A Kinesiology Guide for Riggers and Animators:

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Rigging often relies in anatomical studies and observation to draw conclusions and systems for realistic or stylized animated solutions. These two alone will often limit research, therefore animation and deformations, to superficial and less realistic results.

This research focuses on understanding Body Mechanics from a physiological point of view. The aim is to create a diagram that can summarize movements for the main joints of the body in a more natural and realistic way.

This document will illustrate the main joints of every complex, it's limits, it's range, it's pivots. It will as well define the main mass distributions when movement occurs. Coming from very technical research, it will try to be meet both technical and simple approaches in a in-between line.

It is important to underline that it is not a study about the muscular system, or the human skeleton. It is a study of the joints, that can be defined as a combination of this two systems, identifying the main elements that contribute to movement. Where is the movement originated from and how does it distribute itself over these the same elements.

As well we have to keep in mind that all the figures given here are what can be considered as "normality" in human adults, but these can vary greatly when dealing with different levels of elasticity or physiques (Chagas, 2011).

Now we should define a series of terms.
When we speak about joints we are referring strictly about the juncture between two or more bones. We will refer to more complex combination of joints as a complex. For example, the wrist complex is the union of the wrist joint and the radio-carpal joint.

Given that most of the movements we will be describing can be considered as rotations that originate from an pivot (joint), we will take a 3D gizmo and its axis as reference for movement. The Z axis will be defined as the main axis of rotation, Y as second, and X as the third. This way we can translate this information directly into a 3D environment, work with aliments and start considering Euler angle limitations and solutions.

However more technical terms will be used to describe movement, such as flexion and extension, pronation and supination, abduction and adduction, protraction and retraction, inclination and rotation. If interested the reader can investigate further given that in this paper they will self explanatory and no definition will be given to avoid technical deviations.

Also to describe our movements we need to define the planes where this occur.
The sagittal plane divides the body in left and right.
The frontal or coronal plane divides the body in dorsal and ventral (back and front).
The transverse plane (axial plane) divides the body in upper and lower portions (Sports Coach, 2011).

And we can define active movements as those who are muscle induced, whereas passive movements are induced by pressure or weight induced.

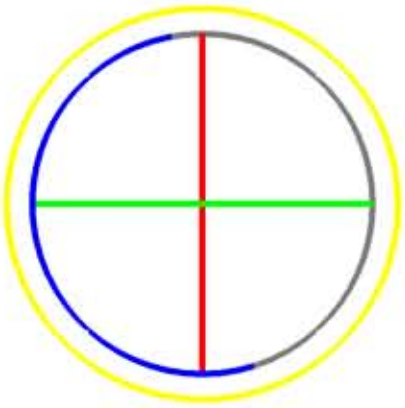
We will divide the Body in three main groups. The vertebral column and trunk, the upper limbs and the lower limbs. However the vertebral column is easier to illustrate if separated in neck and column. Which is our first chapter.

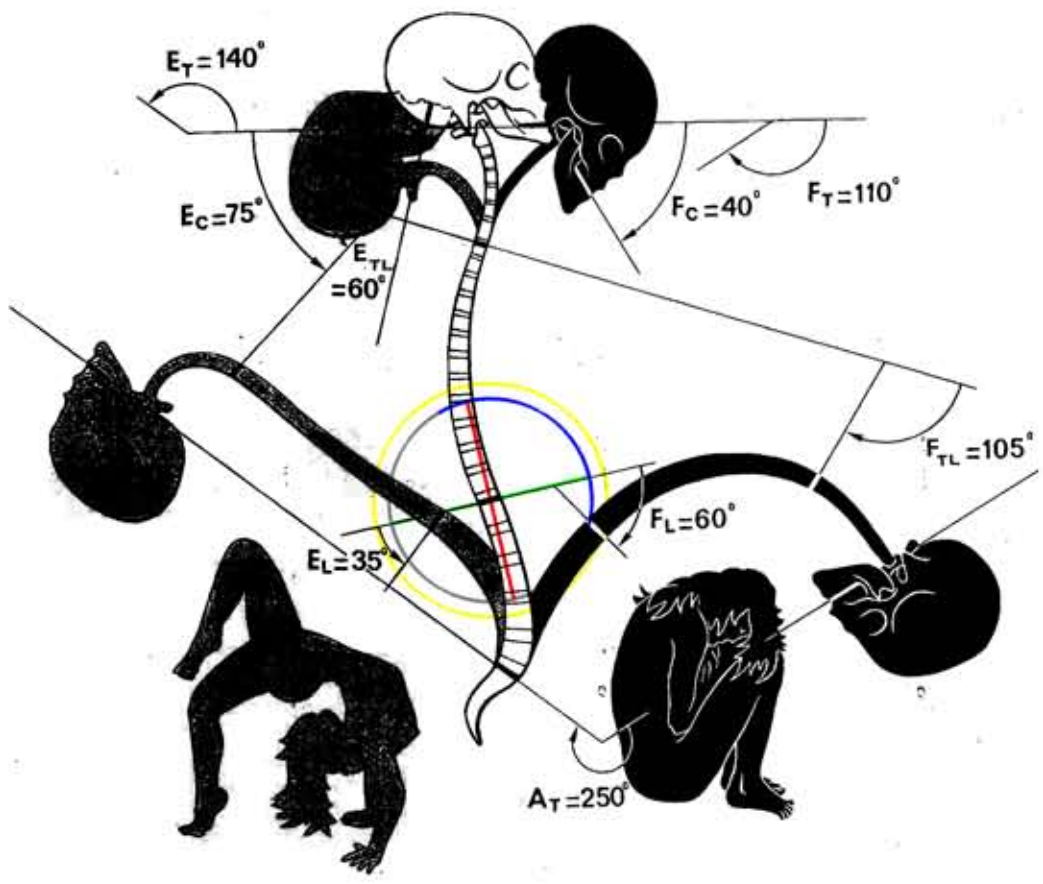
The Vertebral Column:

The first thing that we have to understand and clarify is that rotation in any axis as well as what we know as interpolation happens in a different way depending of the area of the spine we talk about.
The Spine can be dived in Cervical vertebrae, Thoracic vertebrae, Lumbar vertebrae and the Sacral and Coccygeal vertebrae (Altman, 2011).

As a whole the Vertebral Column from the Skull to the Sacrum has three degrees of freedom: Flexion and extension (Z), lateral right and right flexion (X) and axial rotation (Y) (Kapandji, 2008).
The order of this axis is given by the Euler angle limitations, we define the forward and backward rotation as our main axis, the axial rotation as our second, and "lateral bend" as our third, establishing XYZ as our rotation order, that will be maintained in the overall structure.

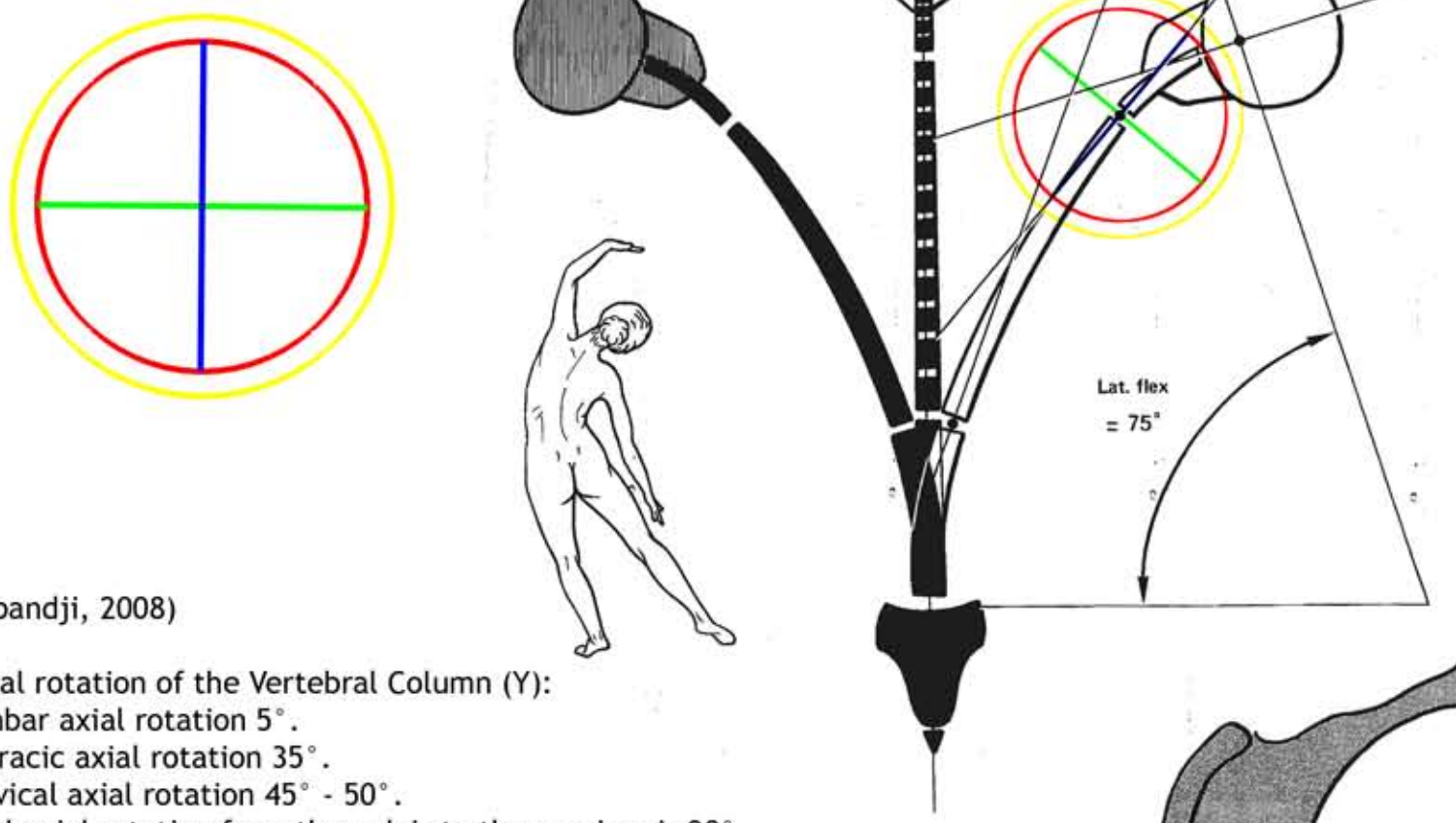
-The flexion and extension (Z) of the Vertebral Column equals 250 degrees and it is distributed over the whole structure as follows:
Lumbar: Flexion 60° - Extension 35°.
Thoraco-Lumbar: Flexion 105° - Extension 60°.
Cervical Flexion: 40° - Extension 75°.
Total rage of Flexion 110° - Extension 140°.





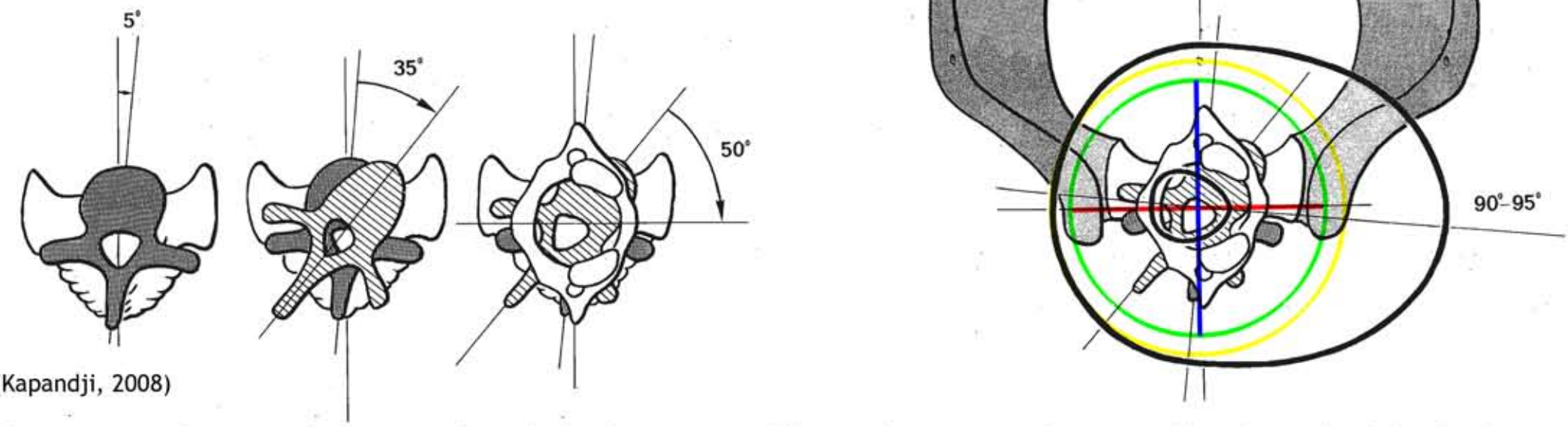
(Kapandji, 2008)

-Lateral flexion of the Vertebral Column (X):
Lumbar lateral flexion 20°.
Thoracic lateral flexion 20°.
Cervical lateral flexion (inclination) 35° - 45°.
Total lateral flexion from the sacrum to the cranium is 75° - 80°.



(Kapandji, 2008)

-Axial rotation of the Vertebral Column (Y):
Lumbar axial rotation 5°.
Thoracic axial rotation 35°.
Cervical axial rotation 45° - 50°.
Total axial rotation from the pelvis to the cranium is 90°.



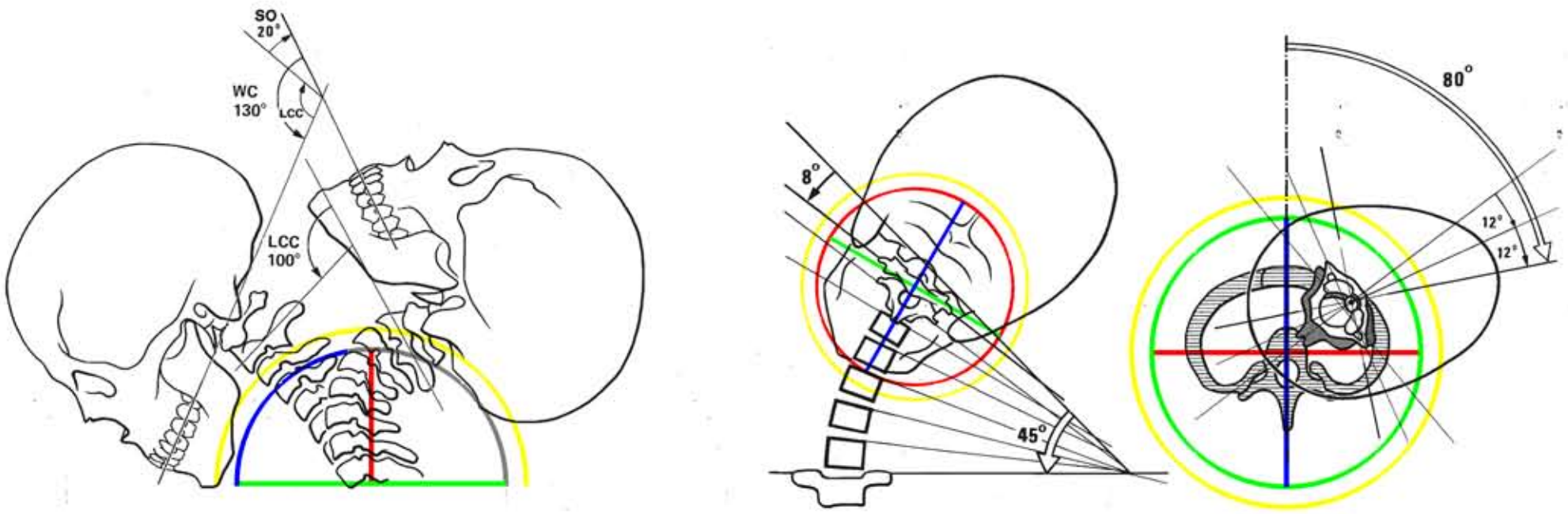
(Kapandji, 2008)

This summarizes the ranges of movement of Vertebral Column, an incredibly complex structure where we could analyze in detail, but for the interest of this research we will try to schematize as much as possible.

The Cervical Column deserves special attention firstly because it's behavior is different to the rest of the spine, and in both real life and animation is more visible due to its location (Chagas, 2011). Not only that but, in animation, it is "always" treated as a separated structure.

The Cervical Column is made by seven vertebrae, of which three are of our interest. The top vertebrae C-1 or Atlas, C-2 or Axis and C-7 or Prominens. The Prominens vertebrae is particularly interesting given it's prominent spinuos process, the high crest we feel in back bottom of our necks (Altman, 2011).

The movement of nodding (flexion and extension, Z), takes place predominantly in the atlanto-occipital joint (in-between the Atlas vertebrae and the occipital bone). Whereas the shaking (axial rotation, Y) takes place mainly in the atlanto-axial joint (in-between the Atlas vertebrae and the Axis vertebrae) (Kapandji, 2008).



(Kapandji, 2008)

Upper Limb:

In animation we isolate complexes, define the rotation axis and classify their ranges. This is a counter intuitive way of analyzing movement given that first, movement it's never really originated from the complex, and secondly as we have already clarified a complex is a far more complex collection of joints. This will be particularly evident in the shoulder and arm, where movement is an aggregation of mechanisms that we will now to schematize.

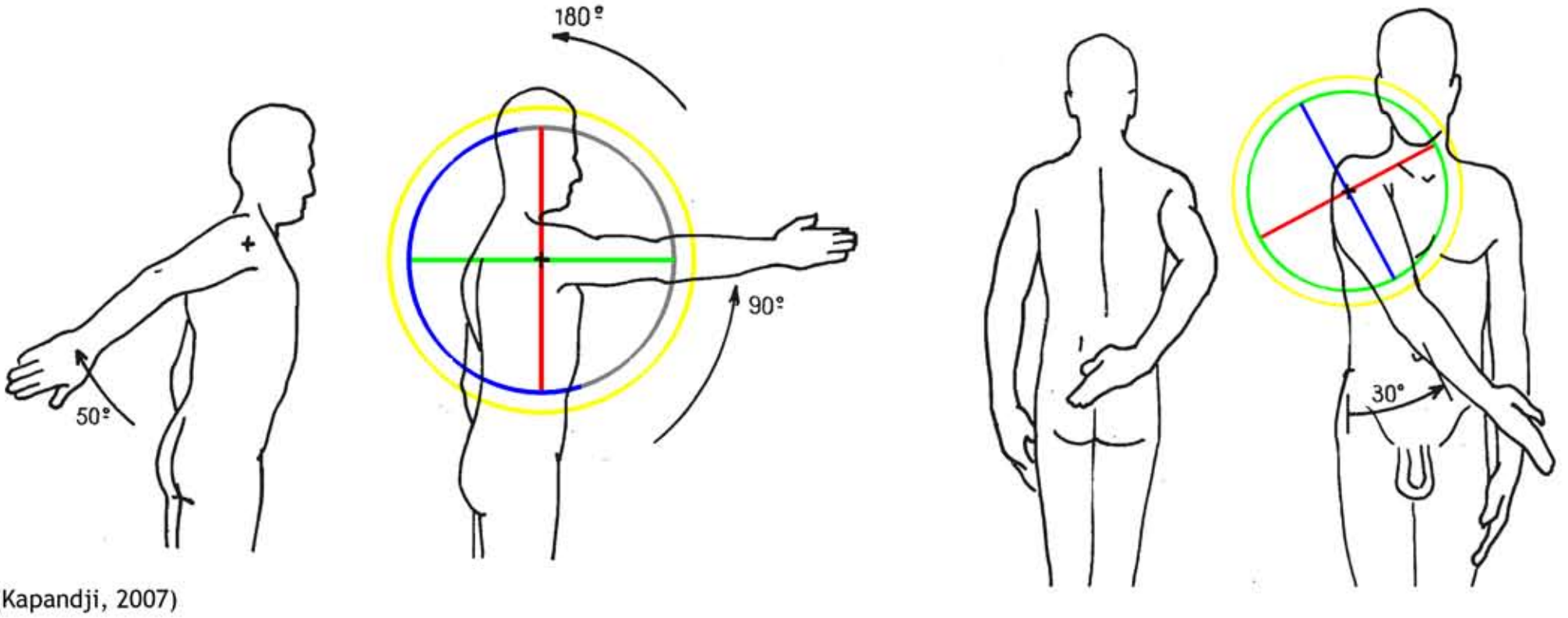
The Shoulder:

The Shoulder, the most mobile of the human joints, is made by the clavicle, the scapula and the humerus. At its end, the clavicle, attaches to the sternum in the Sternoclavicular joint. The Acromioclavicular joint is where the clavicle and the scapula meet, and the Glenohumeral joint is where the head of the humerus attaches to the scapula (Altman, 2011).

Before we describe the movements it is important to underline that these two last joints should exist in animation, as their pivot points are not in the same position, and their differentiation allows for a natural and more mature range of movements.
It is also safe to say that the shoulder movements that do not include the arm, pivot from the Sternoclavicular joint; that is their fixed point and from there the scapula, clavicle and arm position themselves. However after a short range most movements are compound movements of the three joints (Kapandji, 2007).

-Flexion and extension (Z on the Glenohumeral joint, X on the Sternoclavicular joint) and adduction (+Y on the Glenohumeral joint) over saggital plane and transverse axis:
Extension 45° - 50°.
Flexion up to 180°. (Flexion can also be defined as abduction at 180° in axial rotation).

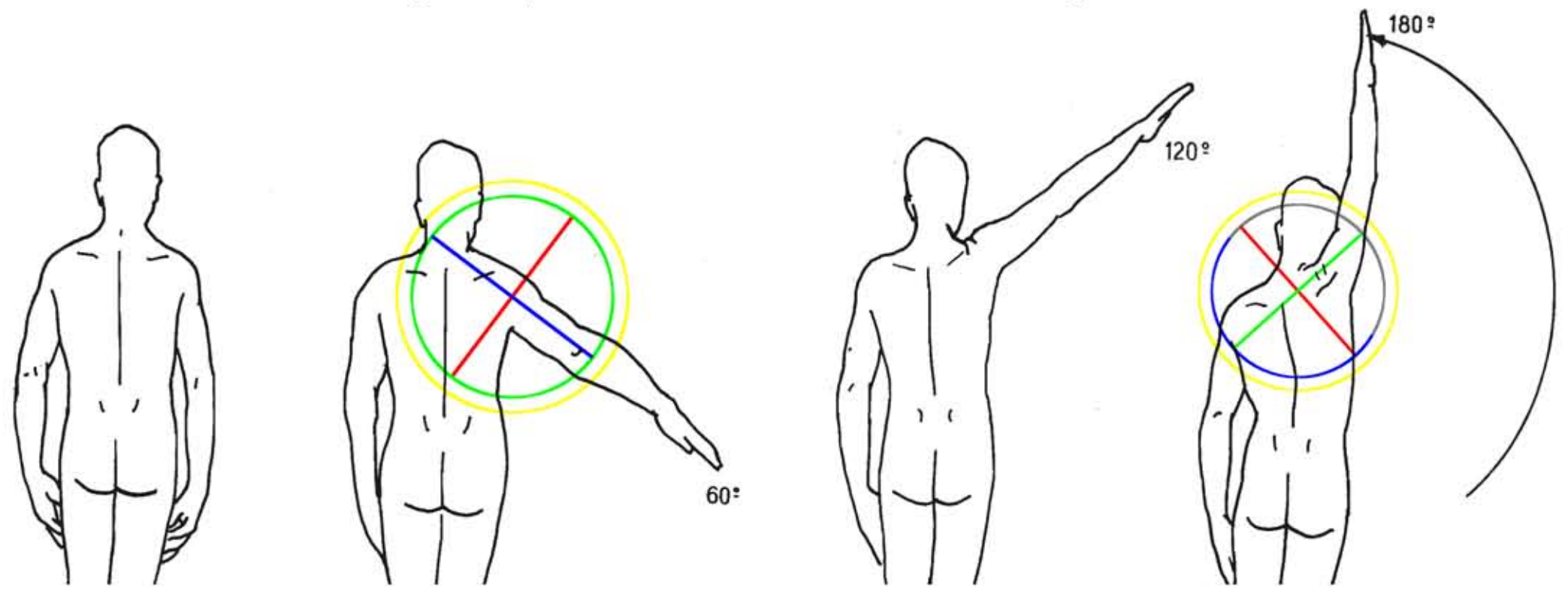
-Adduction starting at a reference position is impossible due to the presence of the trunk. It is therefore possible only if combined with:
Extension, allowing a trace of adduction.
Flexion and adduction 30° - 45°.



(Kapandji, 2007)

-Abduction (-Y on the Glenohumeral joint, and Z on the Sternoclavicular joint) is the movement away from the trunk, that takes place in the frontal plane, and at a full 180° angle will place the arm vertically above the trunk.
The final position of abduction at 180° can also be attained by flexion to 180°.

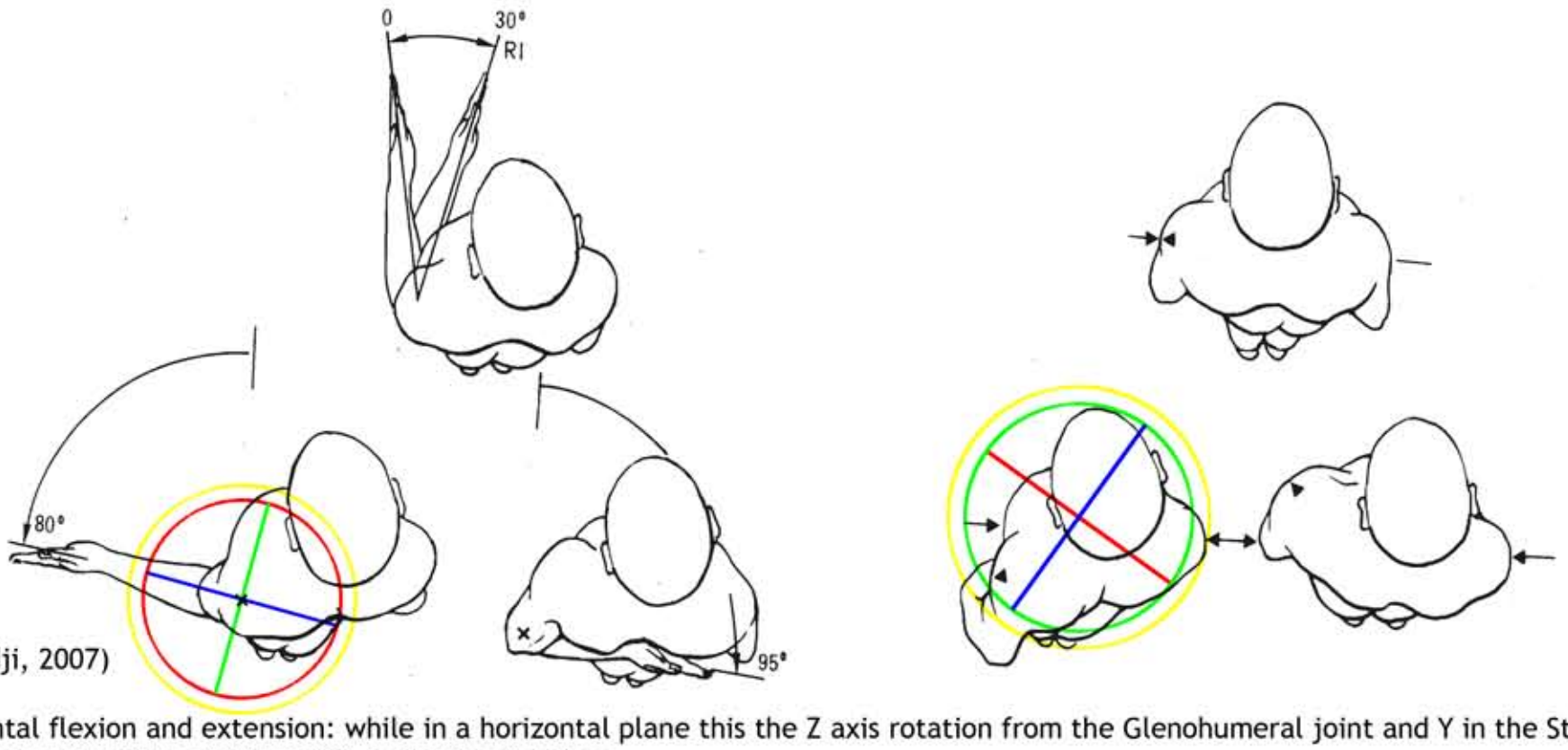
There are three phases to abduction:
From 0° to 60° movement takes place in the Glenohumeral joint.
From 60° to l20° the Sternoclavicular joint is required (the scapula rotates by 60°, Acromioclavicular and Acromioclavicular contribute by 30° each).
From l20° to 180° the Sternoclavicular joint is required and the so the flexion of the trunk to the opposite side.



(Kapandji, 2007)

-Axial rotation of the arm is the rotation of the arm about its own axis. We can identify it as X rotation from the Glenohumeral joint. Having the arm alongside the body the ranges are:

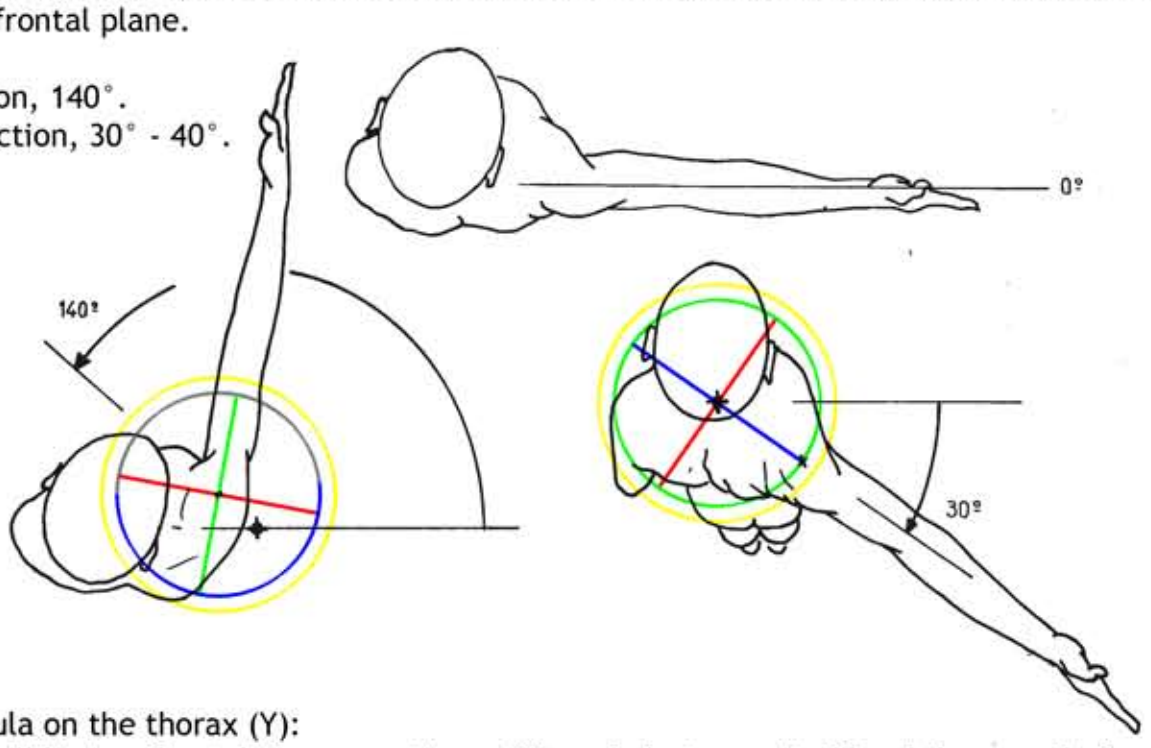
Lateral rotation up to 80°.
Lateral internal rotation up to 30°, after which movements becomes a compound of movement.
Medial rotation up to 100° (by passing the forearm behind the trunk).



(Kapandji, 2007)

-Horizontal flexion and extension: while in a horizontal plane this the Z axis rotation from the Glenohumeral joint and Y in the Sternoclavicular joint. Our reference position starts at 90° in the frontal plane.

Horizontal flexion, associated with adduction, 140°.
Horizontal extension, associated with adduction, 30° - 40°.
Giving an overall range of 180°.



(Kapandji, 2007)

Movements of the Scapula:

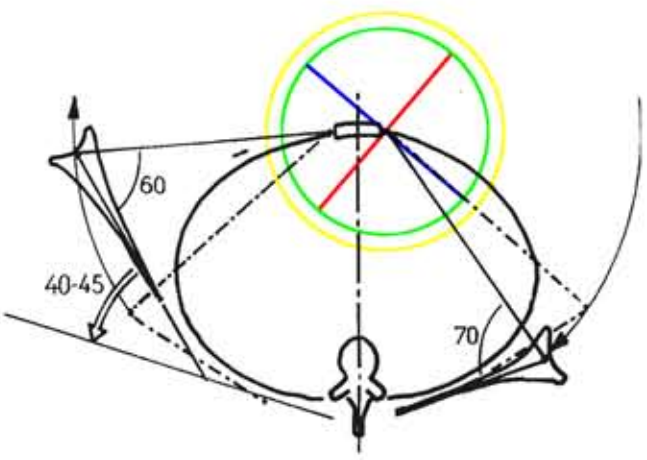
-Medial and lateral movements of the scapula on the thorax (Y):
When have a +Y rotation of the clavicle it will lie in a frontal plane creating a 70° angle between itself and the scapula from the Acromioclavicular joint.
When have a -Y rotation this same angle will close to 60° from the Acromioclavicular joint, making the scapula slide in 40° - 45° from its original plane (Kapandji, 2007).

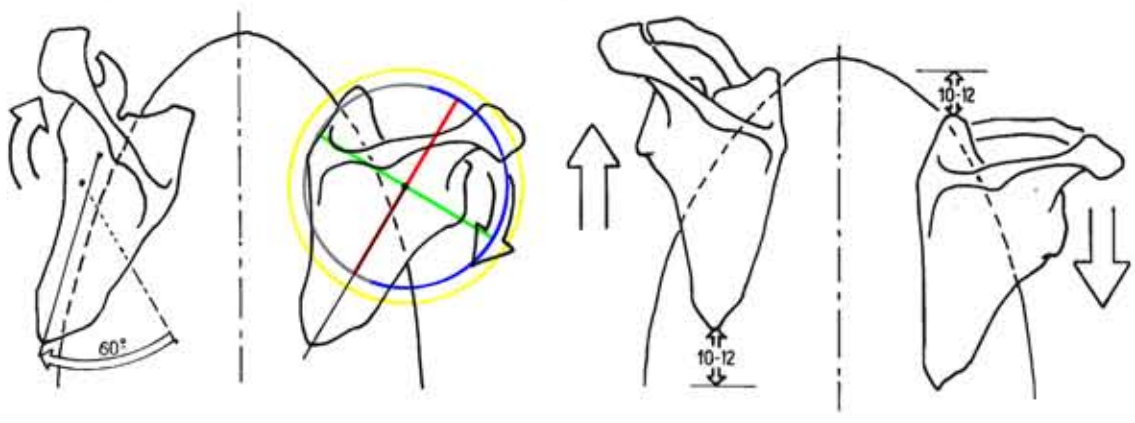
-Medial and lateral movements around the thoracic cage:
Medial displacement.
Lateral displacement.
The total range of this movement is 15 cm.

-Elevation and depression of the scapula (Z):
Depression.
Elevation.
Total range of movements 10 - 12 cm and it is directly associated with tilting.

-Tilting or rotation of the scapula (Z + Y Glenohumeral rotation):
It occurs on a axis perpendicular to the plane of the scapula, below the spine.

Downward rotation, tilting on -Z from its internal axis towards the outside.
Upward rotation, +Z from its internal axis towards the inside.
With a total range of movement 60°.
The inferior angle can displace from 10 - 12 cm and the supero-lateral angle 5 - 6 cm.





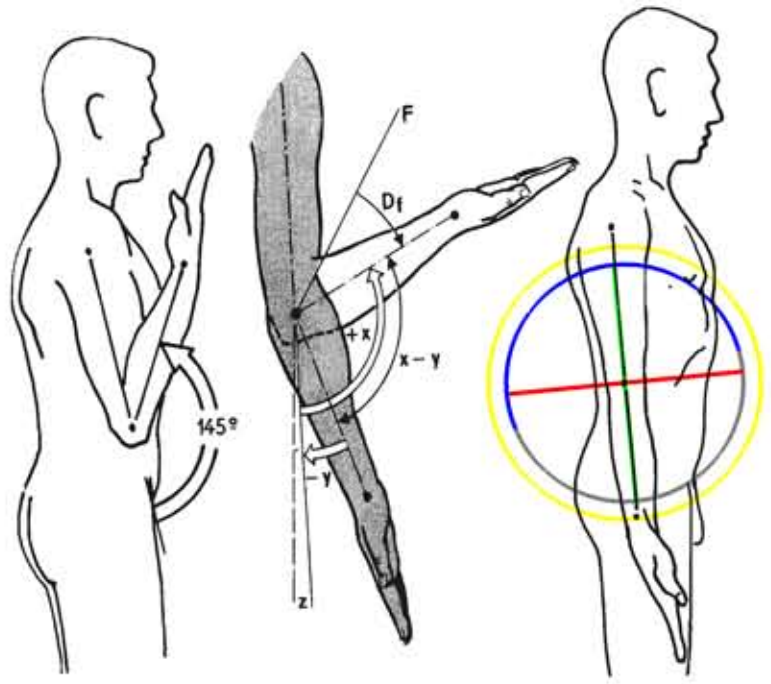
(Kapandji, 2007)

The Elbow:

The elbow is a combination of three joints, but in terms of our study we can group them into one single complex, that has the possibility to do flexion and extension (Z), pronation and supinantion (X). As we saw on the shoulder the Y rotation is derived from Glenohumeral and, although we have a few degrees of freedom while our arm is bent, we have no muscles for this movement that will be completely blocked in extension (Kapandji, 2007).

-Flexion and extension (Z):
Our reference position will be defined when the arm and the forearm are in a straight line.
Therefore we can see that being at its maximum, extension is 0°, except in hyperflexible cases 5° - 10°.
Flexion has a range of 145°.
But if the wrist is separated from the shoulder it can reach 160°.

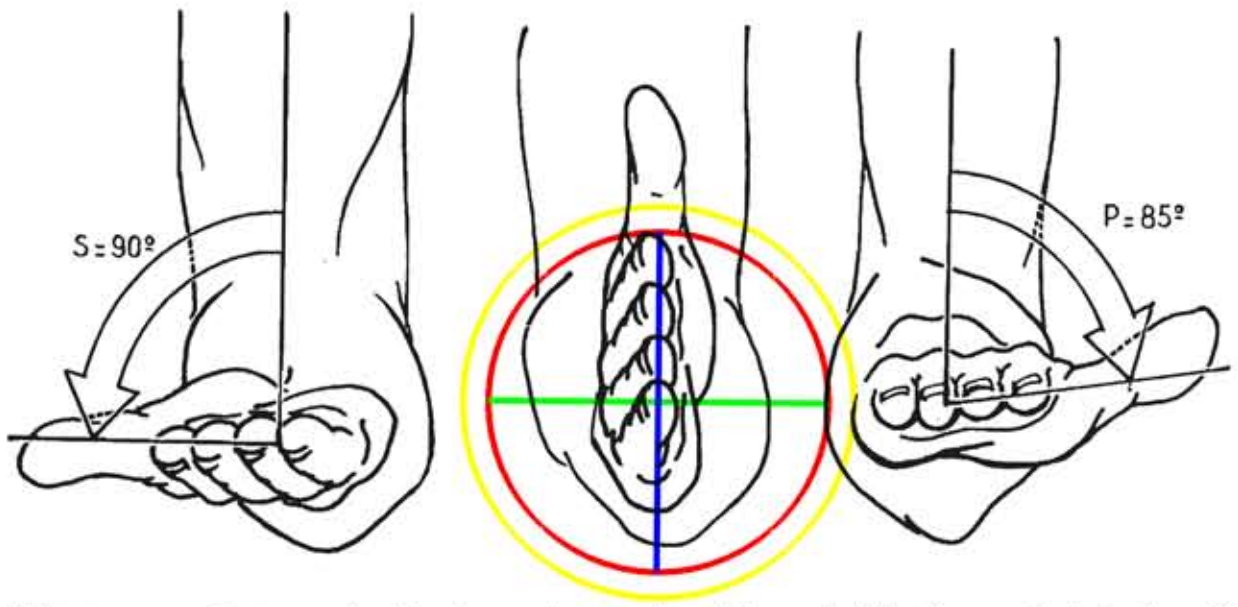
It is important to underline that the elbow complex does not naturally align the shoulder, elbow and wrist when flexed. It will in fact bend naturally over the chest, and we need muscular compensation to be aligned to the shoulder (Chagas, 2011). If we where to offset the axis of arm and forearm we would get a more immediate natural result in movements and a more accurate range.



(Kapandji, 2007)

-Supination and pronation (X) is given by the rotation of the radius and the ulna, and it happens along the whole length of the forearm. With our reference position having the elbow flexed to right angle and the thumb facing up the ranges are:
Supination (palm up) 90°.
Pronation (palm down) 85°.
Total rotation is around 180°.

However if shoulder rotation is included:
Limbs besides trunk 360°.
Limbs abducted at 90° range is 360°.
Shoulder flexed or extended at 90° range is 270°.
Upper limb lies vertically in abduction 180°.



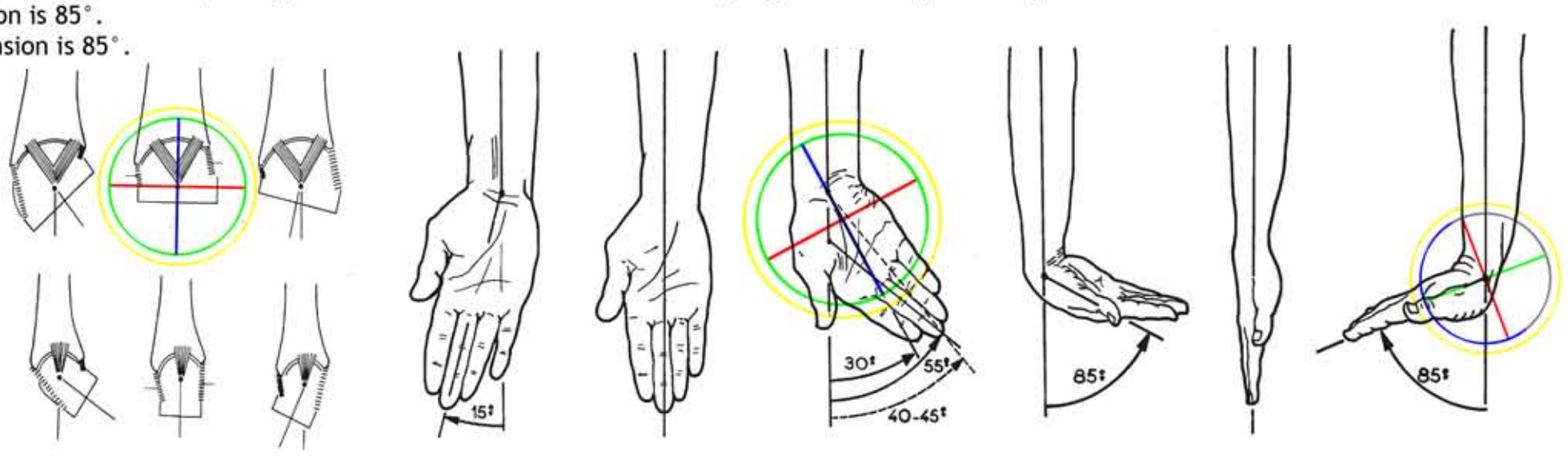
(Kapandji, 2007)

The Wrist:

The wrist is a combination of two joints that have the ability to move in two axis. Flexion and extension (Z), and adduction and abduction (Y). And again following the elbow, we can now see how there is no pronation or supination (X) in the wrist, but it is derived from the forearm rotation (Kapandji, 2007).

-Adduction and abduction can be viewed as a compound movement of the wrist and fingers. And its pivot lies in the middle of the hand on the mid-carpal joint.
Taking a reference position when the middle finger, the third metacarpal and the axis of the forearm are collinear, we can establish the following ranges:
Abduction 15°.
Adduction 45°.

-Flexion and extension, taking the same reference as before and aligning as well the posterior part of the hand with the surface of the forearm:
Flexion is 85°.
Extension is 85°.



(Kapandji, 2007)

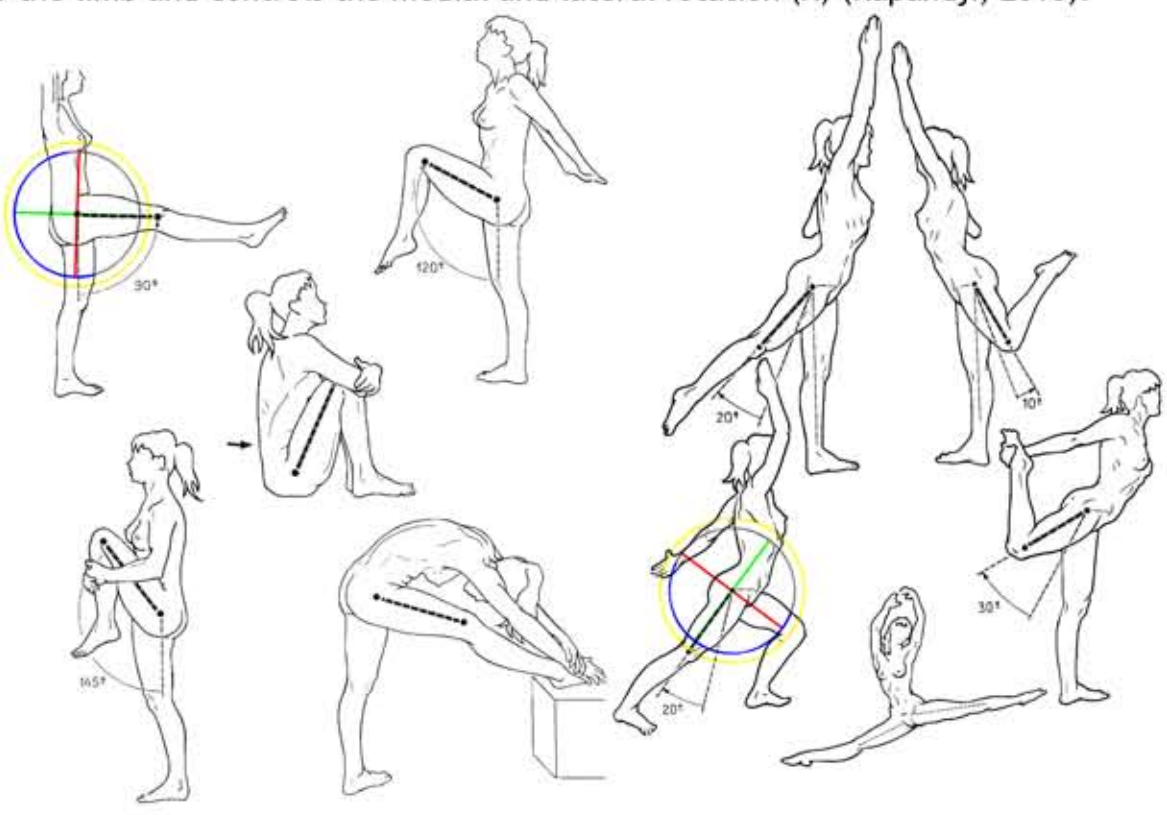
Lower Limb and the Hip:

The lower limbs are again a combination of joints, that similarly to the shoulder do not reside in the same position as we often sum up in animation. It is important for us to understand their positions and separate ranges to achieve more accurate results or consciously disregard them.

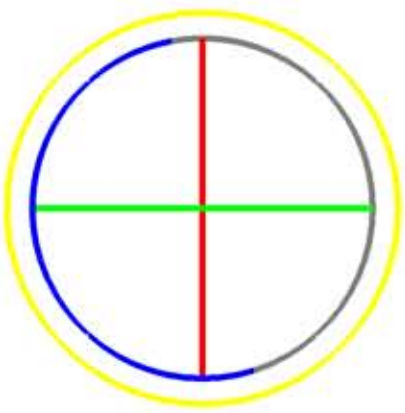
The Hip:

The hip has three degrees of freedom and allows the lower limb to assume any position in space. This movements occur in the coxo-femoral joint, which contrary to the shoulder is an "open" ball-and-socket joint allowing greater freedom.
Flexion and extension in the transverse axis in a frontal plane (Z).
Adduction and abduction in an anteroposterior axis lying in the saggital plane (Y).
And rotation on the vertical axis, which coincides with the axis of the limb and controls the medial and lateral rotation (X) (Kapandji, 2010).

-Flexion (-Z) varies according to the following conditions:
With the knee extended 90°.
With the knee flexed 120°.
Passive flexion is dependent of the knee as well but can reach and exceed 140°.



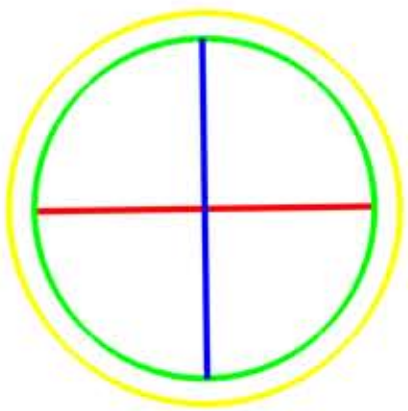
-Extension (+Z):
When the knee is extended 20° or more.
When the knee is flexed 20° given that the hamstrings will not allow further movement.
Passive extension reaches 30° when the limb is pulled back.



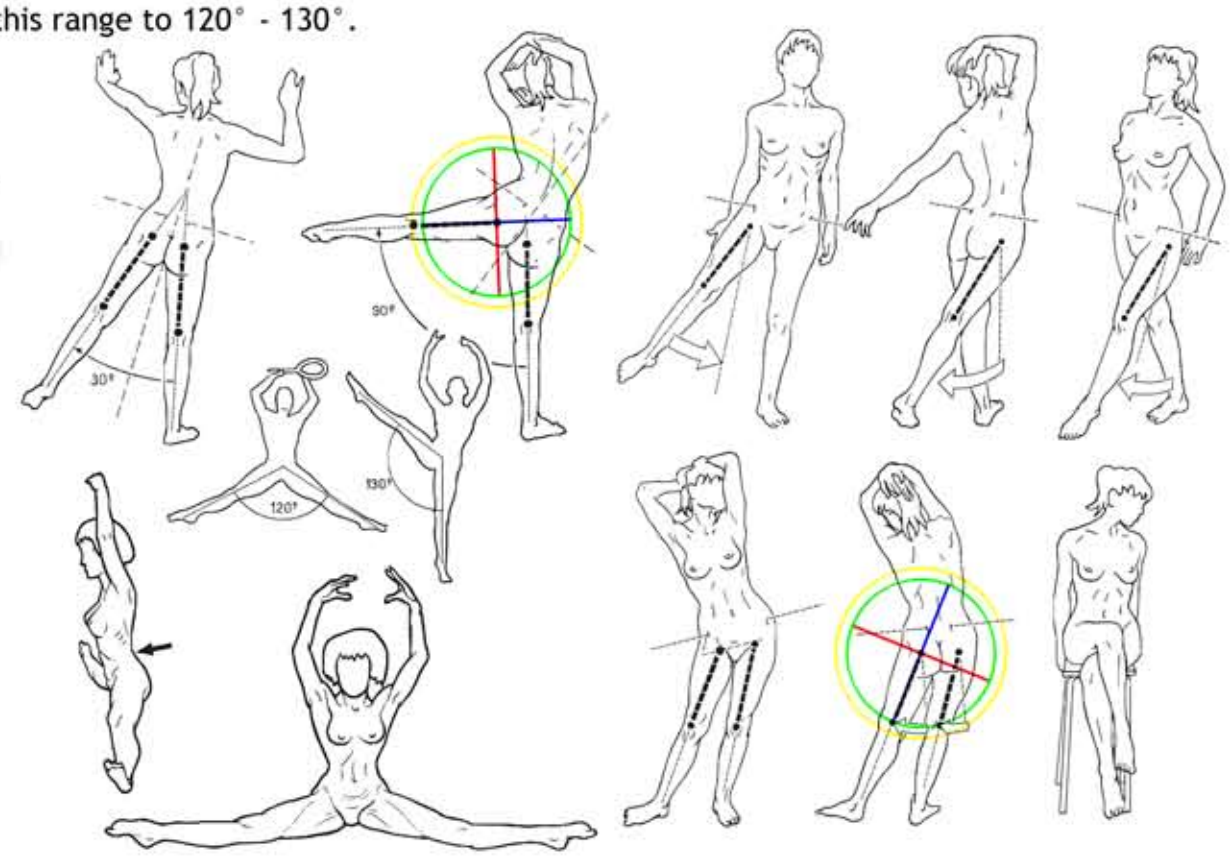
(Kapandji, 2010)

-Abduction (-Y) can happen independently for each limb but it is obvious that it is a complementary movement. As we can clearly see when we abduct over 30°, and the rotation is distributed by 15° in each joint.
Abduction at its maximum creates a right angle in between the two limbs, distributing the rotation at 45° each and tilting the pelvis at 45°, with further compensation of the vertebral column.
It is important to underline that hyperflexibility can extend this range to 120° - 130°.

-Adduction (+Y) is not possible if both limbs are in contact, but if one limb abducts the other one will compensate by adducting, or it can occur by combining extension or flexion.
The maximum range is 30°.

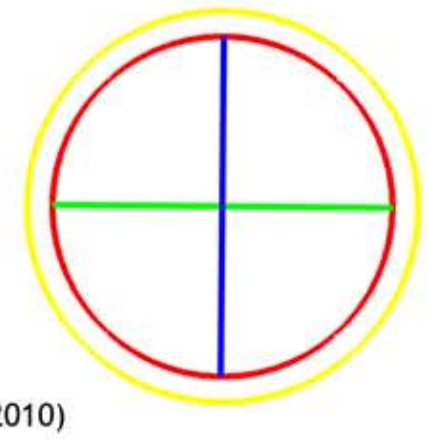


(Kapandji, 2010)

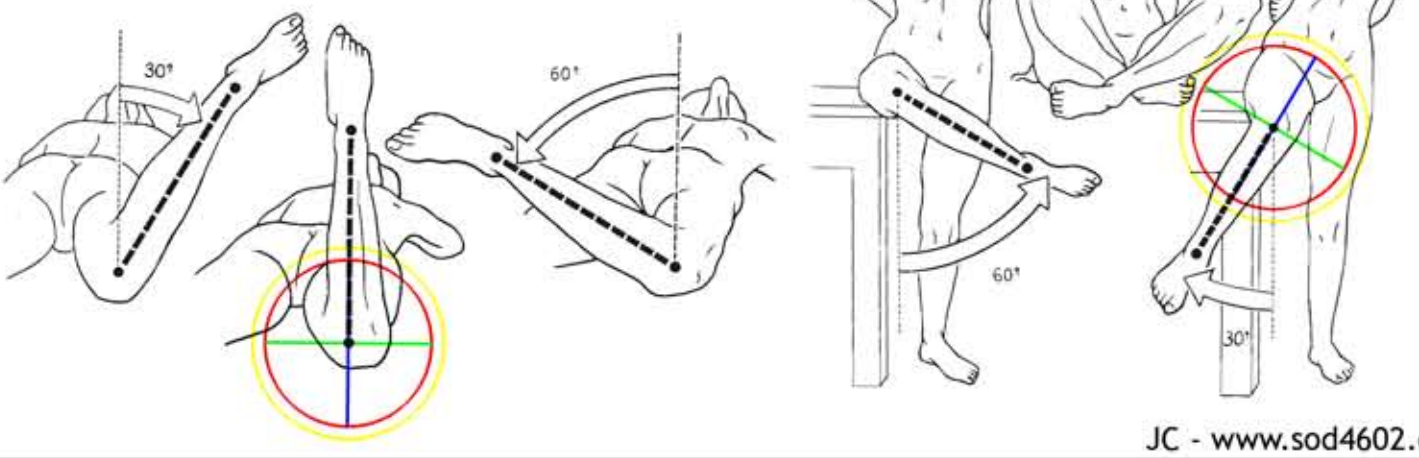


-Rotation of the hip (X) can be divided in lateral rotation, when the limb brings the toes to face outwards, and medial rotation, when the toes are brought inwards. We can take our reference pose when the knee is flexed to 90°.

If the person is lying prone:
Medial rotation 30° - 40°.
Lateral rotation 60°.
If the person is sitting medial rotation can be grater because the ilio and pubofemoral ligaments are relaxed.
While squatting lateral rotation combined with abduction can exceed 90°.



(Kapandji, 2010)



The Knee:

The knee has two degrees of movement, flexion and extension on the saggital plane (Z), and axial rotation (X) (Kapandji, 2010).

-Flexion and extension:

The three complexes, hip, knee and ankle lie on a straight line, which is the mechanical axis of the lower limb. The leg follows this angle but the thigh forms a 6° angle given the offset created from the head of the femur to the knee.

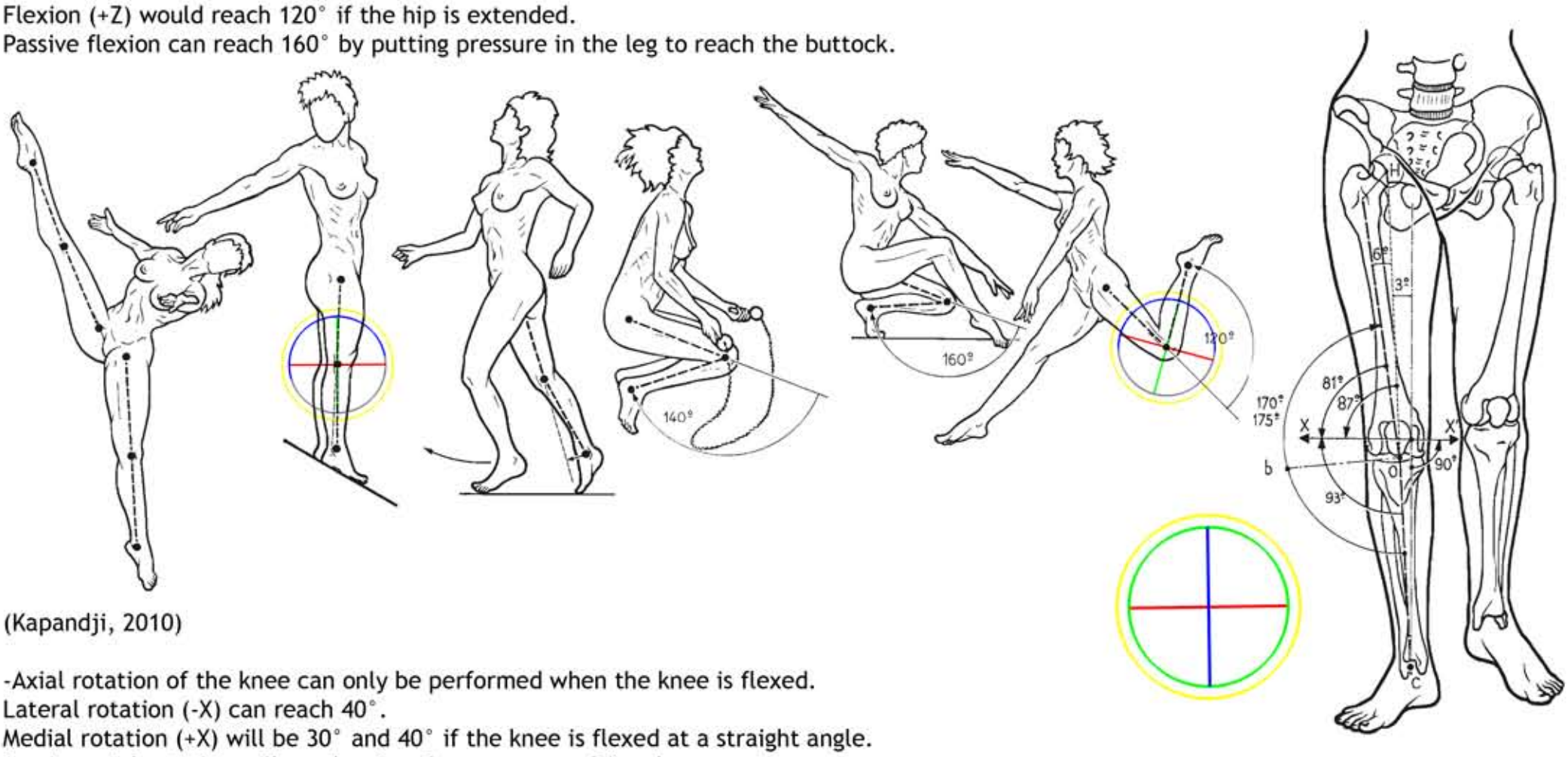
Given that the hips are further apart than the ankles the lower limbs run obliquely creating 3° angle. Therefore over the flexion and extension axis, which is horizontal, the angle of the femur is 81° and the leg is 93°.

There is no extension (-Z) given that the reference position is at maximum extension. But there can be 5° - 10° of extension in hyperflexible cases.

Flexion (+Z) can reach 140° if the hip is flexed.

Flexion (+Z) would reach 120° if the hip is extended.

Passive flexion can reach 160° by putting pressure in the leg to reach the buttock.



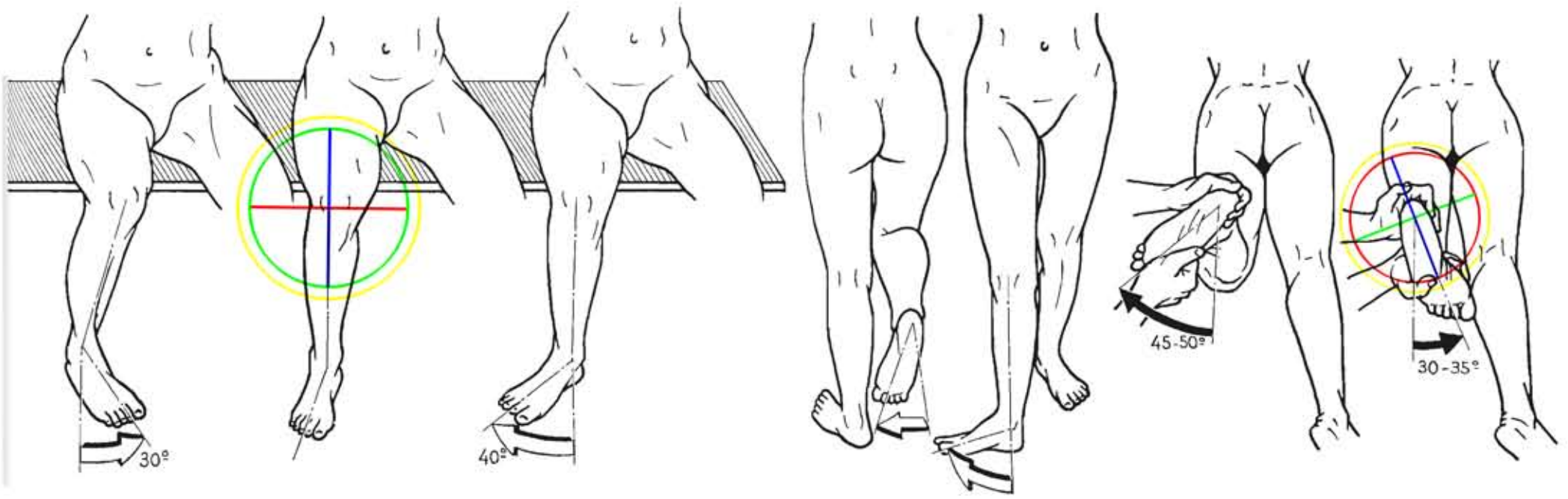
(Kapandji, 2010)

-Axial rotation of the knee can only be performed when the knee is flexed.

Lateral rotation (-X) can reach 40°.

Medial rotation (+X) will be 30° and 40° if the knee is flexed at a straight angle.

Passive axial rotation will reach a few degrees more of freedom.



(Kapandji, 2010)

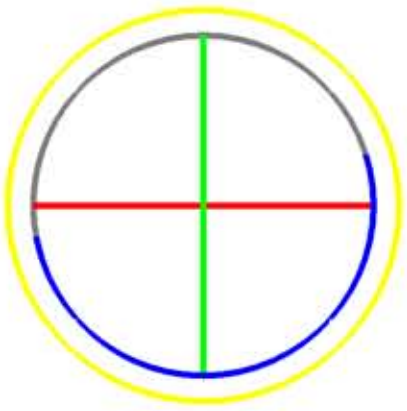
The last very important movement of the knee complex is that of the femur (condyles) over the tibial pleteau during flexion and extension. This is a compound movement of rolling and sliding, where the roll begins without sliding and progressively the sliding becomes more pronounced, until the roll finally disappears and only sliding takes place.

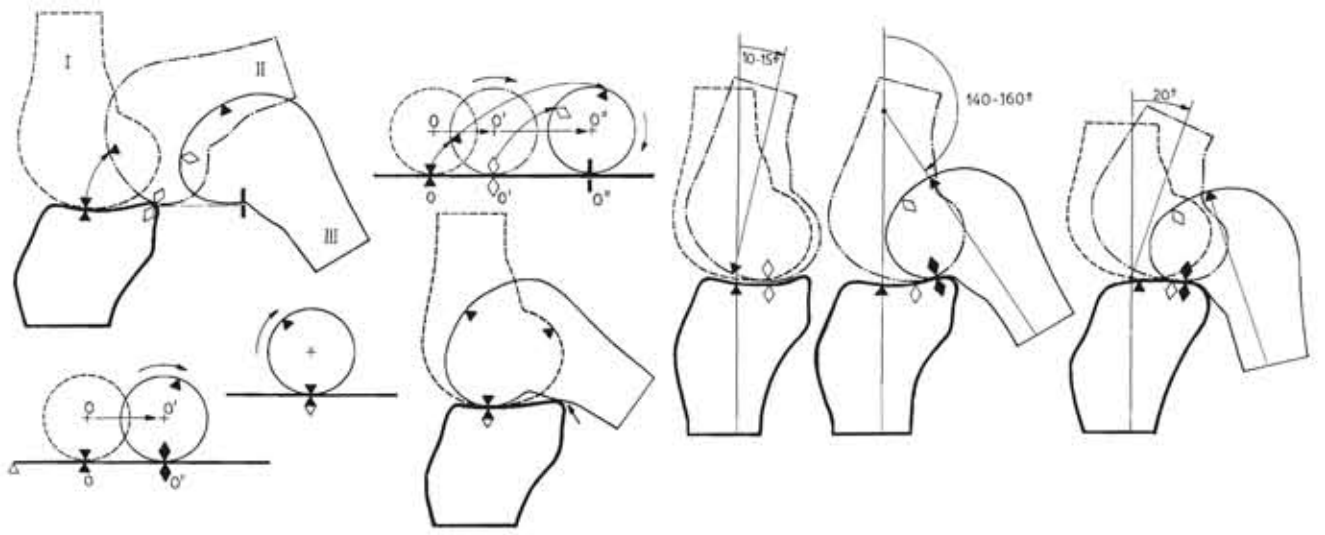
Differentiating outer (lateral) condyle and medial (inner) condyle:

Medial condyle has rolling during the first 10° - 15° of flexion.

Later condyle has rolling until 20° of flexion.

Therefore we can condense the rolling for the knee complex in around 20°.





(Kapandji, 2010)

The Ankle:

Three degrees of rotation intersect in the posterior half of the foot. On the frontal plane, flexion and extension over the saggital plane (Z), on the transverse plane, adduction and abduction possible because of the axial rotation of the flexed knee (Y) and on the saggital plane as well, controlling the movement of the sole, pronation and supinantion (X) (Kapandji, 2010).

-Flexion and extension, taking into account a reference position where the sole of the foot is perpendicular to the leg, this are the ranges:
Flexion 20° - 30°.
Extension 30° - 50°.
If this angles are pushed the tarsal joints are involved in the rage of movement.

(Kapandji, 2010)

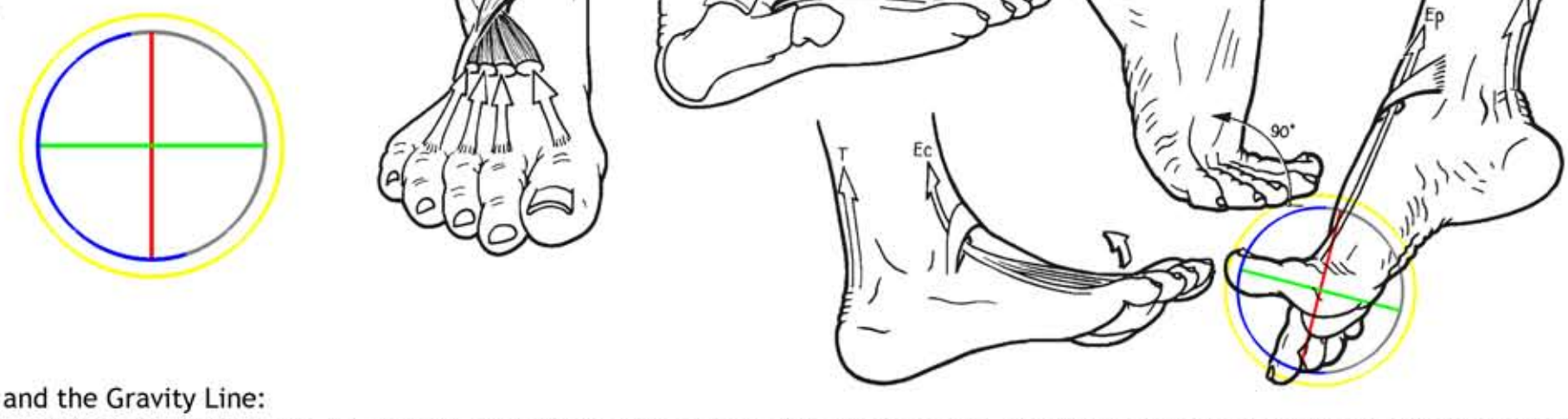
The Foot:

The most important joints of the foot are the talocalnean or subtalar, the midtarsal, the tarsometatarsal and the cuneonavicular joint, who have a dual function (Altman, 2011). They orientate the foot over the Y and X axis (having the ankle lead the Z) and they vary the shape of the foot so it can adapt to surfaces (Kapandji, 2010).
The total range of adduction and abduction would be 35° - 40° (90° in extreme cases).
Supination 52°.
Pronation 25° - 30°.

To sum up these in a 3D environment about the foot, we can establish one or more pivots from which this axial rotation occurs, from the subtalar joint, passing through the midtarsal to the cubonavicular joints, to later affect the toes (Chagas, 2011).

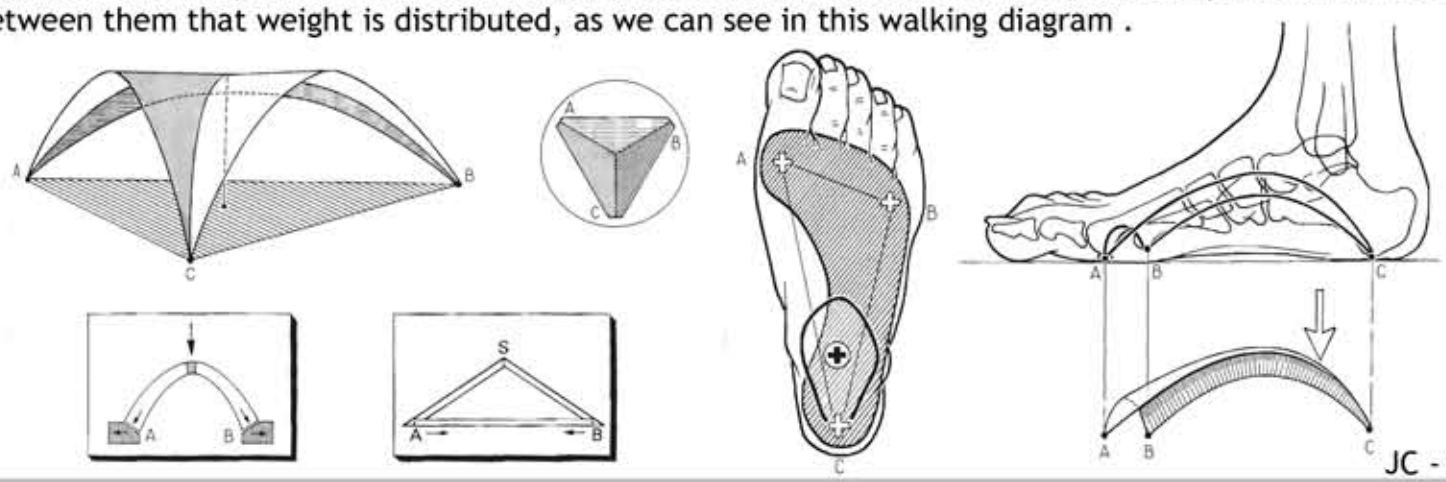
(Kapandji, 2010)

The metatarsophalangeal joint of the big toe, is indispensable while walking, that has been defined in 3d as “foot roll” while accompanied by the interphalangeal joints.
-The the toes has the following ranges:
Active extension 50° - 60°, while passive extension 90° or more.
Active flexion 30° - 40°, while passive flexion 45° - 50°.



(Kapandji, 2010)

The Plantar Vault and the Gravity Line:
The gravity line travels from the hip down, but it does not fall directly over the knee or the heel, it falls at the same level of the fifth metetarsal on the center of the foot. Meaning that the leg is in fact slightly rotated in a relaxed position (Kapandji, 2010).
The main aspect to understand about the plantar vault is that the foot's wait is concentrated in a tripod, created by the head of the main metatarsal, the head of the fifth metatarsal and the posteromedial and lateral tubercles of the calcaneus. These are the pivots that we can consider for animation purposes, for is it between them that weight is distributed, as we can see in this walking diagram .



(Kapandji, 2010)

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* This selected reference was a series of interviews I conducted in the month of April 2011 with Physiologist Laylane Chagas www.physio-postureclinic.co.uk. In these meeting Laylane and I discussed Biomechanics from a medical point of view, and also oriented to understand particular animation problematic. It is the main reference in my research where all the information gathered from other sources was discussed and analized.