Stance and Stability

Readings

1. Hamilton, N., & Luttgens, K. 2002. Kinesiology, Scientific Basis of Human Motion, 10th ed. Boston: McGraw-Hill. Chapter 14, pp. 371-394 and Chapter 15, pp. 399-411
2. Chaffin & Andersson, 1999： Chapter 17
3. Hall, 2003：Chapter 13

Objectives: After studying this topic, the students will be able to

- identify the center of mass, center of gravity, and center of pressure of human body and distinguish their differences
- describe the methods to measure limit of stability and the factors that affect stability and equilibrium
- explain the changes in center of mass and center of pressure at quiet stance and during different perturbed tasks

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COM, COG, and COP

Posture and Balance

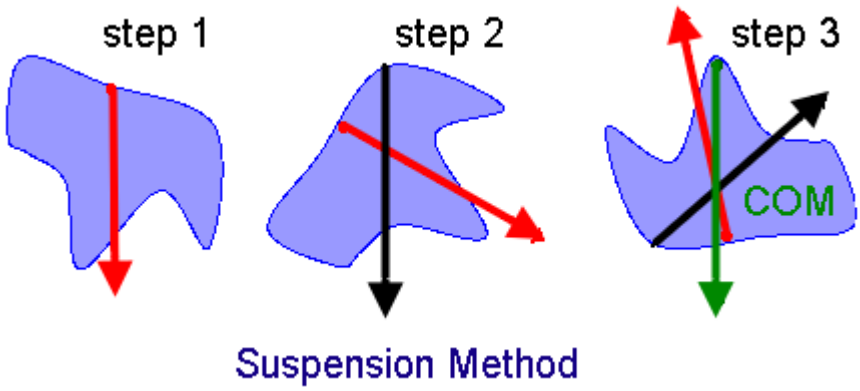
- posture： a term to describe the orientation of any body segment relative to the gravitational vector
- balance： a term to describe the dynamics of body posture to prevent falling

Definition of Center of Mass (COM)

- the point where all the mass of a body is concentrated
- the point about which a body would balance without a tendency to rotate
    - All the linear forces acting on the body is balanced, i.e. $\Sigma F = 0$
    - All the rotary forces acting on the body is balanced, i.e. $\Sigma M = 0$

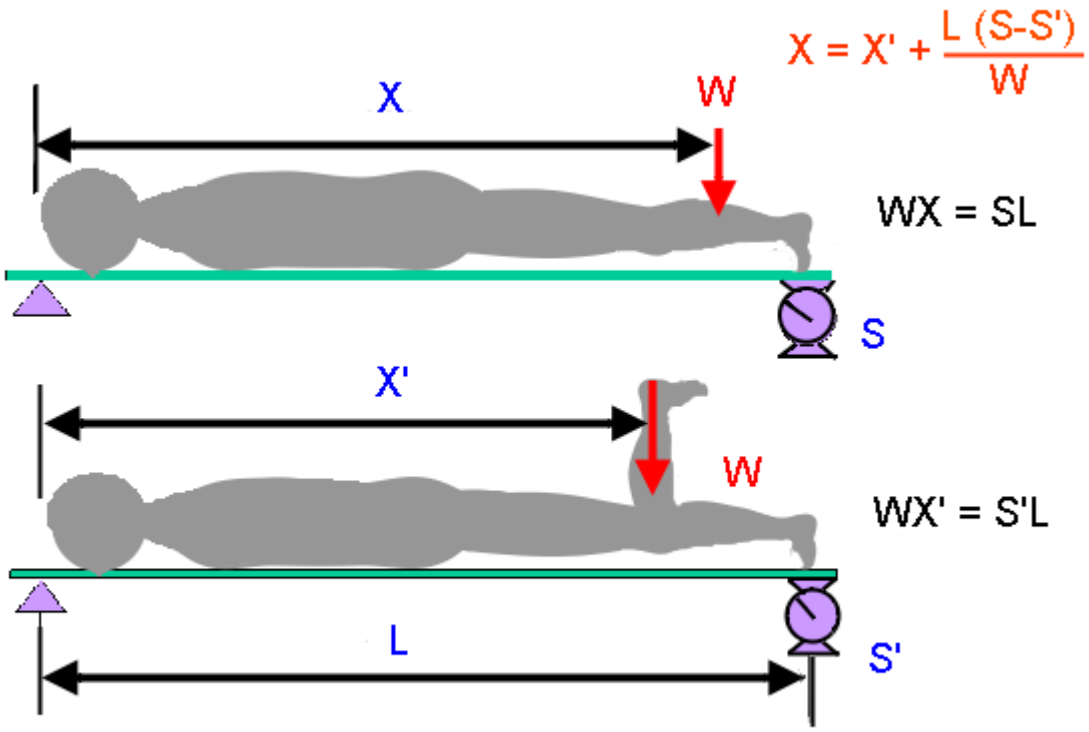
Location of Center of Mass

- its precise location depending on
    - individual's anatomical structure
    - habitual standing posture
    - current position
    - external support
        - NOTE： Location of COM remains fixed as long as the body does NOT change the shape
- location in human body
    - generally accepted that it is located at
        - ~57% of standing height in males
        - ~ 55% of standing height in females
    - varies with body build, posture, age, and gender
        - infant > child > adult (in % of body height from the floor)
- methods to estimate the COM of an object
    - suspension method： to suspend an irregular-shaped object by a string and let it hang until it ceases to move



Suspension Method

    - segment modeling method： weighed average of every segment of the entire body
    - kinetic method： double integration of shear forces from the force platform
    - clinical method： measurement of the PSIS (posterior superior iliac spine) level in the sagittal plane
- methods to locate the COM of one segment



Method for Location of the COM of One Segment

- COM parameters
  - absolute position of the COM in the AP and ML positions
  - excursion of the COM
  - linear acceleration of the COM equals to the difference between the COP and COM

COP - d_{COM} = *ka*

where *k* = constant

a = linear acceleration of the COM

since *(GRF) (COP) - (BW) (d_{COM}) = Iα* $\alpha = \frac{\ddot{x}}{d}$, $(GRF)(COP) - (BW)(d_{COM}) = I\frac{\ddot{x}}{d}$, so

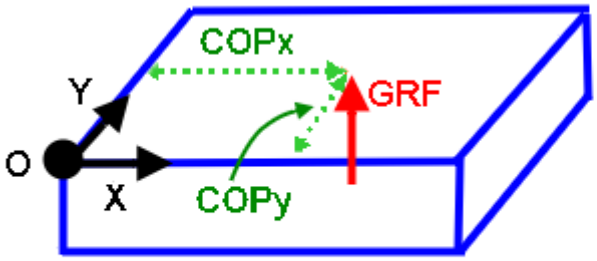
and

$$(COP) - (d_{COM}) = \frac{I \cdot \ddot{x}}{BW \cdot d} = k\ddot{x} = ka$$

Center of Pressure (COP)

- the point where the resultant of all ground reaction forces act
- COP parameters
  - absolute position of the COP in the AP and ML directions
  - excursion of the COP
  - safety margin

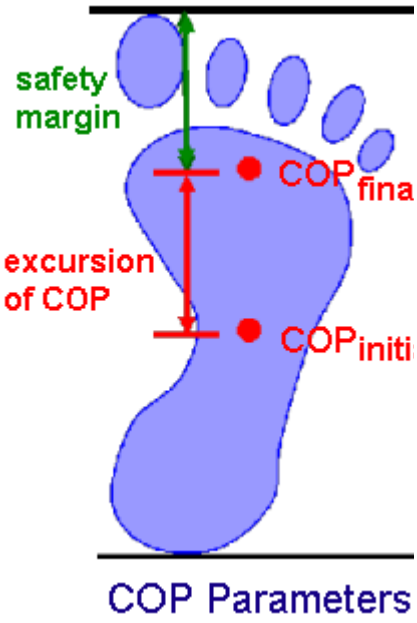
- measurement of the position of the COP
  - single-force-platform method



$$COPx = \frac{My}{Fz}$$

$$COPy = -\frac{Mx}{Fz}$$

Measurement of COP from Single Force Platform



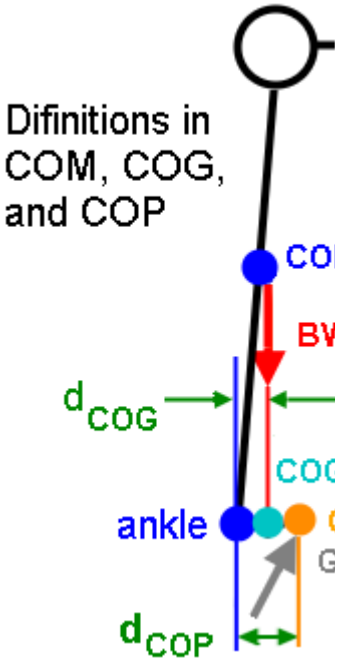
COP Parameters

  - two-force-platform method： measurement the COP with one foot standing on one force plate other foot on the second force plate

$$COP_{net} = COP_L \frac{GRF_{VL}}{GRF_{VL} + GRF_{VR}} + COP_R \frac{GRF_{VL}}{GRF_{VL} + GRF_{VR}}$$

Definition of Centroid and COG

- centroid
  - the point that defines the geometric center of a body
  - If the material composing a body is homogeneous, the weight can be neglected, i.e. centroid = COM
    - Note: human body is not homogeneous
- center of gravity (COG)
  - the vertical projection of the center of mass to the ground



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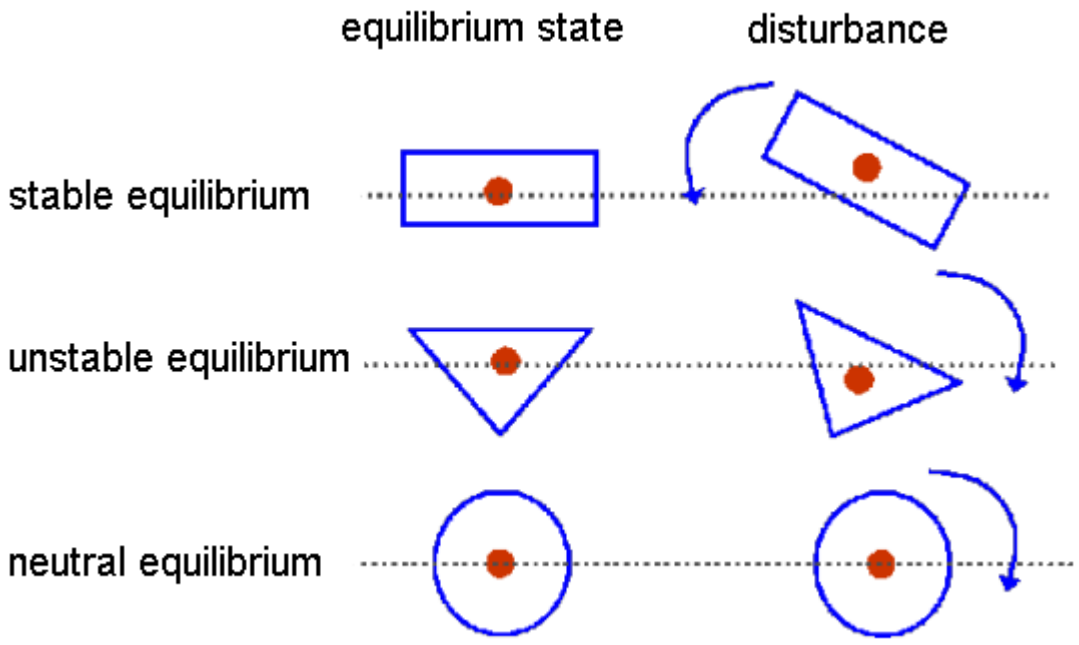
Stability and Equilibrium

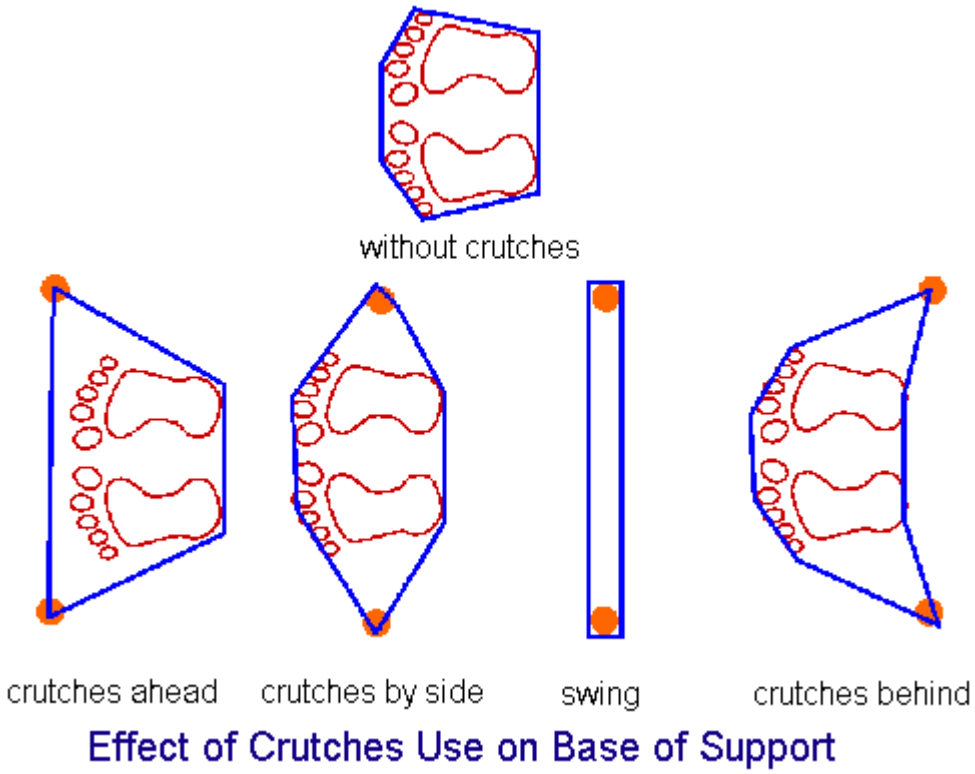
Classification of Equilibrium

- stable equilibrium
  - occurs when an object is placed in such a position that any disturbance effort would raise its COM
  - tend to fall back its original position
  - e.g. BOS or ↓COM
- unstable equilibrium
  - occurs when an object is placed in such a position that any disturbance effort would lower its COM
  - tend to fall into a more stable position
- neutral equilibrium
  - occurs when an object is placed in such a position that any disturbance effort would not change the level of its COM
  - tend to fall into a more stable position



Factors Affecting Stability

- size and shape of base of support (BOS)
  - wide-base stance
  - tandem stance: standing with one foot ahead the other
  - stance with crutches



Effect of Crutches Use on Base of Support

  - Pai *et al.*, 1997： effects of velocity and position of COM on bas of support
- height of COM
- relationship of COG to BOS
- mass of body
- friction
- segmental alignment
- sensory input
  - visual
  - vestibular system
  - proprioception
  - other somatosensory system
- psychological or mental status
- muscle activities
  - postural muscle： the muscle that acts to prevent collapse of the skeleton
    - slow twitch
    - fatigue resistant
  - phasic muscle： fast muscle
- physiological and pathological factors

Tasks Used to Study the Stability of Erect Posture

- quiet stance： to maintain static stability
- externally-perturbed stance： to regain dynamic stability
- self-perturbed stance： to maintain dynamic stability

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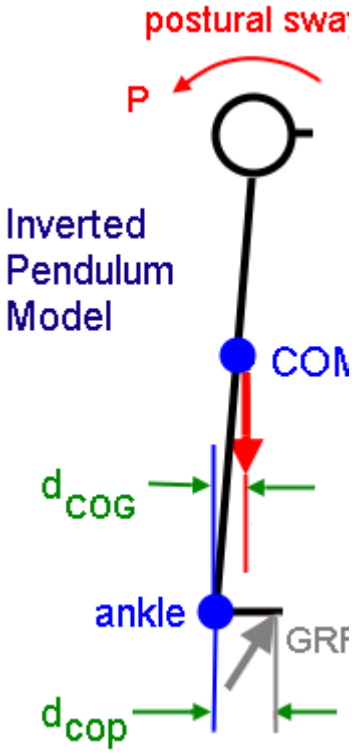
Stability at Quiet Stance

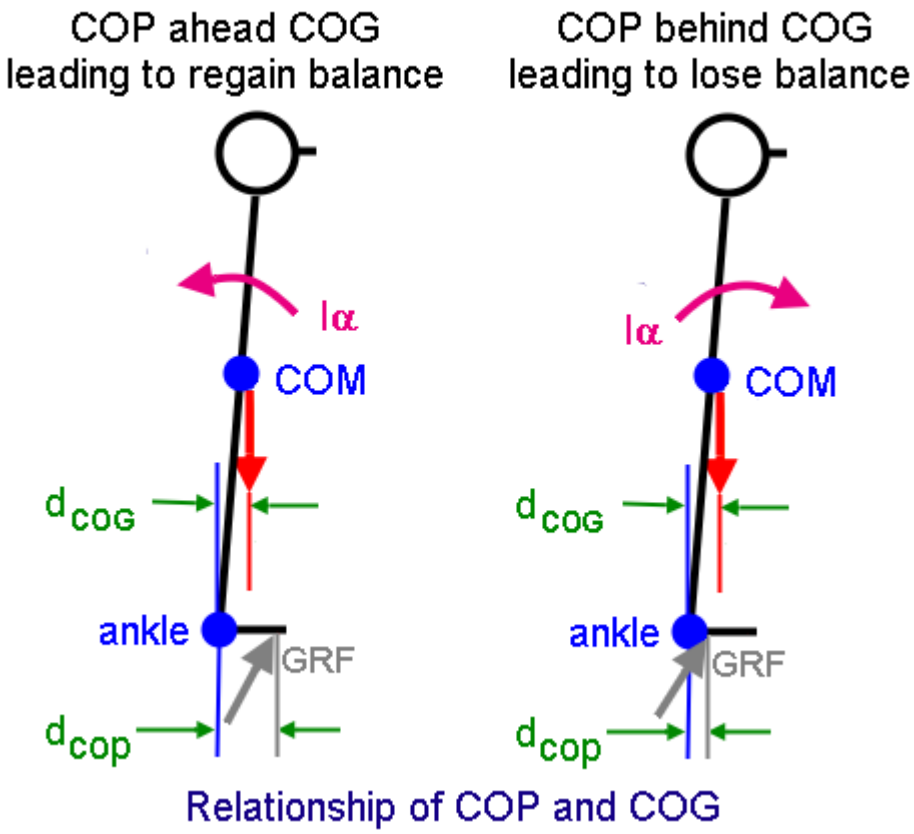
Postural Sway

- the body sways back and forth like an inverted pendulum, pivoting about the ankle, at quiet stance
    - AP sway (anteroposterior sway)
        - sway in the sagittal plane
        - ~ 5-7 mm at quiet stance in young adults
    - ML sway (mediolateral sway)
        - sway in the frontal plane
        - ~ 3-4 mm during quiet stance in young adults



- inverted pendulum model
    - the trunk sways around the ankle joint like an inverted pendulum
    - (GRF) (d_{COP}) = (BW) (d_{COG}) + $I\alpha$
    - assumptions
        1. BW = GRF
        2. body sway around ankle only
        3. ankle acts as a hinge joint

- relationship of COG and COP during quiet stance
    - In the case if the COP ahead the COG (see the sketch below), a counter-clockwise moment ($I\alpha$) is present at the ankle joint, resulting in backward rotation of the trunk and the balance is regained.
    - In the case if the COP behind the COG, a clockwise moment is present at the ankle joint, resulting in forward rotation of the trunk and the balance may be lost and possibly fall forward.



Relationship of COP and COG

- postureal sway strategy
  - the timing and amplitude of the coordinated motor patterns at many joints in order to adjust (reactive or proactive) posture and balance
  - ankle strategy vs. hip strategy

- factors affecting postureal sway strategy
  - age： highly correlated to falls in the elderly
  - fatigue
  - injury
  - bracing
  - obesity
  - stability of the external environment

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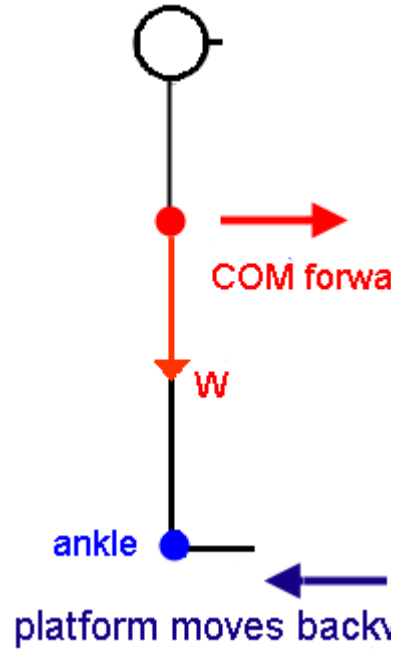
Stability at Externally-Perturbed Stance

- dynamic balance： the ability that the body regains balance at the moment of giving any externally-perturbed situation

- methods of external perturbation
  - changes in direction of perturbation by standing on a moving platform
    - horizontal translation
    - sagittal plane translation
  - changes in surrounding environment

- horizontal translation on a moving platform
  - Nashner (1977)： first researcher to study the effect of a moving platform
  - COM sways backwards when the platform moves backwards
    - NOTE： Actually, what he did is to measure the COP rather than the COM.
  - bottom-up sequence of activities of the participating muscles



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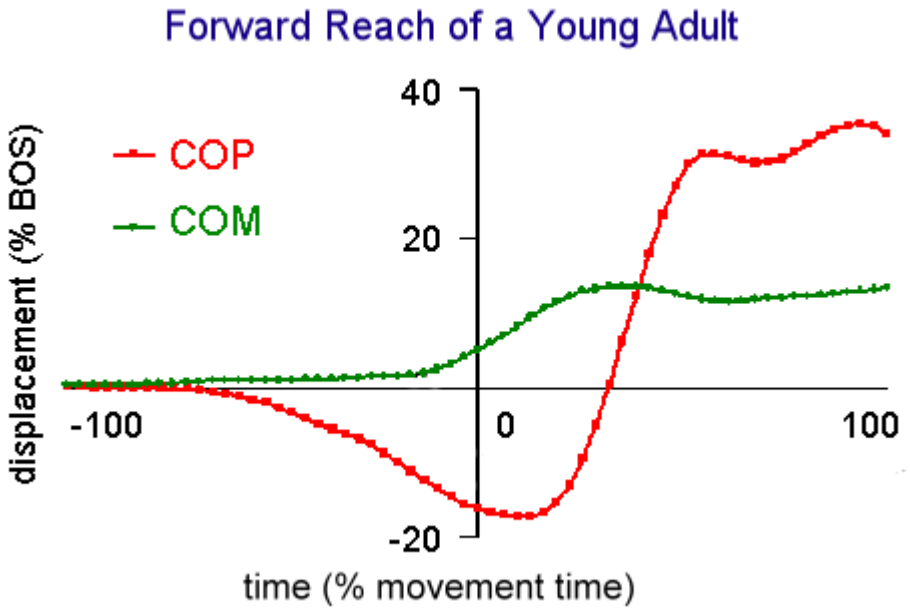
Stability at self-Perturbed Stance

- dynamic balance： the ability that the body maintains balance during a functional task
- methods of self perturbation
  - stance with external support, e.g. using crutches or using canes
  - change in base of support, e.g. wide-base stance, tandem stance, or one-leg stance
  - moving one of body parts, e.g. fast arm raise, reach, or leaning
  - closing eyes
- relationship of COG and COP during forward reach movement



- CNS regulates COG by controlling the net ankle moment that is expressed by COP (Fung and Winter, 1996)

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