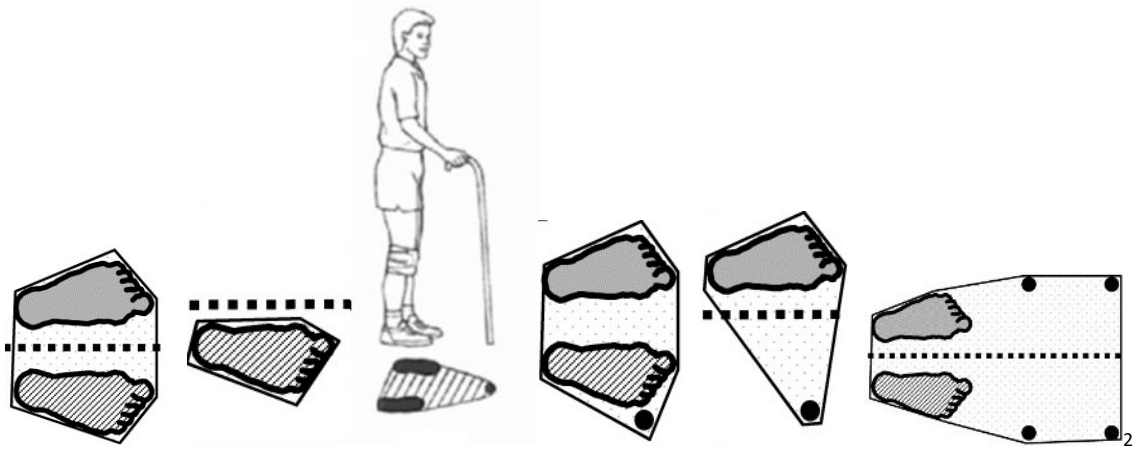
Understanding the Biomechanics of Balance

There are a wide range of systems which interact in the body to allow for the maintenance of balance, posture and gait. Separately, each system provides a piece of the puzzle of maintaining balance and preventing falls, however, aging results in their decline in function and effectiveness [1].

BASE OF SUPPORT

Base of support (BOS) is the minimum horizontal region of ground surface which the body comes in contact with. A small base off support occurs when standing on one toe only, a standard stance provides more stability, then widening the legs increases the area providing even more stability. The introduction of a walking aid increases the amount of surface between the body and the legs of the aid.

When walking the Base of support is constantly moving as the position of the feet on the floor change in relation to one another. A key component of walking is a single leg stance, a motion that has little BOS, introduction of a walking aid increases BOS during this phase of walking.



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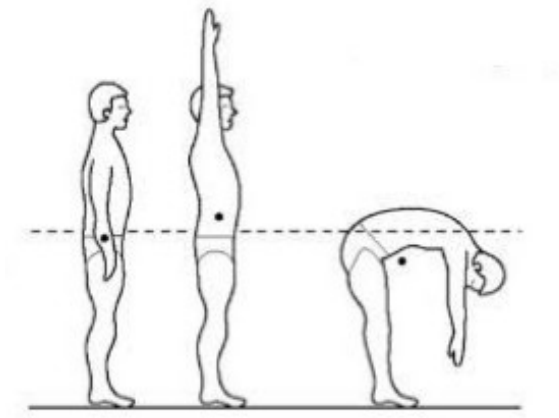
CENTRE OF MASS

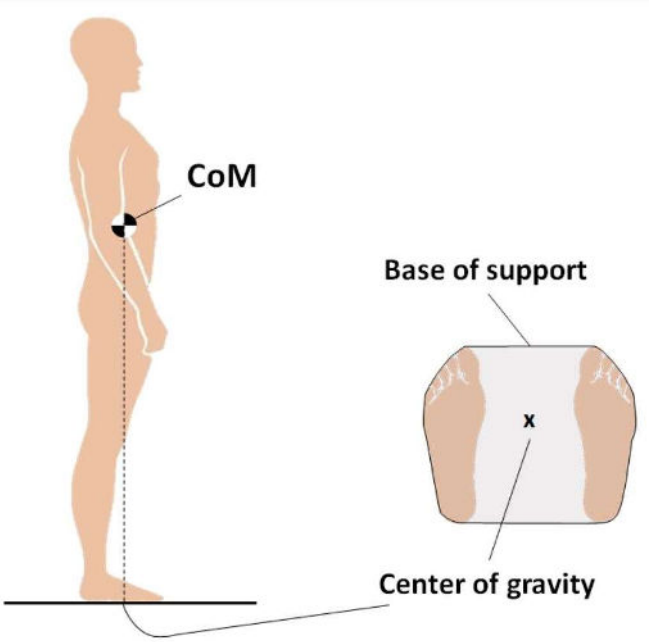


The centre of mass (COM) is the balance point of an object's mass. If a pivot were placed at this point, the object would remain in place and be balanced. The COM of a system is not always at the geometric centre of the system.

In the anatomical position, the COM lies approximately anterior to the second sacral vertebra. However, since human beings do not remain fixed in the anatomical position, the precise location of the COM changes constantly with every new position of the body and limbs and altered if we are carrying a load.

CENTRE OF GRAVITY

The direction of the vertical force of gravity through the body is downward, towards the centre of the earth and through the COM. This line of gravity is important to understand and visualise when determining a person's ability to successfully maintain balance.



The line of gravity extends from centre of mass following gravity down to a position on the surface. The resulting location is the centre of gravity (COG)

When the COG is within the BOS, an object or person is said to be stable. When the COG falls outside the BOS, the object or person is said to be unstable.

A larger BOS increases stability (the line of gravity must move a greater distance to fall outside the BOS). A lower COG increases stability (it's unlikely that the line of gravity will fall outside the BOS)

The closer the line of gravity is to the centre of the base of support the better balanced a person is in this position. If the line of gravity falls outside of the base of support the person must provide corrective muscle action, usually movement otherwise they will fall.

STABILITY

Stability is your body's ability to return to a desired position or trajectory following a disturbance equilibrium when the COG passes outside the BOS.

Equilibrium is a state of no acceleration and can be static (without movement) or dynamic (moving at a constant velocity). Therefore, balance can be both static or dynamic, depending on whether the body is moving or not.

Balance refers to an individual's ability to maintain their COG within their BOS. It can also be described as the ability to maintain equilibrium, where equilibrium can be defined as any condition in which all acting forces are cancelled by each other resulting in a stable balanced system.

Regarding the mechanics of human movement, the goal is to regulate the relationship between the COM and the BOS [3] to maintain equilibrium.

STATIC STABILITY

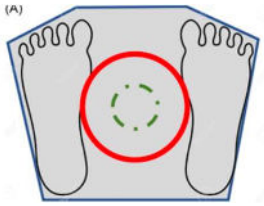
Postural balance is considered to be an important aspect of performance of all individuals whilst undertaking various daily activities, which is achieved by a complex process involving the function of musculoskeletal and neurological systems [4].

Maintaining balance is a complex motor skill involving inputs and interactions between the sensorimotor components, which include the somatosensory, visual, vestibular, brain (cognition), and musculoskeletal systems [1].

Falling is the loss of balance control, when the vertical projection of the COM moves beyond the BOS. Without a successful balance-correcting response or external intervention to arrest the falling state and regain postural equilibrium, a fall (to the ground or some other lower level) will result.

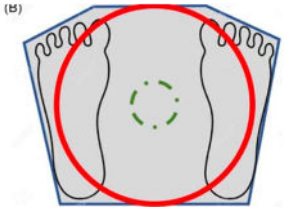
LIMITS OF STABILITY

Limit of stability refers to an area in which the individual is able to shift their COM and maintain balance in a static position without changing the BOS [1].



The base of support can remain the same. If the individual has a greater degree of stability, it allows them to tolerate a greater amount of postural sway or alterations in the COM changing the COG.

Postural sway refers to the outcome of inertial forces and strategies to maintain balance within the limits of stability, with its displacement able to me measures relative to BOS. Postural sway within the limits of gravity is the most routine motions undertaken by the body [5].



A person with a lower limit of stability is more likely to fall as the likelihood of the COG moving beyond this is higher [5]. A lower limit of stability, occurring with age, is a risk factor associated with falls [6].

DYNAMIC STABILITY

The key to dynamic stability is the momentum control of the COM. It is the body's ability to maintain a stable position while undertaking movement.

In dynamic stability, both the BOS and the COM are in motion. Prevention of falls requires effective balance function under dynamic conditions because most falls are caused by sudden motion of the BOS or by sudden acceleration of the COM [3].

The distribution of body mass is such that two-thirds of mass is in the head, arms, and trunk. Because of the large mass and inertia moment of the upper body, its position and movement (forward momentum) can be critical in the overall stability of the upright stance [3].

In response to movement the body must either return COM over BOS or move BOS to encompass the new COG.

MARGIN OF STABILITY

Margin of stability (MOS) is considered a measure of mechanical gait stability.

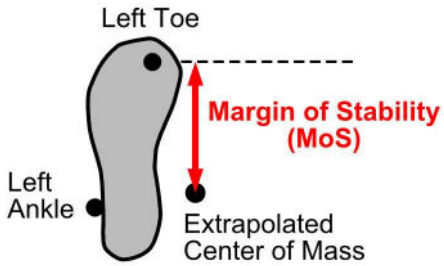
The MOS is a measure of dynamic stability during walking. The strength of this measure is that not only the position, but also the velocity of the COM with respect to the base of support BOS is taken into account.

The MOS is defined as the distance between a velocity adjusted or 'extrapolated' position of the COM and the edge of an individual's BOS at any given instant in time [7].

The MOS expresses the deviation of the COM that an individual can handle before loss of balance occurs. The MOS can be calculated in both the medio-lateral (ML) and anterior–posterior (AP) directions [8].
Decreased mechanical gait stability can be described by decreased mean or increased variability of MOS. Decreased MOS mean indicates less available space between COM and boundaries of base of support. A a more negative MOS indicates that the margin was more exceeded, and the COM is outside of the BOS. Moving the base of support, a stepping response, is the only option to stabilise.

Balance control during walking is critical, as a negative ML MOS will result in deviation from the straight walking trajectory. A negative AP MOS will interrupt forward progression. As a consequence, this will result in a crossover step or a backward step in order to prevent falling sideways or backwards, respectively.

Through changes in step width, step length, step frequency and walking speed ability to maintain or increase MOS in both the ML and AP direction occurs [8].



Walking speed is an important variable influencing the size of the MOS because a reduced walking speed will also reduce the forward velocity of the COM. During unperturbed walking the COM lies typically anterior with respect to the leading foot at initial contact. Strictly seen, the COM is now located outside the border of the base of support, and that is why walking might be seen as unstable in the forward direction. However, this can't be avoided as maintaining forward progression is a requirement for walking forward.

A single step with a negative MOS does not necessarily mean that person will immediately fall, only that corrective action is needed to avoid a fall. Individuals who exhibit more unstable steps need to exert more corrective actions, which requires greater control and greater effort. Decreased muscle strength is a risk factor for falling in the elderly. Having to make more corrective motions with diminished muscle strength would likely increase fall risk [7].

STABILITY IN GAIT

Mobilisation is a fundamental motor skill that significantly affects the level of independence in older adults. There is no unique walking pattern, and the pattern varies from person to person. The amount of variability present in a gait pattern reflects the quality of neuromuscular control. Minor variability indicates better neuromuscular control and gait stability. The gait pattern of individuals becomes more inconsistent as they grow older, and walking patterns are considered stable until there is evidence of a fall [3].

Effective control of balance during gait depends on the interaction of many factors including integration of visual, vestibular, and proprioceptive information concerning body position, appropriate biomechanical alignment, sufficient muscle strength, and quick, coordinated muscle activation patterns. Impairment in any of these domains reduces an individual's ability to balance the multiple connections in the musculoskeletal system during gait [3].

Walking is a dynamic condition wherein the COM is rarely located within the BOS of a stance foot. The walking process does not include an equilibrium state. Instead, the system goal is achieving a stable dynamic control.

Each time a foot is raised it must be replaced by stepping to prevent falling. This is because the momentum of movement forwards moves the COG in front of the BOS, which requires the BOS to move forwards to prevent a fall. The step needs to occur in a timely fashion to allow equilibrium to be reached before the COM and COG move too far forward to be compensated for.

In gait initiation, the role is to put the whole-body centre of mass in motion. This needs to be in the desired direction and toward the future stance foot. This strategy reduces the ML instability during the forthcoming single support, where the BOS is reduced to only one foot. The motor program of this strategy is with coordinated ankle and hip muscles activations and inhibitions [9].

Older adults limit their gait velocity to lessen momentum generation. This is a result of insufficient balance control or strength needed to dissipate momentum generated by faster gait velocity [3].

REACTION TO INSTABILITY

Most falls occur as a result of an inability to react appropriately to an imbalance and produce an effective compensatory response [9].

Postural control is achieved by continually positioning the body's COM over the BOS during both static and dynamic situations.

The sensory system gathers essential information about the position and orientation of body segments in space; the CNS integrates, coordinates, and interprets the sensory inputs and then directs the execution of movements; and the neuromuscular system responds to the orders provided by the CNS [10].

All postural control components undergo changes with aging. Deficits within any single component are not typically sufficient to cause postural instability, because compensatory mechanisms from other components prevent that from happening. However, accumulation of deficits across multiple components may lead to instability and eventually falls [10].

Falls relate to a failure of the postural control system (somatosensory inputs, central processing, musculoskeletal effectors) in responding to a postural challenge. We define a fall as "an unintentional loss of balance that leads to failure of postural stability" [10].

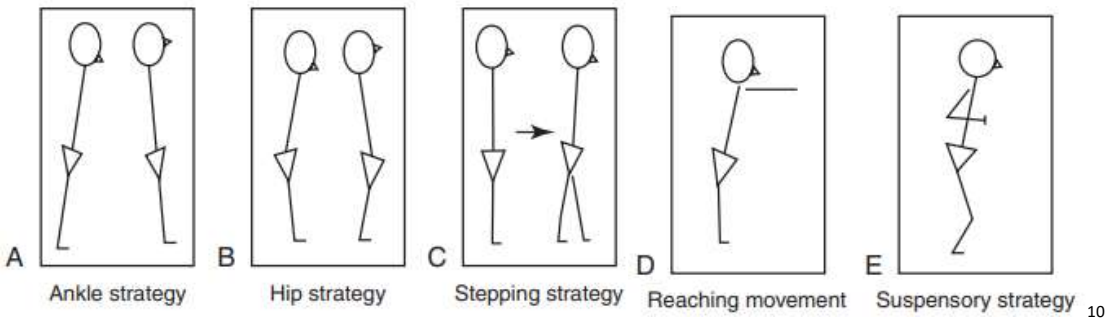
Older adults demonstrate ineffective early reactive postural responses due to slower onset latencies and smaller magnitudes of primary postural muscle responses which result in a longer time required to fully regain balance [3].

A second indication of reduced effectiveness is demonstrated in a longer duration of coactivating both legs. This reflects increased energy expenditure required to regain balance [3].

COMPENSATORY CONTROLS

Situations requiring balance can be classified into three general conditions: maintenance of a stable position, postural adjustment to voluntary movements, and reactions to external predicted and unpredicted perturbations (slipping or tripping). In dynamic stability, both the BOS and the COM are in motion. Prevention of falls requires effective balance function under dynamic conditions because most falls are caused by sudden motion of the BOS or by sudden acceleration of the COM [3].

Five basic strategies have been identified as responses to unexpected postural perturbations. The strategy elicited depends upon the amount of force created and the size of the BOS during the perturbation [10]:



[10]

When these strategies fail to recover the COM over the BOS within the persons limit of stability, a fall will occur.

ASSISTIVE TECHNOLOGY

Mobility aids increase the BOS during mobilisation. This allows for a greater movement of COM and COG, improving the limits of stability and thus decreasing risk of falls.

A mobility Aid allows for decreased MOS in the AP and ML directions and minimises the need for demanding compensatory controls.

Mobility aids can help prevent falls, not only in subsidising for unstable biomechanics, but increasing confidence and decreasing fear of falling.

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