King Saud University

College of Engineering

IE – 341: “Human Factors Engineering”

Spring – 2025 (2^{nd} Sem. 1446H)

Manual Materials Handling

(Chapter 8)

part 1 – Basic Concepts

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Lesson Overview

Part 1 (this part):

- What is MMH?
- MMH Activities
- MMH Effect on Health
- NIOSH Lifting Equation
- Multiplier Values
- Lifting Index

Part 2:

- Case Studies
  - Case 1: Effect of Frequency Factor on RWL
  - Case 2: Effect of Horizontal Distance on RWL
  - Case 3: Effect of Vertical Distance on RWL

What is MMH?

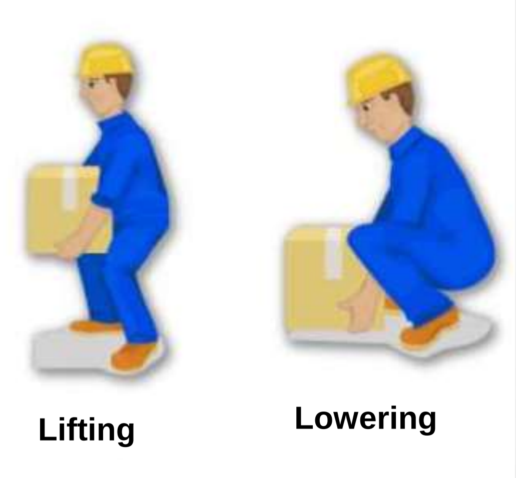
What is Manual Materials Handling?

- Manual Materials Handling (MMH)
  - Important application of ergonomic principles
  - Particularly addresses back injury prevention
  - Almost every worker performs MMH tasks
    - Either one-time (infrequent) duty, or
    - As part of regular work

- MMH involves five types of activities:
  1. Lifting/Lowering
  2. Pushing/Pulling
  3. Twisting
  4. Carrying
  5. Holding


Pushing


Pulling



MMH Activities

MMH Activities

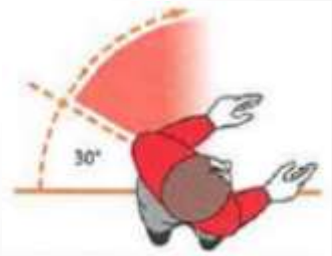
- Lifting/Lowering
  - Lifting: to raise from a lower to a higher level
  - Range of a lift: from the ground to as high as you can reach with your hands
  - Lowering is the opposite activity of lifting

Lifting Lowering

- Pushing/Pulling
  - Pushing: to press against an object with force in order to move the object
  - The opposite is to pull

Pushing Pulling

- Twisting
  - (MMH Def^{n}) act of moving upper body to one side or the other, while the lower body remains in a relatively fixed position
  - Twisting can take place while the entire body is in a state of motion



MMH Activities (cont.)

- Carrying
  - Having an object in one’s grasp or attached while in the act of moving
  - Weight of object becomes a part of the total weight of the person doing the work

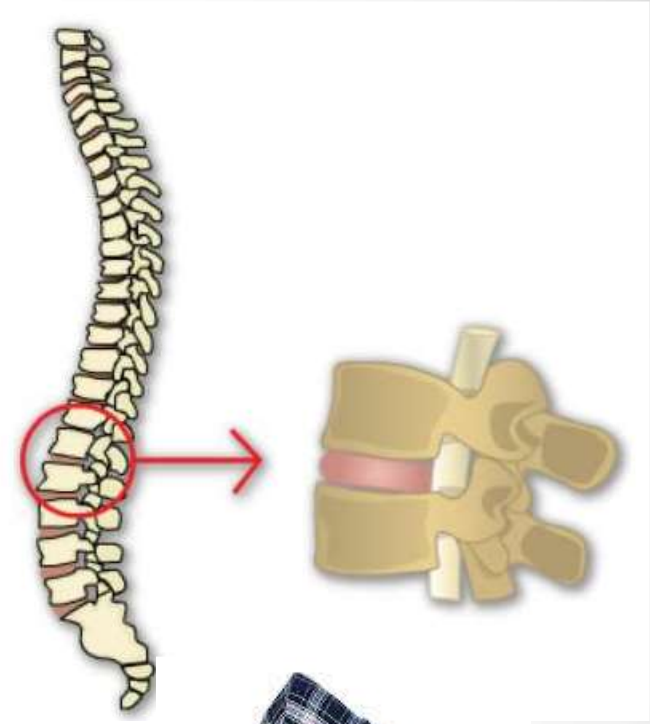
- Holding
  - Having an object in one’s grasp while in a static body position

Carrying

MMH Effect on Health

MMH: Effect on Health

- MMH: most common cause of occupational fatigue and low back pain
- About ¾ workers whose job includes MMH suffer pain due to back injury at some time
- Such back injuries account for ≈ 1/3 of all lost work + 40% of all compensation costs
- More important than financial cost: human suffering
- ⇒ prevention of back injuries: crucial, challenging problem for occupational health and safety

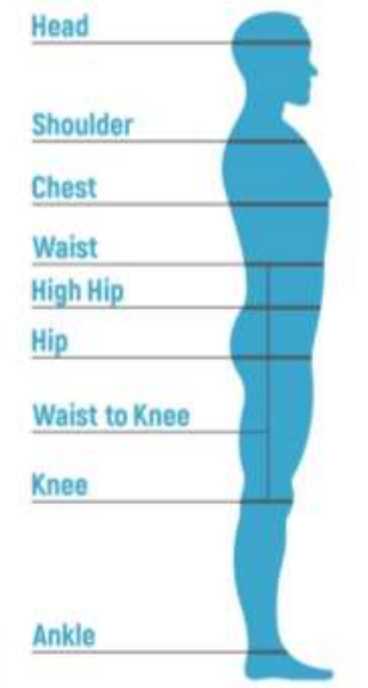


MMH: Effect on Health (cont.)

Work factors causing back injury during MMH

- Most common causes of back injuries
  - Tasks involving MMH > worker's physical capacity
  - Poor workplace layout
- 1. Weight of the load lifted
  - For most workers, lifting loads over 20 kilograms
    ⇒ increased number and severity of back injuries

- 2. Range of the lift
  - Preferred range for lifting is: between knee and waist height
  - Lifting above/below this range is more hazardous (next slide)



MMH: Effect on Health (cont.)

Work factors causing back injury during MMH (cont.)

Most common causes of back injuries (cont.)

- 2. Range of the lift (cont.)

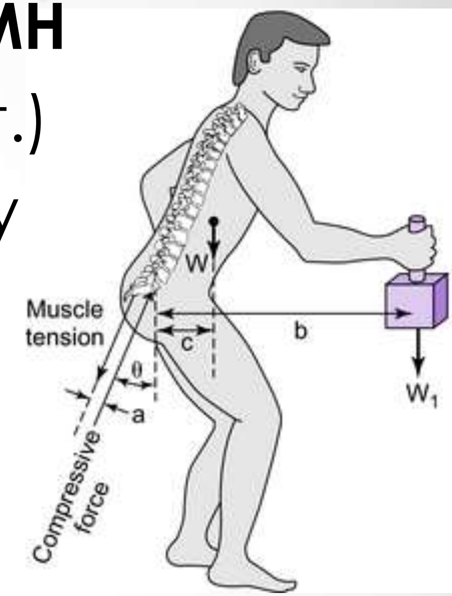
A. Stoop lift **B. Squat lift** **C. Semi-squat lift**

MMH: Effect on Health (cont.)

Work factors causing back injury during MMH

Most common causes of back injuries (cont.)

- 3. Location of load in relation to the body
    - o Load lifted far from the body ⇒ more stress on the back than the same load lifted close to the body (see next slide)



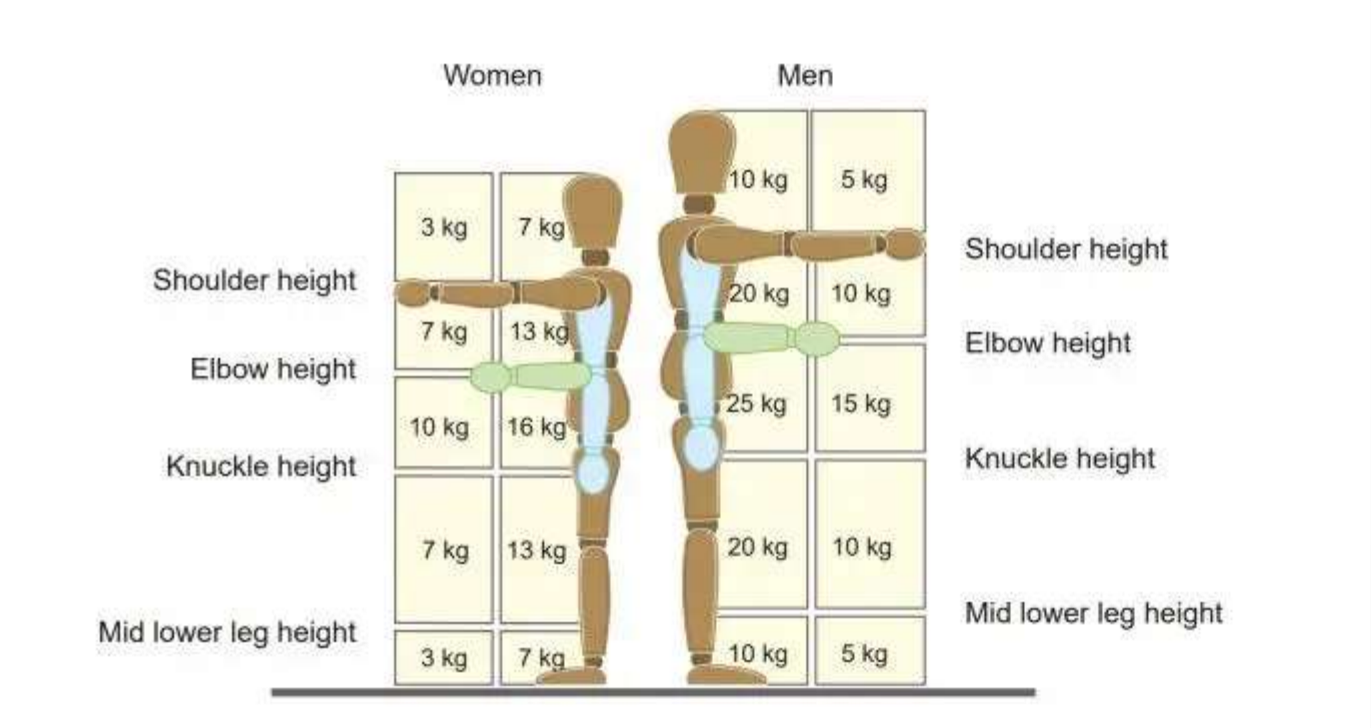
- 4. Size and shape of load
    - o Bulky object is harder to lift than a compact one of the same weight because it (or its center of gravity) cannot be brought close to the body
    - o Lifting a bulky object also forces a worker into an awkward and potentially unbalanced position

MMH: Effect on Health (cont.)

Work factors causing back injury during MMH

Most common causes of back injuries (cont.)

- 3. Location of load in relation to the body (cont.)



HSE's lifting and lowering risk filter (UK Health and Safety Executive) :
- a 25 kg load being manually handled is considered to be a safe upper limit for the average man
- and 16 kg for the average woman
- note, whether the person's arms need to extend is factored in too
Source: https://www.highspeedtraining.co.uk/hub/manual-handling-weight-limits/

MMH: Effect on Health (cont.)

Cont. Work factors causing back injury during MMH

Most common causes of back injuries (Cont.)

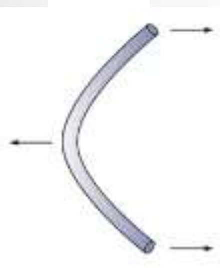
- 5. Number and frequency of lifts performed
  - How often the worker performs MMH tasks, and for how long, are extremely important factors
  - Frequently repeated, long-lasting tasks: most tiring ⇒ the most likely to cause back injury
  - Highly repetitive MMH tasks also make the worker bored and less alert ⇒ safety hazard

MMH: Effect on Health (cont.)

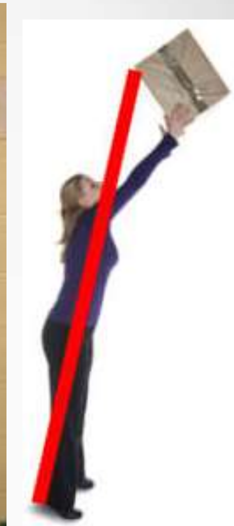
Cont. Work factors causing back injury during MMH

- 6. Excessive bending and twisting

Poor layout of the workplace ⇒ risk for injury ↑:



- e.g. **shelving** that is too deep, too high or too low ⇒ unnecessary bending or stretching
- e.g. **lack of space** to move freely ⇒ increases the need for twisting and bending
- e.g. **unsuitable dimensions** of benches, tables, and other furniture ⇒ force worker to perform MMH tasks in awkward positions ⇒ add stress to the musculoskeletal system
- e.g. **work areas overcrowded** with people or equipment ⇒ stressful body movements



NIOSH Lifting Equation

Establishing if a Lift is too Heavy

- **NIOSH**: National Institute for Occupational Safety and Health (United States)

- Following recommendations are based on "**Revised NIOSH lifting equation** (RNLE) for the design and evaluation of **manual lifting tasks**"

- NIOSH lifting equation takes into account weight, and other variables in lifting tasks that contribute to the risk of injury

Establishing if a Lift is too Heavy (cont.)

- e.g. situation requires frequent lifts or lifting loads far away from the body
  - o ⇒ there is an increased risk of injury
  - o Under these conditions, reduce weight limit:
    - from a baseline weight or "**load constant**" (**LC**)
    - to a **recommended weight limit** (**RWL**)

- A "load constant" (LC)
  - o 51 lb. (about 23 kg)
  - o established by NIOSH: load that, under ideal conditions (e.g. shifts ≤ 8 hr.), is safe for
    - 75% of females
    - 99% of males
    - i.e. 90% of adult employee population*

$$W = m \cdot g$$

- The recommended weight limit (RWL)
  - o Calculated using the NIOSH lifting equation
  - o Discussed in detail in upcoming section

Calculating the RWL: Overview

STEP 1: measure/assess variables related to lifting task

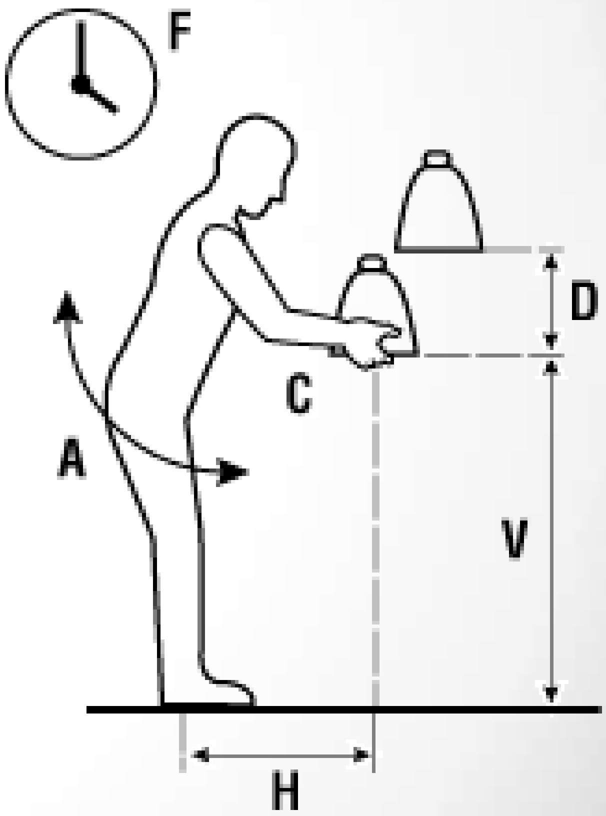
STEP 2: calculate RWL using NIOSH equation

STEP 3: analyze RWL

Calculating the RWL: Overview (cont.)

STEP 1: measure/assess variables related to the lifting task

- Six variables considered in determining RWL:
  1. **horizontal distance** (**H**) the load is lifted, i.e. = distance of hands from midpoint between ankles
  2. **starting height** of the hands from the ground, (vertical location, **V**)
  3. **vertical distance** of lifting (**D**)
  4. **frequency of lifting** or time between lifts (**F**)
  5. **angle of the load in relation to the body** (**A**) (e.g. straight in front of you = 0°, or off to side)
  6. **quality of grasp** or handhold based on the type of handles available (hand-to-load coupling, **C**).



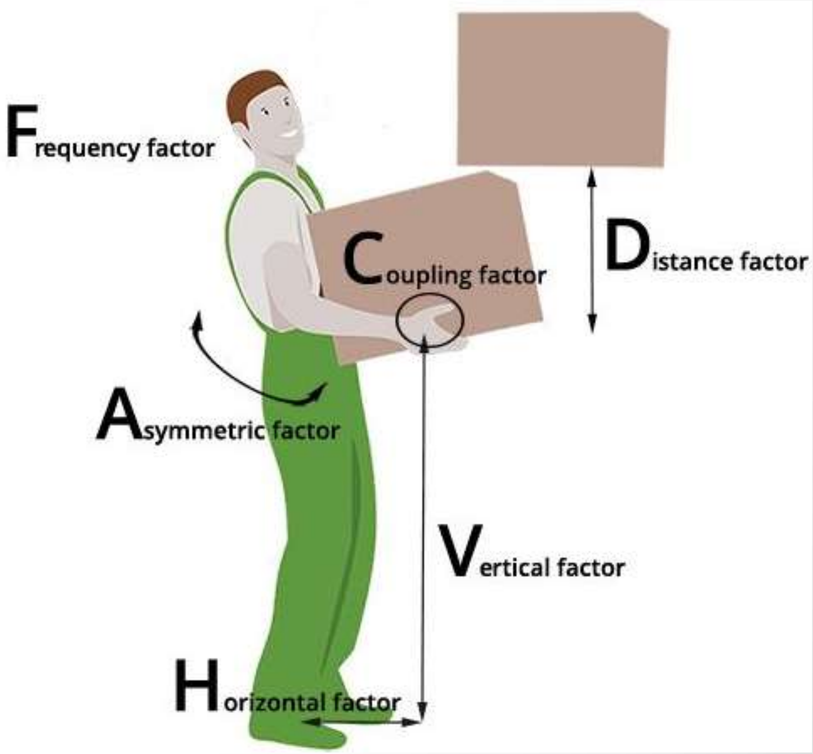
- Each of these variables: assigned a numerical value (**multiplier factor**) from look-up charts/formulas

Calculating the RWL: Overview (cont.)

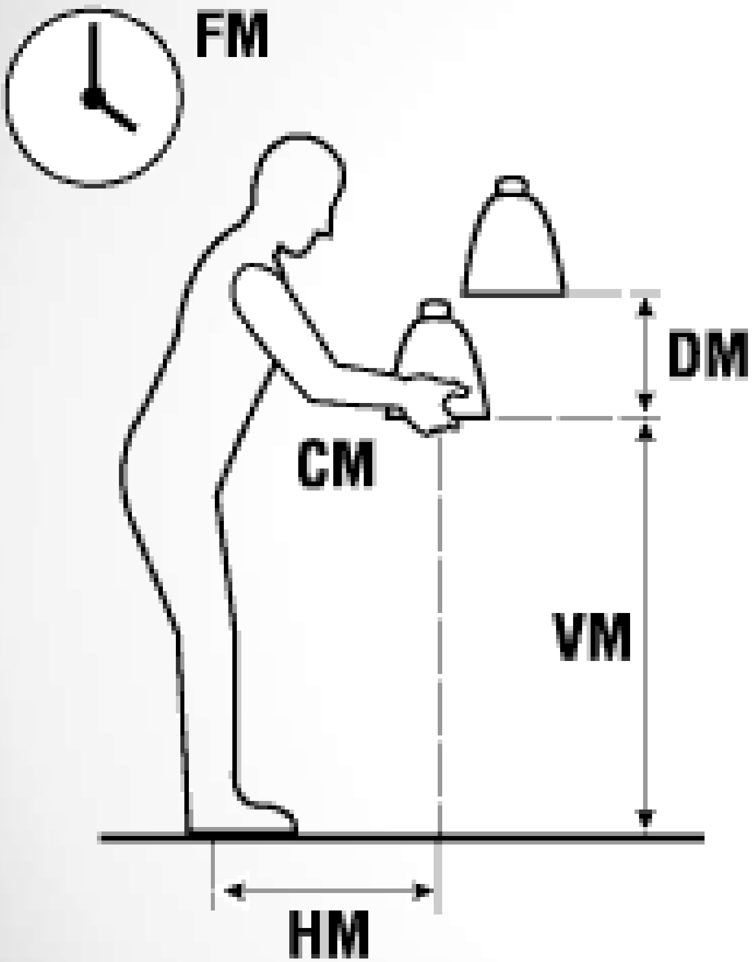
STEP 2: calculate RWL using NIOSH equation (includes six multiplier factors):

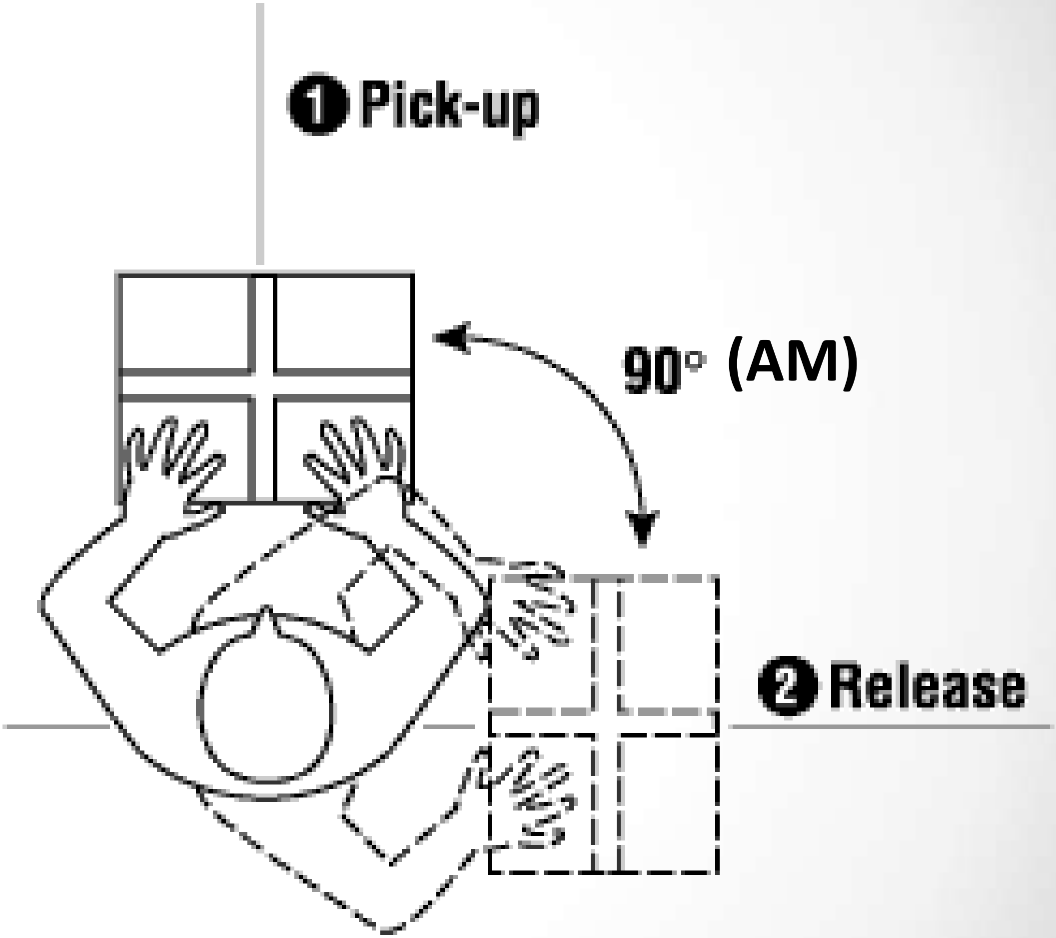
$$RWL = LC * HM * VM * DM * FM * AM * CM$$

- where LC is the load constant (23 kg/ 51 lb.); other factors are:
- **HM**, the "Horizontal Multiplier" factor
- **VM**, the "Vertical Multiplier" factor
- **DM**, the "Distance Multiplier" factor
- **FM**, the "Frequency Multiplier" factor
- **AM**, the "Asymmetric Multiplier" factor
- **CM**, the "Coupling Multiplier" factor



Calculating the RWL: Overview (cont.)

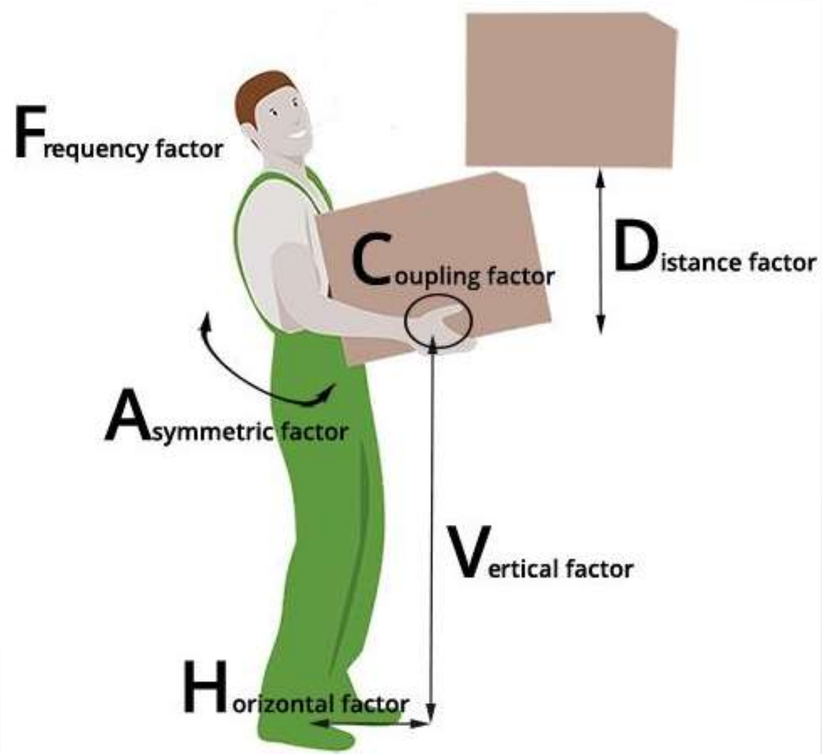




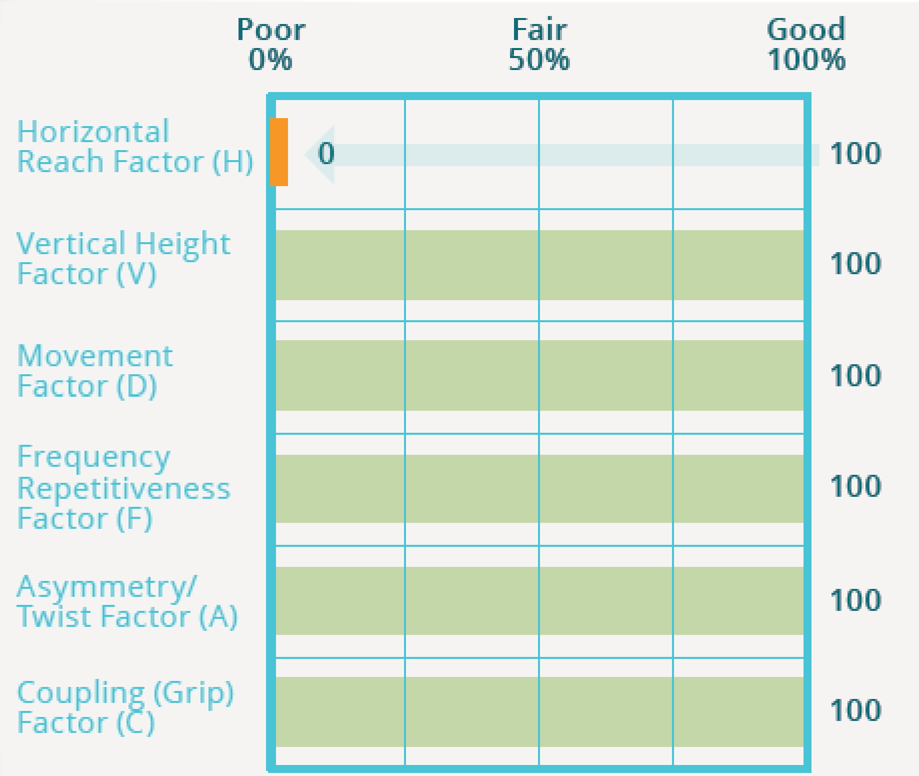
Calculating the RWL: Overview (cont.)

STEP 3: analyze RWL

- If all multiplier factors are in best range (i.e. 1)
  ⇒ weight limit for lifting or lowering:
  23 kg (51 pounds)
- If multipliers are not in best ranges (i.e. < 1)
  ⇒ weight limit must be reduced accordingly



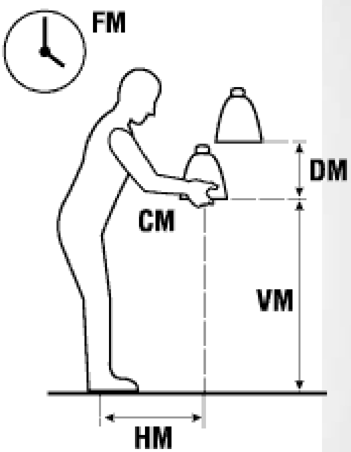
Calculating the RWL: Overview (cont.)



RWL = LC * HM * VM * DM * FM * AM * CM
= (23 kg) * (0) * (1) * (1) * (1) * (1) * (1) = 0

In a perfect lifting situation the load is:

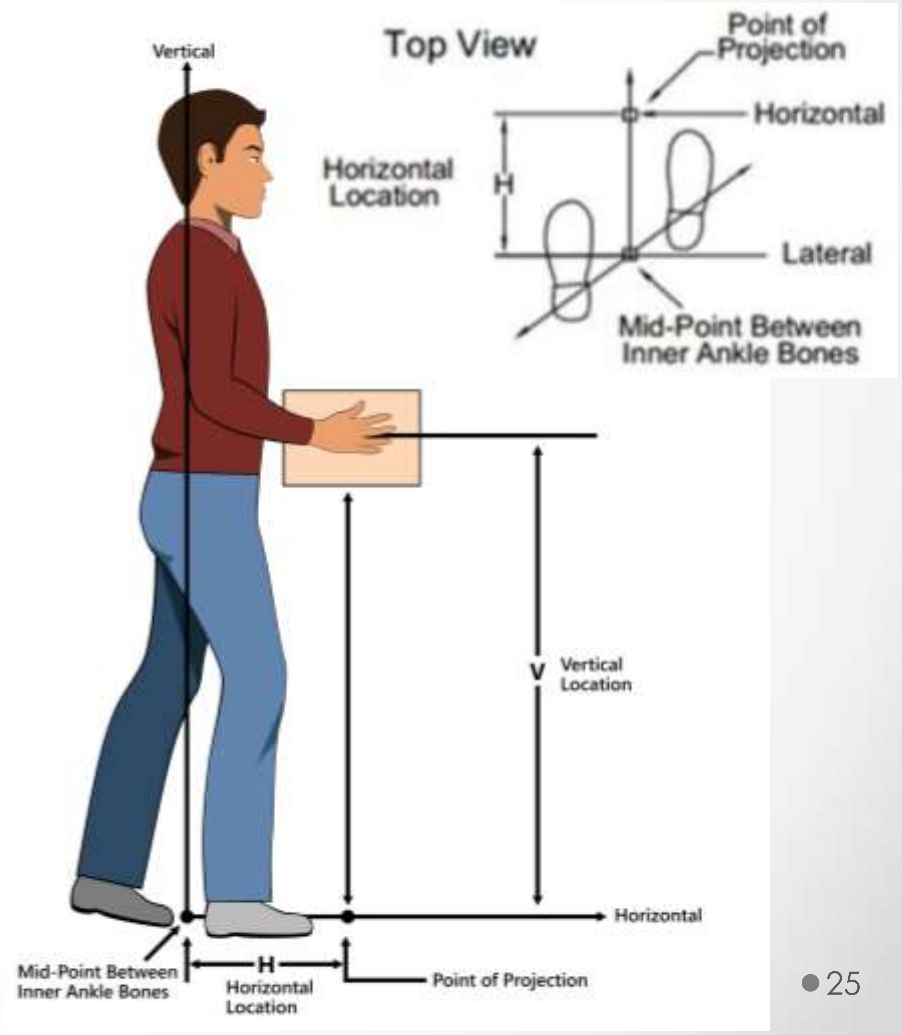
- Close in to the body (HM = 1)
- At waist height (VM = 1)
- Not moved much (DM = 1)
- Infrequently lifted (FM = 1)
- Moved with no twist (AM = 1), and
- Moved with a good grip on the object (CM = 1).



RWL = LC * HM * VM * DM * FM * AM * CM
= (23 kg) * (1) * (1) * (1) * (1) * (1) * (1) = 23 kg

Determining the Multiplier Value

1. Figure out the "horizontal multiplier" (**HM**)
   - Measure the distance the object is from the body: measure (in cm) the distance from in-between the person's ankles to their hands when holding the object
   - Write down this number
   - Look up the number on "horizontal distance" chart, and find matching "multiplier factor" (HM)
   - Use this factor in lifting equation

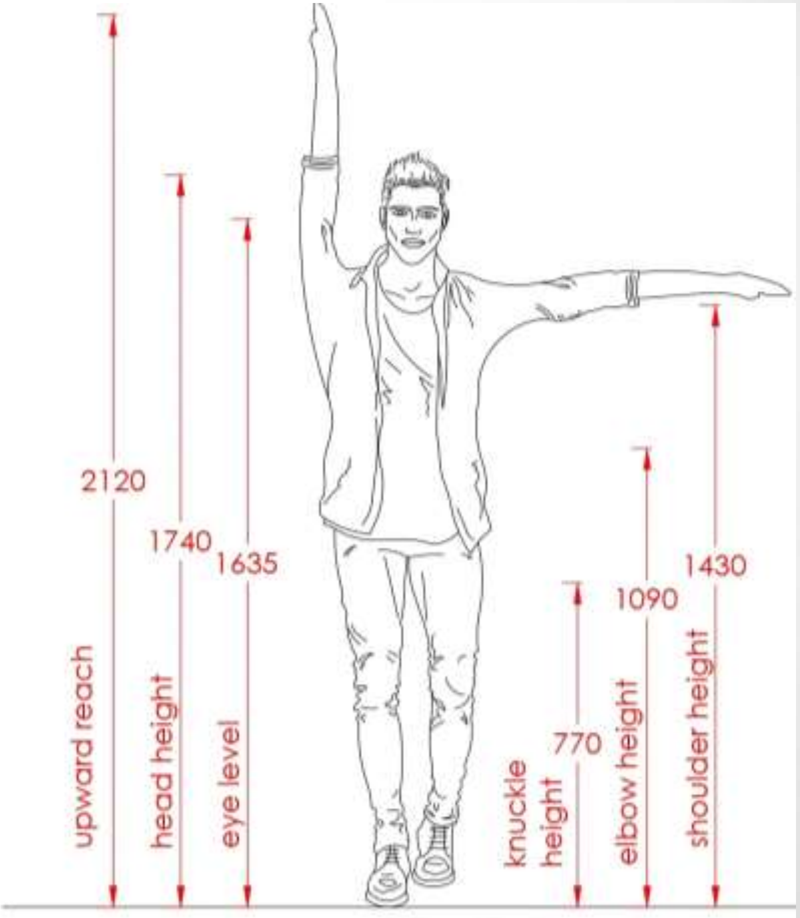


- Repeat this process for the other 5 factors:

Determining the Multiplier Value (cont)

2. Vertical Multiplier (**VM**)

- This's vertical distance of the hands from the ground at the start of the lift
- Measure this distance (cm)
- Note, best (i.e. VM=1) to be 30 in (i.e. 76.2 cm), why?*
- Determine corresponding VM value on the chart



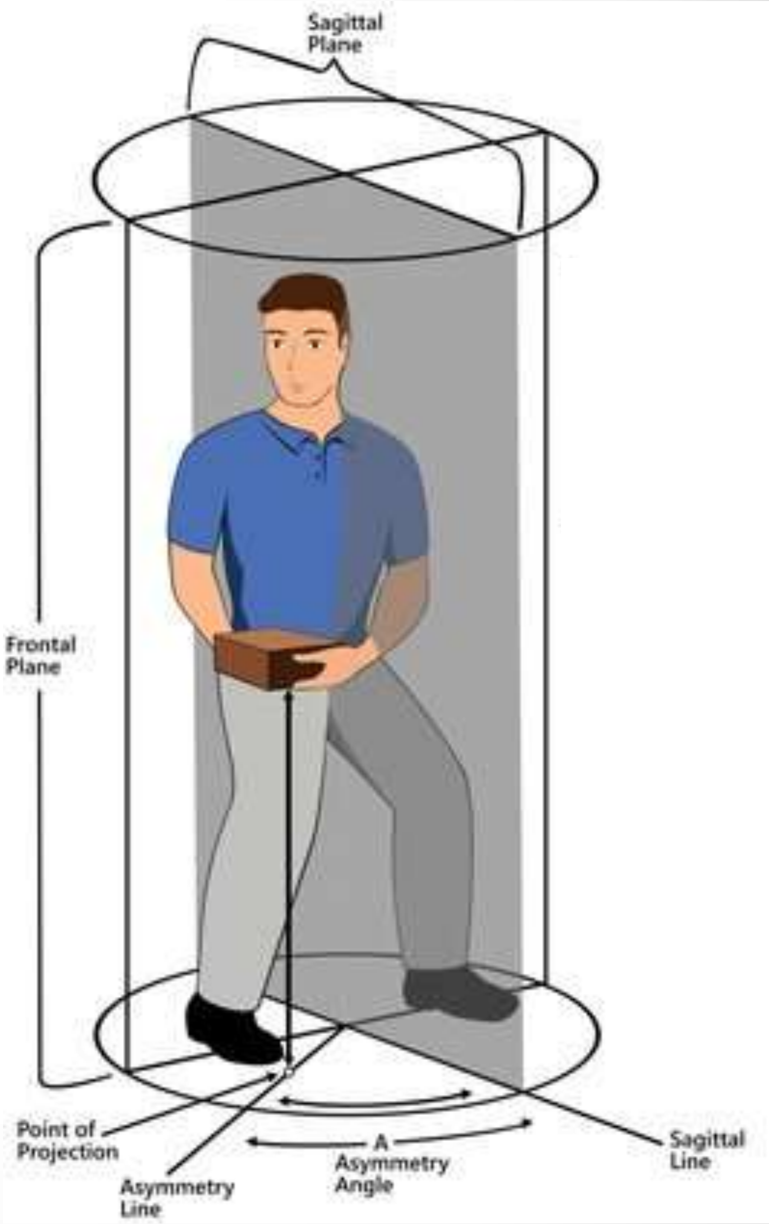
3. Distance Multiplier (**DM**)

- This's distance (cm) load travels up/down from the starting position
- Measure this distance
- Determine corresponding DM value on the chart

Median (50th percentile) UK Dimensions / Heights for Male Adults [mm]
Note, median UK knuckle height for women is 740 mm
Source: https://www.firstinarchitecture.co.uk/average-male-and-female-dimensions/

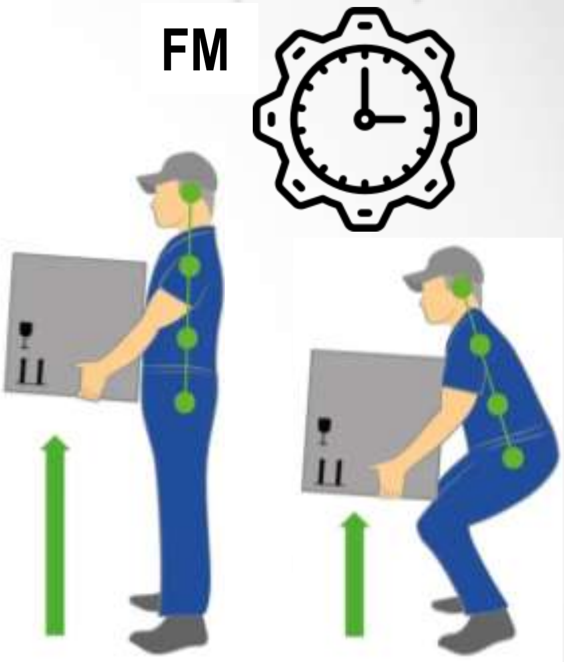
Determining the Multiplier Value (cont)

4. Asymmetric Multiplier (**AM**)
   - This measures if body must twist or turn during lift
   - Measurement is done in degrees (360° being one complete circle)



Determining the Multiplier Value (cont)

5. Frequency Multiplier (**FM**)
   - This's how often lift is repeated in a time period
   - Determine,
     - if the lift is done while
       - **standing** (i.e. $V \geq$ 30 in.) or
       - **stooping** (i.e. $V <$ 30 in.)
     - if the lift is done for more or less than one hour (in total time for the shift)
     - how much time there is between lifts (or # of lifts/minute)

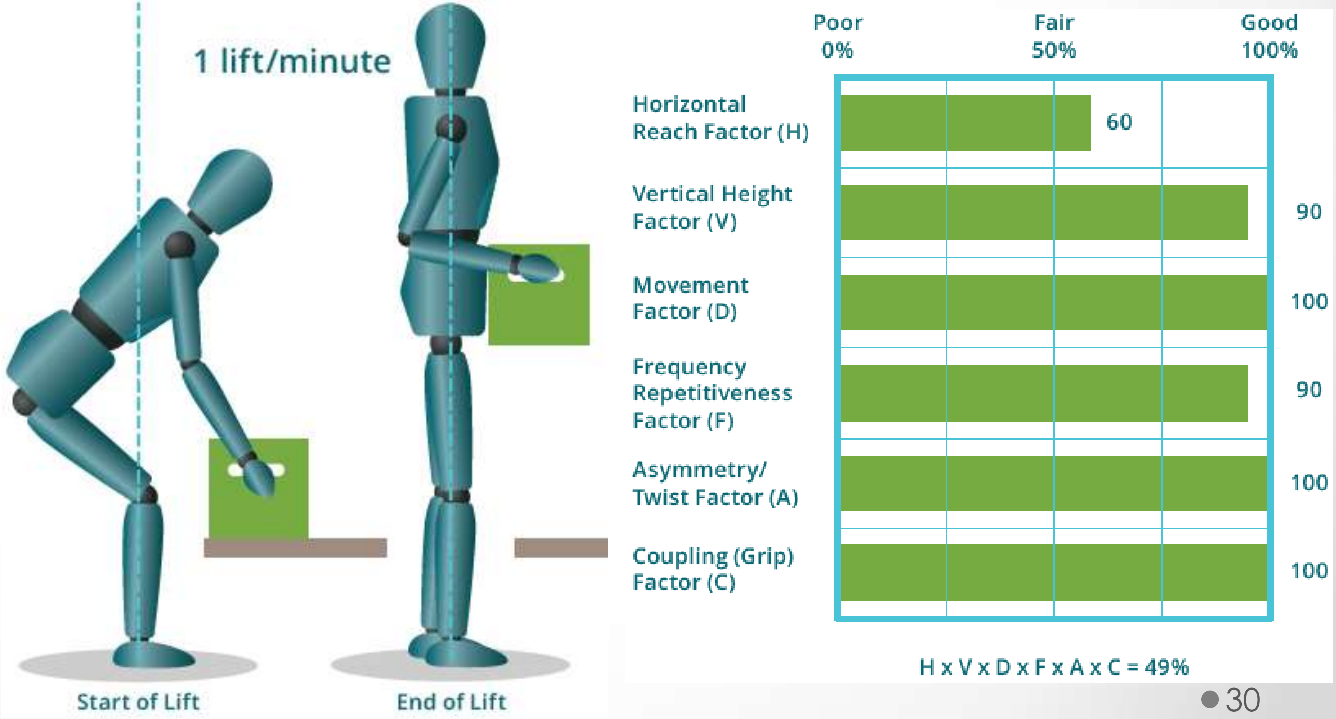


Determining the Multiplier Value (cont)

6. Coupling Multiplier (**CM**)
   - This finds "coupling" i.e. type of grasp person has on the container
   - It rates the type of handles as
     - good
     - fair
     - poor
   - You also need to know if the lift is done in a standing or stooping position

Determining the Multiplier Value (cont)

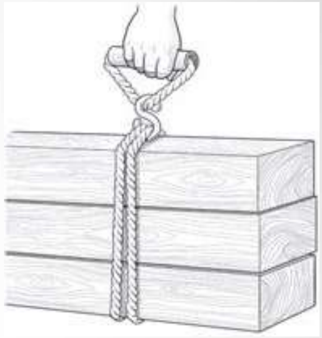
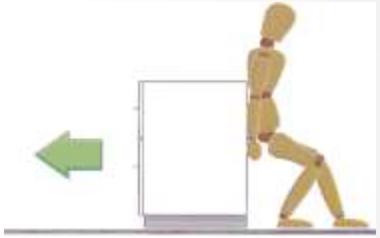
- Once you have all these values ⇒ use Revised lifting equation to determine the RWL
- Compare RWL to actual weight of the object (L)
- If the RWL < L:
  - ⇒ determine which factor(s) contribute to the highest risk
  - factors that are contributing the **highest risk** have the **lowest multiplier** values
  - Modify the lift accordingly



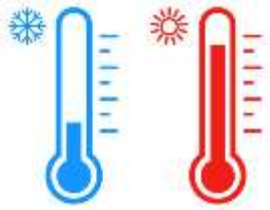
Applicability of NIOSH Lifting Equation

- It does not apply when lifting/lowering,
  - with one hand
  - for over 8 hours
  - while seated or kneeling
  - in a restricted work space
  - unstable objects
    (e.g. buckets, liquids containers)
  - while pushing or pulling
  - with wheelbarrows or shovels
  - with high speed motion
    (faster than about 30 inches/second
    = 0.76 meters/second)
  - extremely hot or cold objects or in
    extreme temperatures
  - with poor foot/floor coupling (high risk of a slip or fall)



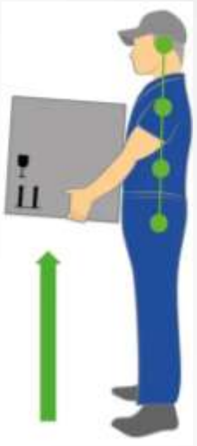





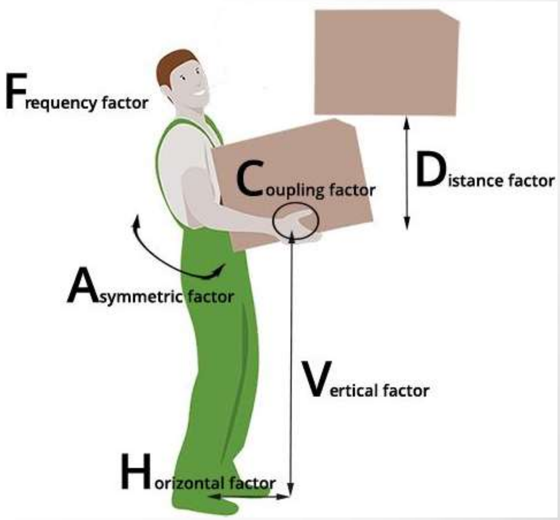



Applicability of NIOSH Lifting Equation

- It does apply (mostly) with
  - two-handed lifting,
  - comfortable lifting postures, and
  - comfortable environments and non-slip floorings



- Why is equation called “revised”?
  - NIOSH published their first lifting equation in 1981*
  - In 1993: new "revised" equation was published
  - It took into account new research findings and other variables not used in the first equation
  - “revised” equation can be used in a wider range of lifting situations than the first equation

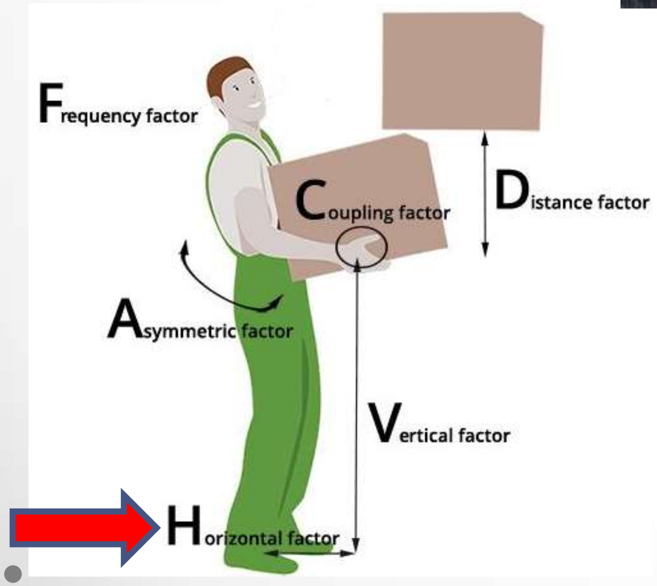


Multiplier Values

Multiplier Values

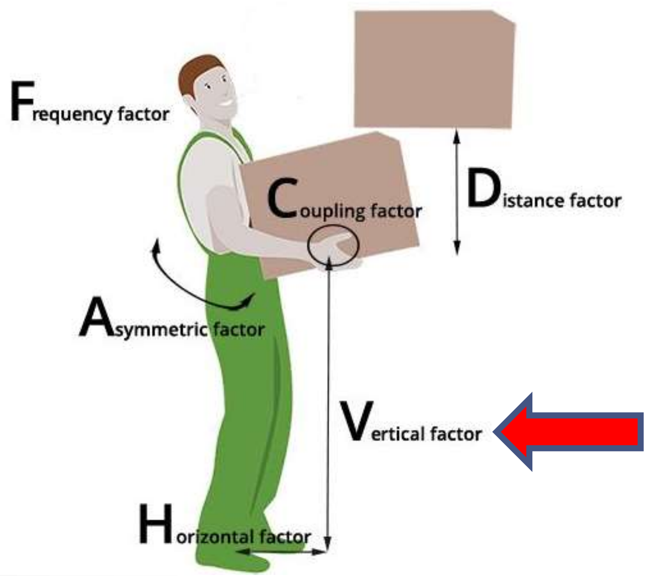
1. Horizontal Multiplier (**HM**)
   - Find horizontal distance (H, in cm) from midpoint between ankles to point projected on floor directly below the mid-point of hand grasps (i.e. the load-center) while holding object, or distance to large middle-knuckle of hand
   - Determine HM (discrete values) from chart below
   - Q: What to do for intermediate values?

H = Horizontal Distance (cm)	HM Factor
25 or less	1.00
30	0.83
40	0.63
50	0.50
60	0.42
63	0.40
>63	0



Multiplier Values (Cont.)

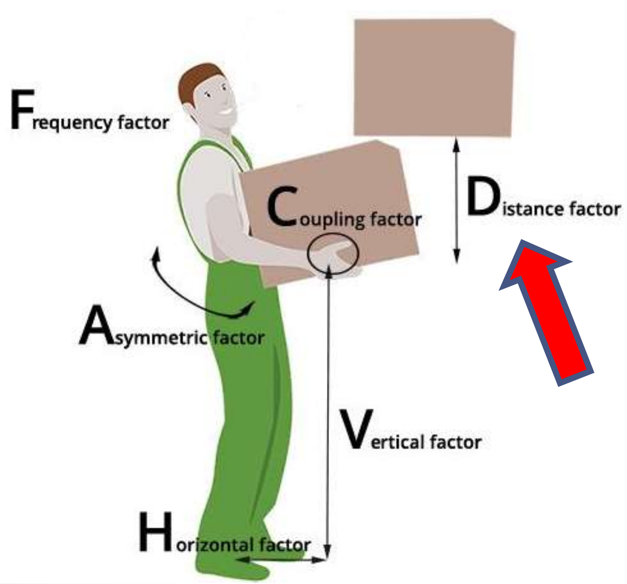
2. Vertical Multiplier (**VM**)
   - Find the vertical distance (V, in cm) of the hands from the ground at the start of the lift
   - Determine VM (discrete values) from chart below



V = Starting Height (cm)	VM Factor
0	0.78
30	0.87
50	0.93
70	0.99
80	0.99
100	0.93
150	0.78
175	0.70
>175	0

Multiplier Values (Cont.)

3. Distance Multiplier (**DM**)
   - Find the vertical distance (D, in cm) that the load travels
   - Determine DM (discrete values) from chart below

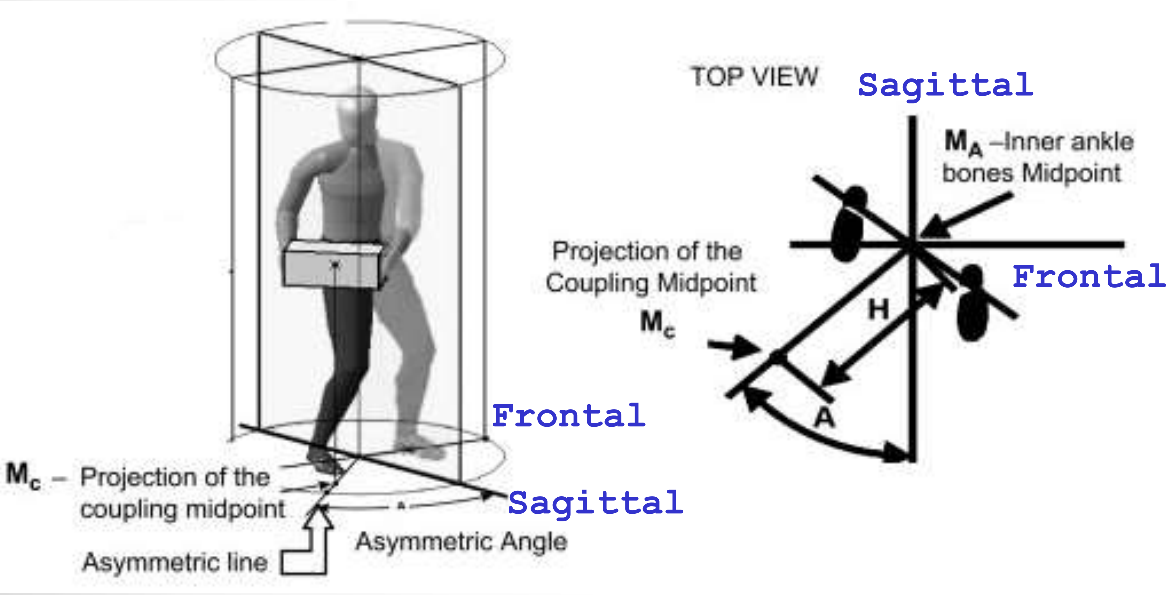


D = Lifting Distance (cm)	DM Factor
25 or less	1.00
40	0.93
55	0.90
100	0.87
145	0.85
175	0.85
>175	0

Multiplier Values (Cont.)

4. Asymmetric Multiplier (**AM**)
   - Find the twisting angle (A) in degrees (°) of the body from the midline (AKA the **sagittal line**) while lifting
   - Determine AM (discrete values) from chart below

A = Angle (°)	AM Factor
0	1.00
30	0.90
45	0.86
60	0.81
90	0.71
105	0.66
120	0.62
135	0.57
>135	0



Multiplier Values (Cont.)

5. Frequency Multiplier (**FM**)

- Find the frequency of lifts (F) and the duration of lifting (in minutes or seconds) over a work shift
- Determine FM (discrete values) from chart below (see also more detailed chart on the following slide)

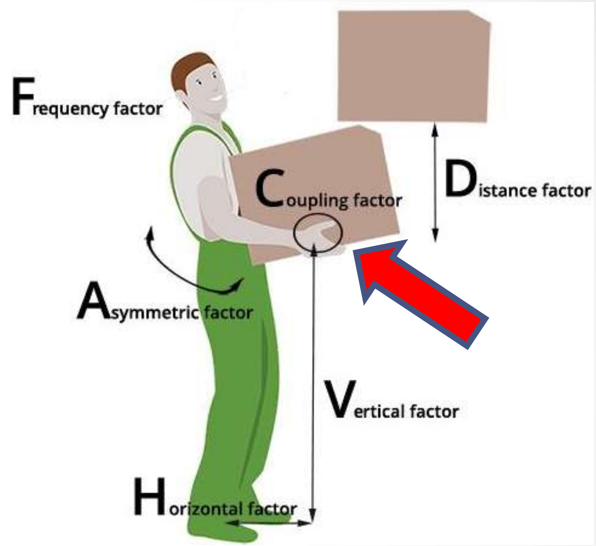
F = Time Between Lifts	FM Factor					
	Lifting While Standing (V ≥ 75 cm)			Lifting While Stooping (V < 75 cm)		
	≤ 1 hr.	>1 & ≤ 2 hr.	>2 & ≤ 8 hr.	≤ 1 hr.	>1 & ≤ 2 hr.	>2 & ≤ 8 hr.
≥5 min	1.00	0.95	0.85	1.00	0.95	0.85
2 min	0.97	0.92	0.81	0.97	0.92	0.81
1 min	0.94	0.88	0.75	0.94	0.88	0.75
30 sec	0.91	0.84	0.65	0.91	0.84	0.65
15 sec	0.84	0.72	0.45	0.84	0.72	0.45
10 sec	0.75	0.50	0.27	0.75	0.50	0.27
6 sec	0.45	0.26	0.13	0.45	0.26	0
5 sec	0.37	0.21	0	0.37	0	0

Frequency Lifts/min (F) ‡	Work Duration					
	≤ 1 Hour		> 1 but ≤ 2 Hours		> 2 but ≤ 8 Hours	
	V < 30 †	V ≥ 30	V < 30	V ≥ 30	V < 30	V ≥ 30
≤ 0.2	1.00	1.00	.95	.95	.85	.85
0.5	.97	.97	.92	.92	.81	.81
1	.94	.94	.88	.88	.75	.75
2	.91	.91	.84	.84	.65	.65
3	.88	.88	.79	.79	.55	.55
4	.84	.84	.72	.72	.45	.45
5	.80	.80	.60	.60	.35	.35
6	.75	.75	.50	.50	.27	.27
7	.70	.70	.42	.42	.22	.22
8	.60	.60	.35	.35	.18	.18
9	.52	.52	.30	.30	.00	.15
10	.45	.45	.26	.26	.00	.13
11	.41	.41	.00	.23	.00	.00
12	.37	.37	.00	.21	.00	.00
13	.00	.34	.00	.00	.00	.00
14	.00	.31	.00	.00	.00	.00
15	.00	.28	.00	.00	.00	.00
> 15	.00	.00	.00	.00	.00	.00

Multiplier Values (Cont.)

6. Coupling Multiplier (**CM**)

- Find the quality of grasp (or coupling, C) classified as:
  - **Good**: fingers wrap completely around object or handles
  - **Fair:** only a few fingers grasp firmly around object
  - **Poor:** only few fingers or fingertips are partially under or around object (See also table 5.3 on next slide for further information)
- Also depends on body position (either standing or stooping)
- Determine CM (discrete values) from chart below



C = Grasp	CM Factor:	
	Standing	Stooping
Good (handles)	1.00	1.00
Fair	1.00	0.95
Poor	0.90	0.90

Multiplier Values (Cont.)

6. Cont. Coupling Multiplier (**CM**)*

Table 5.3 Hand-to-Contour Coupling Classification

Good	Fair	Poor
1. For containers of optimal design such as some boxes, crates, etc., a "good" hand-to object coupling would be defined as handles or handhold cutouts of optimal design (see notes 1–3)	1. For containers of optimal design, a "fair" hand-to-object coupling would be defined as handles or handhold cutouts of less than optimal design (see notes 1–4)	1. Containers of less than optimal design or loose parts or irregular objects that are bulky, are hard to handle, or have sharp edges (see notes)
2. For loose parts or irregular objects, which are not usually containerized, such as castings, stock, and supply materials, a "good" hand-to-object coupling would be defined as a comfortable grip in which the hand can be easily wrapped around the object (see note 6)	2. For containers of optimal design with no handles or handhold cutouts or for loose parts or irregular objects, a "fair" hand-to-object coupling is defined as a grip in which the hand can be flexed about 90° (see note 4)	2. Lifting nonrigid bags (i.e., bags that sag in the middle)

Source: ***Introduction to Human Factors and Ergonomics for Engineers***, Second Edition, By Mark R. Lehto, Steven J. Landry, 2013.

Multiplier Values: Alternative Equations

- Alternative formulas for multipliers:
  - **HM = [25/H]** {note, 25 ≤ H [cm] ≤ 63 cm}
  - **VM = [1 – (0.003|V – 75|)]** {note, 0 ≤ V [cm] ≤ 175 cm}
  - **DM = [0.82 + (4.5/D)]** {note, 25 ≤ D [cm] ≤175 cm}
  - **AM = [1 – (0.0032A)]** {note, 0° ≤ A ≤ 135°}

- What about FM and CM?

Multiplier Values: Alternative Equations

- Compare between values obtained from look-up charts and above formulas
- Compare formulas for SI (metric) and US units:

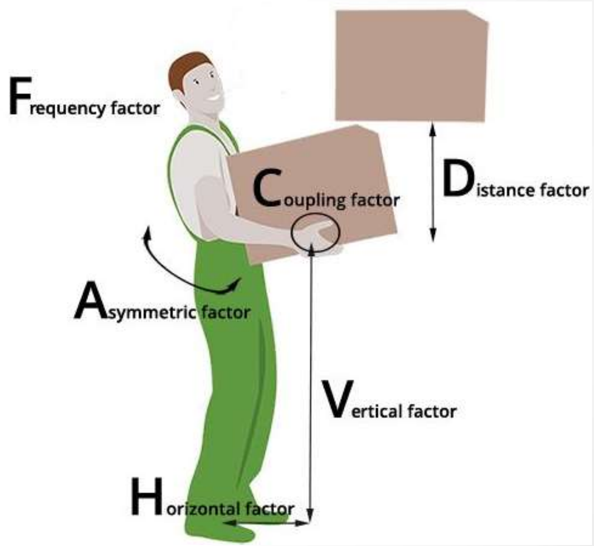
		Metric	U.S. Customary
Load Constant	LC	23kg	51lb
Horizontal Multiplier	HM	(25/H)	(10/H)
Vertical Multiplier	VM	1– (.003|V-75|)	1– (.0075|V-30|)
Distance Multiplier	DM	.82 + (4.5/D)	.82 + (1.8/D)
Asymmetric Multiplier	AM	1– (.0032A)	1– (.0032A)

NIOSH Lifting Equation Calculator

- Revised NIOSH Lifting Equation:

$$\mathbf{RWL = 23}\ \mathrm{Kg} * \mathbf{HM} * \mathbf{VM} * \mathbf{DM} * \mathbf{AM} * \mathbf{FM} * \mathbf{CM}$$

- Summary of steps:
  - Carefully read and inspect the problem
  - Determine the six variables: **H**, **V**, **D**, **F**, **A**, **C**
  - Find out the values for the different **multipliers** for the MMH in question
  - solve for the **RWL**
  - If RWL ≥ L (weight of the object handled) ⇒
    - task is safe
  - If the RWL < L ⇒
    - task is dangerous
    - task must be redesigned



Lifting Index

Lifting Index

- **Lifting Index (LI):**
  - Relative estimate to physical stress associated with certain MMH task
  - Difference between RWL and LI:
    - RWL: answers question… "Is this weight too heavy for the task?"
    - LI: answers question… "How serious/significant is the risk?"
  - Determined by relation between **RWL** and lifted load (**L**) in kg or lb.:

$$LI = L / RWL$$

  - LI **> 1.0** pose an increased risk for lifting-related low back pain
  - $\Rightarrow$ goal should be to design all lifting jobs to achieve a LI of 1.0 or less
  - As LI $\uparrow$ $\Rightarrow$ smaller fraction of workers capable of safely sustaining activity
  - Also, suspected hazardous jobs could be rank-ordered according to the LI
  - Experts (unique workforce) *may* be able to work above a lifting index of 1.0: i.e. $\mathbf{1 < LI \leq 3}$
  - For: **LI > 3.0** is highly stressful lifting tasks $\Rightarrow$ increased risk of a work-related injury
  - A more detailed classification is shown on the following slide

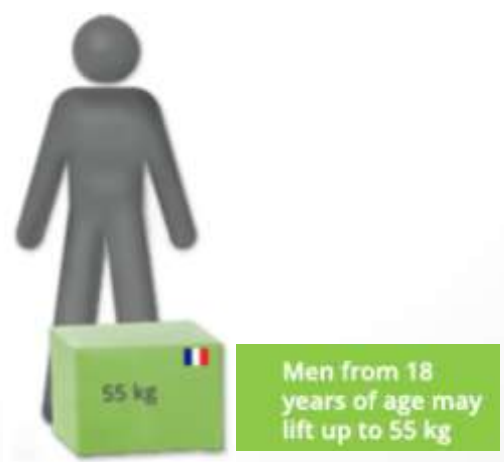
Lifting Index (cont.)

- **Lifting Index (LI)** (cont.):

$$LI = L / RWL$$

LI	Risk	Action
≤1.00	Very Low Risk	No action required for the healthy population.
1.01 - 1.50	Low Risk	Pay attention to low frequency/high load conditions and to extreme or static postures. Consider efforts to lower the LI to 1.0 or below.
1.51 – 2.00	Moderate Risk	Redesign tasks and workplaces according to priorities to reduce the LI.
2.01 – 3.00	High Risk	Changes to the task to reduce the LI should be a high priority.
> 3.00	Very High Risk	Changes to the task to reduce the LI should be made immediately.

Source: https://www.ehs.com/2020/03/a-how-to-guide-the-niosh-lifting-equation/



Source: https://2lift.com/manual-handling/

Lifting Index (cont.)

- **Lifting Analysis Worksheet** is shown in the next slide by OSHA: Occupational Safety and Health Administration (US)

LIFTING ANALYSIS WORKSHEET

DEPARTMENT ______________________ JOB DESCRIPTION

JOB TITLE ______________________ ______________________________

ANALYST'S NAME ______________________ ______________________________

DATE

STEP 1. Measure and record task variables

Object Weight (kg)		Hand Location				Vertical Distance	Asymmetric Angle (deg.)		Frequency Rate	Duration	Object Coupling
		Origin		Dest			Origin	Destination	lifts/min	Hrs	
L(AVG)	L(MAX)	H	V	H	V	D	A	A	F		C

STEP 2. Determine the multipliers and compute the RWLs

RWL = LC x HM x VM x DM x AM x FM x CM

			LC		HM		VM		DM		AM		FM		CM		
ORIGIN	RWL	=	23	x		x		x		x		x		x		=	
DEST.	RWL	=	23	x		x		x		x		x		x		=	

STEP 3. Compute the LIFTING INDEX

ORIGIN LIFT INDEX $\frac{\text{OBJECT WEIGHT}}{\text{RWL}}$ = ______________________ = ______________________

DESTINATION LIFT INDEX $\frac{\text{OBJECT WEIGHT}}{\text{RWL}}$ = ______________________ = ______________________

NIOSH Lifting Equation Calculator

- NIOSH Lifting Equation Calculator
  - Several websites/software available, e.g.:
  - Online software provided by [Ergo Plus](https://ergo-plus.com/niosh-lifting-equation-calculator/): https://ergo-plus.com/niosh-lifting-equation-calculator/
  - See website input window (and sample figures):

Origin Destination

Some MMH Videos

- Manual Material Handling/Safe Lifting: https://youtu.be/rrl2n8qehrY
- Assessing Manual Handling Tasks: https://youtu.be/L0Px8k5zcwI
- PLAD The Personal Lift Assist Device: https://youtu.be/LlhAUQCzITY

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4. ***Applications Manual For the Revised NIOSH Lifting Equation***. Centers for Disease Control & Prevention. Thomas R. Waters, Ph.D., Vern Putz-Anderson, Ph.D., Arun Garg, Ph.D. Centers for Disease Control & Prevention. Publication date: 01/01/1994. Online at:

   https://wonder.cdc.gov/wonder/prevguid/p0000427/p0000427.asp#head005001002000000

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5. ***A Step-by-Step Guide to Using the NIOSH Lifting Equation for Single Tasks.*** Mark Middlesworth. *Ergonomics Plus.* Online at: http://ergo-plus.com/niosh-lifting-equation-single-task/