with the arms fully extended outward at each side. This dimension may be used in determining the workspace needed in standing or seated workstation.
	27. Elbow Span	The distance from the tip of one elbow to the tip of the other elbow, measured with the upper arm fully extended outward at each side, with the forearms folded inward. This dimension may be used in determining the width of access openings to roof areas or machines.
		The graphic shown on the left demonstrates the work height range for a 95 th percentile male versus a 5 th percentile female (data shown based on US and Canada populations).

Appendix C – Forward Reach Values (Equipment/Workplace Design)

The table below identifies the values for optimal and infrequent horizontal reach distances (in inches and cm) of global populations. For further information or illustration of the reach criteria, go to Section 4.5.

Global Reach Guidelines

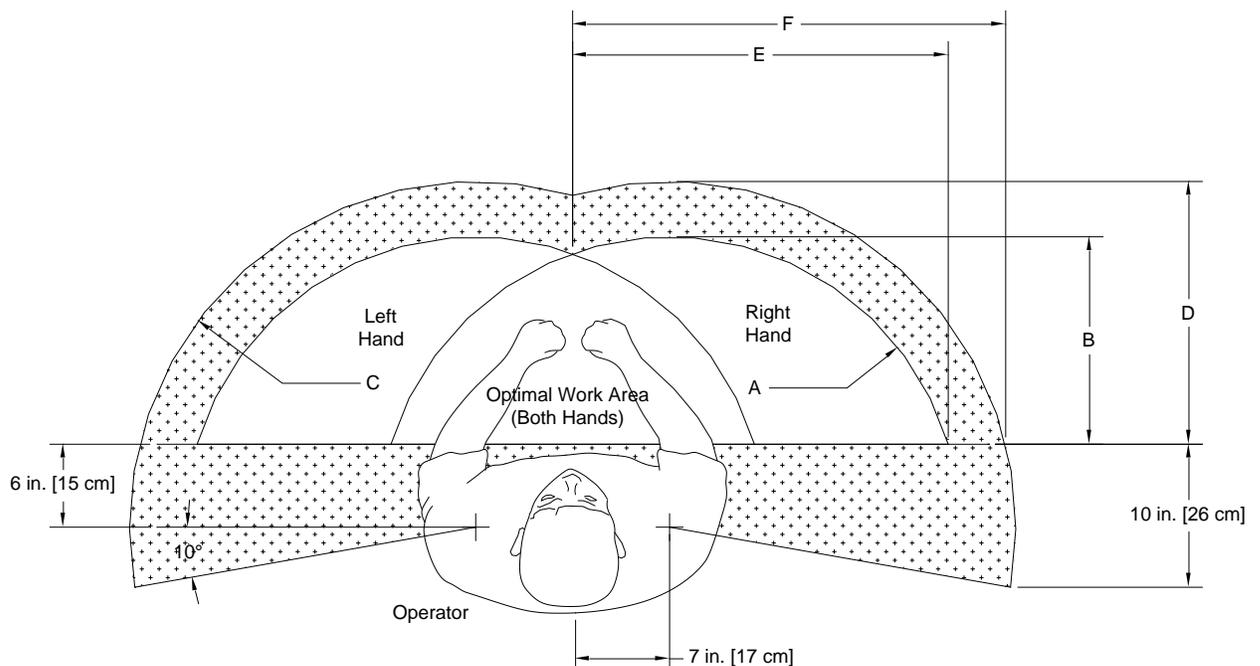
Symbol on Diagram that shows reach dimension	Optimal reach (radial distance measured from shoulder)		Optimal reach (distance measured from front of table)		Infrequent Reach Only (radial distance measured from shoulder)		Infrequent Reach Only (distance measured from front of table)		Optimal Side Reach (distance measured from center of table)		Infrequent Side Reach (distance measured from center of table)	
	A	B	C	D	E	F	Inches	cm	Inches	cm	Inches	cm
Latin American (Indian)	19	48	13	33	24	61	18	46	25	63.5	30	76
South India	19	48	13	33	24	61	18	46	25	63.5	30	76
So. East. Africa	20	51	14	35.6	24	61	18	46	26	66	30	76
North India	20	51	14	35.6	24	61	18	46	26	66	30	76
South China	20	51	14	35.6	24	61	18	46	26	66	30	76
South East Asia	20	51	14	35.6	24	61	18	46	26	66	30	76
U.S.	21	53	15	38	25	63.5	19	48	27	68.6	31	79
Latin Am (Euro-Negroid)	21	53	15	38	25	63.5	19	48	27	68.6	31	79
Central Europe	21	53	15	38	25	63.5	19	48	27	68.6	31	79
East. Europe	21	53	15	38	25	63.5	19	48	27	68.6	31	79
So. East. Euro.	21	53	15	38	25	63.5	19	48	27	68.6	31	79
France	21	53	15	38	25	63.5	19	48	27	68.6	31	79
Iberian Peninsula	21	53	15	38	25	63.5	19	48	27	68.6	31	79
North Africa	21	53	15	38	25	63.5	19	48	27	68.6	31	79
West Africa	21	53	15	38	25	63.5	19	48	27	68.6	31	79
Near East	21	53	15	38	25	63.5	19	48	27	68.6	31	79
North Asia	21	53	15	38	25	63.5	19	48	27	68.6	31	79
Australia	21	53	15	38	25	63.5	19	48	27	68.6	31	79
Japan	21	53	15	38	25	63.5	19	48	27	68.6	31	79
Northern Europe	21	53	15	38	25	63.5	19	48	27	68.6	31	79



Infrequent Reaches Only



Optimal Work Area for Repetitive and Infrequent Reaches



Appendix D – Vertical Hand Height (Equipment/Workplace Design)

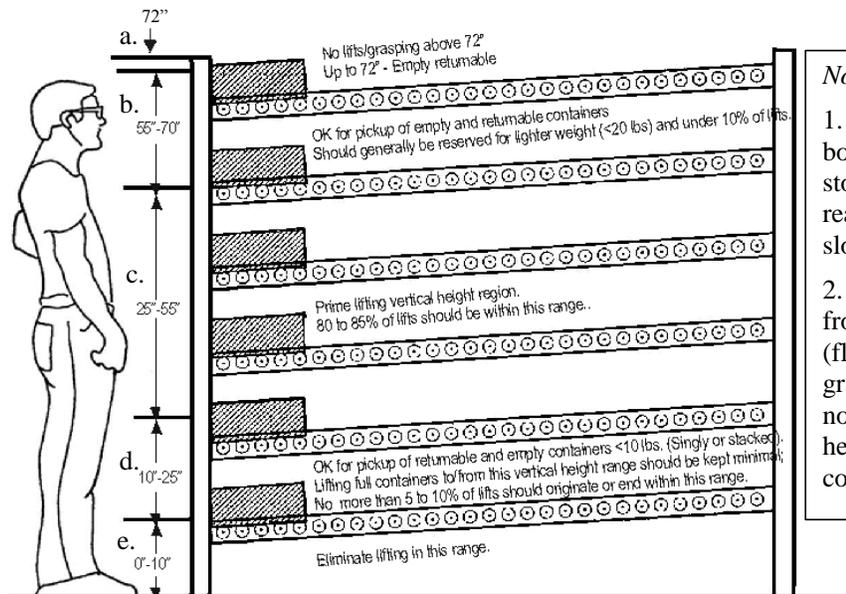
The table below quantifies the vertical hand height, for various global populations (measured from the standing surface to where the hands perform work). For further information or illustration, see Sections 4.2 & 4.3.

REGION	Precision			Light			Heavy		
	[parts < 2 lbs. (0.9 kg)]			[parts > 2 lbs. (0.9 kg) but < 10 lbs. (4.5 kg)]			[parts > 10 lbs. (4.5 kg)]		
	High Value in (cm)	Low Value in (cm)	Preferred in (cm)	High Value in (cm)	Low Value in (cm)	Preferred in (cm)	High Value in (cm)	Low Value in (cm)	Preferred in (cm)
Latin America (Native)	45 (114)	38 (97)	40 (102)	43 (109)	35 (89)	39 (99)	37 (94)	29 (74)	33 (84)
Latin America (Euro - Negro)	49 (124)	43 (109)	45 (114)	45 (114)	37 (94)	41 (104)	39 (99)	31 (79)	35 (89)
North Europe	51 (130)	44 (112)	46 (117)	46 (117)	38 (97)	42 (107)	40 (102)	32 (81)	36 (91)
Central Europe	50 (127)	43 (109)	45 (114)	45 (114)	37 (94)	41 (104)	39 (99)	31 (79)	35 (89)
East Europe	50 (127)	43 (109)	45 (114)	45 (114)	37 (94)	41 (104)	39 (99)	31 (79)	35 (89)
South East Europe	49 (124)	43 (109)	45 (114)	45 (114)	37 (94)	41 (104)	39 (99)	31 (79)	35 (89)
France	49 (124)	43 (109)	45 (114)	46 (117)	38 (97)	42 (107)	40 (102)	32 (81)	36 (91)
Iberian Peninsula	49 (124)	42 (107)	44 (112)	45 (114)	37 (94)	41 (104)	39 (99)	31 (79)	35 (89)
North Africa	48 (122)	42 (107)	44 (112)	44 (112)	36 (91)	40 (102)	38 (97)	30 (76)	34 (86)
West Africa	46 (117)	40 (102)	42 (107)	44 (112)	36 (91)	40 (102)	38 (97)	30 (76)	34 (86)
So.East. Africa	48 (122)	41 (104)	43 (109)	44 (112)	36 (91)	40 (102)	38 (97)	30 (76)	34 (86)
Near East	50 (127)	43 (109)	45 (114)	44 (112)	36 (91)	40 (102)	38 (97)	30 (76)	34 (86)
North India	47 (119)	40 (102)	42 (107)	44 (112)	36 (91)	40 (102)	38 (97)	30 (76)	34 (86)
South India	45 (114)	38 (97)	40 (102)	43 (109)	35 (89)	39 (99)	37 (94)	29 (74)	33 (84)
North Asia	48 (122)	42 (107)	44 (112)	44 (112)	36 (91)	40 (102)	38 (97)	30 (76)	34 (86)
South China	46 (117)	40 (102)	42 (107)	43 (109)	35 (89)	39 (99)	37 (94)	29 (74)	33 (84)
South East Asia	46 (117)	40 (102)	42 (107)	43 (109)	35 (89)	39 (99)	37 (94)	29 (74)	33 (84)
Australia	50 (127)	44 (112)	46 (117)	46 (117)	38 (97)	42 (107)	40 (102)	32 (81)	36 (91)
Japan	49 (124)	42 (107)	44 (112)	44 (112)	36 (91)	40 (102)	38 (97)	30 (76)	34 (86)

Appendix E – Vertical Hand Height (Material Handling, Racks/Shelves)

The table below quantifies the vertical hand heights for various global populations (measured from standing surface to where hands grasp container). For further information or illustration, see Section 6, Supermarkets.

		Item				
		a	b	c	d	e
		5th Percentile, Female, Standing Overhead Reach (X) No lifting or grasping above height X	OK for pick up of empty & returnable containers. Should generally be reserved for lighter weights (<20 lbs. and fewer than 10% of lifts)	Prime lifting vertical height region. 80 - 85% of lifts should be within this range.	OK for pick up of returnable & empty containers <10 lbs. (single or stacked). Lifting containers to/from this vertical height should be kept minimized. Not more than 5-10% of lifts should begin/ end within this range.	Eliminate lifting in this range
		X	(X-17)" to (X-2)"	(X-47)" to (X-17)"	(X-62)" to (X-47)"	0 to (X-62)"
Latin America	Latin America (Indian population)	68.8	51.8 to 66.8	21.8 to 51.8	6.8 to 21.8	0 to 6.8
	Latin America (European population)	75.3	58.3 to 73.3	28.3 to 58.3	13.3 to 28.3	0 to 13.3
Asia/Pacific	S. Korea / Japan	74.8	57.8 to 72.8	27.8 to 57.8	12.8 to 27.8	0 to 12.8
	China	70.8	53.8 to 68.8	23.8 to 53.8	8.8 to 23.8	0 to 8.8
	S-E Asia	71.3	54.3 to 69.3	24.3 to 54.3	9.3 to 24.3	0 to 9.3
Europe	Northern Europe	78.3	61.3 to 76.3	31.3 to 61.3	16.3 to 31.3	0 to 16.3
	Central Europe	76.8	59.8 to 74.8	29.8 to 59.8	14.8 to 29.8	0 to 14.8
	Eastern Europe	76.3	59.3 to 74.3	29.3 to 59.3	14.3 to 29.3	0 to 14.3
North America	North America	76.3	59.3 to 74.3	29.3 to 59.3	14.3 to 29.3	0 to 14.3



Notes:

1. Rack heights apply to both sides of material storage system. For this reason, rack lengths and slope must be considered.
2. Heights are measured from the standing surface (floor) to where the hands grasp the container (this is not necessarily the same height as where the container handholds are).

Appendix F - Cumulative Trauma Disorders (CTD)

A cumulative trauma disorder (CTD) is defined as damage to body tissue by outside forces that has built up over time. This damage interferes with the normal, healthy functioning of the body. Continued exposure to the sources of cumulative trauma (repeated or forceful exertions, awkward postures, vibration, contact stress) leads to health effects like joint inflammation, muscle soreness, or nerve entrapment. This can ultimately cause a serious and possibly disabling injury. Typically, CTD's occur in the upper extremities or low back. Blood vessels, nerves, and tendons in these two areas often come into contact with bones and ligaments. This makes them more prone to injury.



Tendonitis is inflamed and sore tendons. Symptoms include pain, swelling, tenderness and weakness in either your hand, elbow or shoulder.

Cause: Outside stress/force, excessive repetitive movement

Swollen sheath



Tenosynovitis is the swelling of the tendon and the sheath that covers it. Symptoms include swelling, tenderness and pain in you hand and arm.

Cause: Outside stress / force, excessive repetitive movement

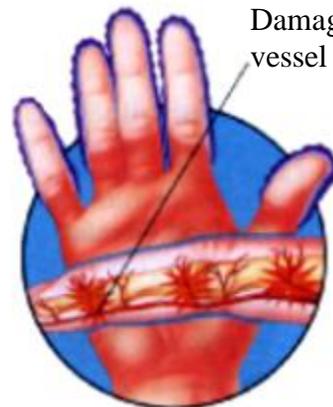
Pressure on nerve



Carpal tunnel syndrome is caused by too much pressure on the median nerve (the nerve that runs through your wrist). Symptoms include numbness, tingling, an aching sensation and pain in your wrist (mostly at night).

Cause: Repetitive movement of the hand and wrist. Hyper-extension and flexion.

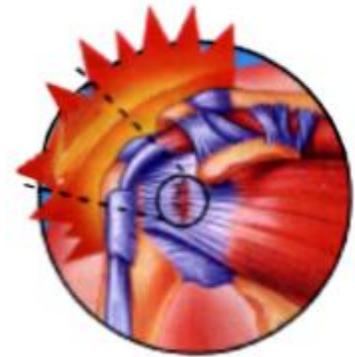
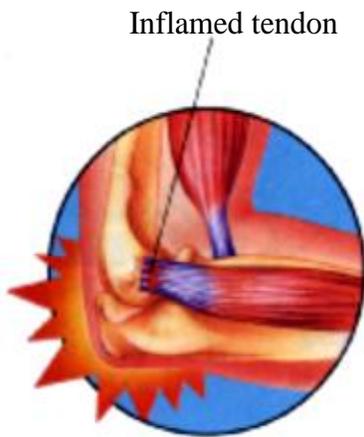
Damaged blood vessel



White finger occurs when blood vessels in your fingers are damaged. Symptoms include paleness in fingers, numbness, tingling, and a sense that your finger is “on fire”.

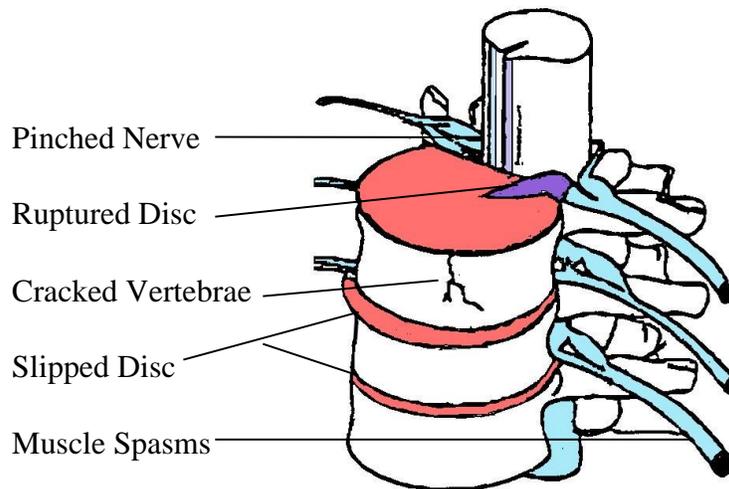
Cause: Repetitive exposure to vibrating tools or equipment.

Types of CTD's continued:



Epicondylitis (also called “tennis elbow”) is due to inflammation of the tendons in your elbow. Symptoms include pain with some swelling and weakness.
Cause: Repeated upward twisting of the forearm, extension and flexion.

Rotator cuff injury occurs when one or more of the four rotator cuff tendons in your shoulder is inflamed. Symptoms include pain and limited movement of your shoulder.
Cause: Repeated arm movement above shoulder, accompanied by force or for prolonged periods of time.



Common lower back disorders are debilitating and painful.
Cause: Repeated heavy lifting and / or twisting of trunk.

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