

# #8 Biomechanics

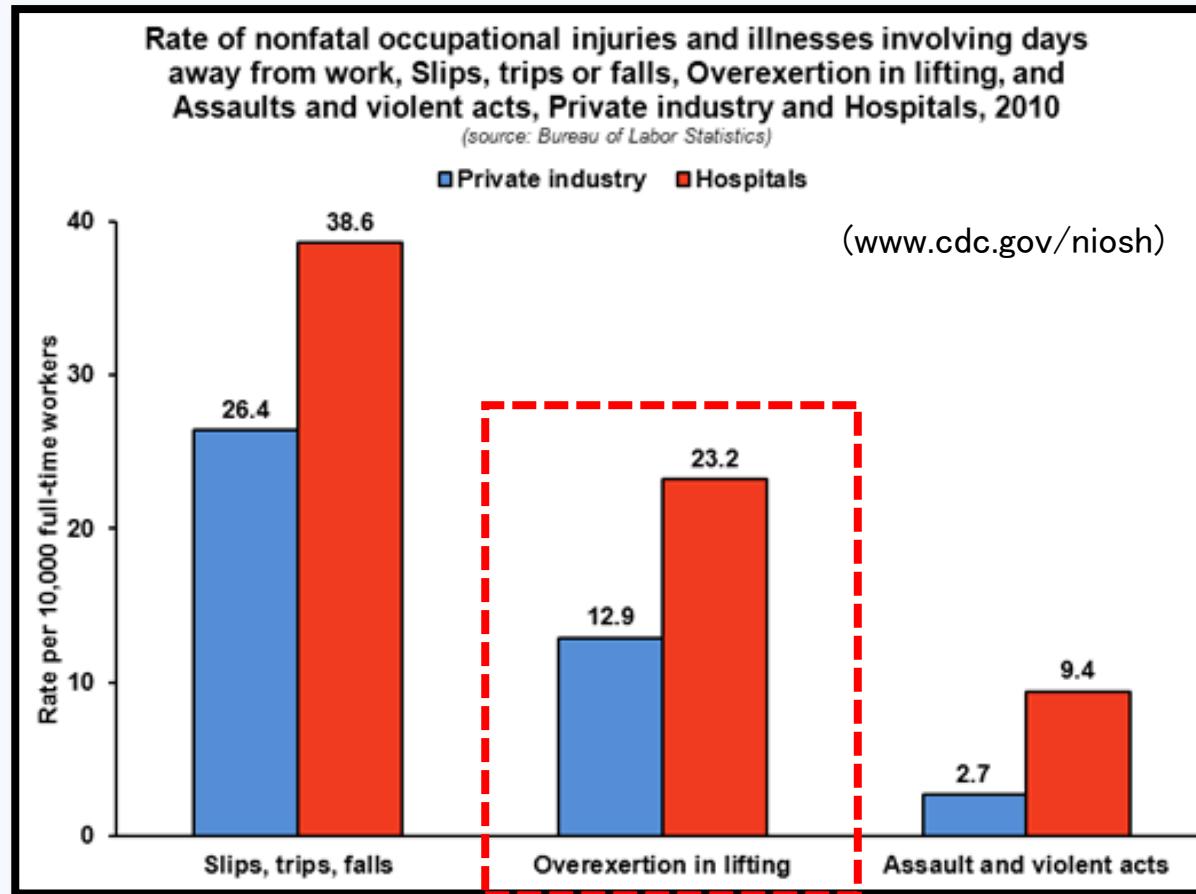
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[www.elcosh.org](http://www.elcosh.org)



# Why biomechanics is important ?



The two most prevalent musculoskeletal problems are :

- **LOW BACK PAIN**
  - **UPPER-EXTRIMITY** (fingers, hands, wrists, arms, and shoulders)
- CUMULATIVE TRAUMA DISORDERS**

Biomechanics Evaluation

# Definition of Biomechanics

- Biomekanika adalah ilmu pengetahuan yang mempelajari interaksi fisik antara pekerja dengan mesin, material dan peralatan dengan tujuan untuk meminimumkan keluhan pada sistem kerangka otot agar produktivitas kerja dapat meningkat.
- Pendekatan biomekanika → tubuh manusia sebagai suatu sistem yang terdiri dari elemen-elemen yang saling berkait dan terhubung satu sama lain, melalui sendi-sendi dan jaringan otot yang ada.
- **Prinsip-prinsip fisika digunakan untuk menyatakan tegangan mekanik pada tubuh dan gaya otot yang diperlukan untuk membagi tegangan-tegangan tersebut.**

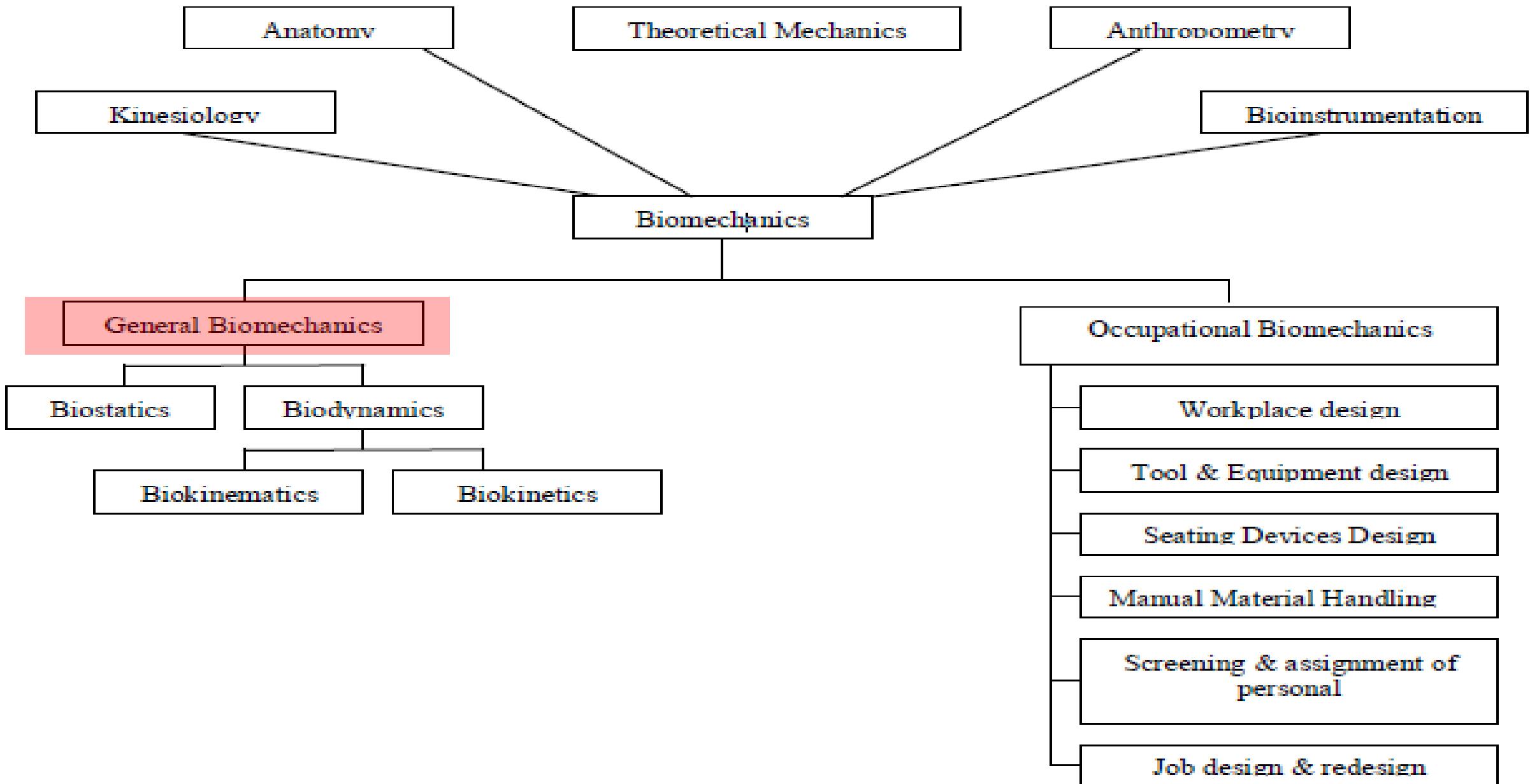


Figure 1.1 Biomechanics Science Diagram (Contini dan Drill, 1966)

# **Defining Occupational Biomechanics**

**Occupational biomechanics** is a science concerned with the mechanical behavior of musculoskeletal system and component tissues when physical work is performed (Chaffin et.al, 1999).

Biomechanics analyzes the human **musculoskeletal system as a mechanical system** that obeys laws of physics (Wickens et.al, 2004).

**Arm Lift**



**Torso Lift**



**Leg Lift**



# Biostatic

Static strength is the maximal voluntary isometric muscle exertion level.

**High Far Lift**



**Floor Lift**



**High Near Lift**

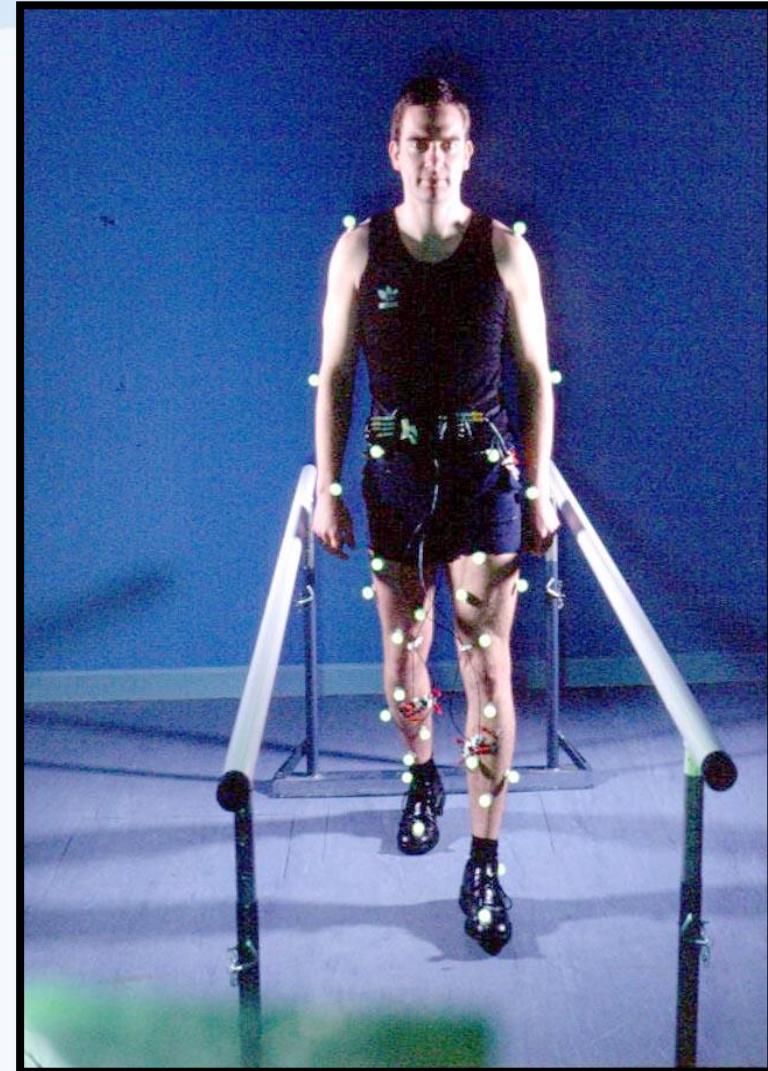


Each lasts about 4 to 6 sec, with 30 to 120 sec rests provided between exertions.

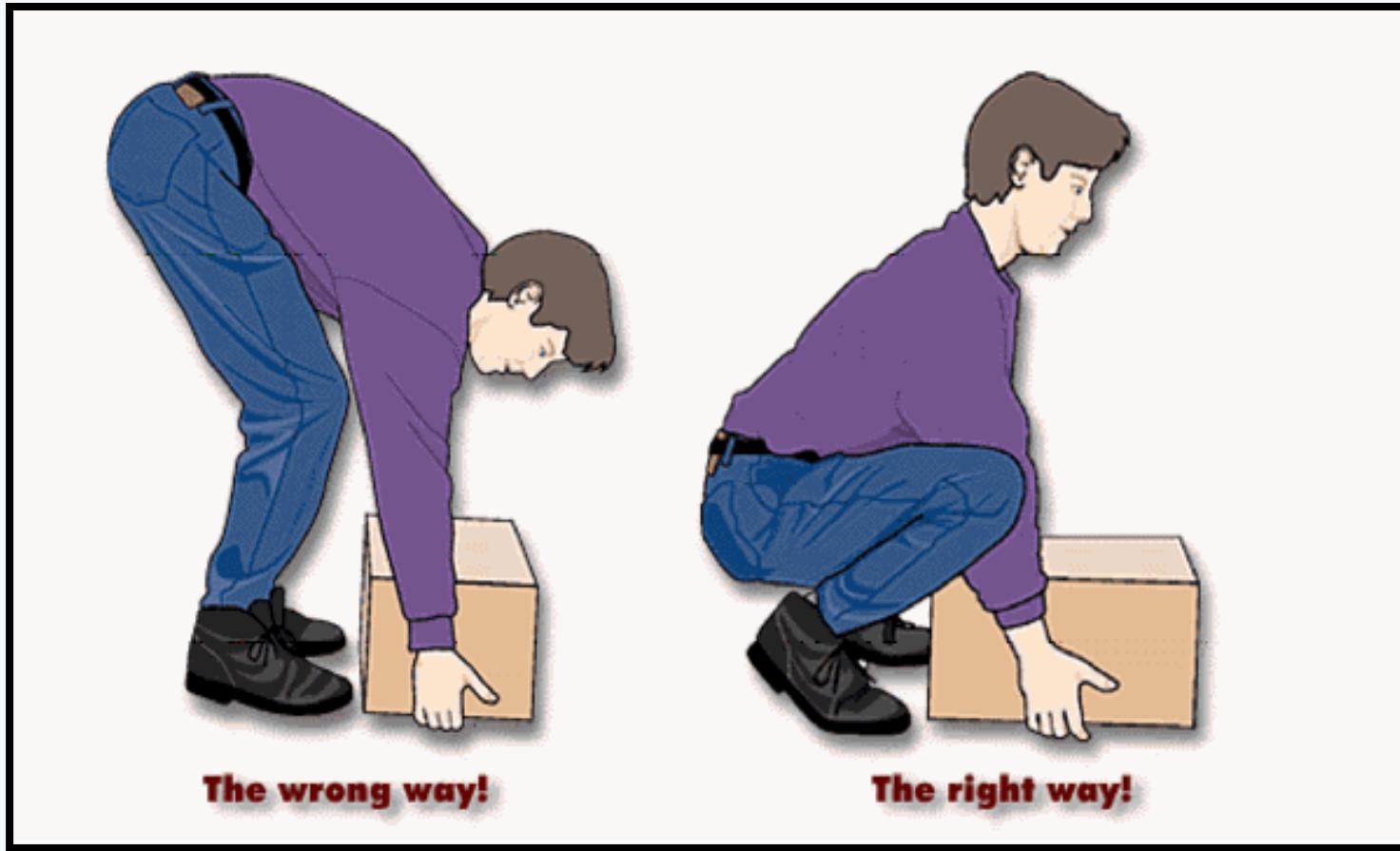
# Biodynamic



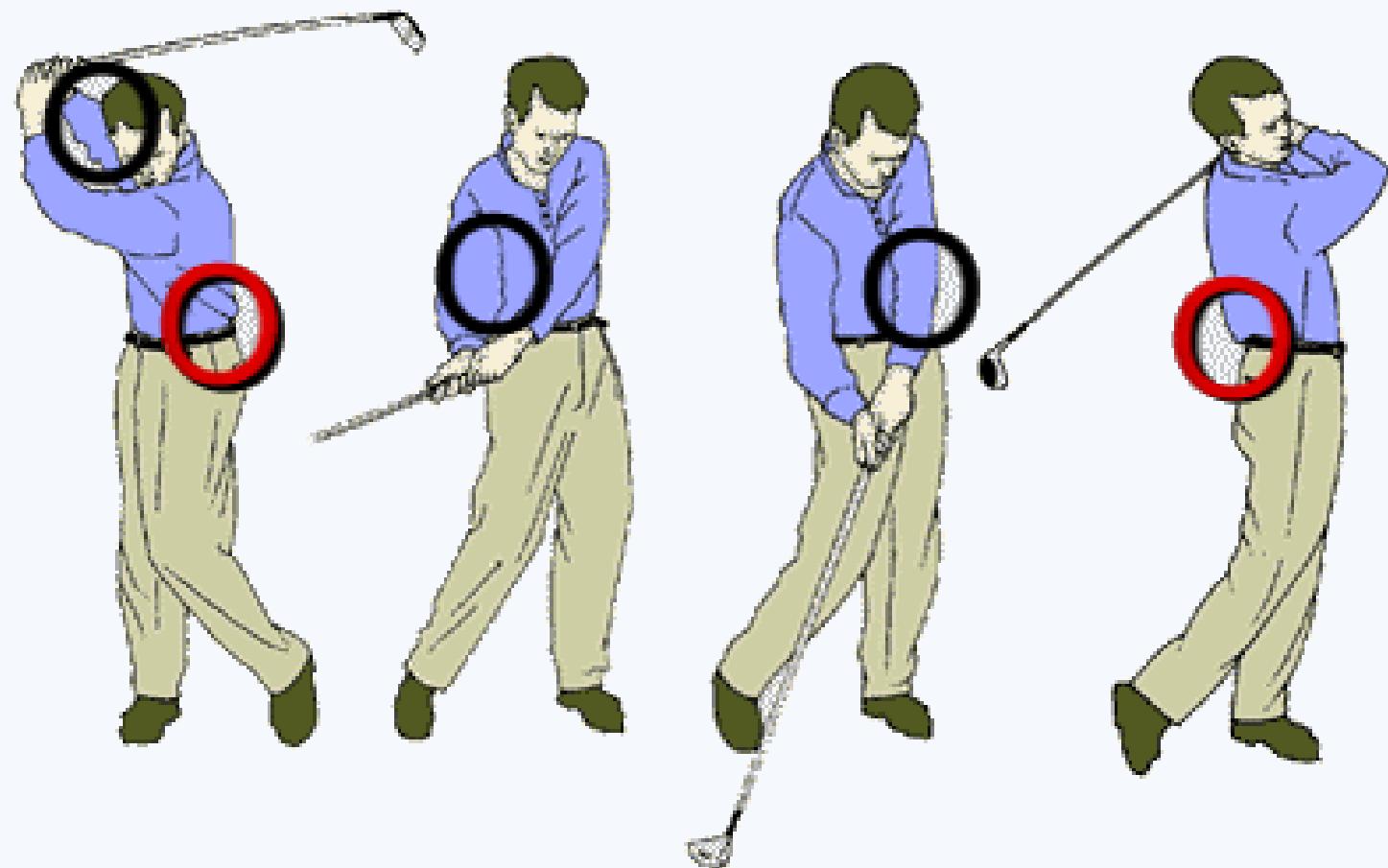
Dynamics strength data can vary considerably depending on the dynamic of the task and the way which the subjects perform it.



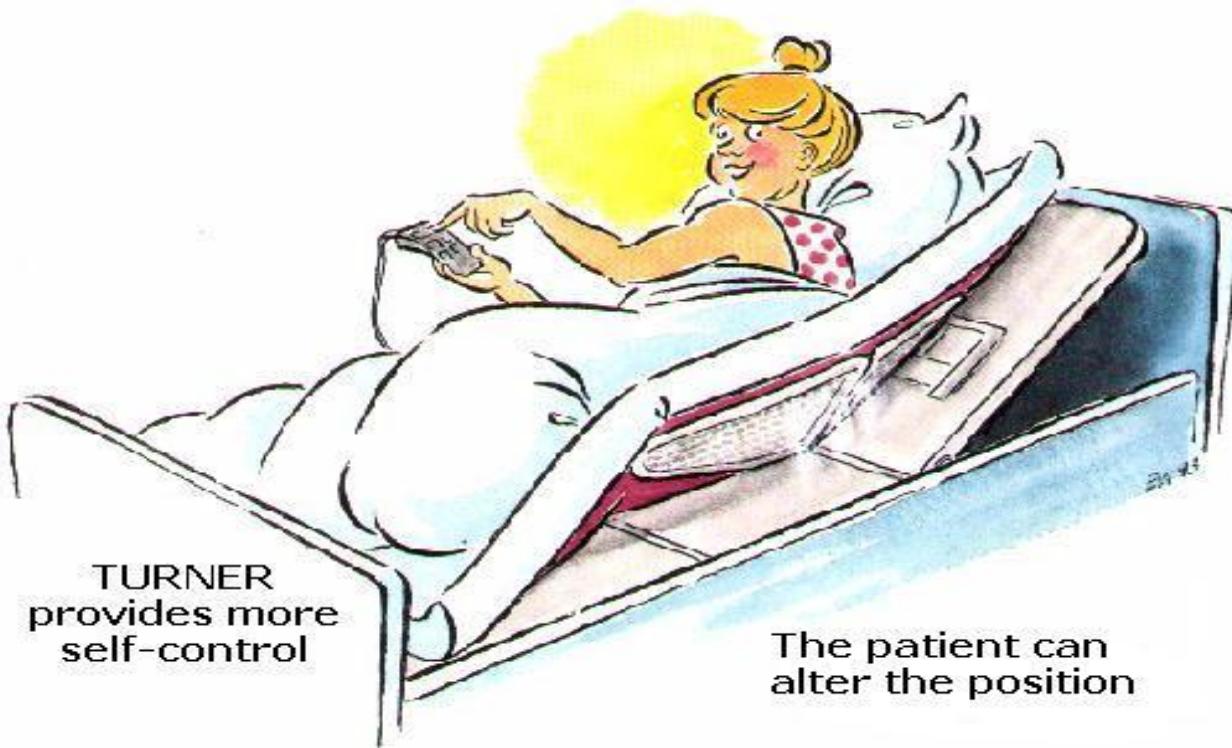
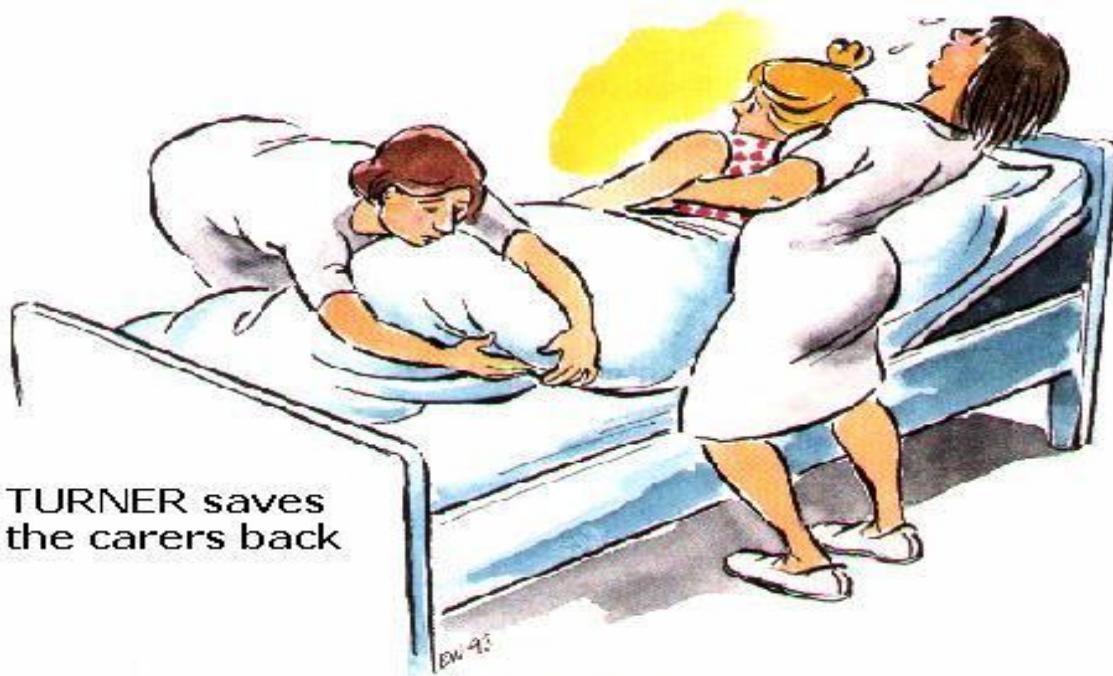
# Application of Biomechanics >> Manual Task



# Application of Biomechanics >> Sports

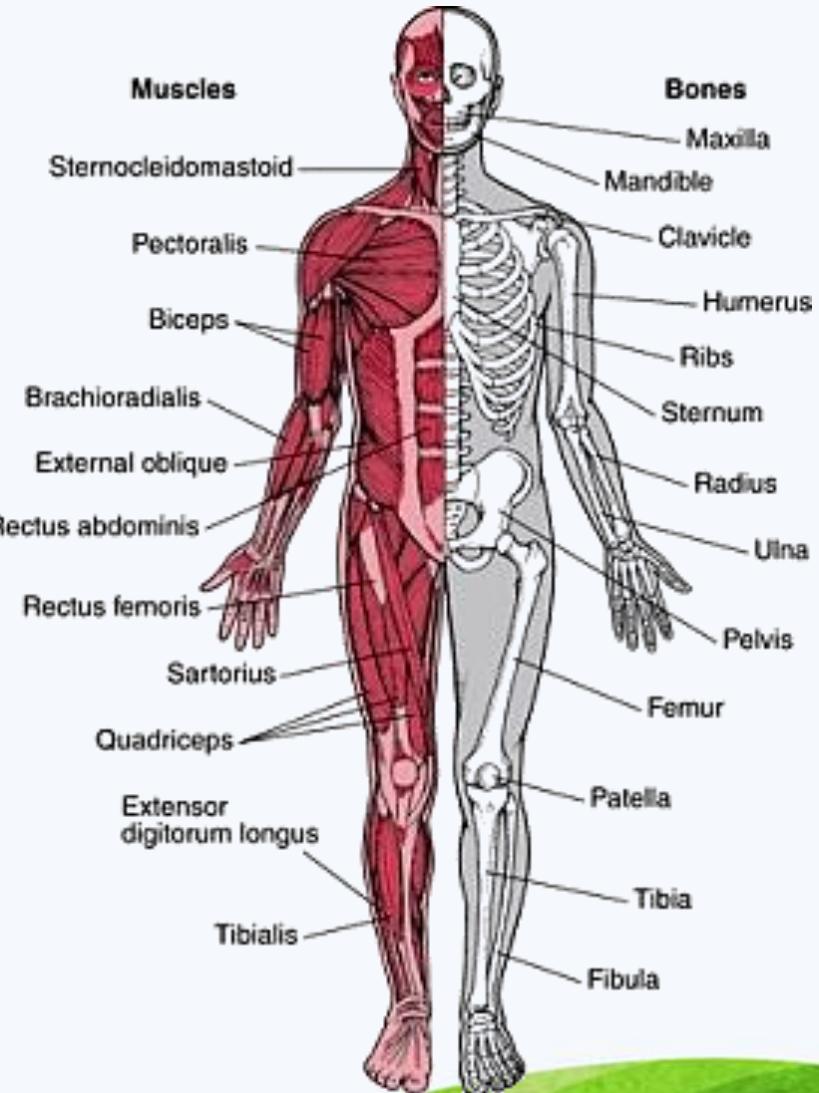


# Application of Biomechanics >> Hospital's activities



# Struktur Tubuh Manusia (The Musculoskeletal System)

- TULANG (BONES) → investigasi pada L5/S1.
- SAMBUNGAN (JOINTS) → aplikasi teori fisika (beban, massa, gaya, momen) pada tubuh manusia.
- OTOT (MUSCLE) → aerobic & anaerobic metabolism.



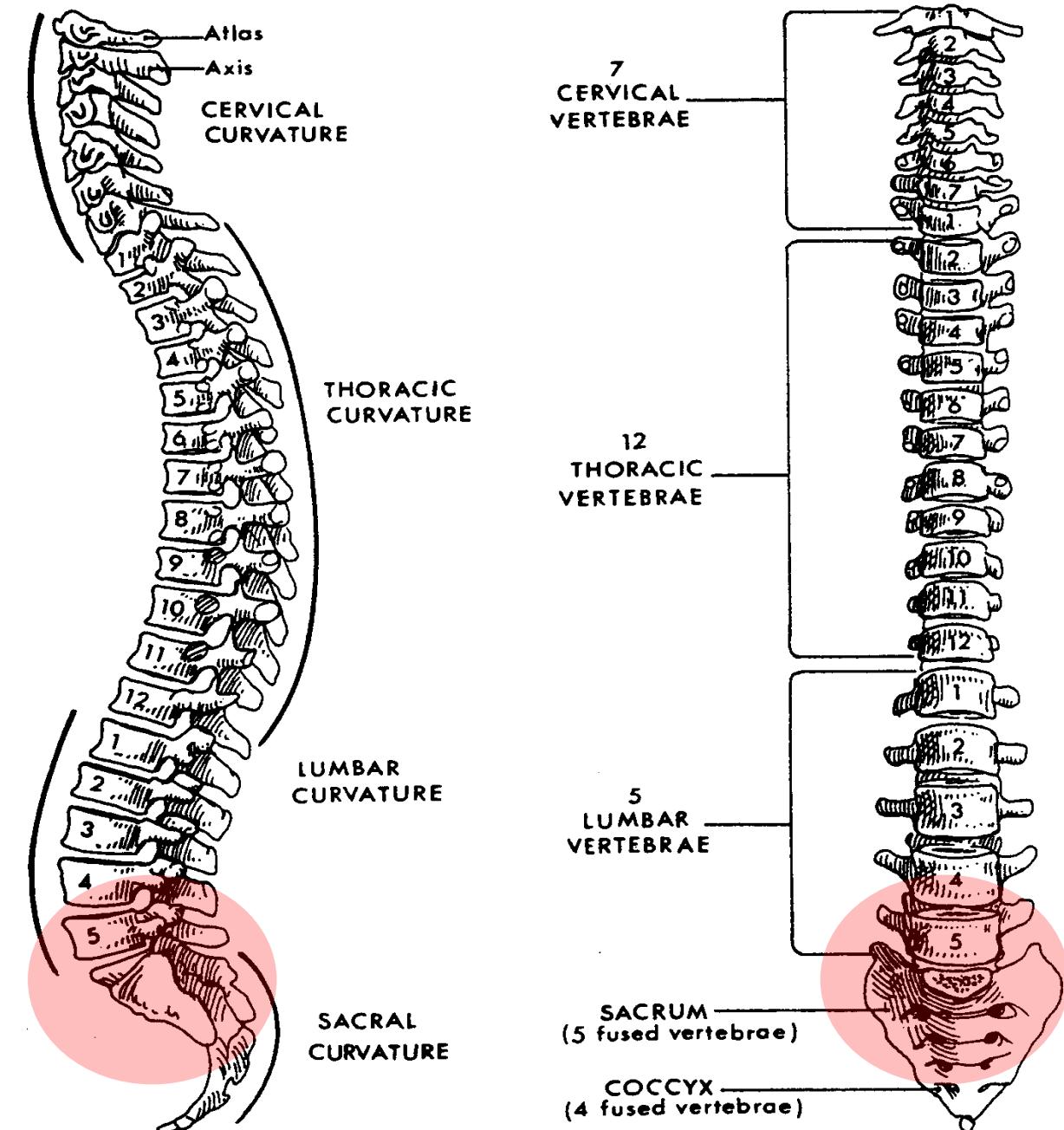
# Bones

- 206 bones in a human body
- Formed from the rigid skeletal structure
- Function :
  - supportive body : long bones of the upper and lower extremities
  - protective body : skull (protects brain), rib cage (shields the lungs and heart)



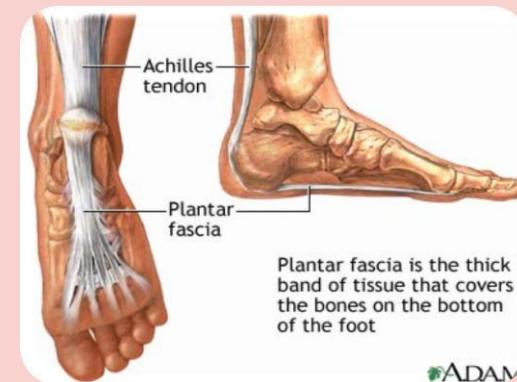
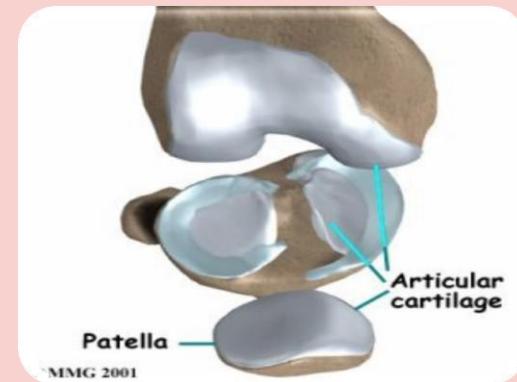
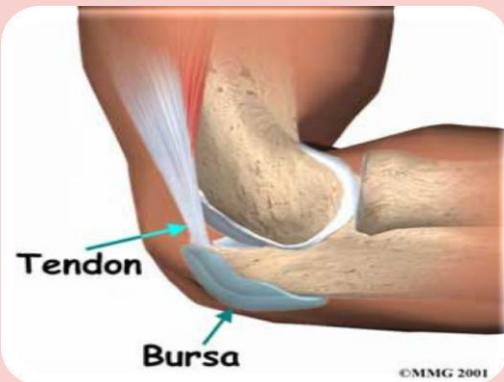
# Lumbar – Sacrum

- Dalam banyak kegiatan penanganan material seperti mengangkat, membawa, mendorong dan menarik, gaya-gaya yang signifikan terjadi pada tulang belakang bagian bawah yaitu pada **ruas lumbar ke-5 dan sacrum ke-1 (L5/S1)**, lokasi dimana sering terjadi cedera punggung.



Frontal (right) and left lateral (left) views of the human spine.

# Connective Tissues (Jaringan Ikat)



## Tendons

- Dense, fibrous
- Attach muscle to bones
- Transmit the forces exerted by muscles

## Ligaments

- Dense, fibrous
- Connect the articular extremities of bones
- Help stabilize the articulations of bones at joints

## Cartilage

- Translucent elastic tissue
- On some articular bony surfaces, ex : nose, ear

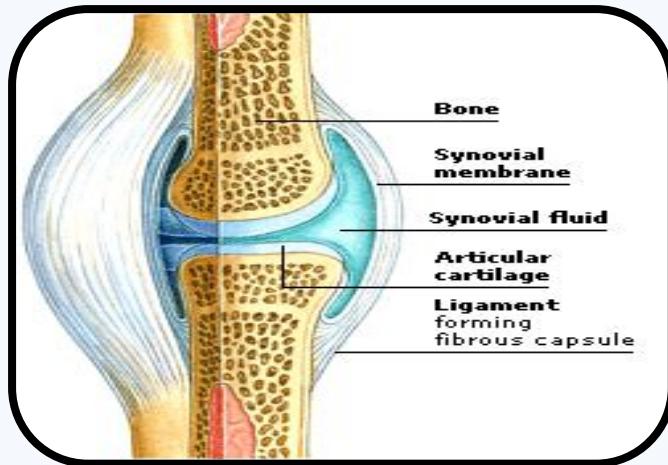
## Fascia

- Covers body structures, and separates them from each other

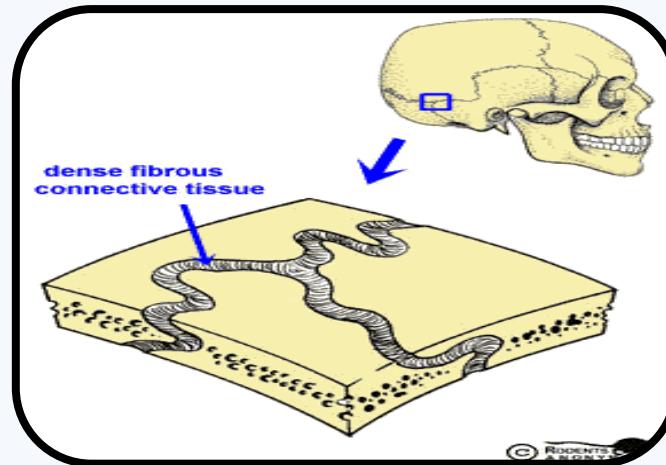
# Link – Joint

- Didalam melakukan analisa biomekanik, tubuh manusia dipandang sebagai suatu sistem yang terdiri dari *link* (penghubung) dan *joint* (sambungan).
- Menurut *Ghaffin & Anderson (1984)*, tubuh manusia terdiri dari enam link yaitu:
  - Link lengan bawah yang dibatasi joint pergelangan tangan dan siku.
  - Link lengan atas yang dibatasi joint siku dan bahu.
  - Link punggung yang dibatasi joint bahu dan pinggul.
  - Link paha yang dibatasi joint pinggul dan lutut.
  - Link betis yang dibatasi joint lutut dan mata kaki.
  - Link kaki yang dibatasi joint mata kaki dan telapak kaki.

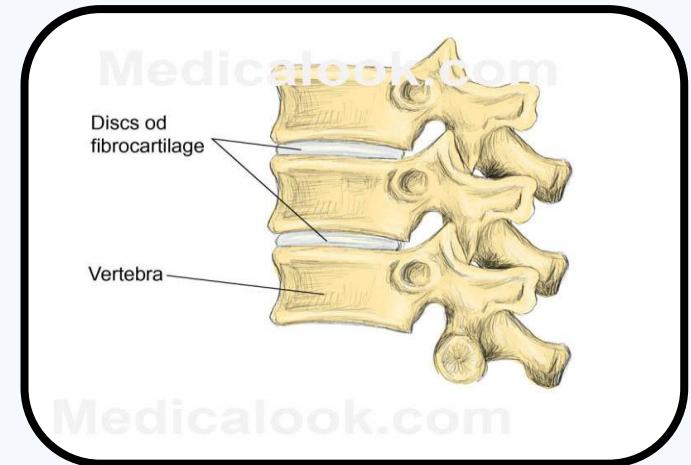
# Types of Joint based on Its Function



Synovial joints : no tissue exists between the highly lubricated joint surfaces.

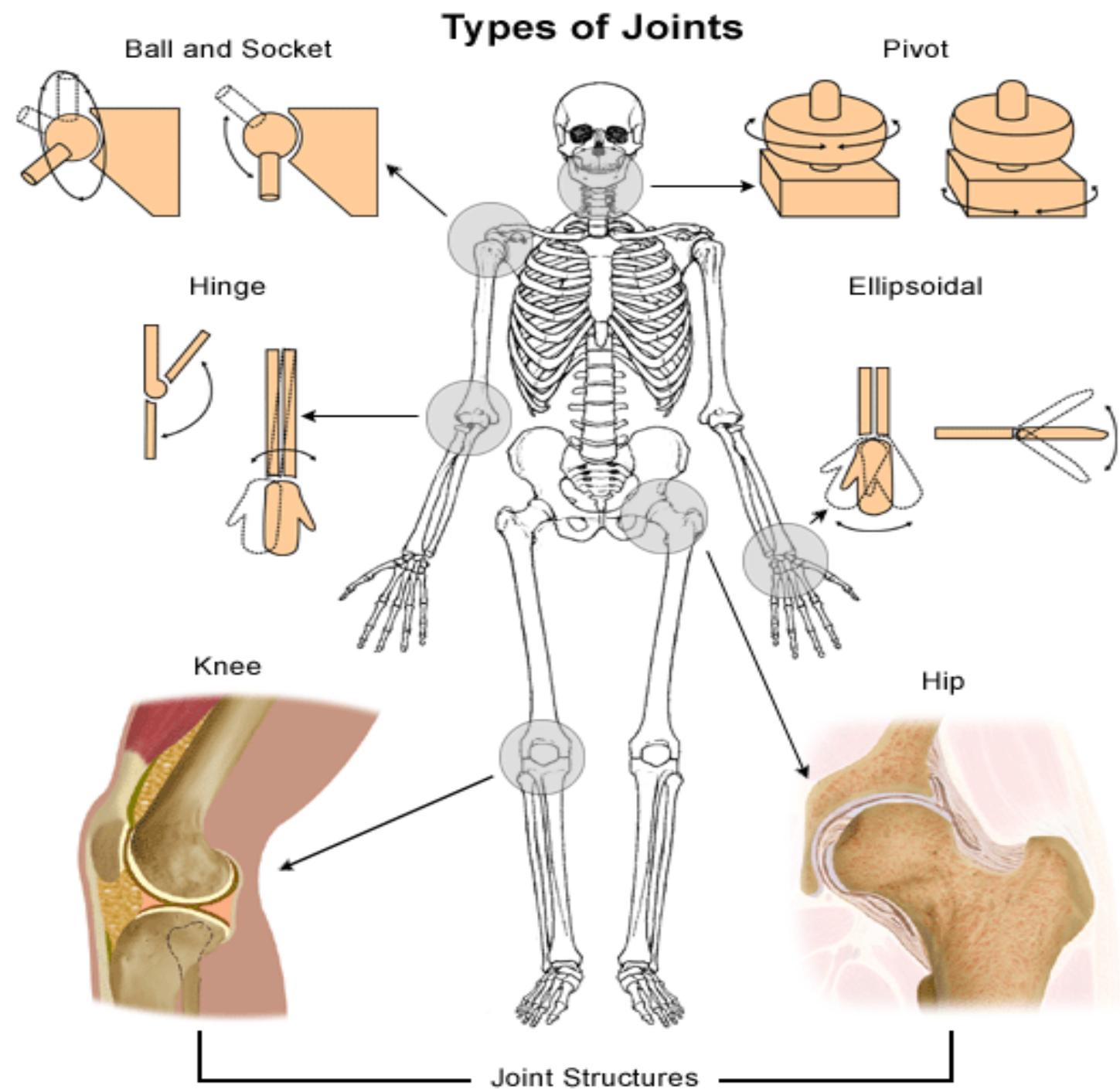


Fibrous joints : connecting the bones of the skull through fibrous tissues.



Cartilaginous joints : bridging vertebral bones and invertebral discs.

# Types of Joint based on Its Movement



# Muscles

- About 400 muscles in a human body, which make up about 40%–50% of the body weight.
- Muscles consume almost 50% of the body's metabolism.
- Muscles also supplies the energy for maintaining body posture, producing body motion, and generating heat/body temperature.
- Muscles with larger cross-sections are able to exert larger forces.

# Types of muscle contraction

- Concentric / isotonic : muscle **shortens** while contracting and producing a constant internal muscle force.
  - Example : arm flexor muscle when object is lifted upward
- Eccentric : muscle **lengthens** while contracting, which occurs when the external force is greater than the internal muscle force.
  - Example : a person picks up a heavy object and unable to hold it in the desired position
- Isometric : the muscle length remains **unchanged** during the contraction process.
  - Example : a person pauses during lifting and holds the object in a static position.

Muscle contraction produces muscle force or tension, which is transmitted to bones through tendons and is used to maintain body posture and perform physical work.

# Aerobic vs Anaerobic Metabolism

- Aerobic
  - Use of O<sub>2</sub>, efficient, high capacity
- Anaerobic
  - No O<sub>2</sub>, inefficient, low capacity
- Aerobic used during normal work (exercise) levels, anaerobic added during extreme demands
- Anaerobic metabolism → lactic acid (pain, cramps, tremors)

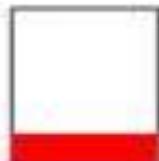


## Resting

**Blood  
Needed**

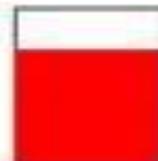


**Blood  
Flow**



## Dynamic Effort

**Blood  
Needed**

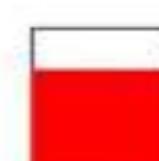


**Blood  
Flow**

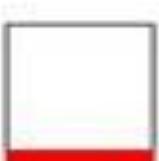


## Static Effort

**Blood  
Needed**

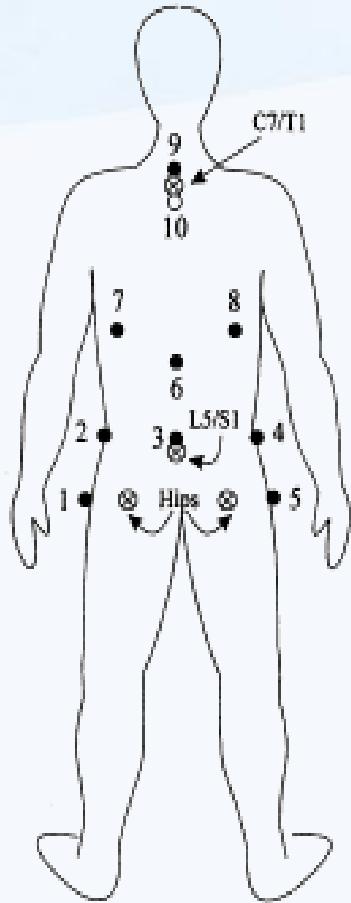


**Blood  
Flow**

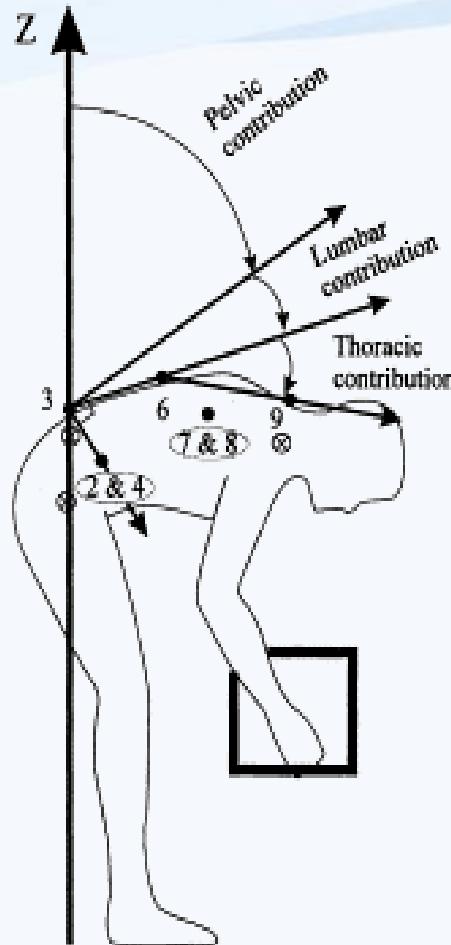


○ : Front marker

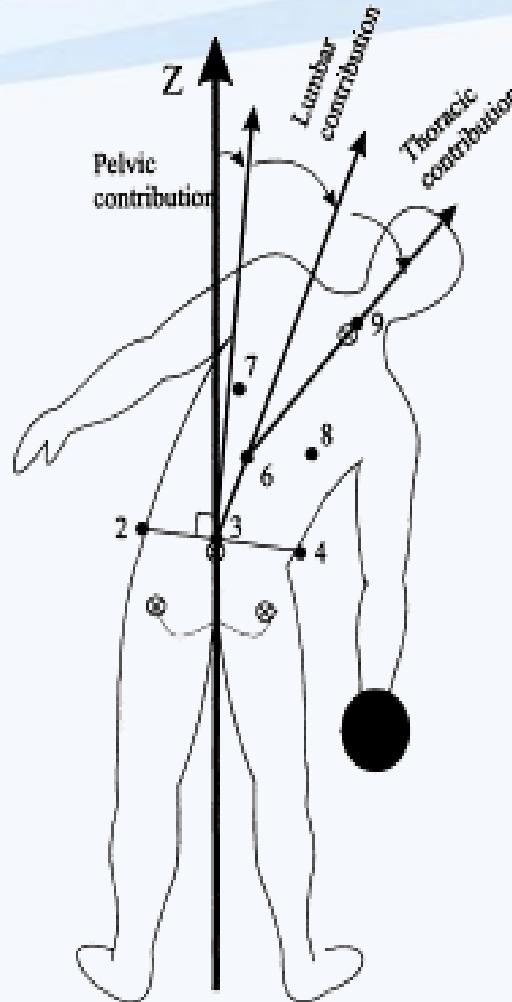
◎ : Joint center



A) Anatomical  
calibration



B) Flexion-extension  
tasks



C) Lateral bending  
tasks

## Biomechanics Analysis

Causes of bones fracture and muscle fatigue :

- ✓ Excess amount of load
- ✓ The number of repetition loading
- ✓ Forming a bending posture / forces

# **How to Measure ?**

## **Biostatics :**

- Apply Newton's Law
- Use RULA (Rapid Upper Limb Assessment)
- Use REBA (Rapid Entire Body Assessment)

## **Biodynamic :**

- Apply advanced Newton's Law
- Manual material handling (NIOSH's Law)
- Simulation

# Biomechanical Models

- Biomechanical models are mathematical models of the mechanical properties of the human body.
- Biomechanical models allow one to predict the stress levels of specific **musculoskeletal components** quantitatively with established methods of physics and mechanical engineering and thus can serve as an analytical tool to help job designers identify and avoid hazardous job situations.

# The Set of Three Newton's Law

1. A mass remains in uniform motion or at rest until acted on by an unbalanced external force.
2. Force is proportional to the acceleration of a mass.
3. Any action is opposed by reaction of equal magnitude.

**Static equilibrium :**

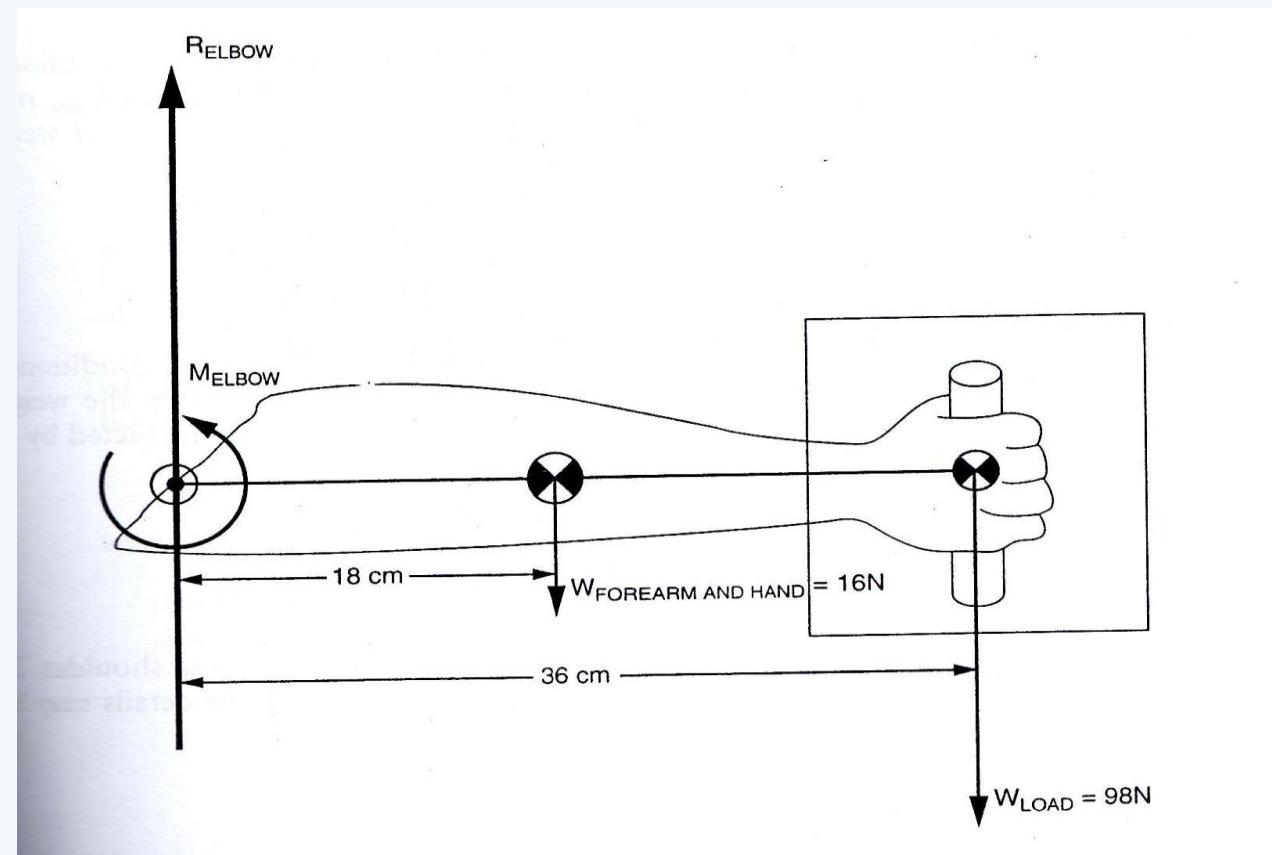
When a body or a body segment is not in motion

The sum of all external forces acting on the object must be equal to zero  
 $(\Sigma F=0)$

The sum of all external moments acting on the object must be equal to zero  
 $(\Sigma M=0)$

# Single-Segment Planar Static Model

- Suppose a person is holding a load of 20-kg mass with both hands in front of his body and his forearms are horizontal.
- Calculate  $R_{\text{elbow}}$  and  $M_{\text{elbow}}$  !



# Solution

$$W = mg = 20 \text{ kg} \times 9.8 \text{ m/s}^2 = 196 \text{ N}$$

$$W_{\text{on-each hand}} = 98 \text{ N}$$

$$\Sigma (\text{forces at the elbow}) = 0$$

$$-16 \text{ N} - 98 \text{ N} + R_{\text{elbow}} = 0$$

$$R_{\text{elbow}} = 114 \text{ N}$$

$$\Sigma (\text{moments at the elbow}) = 0$$

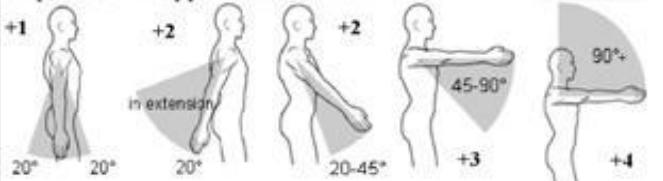
$$(-16 \text{ N})(0.18 \text{ m}) + (-98 \text{ N})(0.36 \text{ m}) + M_{\text{elbow}} = 0$$

$$M_{\text{elbow}} = 38.16 \text{ N/m}$$

# RULA Employee Assessment Worksheet

## A. Arm and Wrist Analysis

### Step 1: Locate Upper Arm Position:



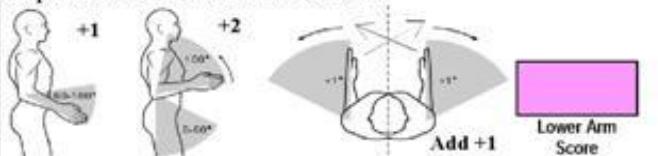
Step 1a: Adjust...

If shoulder is raised: +1

If upper arm is abducted: +1

If arm is supported or person is leaning: -1

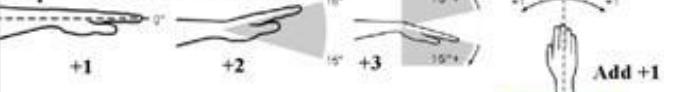
### Step 2: Locate Lower Arm Position:



Step 2a: Adjust...

If either arm is working across midline or out to side of body: Add +1

### Step 3: Locate Wrist Position:



Step 3a: Adjust...

If wrist is bent from midline: Add +1

### Step 4: Wrist Twist:

If wrist is twisted in mid-range: +1

If wrist is at or near end of range: +2

### Step 5: Look-up Posture Score in Table A:

Using values from steps 1-4 above, locate score in Table A

### Step 6: Add Muscle Use Score

If posture mainly static (i.e. held>10 minutes),  
Or if action repeated occurs 4X per minute: +1

### Step 7: Add Force/Load Score

If load < .4 lbs (intermittent): +0

If load 4.4 to 22 lbs (intermittent): +1

If load 4.4 to 22 lbs (static or repeated): +2

If more than 22 lbs or repeated or shocks: +3

### Step 8: Find Row in Table C

Add values from steps 5-7 to obtain  
Wrist and Arm Score. Find row in Table C.

## SCORES

Table A: Wrist Posture Score

Upper Arm	Lower Arm	1	2	3	4
		Wrist Twist	Wrist Twist	Wrist Twist	Wrist Twist
1	1	1	2	2	2
1	2	2	2	2	3
1	3	2	3	3	3
2	1	2	3	3	3
2	2	3	3	3	3
2	3	3	4	4	4
3	1	3	3	4	4
3	2	3	4	4	4
3	3	4	4	4	5
4	1	4	4	4	4
4	2	4	4	4	5
4	3	4	4	5	5
5	1	5	5	5	6
5	2	5	6	6	6
5	3	6	6	7	7
6	1	7	7	7	7
6	2	8	8	8	8
6	3	9	9	9	9

Table C: Neck, trunk and leg score

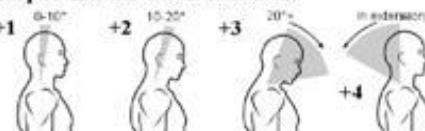
Wrist and Arm Score	1	2	3	4	5	6	7+
	Legs						
1	1	2	3	3	4	5	5
2	2	2	3	4	4	5	5
3	3	3	3	4	4	5	6
4	3	3	3	4	5	6	6
5	4	4	4	5	6	7	7
6	4	4	5	6	6	7	7
7	5	5	6	6	7	7	7
8+	5	5	6	7	7	7	7

Scoring: (final score from Table C)  
1 or 2 = acceptable posture  
3 or 4 = further investigation, change may be needed  
5 or 6 = further investigation, change soon  
7 = investigate and implement change

Final Score

## B. Neck, Trunk and Leg Analysis

### Step 9: Locate Neck Position:



Neck Score

Step 9a: Adjust...

If neck is twisted: +1

If neck is side bending: +1

### Step 10: Locate Trunk Position:



Trunk Score

Step 10a: Adjust...

If trunk is twisted: +1

If trunk is side bending: +1

### Step 11: Legs:

If legs and feet are supported: +1

If not: -2

Leg Score

Neck Posture Score	1	2	3	4	5	6
	Legs	Legs	Legs	Legs	Legs	Legs
1	1	3	2	3	4	5
2	2	3	2	3	4	5
3	3	3	3	4	5	6
4	5	5	5	6	7	7
5	7	7	7	7	8	8
6	8	8	8	8	8	9

### Step 12: Look-up Posture Score in Table B:

Using values from steps 9-11 above,  
locate score in Table B

Posture Score B

### Step 13: Add Muscle Use Score

If posture mainly static (i.e. held>10 minutes),  
Or if action repeated occurs 4X per minute: +1

Muscle Use Score

### Step 14: Add Force/Load Score

If load < .4 lbs (intermittent): +0

If load 4.4 to 22 lbs (intermittent): +1

If load 4.4 to 22 lbs (static or repeated): +2

If more than 22 lbs or repeated or shocks: +3

Force/Load Score

### Step 15: Find Column in Table C

Add values from steps 12-14 to obtain  
Neck, Trunk and Leg Score. Find Column in Table C.

Neck, Trunk & Leg Score

## CHOOSE A PART OF THE BODY

- Upper Arm       Wrist       Neck       Legs  
 Lower Arm       Wrist twist       Trunk       Muscle use and Load



RESULT



DATABASE

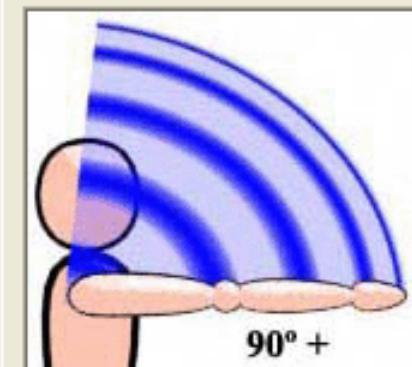
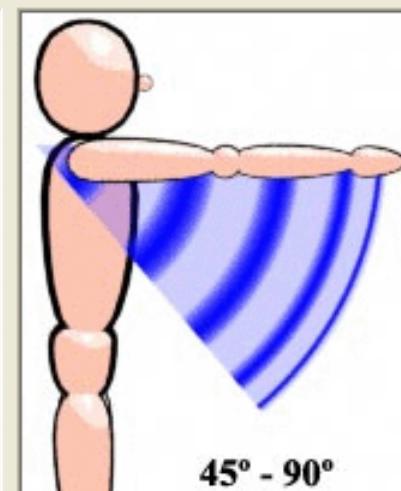
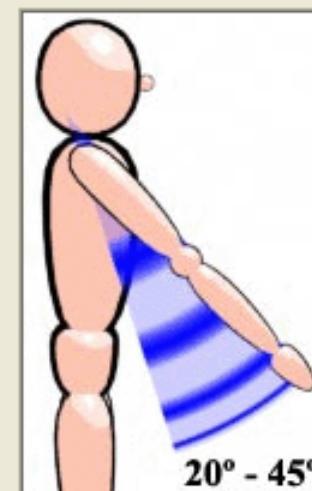
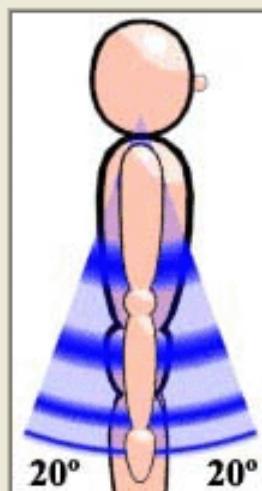
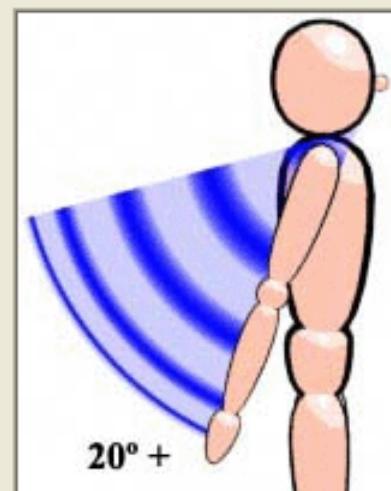


CONTROL



INFORMATION

## Upper Arm



## Additional

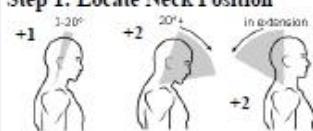
- Upper arm is abducted  
 Shoulder is raised  
 Leaning or supporting the weight of the arm

# REBA Employee Assessment Worksheet

based on Technical note: Rapid Entire Body Assessment (REBA), Hignett, McAtamney, Applied Ergonomics 31 (2000) 201-205

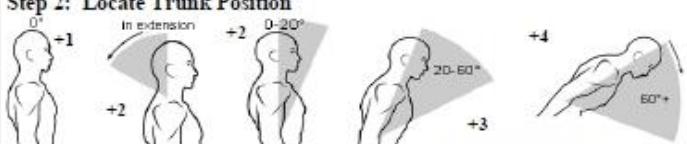
## A. Neck, Trunk and Leg Analysis

### Step 1: Locate Neck Position



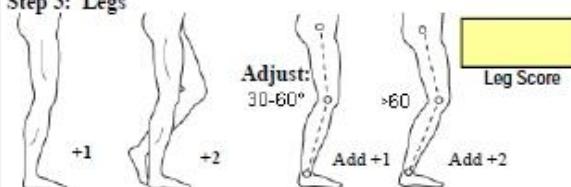
Step 1a: Adjust...  
If neck is twisted: +1  
If neck is side bending: +1

### Step 2: Locate Trunk Position



Step 2a: Adjust...  
If trunk is twisted: +1  
If trunk is side bending: +1

### Step 3: Legs




**Step 4: Look-up Posture Score in Table A**  
Using values from steps 1-3 above, locate score in Table A

### Step 5: Add Force/Load Score

If load < 11 lbs : +0  
If load 11 to 22 lbs : +1  
If load > 22 lbs: +2  
Adjust: If shock or rapid build up of force: add +1



### Step 6: Score A, Find Row in Table C

Add values from steps 4 & 5 to obtain Score A.  
Find Row in Table C.

### Scoring:

- 1 = negligible risk
- 2 or 3 = low risk, change may be needed
- 4 to 7 = medium risk, further investigation, change soon
- 8 to 10 = high risk, investigate and implement change
- 11+ = very high risk, implement change

## SCORES

Table A	Neck		
	1	2	3
Legs	1 2 3 4	1 2 3 4	1 2 3 4
1	1 2 3 4	1 2 3 4	1 2 3 4
2	2 2 3 4	3 4 5 6	4 5 6 7
3	3 2 4 5	6 4 5 7	7 5 6 8
4	4 3 5 6	7 5 6 8	8 7 8 9
5	5 4 6 7	8 6 7 8	9 7 8 9

Table B	Lower Arm		
	1	2	3
Wrist	1 2 3	1 2 3	1 2 3
1	1 1 2 2	1 2 3 2	1 2 3 4
2	2 1 2 3	3 2 3 4	
3	3 3 4 5	4 5 5 5	
4	4 4 5 5	5 6 7 8	
5	5 6 7 8	7 8 9 9	
6	6 7 8 8	8 9 9 9	

Score A (score from table A +load/force score)	Score B, (table B value +coupling score)											
	1	2	3	4	5	6	7	8	9	10	11	12
1	1 1 1 2 3 3 4 5 6 7 7 7											
2	1 2 2 3 4 4 5 6 6 6 7 7 8											
3	2 3 3 3 4 5 6 7 7 7 8 8 8											
4	3 4 4 4 5 6 7 8 8 9 9 9 9											
5	4 4 4 5 6 7 8 8 9 9 9 9 9											
6	6 6 6 7 8 8 9 9 10 10 10 10 10											
7	7 7 7 8 9 9 9 10 10 10 11 11 11											
8	8 8 8 9 10 10 10 10 10 11 11 11 11											
9	9 9 9 10 10 10 11 11 11 12 12 12 12											
10	10 10 10 11 11 11 11 12 12 12 12 12 12											
11	11 11 11 11 12 12 12 12 12 12 12 12 12											
12	12 12 12 12 12 12 12 12 12 12 12 12 12											

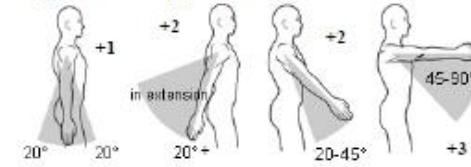
+      +

Table C Score      Activity Score

Final REBA Score

## B. Arm and Wrist Analysis

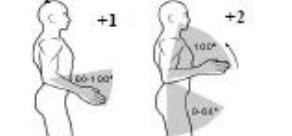
### Step 7: Locate Upper Arm Position:



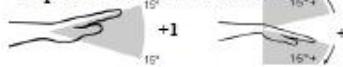
Step 7a: Adjust...  
If shoulder is raised: +1  
If upper arm is abducted: +1  
If arm is supported or person is leaning: -1




### Step 8: Locate Lower Arm Position:




### Step 9: Locate Wrist Position:



Step 9a: Adjust...  
If wrist is bent from midline or twisted : Add +1

### Step 10: Look-up Posture Score in Table B

Using values from steps 7-9 above, locate score in Table B

### Step 11: Add Coupling Score

Well fitting Handle and mid rang power grip, *good*: +0  
Acceptable but not ideal hand hold or coupling  
acceptable with another body part, *fair*: +1  
Hand hold not acceptable but possible, *poor*: +2  
No handles, awkward, unsafe with any body part,  
*Unacceptable*: +3

Step 12: Score B, Find Column in Table C  
Add values from steps 10 & 11 to obtain  
Score B. Find column in Table C and match with Score A in  
row from step 6 to obtain Table C Score.

### Step 13: Activity Score

- +1 1 or more body parts are held for longer than 1 minute (static)
- +1 Repeated small range actions (more than 4x per minute)
- +1 Action causes rapid large range changes in postures or unstable base

Task name: \_\_\_\_\_ Reviewer: \_\_\_\_\_ Date: \_\_\_\_\_ / \_\_\_\_\_ / \_\_\_\_\_

This tool is provided without warranty. The author has provided this tool as a simple means for applying the concepts provided in REBA .

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## CHOOSE AN OPTION BELOW

 Neck, trunk and legs Load Upper arm, lower arm and wrist Coupling Activity

RESULT



SAVE



DATABASE



CONTROL



INFORMATION

## Neck, trunk and legs

## Neck

 In extension 0 to 20 degrees More than 20 degrees

## Additional

 Neck is twisted or side bending

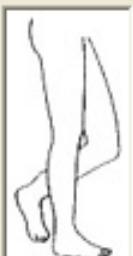
## Trunk

 In extension Straight 0 to 20 degrees 20 to 60 degrees More than 60 degrees

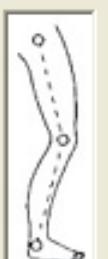
## Additional

 Trunk is twisted or side bending

## Legs

 Support in the two legs, walking or seated Support in one leg

## Additional

 30 to 60 degrees More than 60 degrees

# Low-Back Biomechanics of Lifting

$$M_{\text{load-to-torso}} = W_{\text{load}} \times h + W_{\text{torso}} \times b$$

$h$  = the horizontal distance from the load to the L5/S1 disc

$b$  = the horizontal distance from the center of mass of the torso to the L5/S1 disc

$$F_{\text{muscle}} \times 5 = W_{\text{load}} \times h + W_{\text{torso}} \times b$$

(Suppose :  $h = 40 \text{ cm}$ ,  $b = 20 \text{ cm}$ )

$$F_{\text{muscle}} = W_{\text{load}} \times (40/5) + W_{\text{torso}} \times (20/5)$$

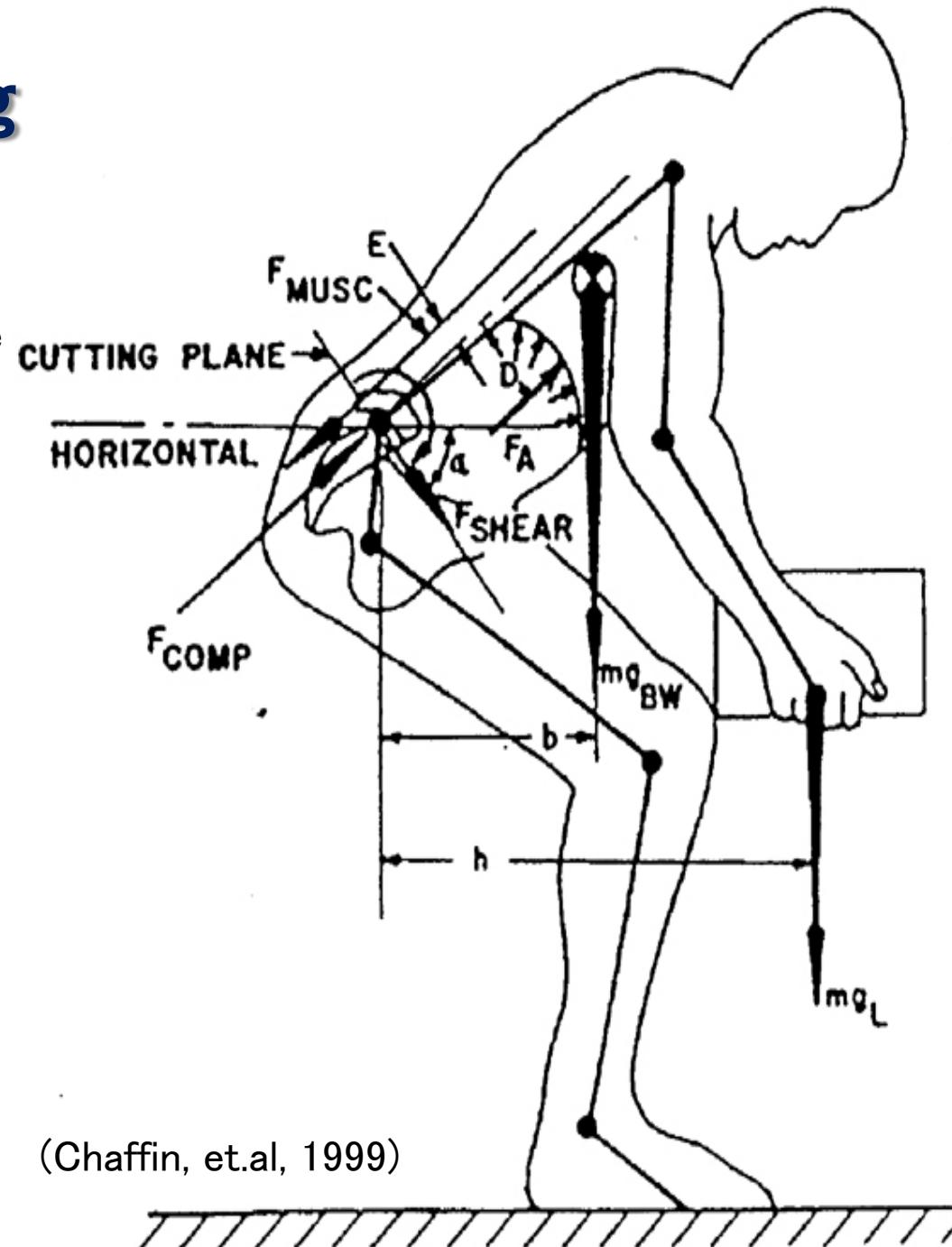
$$F_{\text{muscle}} = 8 \times W_{\text{load}} + 4 \times W_{\text{torso}}$$

(Suppose :  $W_{\text{load}} = 450 \text{ N}$ ,  $W_{\text{torso}} = 350 \text{ N}$ ,  $\alpha = 55^\circ$ )

$$F_{\text{muscle}} = 8 \times W_{\text{load}} + 4 \times W_{\text{torso}} = 5000 \text{ N}$$

$$\begin{aligned} F_{\text{compression}} &= W_{\text{load}} \times \cos \alpha + W_{\text{torso}} \times \cos \alpha + F_{\text{muscle}} \\ &= 450 \times \cos 55 + 350 \times \cos 55 + 5000 \\ &= 5458 \text{ N} \end{aligned}$$

Disc compression at this level can be hazardous to many workers.



(Chaffin, et.al, 1999)

# **Musculoskeletal Disorder (MSDs)**

- **Musculoskeletal disorders (MSDs)** atau gangguan otot rangka merupakan kerusakan pada otot, saraf, tendon, ligament, persendian, kartilago, dan discus invertebralis.
- **Kerusakan pada otot** dapat berupa ketegangan otot, inflamasi, dan degenerasi.
- Sedangkan **kerusakan pada tulang** dapat berupa memar, mikro faktur, patah, atau terpelintir.

# Penyebab MSDs



- 1. Kelelahan dan keletihan terus menerus** yang disebabkan oleh frekuensi atau periode waktu yang lama dari usaha otot, dihubungkan dengan pengulangan atau usaha yang terus menerus dari bagian tubuh yang sama meliputi posisi tubuh yang statis;
- 2. Kerusakan tiba-tiba** yang disebabkan oleh aktivitas yang sangat kuat/berat atau pergerakan yang tak terduga.

# Jenis-jenis Keluhan MSDs

1. **Sakit Leher** → peningkatan tegangan otot atau myalgia, leher miring atau kaku leher.
2. **Nyeri Punggung** → gejala nyeri punggung yang spesifik seperti herniasi lumbal, arthritis, ataupun spasme otot.
3. **Carpal Tunnel Syndrome** → kumpulan gejala yang mengenai tangan dan pergelangan tangan yang diakibatkan iritasi dan nervus medianus.
4. **De Quervains Tenosynovitis** → Penyakit ini mengenai pergelangan tangan, ibu jari, dan terkadang lengan bawah, disebabkan oleh inflamasi tenosinovium dan dua tendon yang berasa di ibu jari pergelangan tangan.
5. **Thoracic Outlet Syndrome** → Merupakan keadaan yang mempengaruhi bahu, lengan, dan tangan yang ditandai dengan nyeri, kelemahan, dan mati rasa pada daerah tersebut
6. **Tennis Elbow** → keadaan inflamasi tendon ekstensor, tendon yang berasal dari siku lengan bawah dan berjalan keluar ke pergelangan tangan.
7. **Low Back Pain** → terjadi apabila ada penekanan pada daerah lumbal yaitu L5 dan S1. Apabila dalam pelaksanaan pekerjaan posisi tubuh membungkuk ke depan maka akan terjadi penekanan pada discus.

A stylized illustration of a tree with a brown trunk and branches. The leaves are large, rounded, and colored in shades of purple and pink. The tree stands on a green, rolling hill. In the background, there are blue and white horizontal stripes, suggesting a sky or water surface.

*Thank you. . .*

**Have an enjoy study and  
see you next week...**