CHARLES UNIVERSITY IN PRAGUE

Faculty of Physical Education and Sport

DIFFERENCES IN POSTURAL ACTIVITY DURING QUIET STANDING WHEN BREATHING ABDOMINALLY

Master's Thesis

Supervised by:

doc. PaedDr. Dagmar Pavlů, CSc.

Submitted by:

Bc. Sebastjan Gantar

Prague, March 2016

Abstract

Title:

Differences in postural activity during quiet standing when breathing abdominally.

Aim and purpose:

Aim of this study was to examine the effects of abdominal breathing on selected muscles and stability during quiet standing to find empirical evidence if it can reduce the strain and change the activity pattern, which erect standing demands from the muscles.

Methods and materials:

This thesis begins with an introduction to theoretical part in which we gathered all the already existing and written information needed to form the knowledge base for our experiment. Continuing in 9th chapter, methodology and experiment procedure are described where we measured muscle activity using surface EMG and to monitor changes in stability we used force-plate for posturography where only linear parameters were acquired. Both devices were used simultaneously while the subject was in quiet stance for a period of 90 seconds.

Results:

Results shown decrease in most of the muscles, with a higher increase in body sway in medio-lateral than in antero-posterior direction. Signal didn't change to a more distinct wave-like pattern of rhythmic oscillations, as we had thought it would.

Keywords:

Posture, quiet standing, abdominal breathing, diaphragm, system interrelation, EMG, posturography

Abstrakt

Název:

Rozdíly v posturální aktivitě během klidného stání při abdominálním dýchání.

Cíl a účel:

Cílem této studie bylo zkoumat účinnost břišního dýchání u vybraných svalů a stabilitu při klidném stoji. Hledaly se empirické důkazy, zda to může snížit námahu a změnit jeho schéma aktivit, který si vzpřímený postoj nárokuje ze svalů.

Metody a materiály:

Tato práce začíná úvodem do teoretické části, kde jsme shromáždili všechny již existující a písemné informace potřebné k vytvoření znalostního základu pro experiment. V deváté kapitole jsme popsali metodologii a experimentální proceduru. Experiment spočíval v měření aktivity svalů s použitím povrchového EMG a pro sledované změny ve stabilitě byla použita silová deska pro posturografii, kde byly pořízeny pouze lineární parametry. Oba přístroje byly použity zároveň, zatímco subjekt setrval 90 sekund v klidném stoji.

Výsledky:

Výsledky uvádí snížení aktivity ve většině svalů s vyšším vychylováním v mediolaterálním než anterioposteriorním směru. Signál se nezměnil na výraznější vlny rytmických oscilací, které by vypadaly jako vzorové pro klidný stoj, jak jsme původně předpokládali.

Klíčová slova:

Držení těla, klidný stoj, břišní dýchání, bránice, vzájemné systémové vztahy, EMG, posturografie.

I declare that this master thesis has been developed and written solely by myself and that it has not been submitted in any previous application for a degree. Except where stated otherwise by reference or acknowledgment, the work presented is entirely my own.

The work was done under the guidance of professor doc. PaedDr. Dagmar Pavlů, CSc.

In Prague, ____________

Author's signature

____

CONTENTS

1 INTRODUCTION

Through evolution human beings have assumed an upright erect or bipedal posture. The term posture does not necessarily only mean erect standing in a static position but also can be recognized in many positions, therefore does not represent one static position only, but also captures a moment during dynamic movement. Even in a static quiet standing human body sways, where movement is not so obviously perceivable.

Body is not immune to changes, being sudden or during long term as a result of progress lasting for extended amounts of time; here we are talking about days, weeks and more. To avoid that, body strives to attain an optimal position to minimize overuse and deterioration, while also minimizing muscular work requirement, meaning it won’t put more effort to maintain a position than it is necessary. Therefore must be an optimal or ideal position where body achieves just that in its constant push against gravity in case of upright stance. Any kind of a whole body position, or posture, that does not in segmental organization fall into a group of optimally aligned elements is seen as wrong, or in long term pathological, and will result in structural disbalances and ultimately manifesting in pain.

In today’s clinical practice and for practical purposes, the assessment of posture usually presents one of the first steps in analysing someone’s body segment alignment. Through history various concepts have been developed of what the ideal upright position may be. For this reason, one of many quiet standing definitions is used to show us the model we want to attain. This predefined ideal posture is compared to the person under investigation where all the results of balance and disbalance can be observed.

Many mechanisms are utilized to maintain function and produce movement and they are all interconnected through a common network of bones, muscles, fasciae and ligaments. Most important segment for functional integrity is the abdominal part with the muscles surrounding it. Not only that this area is greatly responsible for maintenance of stable posture through its effect on the spine and pelvis, it is also set as pre-activating mechanism for the movement of other extremities. Repeatedly, it has been experimentally observed that the activation of the diaphragm, pelvic floor, abdominal and back muscles precede movement activity of the upper and lower extremities. Every movement in the segment is in this way transferred into the whole posture. Every movement manoeuvre includes transfer of stabilization through the insertionally roped regions into the whole body.

Control over skeletal muscles can be volitionally influenced, even on the muscles responsible for breathing. Breathing is a life sustaining activity common to us all, it is what we repeatedly do from partus to our last breath. Most important muscle in breathing is the diaphragm, also seen as the second most important muscle after the heart. With its contraction not only influences the flow of air coming to and leaving from the lungs, but also contributes in increase of the abdominal pressure which results in increased stability of the lumbar part of the spine. Diaphragm greatly reduces the work of other muscles and tension placed on ligaments, which can be in functional disbalance to maintain body in sufficient position or produce movement.

2 POSTURE

Elegance is achieved when all that is superfluous has been discarded and the human being discovers simplicity and concentration: the simpler and more sober the posture, the more beautiful it will be (Coelho, 2008).

Through evolution human beings have assumed an upright erect or bipedal posture. The ability to stand upright on two feet is important in and of itself or as a precursor to initiation of other activities of daily living. This ability acquired early in life is performed automatically (Winter D. , Patla, Prince, Ishac, & Perczak, 1998). The advantage of an erect posture is that it enables the hands to be free and the eyes to be farther from the ground so that the individual can see further ahead. The disadvantages include an increased strain in the spine, pelvis and lower limbs, reduced stability and comparative difficulties in respiration and transport of the blood to the brain, increasing the work of the heart (Magee, 2014) (Levangie & Norkin, 2001).

Over the past two centuries it has come to define a wide range of assumptions in the West from what makes human beings human (from Lamarck to Darwin and beyond) to the efficacy of the body in warfare (from Dutch drill manuals in the 17th century to German military medical studies of soldiers in the 19th century). Dance and sport both are forms of posture training in terms of their own claims. Posture separates 'primitive' from 'advanced' peoples and the 'ill' from the 'healthy.' Indeed an entire medical sub-specialty developed in which gymnastics defined and recuperated the body. But all of these claims were also part of a Western attempt to use posture (and the means of altering it) as the litmus test for the healthy modern body of the perfect citizen (Gilman S. L., 2014).

The postures we assume provide clues to not only the condition of our bodies - traumas or injuries old and new, and mild or more serious pathologies - but also how we feel about ourselves - our confidence (or lack of it), how much energy we have (or are lacking), how enthusiastic (or unenthusiastic) we feel, or whether we feel certain and relaxed (or anxious and tense). Intriguingly, we all almost always adopt the same posture in response to the same emotions (Johnson, 2011). Body usage – good and bad – is a representation of mood, feelings, and personality (Bond, 2006).

2.1 DEFINING POSTURE

Posture is understood to be an active holding of the body's movement segments against the acting of external forces from which, in everyday life, gravitational force seems to have the greatest significance. Posture depends on the gravity system (Newton, 1997). Posture is not just a synonym to erect standing on two extremities or to sitting, which is how it has most frequently been presented, but it is a part of any position (for example, in an infant, the erect head position while laying prone or lifting lower extremities against gravity while in supine) and, most of all, of every movement. Posture is the main component required for movement and not vice versa. Even Rudolf Magnus wrote "*posture follows movement like a shadow*" (Kolar, 2013). We cannot separate posture from movement or activity from how we stabilize our bodies in order to act. How we stabilize ourselves determines our posture and the freedom, efficiency, and grace with which we move. The essence of posture is the unique way in which each of us negotiates between moving and holding still in relationship to gravity (Bond, 2006).

Posture can be either static or dynamic. Static posture – when the body is stationary – with its segments aligned and maintained in certain positions and is affected by both changes in load distribution across joints and resting muscle length. Such postures include standing, sitting, kneeling and lying. Dynamic posture - body position during movement - can give information about body segment alignment, muscle actions, and motor skill. Typical dynamic postures are walking, running, jumping, and lifting. An understanding of static posture forms the basis for understanding dynamic posture. Good posture is therefore effortless, non-fatiguing, and painless when the person remains erect for reasonable periods. Muscles function most efficiently in such an alignment, and the joints are optimally positioned (Norris, 2008) (Levangie & Norkin, 2001).

Posture, which is the relative disposition of the body at any one moment, is a composite of the positions of the different joints of the body at that time. The position of each joint has an effect on the position of the other joints. Correct posture is the position in which minimum stress is applied to each joint. Any static position that increases the stress to the joints may be called faulty posture (Magee, 2014).

2.2 EXAMINATION - COMPARISON TO THE IDEAL

Structural examination is a static observation of the patient. This is an extremely important part of the total examination process. You can obtain a considerable amount of information regarding the patient on the basis of *structure* alone. The structural examination will help you gain a better understanding of the patient's predisposition to overuse or to injury. The structural examination allows you to integrate the structure and function of all the joints (Gross, Fetto, & Rosen, 2009). Evaluation of posture forms part of the physical assessment of patients who present with certain musculoskeletal signs. While there is no certainty that the patient's posture has been the cause of symptoms or signs or that they have contributed to the adaptive posture, the possibility of such a relationship needs to be acknowledged and postural changes monitored as treatment progresses (Magee, 2014).

Clinically, posture is judged visually by noting alignment and symmetry of body parts and co-contraction of muscles around joints, the summed control of each part adding to a composite, balanced whole (Bertoti, 1988). When evaluating postural functions, or determining the degree of dysfunction, the main problem is the lack of normative values due to the varied views of individual authors who have tried to define such norms (Kolar, 2013). Before you can diagnose changes in alignment, however, you need a standard of optimal posture (Norris, 2008).

Through the late western history, following concepts were created, to name a few:

The Posture Committee of American Academy of Orthopaedic Surgeons, 1947, defined posture by stating (Gilman M. , 2014) (Saunders, Macnaughton, & Fuller, 2015) (Preachuk, 2012):

> Posture is usually defined as the relative arrangement of the parts of the body. Good posture is that state of muscular and skeletal balance which protects the supporting structures of the body against injury or progressive deformity, irrespective of the attitude (erect, lying, squatting, or stooping) in which these structures are working or resting. Under such conditions the muscles will function most efficiently and the optimum positions are afforded for the thoracic and abdominal organs. Poor posture is a faulty relationship of the various parts of the body which produces increased *strain on the supporting structures and* in which there is less efficient balance of the body over its base of support.

Kendall et al., used this postulate (Kendall, McCreary, Provance, Rodgers, & Romani, 2005):

> Posture is a composite of the positions of all the joints of the body at any given moment, and static postural alignment is best described in terms of the positions of the various joints and body segments.

Vladimir Janda described posture in his own way (Janda, 1983):

> Posture is considered mainly as a static function rather than being related to general mobility. Under ideal physiological situations, the *erect standing* position is so well balanced that little or no activity is necessary to maintain it. When activity does occur to a small degree, it does so irregularly. Thus there is a dilemma: we consider as postural

> muscles those which maintain erect standing, but for maintaining erect standing no muscle activity is needed. Limitation of postural muscles exclusively to erect standing is, at least from the clinical point of view, incorrect. The basic and primary function of the motor system is 'motion' and all static functions should be derived from this basic kinetic or dynamic performance. Therefore the question should be raised in an opposite way: not 'what is the basic posture of man?' but 'what is the basic movement pattern?' and from this, the statics should be derived.

Cambridge Dictionaries Online present this description under the search term ‘posture’ (Cambridge Dictionaries Online, 2015):

> The way in which someone usually holds their shoulders, neck, and back, or a particular position in which someone stands, sits, etc. .

Brugger’s concept, among others, assesses and teaches posture (body posture) differently than Pilates. František Vele states that the establishment of one standard for correct body posture is impossible because everybody’s correct postural alignment is varied (Vele, 1997) (Kolar, 2013).

2.2.1 Posture through morphological ontogenesis

When assessing posture, we base our observations on so called “ideal posture”, which we derive from central programs of postural ontogenesis. To be able to define ideal posture, we must draw on biomechanical *and* neurophysiologic functions. The *biomechanical* function is meant to describe the nature of loading, while *neurophysiologic* function describes control processes of muscles that allow for integration of stabilizing or postural muscle function (even during movement) so that the loading in the joint system is optimal. Their interconnection is part of postural development. Ideal posture is determined by a central program. Therefore postural assessment during static and locomotor functions needs to be understood within the ontogenetic context. Supporting this concept is the fact that postural development is synchronized with the development of our anatomy, which even, to a certain extent, predetermines this development (Kolar, 2013).

2.3 ERECT STANDING

Upright posture is the normal standing posture for humans. If the upright posture is correct, minimal muscle activity is needed to maintain the position (Magee, 2014). Good posture is a good habit that contributes to the wellbeing of the individual. The structure and function of the body provide the potential for attaining and maintaining good posture. The ideal, or standard, skeletal alignment is therefore effortless, non-fatiguing, and painless when the person remains erect for *reasonable* periods. Muscles function most efficiently in such an alignment, and the joints are optimally positioned. It involves a minimal amount of stress and strain and is conducive to maximal efficiency of the body (Kendall, McCreary, Provance, Rodgers, & Romani, 2005) (Norris, 2008).

Analysis of standing posture provides a clinician with a wealth of information about the status of the muscular system. It also provides cues for subsequent clinical tests, such as muscle length or strength testing or evaluation of particular movement patterns, to confirm or refute what is observed (Page, Frank, & Lardner, 2010). In the standard position, the spine presents the normal curves, and the bones of the lower extremities are in ideal alignment for weight bearing. The "neutral" position of the pelvis is conducive to good alignment of the abdomen and trunk and of the extremities below. The chest and upper back are in a position that favours optimal function of the respiratory organs. The head is erect and in a well-balanced position that minimizes stress on the neck musculature (Kendall, McCreary, Provance, Rodgers, & Romani, 2005).

Classically, ideal static postural alignment (viewed from the side), can be assessed through comparisons to a standard reference line that represents the line of gravity and is *defined as a straight line* that passes through the earlobe, the bodies of the cervical vertebrae, the tip of the shoulder, midway through the thorax, through the bodies of the lumbar vertebrae, slightly posterior to the hip joint, slightly anterior to the axis of the knee joint, and just anterior to the lateral malleolus. This method has been shown to be as effective as projected shadow measures and electromagnetic evaluation to assess suboptimal posture (Norris, 2008) (Magee, 2014).

The optimal, most efficient posture is symmetrical and balanced. Recognizing that no one is perfectly symmetrical, minor variations are considered to be functional. Significant differences may be secondary to anatomical malposition which is either congenital or acquired; mechanical dysfunction whether hypomobile or hypermobile; or dysfunction of the soft tissue whether hypertrophied, atrophied, taut, or slack (Gross, Fetto, & Rosen, 2009).

One of the main principles of motor ontogenesis is the development of body posture, or the ability to qualitatively attain joint positions with their reinforcement via coordinated muscle activity and the development of stepping and supporting function. Holding the body’s axis in a lordo-kyphotic curvature, and setting the pelvic and chest alignment (the shape of chest is changing due to this), are all developing during the first part of motor development in postural ontogenesis. This is allowed by a balanced synergy between the spinal extensors and neck flexors and intra-abdominal pressure (i.e. this is the interplay of the diaphragm, abdominal muscles and pelvic floor muscles). The linkage of anatomical and biomechanical principles with the principles of neurophysiology is the most distinct in the view of posture, or morphological ontogenesis. Here, the principles are mutually conditioned and can never be viewed separately (Kolar, 2013).

3 BIOMECHANICS OF A HUMAN BODY

Machines are part of our daily lives, from simple can openers to complex computers, cars, and copy machines. According to *Webster*'s dictionary, a machine is "an assemblage of parts that transmit forces, motion, and energy one to another in a predetermined manner." So even the most intricate machines are composed of simpler parts such as levers, fulcra, latches, notches, receptors, energy sources, wires, and cables that combine to create the more involved structure we define as a machine. If you think about your body as a machine and its systems and organs as parts, you can more easily comprehend the structure and function of the machinery we call the human body (Tortora & Nielsen, 2012).

Biomechanics has been defined as the study of the movement of living things using the science of mechanics (Knudson, 2003). Human body mechanics describes human body, concentrated on the movement and the balance of separate bodies. When describing living organisms mechanically, we use many simplifications as we are trying to understand the basic laws which are important at certain occurrences. This laws are generalized. We can observe incredibly similar movements in totally different activities. Change in movement direction is achieved in the same way either in ice skating or ball games, driving a stake, playing golf and chopping wood (Sevšek, 2004).

Kinesiology is the scholarly study of human movement, and biomechanics is one of the many academic sub disciplines of kinesiology. Biomechanics in kinesiology involves the precise description of human movement and the study of the cause of human movement. The study of biomechanics is relevant to professional practice in many kinesiology professions. The physical educator or coach who is teaching movement technique and the athletic trainer or physical therapist treating an injury use biomechanics to qualitatively analyse movement (Knudson, 2003).

3.1 KEY MECHANICAL CONCEPTS

3.1.1 Mechanics

Mechanics is the branch of physics that studies the motion of objects and the forces that cause that motion. The science of mechanics is divided into many areas, but the three main areas most relevant to biomechanics are: rigid body, deformable body, and fluids (Knudson, 2003).

In rigid-body mechanics, the object being analysed is assumed to be rigid and the deformations in its shape so small they can be ignored. While this almost never happens in any material, this assumption is quite reasonable for most biomechanical studies of the major segments of the body; the rigid-body assumption in studies saves considerable mathematical and modelling work without great loss of accuracy. Some biomechanists, however, use deformable-body mechanics to study how biological materials respond to external forces that are applied to them. Deformable-body mechanics studies how forces are distributed within a material, and can be focused at many levels (cellular to tissues/ organs/ system) to examine how forces stimulate growth or cause damage. Fluid mechanics is concerned with the forces in fluids (liquids and gasses). A biomechanist would use fluid mechanics to study heart valves, swimming, or adapting sports equipment to minimize air resistance (Knudson, 2003).

Most sports biomechanics studies are based on *rigid-body models* of the skeletal system. Rigid-body mechanics is divided into statics and dynamics. Statics is the study of objects at rest or in uniform (constant) motion. Dynamics is the study of objects being accelerated by the actions of forces. Most importantly, dynamics is divided into two branches: kinematics and kinetics (Knudson, 2003) (McGinnis, 2004) (Whiting & Zernicke, 2008).

Kinematics is motion description and it involves five primary variables (Whiting & Zernicke, 2008):

- Temporal (timing) characteristics of movement
- Position or location
- Displacement (describing what movement has occurred)
- Velocity (a measure of how fast something has moved)
- Acceleration (an indicator of how quickly the velocity has changed)

The last four variables (position, displacement, velocity, and acceleration) can be expressed in linear (meters, feet, etc.) or angular (radians, degrees, etc.) form, giving rise to the general description of linear kinematics and angular kinematics. Examples of kinematics of running could be the speed of the athlete, the length of the stride, or the angular velocity of hip extension (Knudson, 2003).

Kinetics (the study of forces and their effects) is concerned with determining the causes of motion. Examples of kinetic variables in running are the forces between the feet and the ground or the forces of air resistance (Knudson, 2003) (Whiting & Zernicke, 2008).

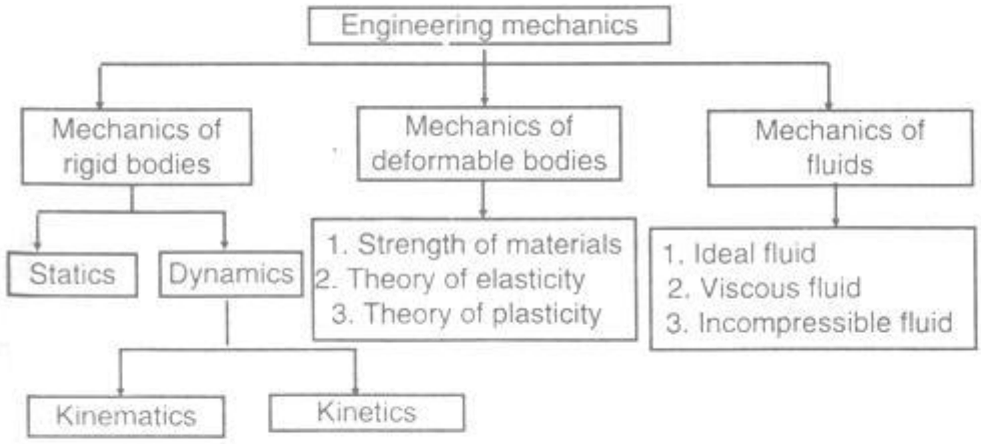

Figure 1: mechanics classification diagram (Mukherjee, 2011) (Transweb Global Inc., 2016).

You can use descriptions of both position (kinematic) and force (kinetic) to assess posture (Norris, 2008). Kinetic information is often more powerful in improving human motion because the causes of poor performance have been identified. For example, knowing that the timing and size of hip extensor action is weak in the take-off phase for a long jumper may be more useful in improving performance than knowing that the jump was shorter than expected (Knudson, 2003).

When describing general motion, we use a combination of angular and linear *motion*. When describing in kinetic terms, we use words like linear or angular *kinetics* (McGinnis, 2004):

- Linear motion is also referred to as translation. It occurs when all points on a body or object move the same distance, in the same direction, and at the same time.
- Angular motion is also referred to as rotary motion or rotation and explains the causes of rotatory motion. It occurs when all points on a body or object move in circles (or parts of circles) about the same fixed central line of axis. Angular motion can occur about an axis within the body or outside of the body. A child on a swing is an example of angular motion about an axis of rotation external to the body (McGinnis, 2004) (Knudson, 2003).

Two kinetic concepts are important to mention, Newton's laws of motion (form the basis of classical - Newtonian – mechanics) and equilibrium (Whiting & Zernicke, 2008).

3.1.2 **Newton's laws of motion**

- **Newton's first law of motion – Law of inertia**

Outlines the key property of matter related to motion. Objects tend to stay at rest or in uniform motion unless acted upon by an unbalanced force (Knudson, 2003).

Newton's first law states that every body continues in its state of rest, or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed upon it. Sometimes referred to as the law of inertia (Knudson, 2003). Generally, inertial forces are ignored in static postures because little or no acceleration is occurring except during postural sway (Levangie & Norkin, 2001).

- **Newton's second law of motion – Law of momentum or acceleration**

This law describes what happens when external forces do act on an object. It states that the change in motion of an object is proportional to the force impressed and is made in the direction of the straight line in which the force is impressed (Knudson, 2003) (McGinnis, 2004).

It's arguably the most important law of motion because it shows how the forces that create motion (kinetics) are linked to the motion (kinematics).

- **Newton's third law of motion – Law of reaction**

For every action there is an equal but opposite reaction.

For a static mechanical system, the conditions of *equilibrium* must always be fulfilled, *i.e.* the resulting force and the resulting moment acting on the system must be zero. These conditions must be valid for the whole mechanical system as well as for any part of the system. To avoid collapse of a static mechanical system, satisfaction of the conditions of equilibrium of the system are necessary but not sufficient. In addition *mechanical stability* must be maintained (Bergmark, 1989) (Knudson, 2003).

3.1.3 Equilibrium

An important concept that grows out of Newton's first and second laws is equilibrium. Word implies a balanced condition. Mechanical equilibrium occurs when the forces and torques acting on an object sum to zero. Newton's first law refers to the two conditions if static equilibrium (sum of forces equals zero, $\sum F= 0$), where an object is motionless or moving at a constant velocity. Dynamic equilibrium is used to refer to the kinetics of accelerated bodies using Newton's second law (sum of forces equals mass times acceleration, $\sum F= m \times a$).

Equilibrium and angular kinetics are the mechanical tools most often used in the study of balance. Inertia (mass and moment of inertia) and other external forces, like friction between the base and supporting surface, all affect the equilibrium of an object. There are also biomechanical factors (muscle mechanics, muscle moment arms, angles of pull, and so on) that affect the forces a person can create to resist forces that would tend to disrupt their balance (Knudson, 2003).

One aspect of balance is aligning body segments such that we attain and maintain equilibrium, and another aspect is righting the body - that is, bringing the body into alignment as we move from one position to another. Aligning the body segments and righting the body together can be termed posture (Haywood, Roberton, & Getchell, 2012). The position by which the equilibrium is maintained is called the reference position; characterized by a reference point on a supporting surface (a set point or attracting point) (Zatsiorsky & Duarte, 1999).

Equilibrium and balance are affected not only by forces but by torques as well (McGinnis, 2004).

3.1.4 **Torque**

The rotating effect of a force is called a torque or moment of force. Moment of force or torque is a vector quantity, and the usual two dimensional convention is that counter clockwise rotations are positive. Torque is calculated as the product of force and the moment arm. The moment arm or leverage is the perpendicular displacement (⊥d) from the line of action of the force and the axis of rotation. An important point is that the moment arm is always the shortest displacement between the force line of action and axis of rotation (Knudson, 2003).

Torques cause changes in angular motion. The movements of our limbs at joints are controlled by the torques produced by muscles. Muscles create the torques that turn our limbs. A muscle creates a force that pulls on its points of attachment to the skeletal system when it contracts. The line of action (or line of pull) of a muscle force is along a line joining its attachment and is usually indicated by the direction of its tendons. The bones that a muscle attaches to are within the limbs on either side of a joint, or two or more joints in some cases. When a muscle contracts it creates a pulling force on these limbs. Because the line of action of the muscle force is some distance from the joint axis, a moment arm exists, and torques about the joint axis are produced by the muscle force on the limbs on either side of the joint where the muscle attaches. Torques are important even if you aren't moving (McGinnis, 2004). Practical example are position variations where the therapist can provide resistance with a hand dynamometer to manually test the isometric strength of the elbow extensors. By positioning their arm more distal, the therapist increases the moment arm and decreases the force they must create to balance the torque created by the patient and gravity (Knudson, 2003).

The gravitational torque imposed on one side of the body should equal that of the other side to remain in balance (Norris, 2008).

3.1.5 Internal forces

These are forces that act within the object or system whose motion is being investigated. Remember, forces come in pairs - action and reaction. With internal forces, the action and reaction forces act on different parts of the system (or body). Each of these forces may affect the part of the body it acts on, but the two forces do not affect the motion of the whole body because the forces act in opposition. The human body is a system of structures – organs, bones, muscles, tendons, ligaments, cartilage, and other tissues. These structures exert force on one another. Muscles pull on tendons, which pull on bones. If pulling forces act on the ends of an internal structure, the internal pulling forces are referred to as tensile forces, and the structure is under tension. If pushing forces act on the ends of an internal structure, the internal pushing forces are referred to as compressive forces, and the structure is under compression. Internal forces hold things together when the structure is under tension or compression (McGinnis, 2004).

When a load (stress) is applied to a solid at rest, there is some degree of deformation (strain) of the solid. As the load increases, the solid becomes ‘‘fully engaged’’ and enters the elastic zone. This portion of the curve is governed by Hooke’s law: for small displacements, the size of the deformation is proportional to the deforming force. The relation is linear, and when the stress is removed, the strain totally recovers. Larger stresses may exceed the limits of the elastic zone and the yield point to enter the plastic zone. Hooke’s law no longer applies, and the solid develops a permanent set or deformation that does not change when the stress is removed. If greater loads are applied, the solid may reach the point of failure (ultimate strength). The removal of stress before the yield point results in recovered energy and is a measure of the solid’s resilience (Kowalski, Ferrara, & Benzel, 2005).

The fact that the stabilization function is integrated into almost all movements underscores the significance of the activity of internal forces (i.e. forces acting on a joint via musculature and optimized for ideal stabilization of segments) not only in their quality, but also in their substantial stereotypical repeating, or quantity. Under the assumption that the so called internal forces elicit non-physiological loading of a segment, it is then only a question of time when the impediments begin to occur, including morphological changes (osteophytes, arthritic changes etc.). It is also essential that while purposeful movement is freely controlled, reactive stabilization functions occur automatically and subconsciously (Kolar, 2013).

3.2 GRAVITY

We can define gravity as a field of influence, because we know how it operates in the universe. And some scientists think that it is made up of particles called gravitons which travel at the speed of light. However, if we are to be honest, we do not know what gravity "is" in any fundamental way - we only know how it behaves. Here is what we do know. Gravity is a force of attraction that exists between any two masses, any two bodies, and any two particles. Gravity is not just the attraction between objects and the Earth. It is an attraction that exists between all objects, everywhere in the universe. Sir Isaac Newton (1642 - 1727) discovered that a force is required to change the speed or direction of movement of an object. He also realized that the force called "gravity" must make an apple fall from a tree, or humans and animals live on the surface of our spinning planet without being flung off. Furthermore, he deduced that gravity forces exist between all objects. The effect of gravity extends from each object out into space in all directions, and for an infinite distance. However, the strength of the gravitational force reduces quickly with distance. Humans are never aware of the Sun's gravity pulling them, because the pull is so small at the distance between the Earth and Sun. Yet, it is the Sun's gravity that keeps the Earth in its orbit! Neither are we aware of the pull of lunar gravity on our bodies, but the Moon's gravity is responsible for the ocean tides on Earth (Dejoie & Truelove, 2001).

The centre of gravity is the location in space where the weight (gravitational force) of an object can be considered to act. The centre of small rigid objects (pencil, pen, bat) can be easily found by trying to balance the object on the finger. The point where the object balances is in fact the centre of gravity, which is the theoretical point in space where you could replace the weight of the whole object with one downward force. There is no requirement for this location to be in a high-mass area, or even within or on the object itself. Think about where the centre of gravity of a basketball would be (Knudson, 2003). Or of a tyre, hula hoop, American doughnut or any other ring. Try to put this book in different positions while it’s laying on the table and visualize where COG is.

In the child, the centre of gravity is at the level of the twelfth thoracic vertebra. As the child grows older, the centre of gravity drops, eventually reaching the level of the second sacral vertebra in adults (slightly higher in males). The child stands with a wide base to maintain balance, and the knees are flexed (Magee, 2014). The centre of gravity of the human body can move around, because joints allow the masses of body segments to move. In the anatomical position, an ideally aligned posture in a so-called average adult human being, the typical location of a body's centre of gravity in the sagittal plane is at a point equivalent to 57 and 55% of the height for males and females, respectively (Knudson, 2003) (Kendall, McCreary, Provance, Rodgers, & Romani, 2005).

3.3 CENTRE OF MASS - COM

When an idealized force vector is developed, many vectors are reduced to a single vector. A similar process can be applied to the mass of a body reducing its distributed mass to a single point (point mass) that represents the entire body. COM is therefore a point equivalent of the total body mass and is the weighted average of the COM of each body segment in 3D space. It is a passive variable controlled by the balance control system. This type of simplification will facilitate analysis but with loss of information (Winter D. A., 1995) (Whiting & Zernicke, 2008).

The centre of mass is not necessarily located in the body. For all practical purposes, the centre of gravity and the centre of mass are coincident, although in strict physical terms, there is an infinitesimal difference between the two (Rodgers & Cavanagh, 1984). They're only the same when the gravitational field is uniform across the object, or at least close enough to be uniform that it isn't worth discussing. With small objects near the surface of the Earth, that's always the case. But once you start putting spaceships in space, suddenly things get weird (Wood, 2015).

3.4 CENTRE OF PRESSURE - COP

Whenever the body contacts the ground, the ground pushes back on the body. This force is known as the ground reaction force or GRF (*remember Newton's 3rd law)*. The GRF is a composite (or resultant) force typically described as having three components: a vertical component force and two force components directed horizontally. One of the two horizontal forces is in a medial-lateral direction, whereas the other horizontal force is in an anterior-posterior direction along the ground. The composite or resultant *ground reaction force vector* (GRFV) is equal in magnitude but opposite in direction to the gravitational force in the erect static standing posture. The GRFV indicates the magnitude and direction of loading applied to the foot. The point of application of the GRFV is at the body's centre of pressure - COP (Enoka, 1994).

When we measure the ground reaction force with a force platform, the magnitude of the force represents the sum of the pressure distributed under the foot. The location (point of application) of the ground reaction force under the foot corresponds to the centre of pressure. It is simply the central point of the pressure distribution. The distribution of force over an area is measured as pressure, which has the unit of measurement of Pascal (Pa; 1 Pa = 1 N/ m^2) (Enoka, 2015). COP represents a weighted average of all the pressures over the surface of the area in contact with the ground. It is totally *independent* of the COM. If one foot is on the ground the net COP lies within that foot. If both feet are in contact with the ground the net COP lies somewhere between the two feet, depending on the relative weight taken by each foot. Thus when both feet are in contact there are separate COPs under each foot. When one force platform is used only the net COP is available. Two force platforms are required to quantify the COP changes within each foot. The location of the COP under each foot is a direct reflection the neural control of the ankle muscles. Increasing plantar flexor activity moves the COP anteriorly, increasing invertor activity moves it laterally (Winter D. A., 1995) (Schilling, et al., 2009) (Robertson, Caldwell, Hamill, Kamen, & Whittlesey, 2004).

The path of the COP that defines the extent of the sway envelope can be determined by plotting the COP at regular intervals when a person is standing on a force plate system (Enoka, 1994). COP is a measure of whole-body dynamics, it represents the summed effect of a number of different neuromusculoskeletal components acting at a number of different joints (Collins & De Luca, 1993).

In the literature there is a major misuse of the COP when it is referred to as 'sway', thereby inferring that it is the same as the COG, for example in Enoka, 1994 (Enoka, 1994). Unfortunately some researchers even refer to the COP directly as the COG, but the difference between the COG and COP has been recognized by a number of researchers. The dynamic range of the COP must be somewhat greater than that of the COG, while over an extended period of time during quiet standing, the average of the COP must equal the average of the COG (Winter D. A., 1995). The ground reaction force vector and line of gravity have coincident action lines in the static erect posture. In many dynamic postures, the intersection of the LOG with the supporting surface may not coincide with the point of application of the GRFV. The horizontal distance from the point on the supporting surface where the LOG intersects the ground and the COP (where the GRFV acts) indicates the magnitude of the moment that must be opposed to maintain a posture and keep the person from falling (Enoka, 1994).

3.4.1 Measuring the COP

The human kinematics can be measured through determination of mechanical *quantities*, like the spatial position of body parts and the determination of external forces and momentums. Posturography is a group of methods allowing the evaluation of the posture control and static tests are another kind of posturographic examinations. COG is a whole body characteristic that is difficult to directly measure, so *typically* the COP is used instead. The study of postural control sway is performed by analysing the stabilogram which is the representation of COP's displacement in anteroposterior (AP) and mediolateral (ML) direction, and it can be registered as a function of time. The application of force platforms provides us with comprehensive data related to the oscillation of the COP to generally *quantify* postural sway (Kubisz, Werner, Bosek, & Weiss, 2011) (Soha, Szabó, & Budai, 2012) (Schilling, et al., 2009) (Stemplewski, Maciaszek, Osiński, & Szeklicki, 2011) (Maatar, Fournier, Lachiri, & Nait-Ali, 2011).

There are several kinds of force-measuring devices used in biomechanics to study how forces modify movement. Two important devices are the force platform (or force plates) and pressure sensor arrays. The most commonly used type of force transducer in biomechanics is the force platform (or force plate), which is an instrumented plate installed flush with the ground for the registration of the ground reaction forces that are equal and opposite to the forces people make against the ground. It measures the forces and torques in all three dimensions applied to the surface of the platform. Since the 1980s, miniaturization of sensors has allowed for rapid development of arrays of small-force sensors that allow measurement of the distribution of forces (and pressure because the area of the sensor is known) on a body (Knudson, 2003) (Robertson, Caldwell, Hamill, Kamen, & Whittlesey, 2004). The force plate provides an efficient way to follow the balancing motion of standing trough the determination of the COP coordinates. Under nearly static conditions, the COP is simply the vertical projection of the COM coordinates. During dynamic motion the vertical projection of the COM coordinates, called the gravity line, deviate from the COP coordinates (Soha, Szabó, & Budai, 2012). The position of COP measured from the ankle joints in the anterior direction is a positive quantity due to a forward leaning position during quiet standing with an average value typically around 5 cm (Borg, Finell, Hakala, & Herrala, 2007).

Different researches used different times to measure COP (or COF) movements during standing. They can range to 10 minutes or more (Sakaguchi, Taguchi, Miyashita, & Katsuno, 1994) (Van der Kooij, Campbell, & Carpenter, 2011) (Schubert, Kirchner, Schmidtbleicher, & Haas, 2012). One research was assessing the repeatability of force plate postural stability measurements with common parameters. Optimum test retest reliability was obtained at 20-s and 30-s trial periods. COP measures increased with increased test duration while ground reaction forces and velocity decreased slightly (Le Clair & Riach, 1996). In another research significant difference was noticed between the excursions of the COP during the first to fifth minutes and any stability analysing under 1 minute based on the sway of the COP was not recommended (Taghi, Jamshidi, Bahreinizad, Bani, & Omar, 2014).

With innovation and increase in amount of information, new concepts and methods for studying postural control have been introduced. Currently, COP data have been evaluated not only with conventional linear measures, which provide an “average” picture and lose the temporal aspects, but also with nonlinear measures, which describe the temporal organization of the postural sway pattern. Nonlinear measures can provide new insights in the ways that the nervous system controls the complexity of dynamic balance. Moreover, nonlinear measures unveil different features of the COP data. For example, range and the length of path traced by the COP, which are traditional linear measures, evaluate the quantity of movement variations of the COP during a specific task independently of their order in the distribution. On the other hand, Lyapunov Exponent (LyE) and Approximate Entropy (ApEn), which are nonlinear measures, they are able to capture the temporal component of the movement variation in COP regarding how motor behaviour emerges in time. Temporal organization or “structure” can be measured by the extent to which values of COP data emerge in a predictable way. The usage of these measures has increased recently because they allow the quantification of constructs such as regularity, complexity, and stability. Nonlinear systems are more complex than linear systems, necessitating the use of sets of equations producing unpredictable outcomes that exhibit chaotic features. In general, biological systems, including humans, are complex, nonlinear systems with inherent variability in all healthy organisms. Thus, nonlinear analyses of the COP data can, for example, provide a window into the neurological status (Kyvelidou, Harbourne, Shostrom, & Stergiou, 2011) (Harbourne & Stergiou, 2009).

Stabilogram is considered as non-stationary signal, produced by a non-linear system. To analyse such a signal, numerous techniques have been proposed. For instance, the Empirical Mode Decomposition (EMD) which allows an efficient extraction of intrinsic mode functions, called IMF. Standard Fourier transform has also been used to analyse human posture stability. In particular, it has been used to highlight the correlation between the fear of falling and strategies produced by human postural control. On the other hand, wavelet analysis has been employed in numerous studies for the purpose to determine both short-term and long-term diffusion coefficients from the stabilogram diffusion control (Maatar, Fournier, Lachiri, & Nait-Ali, 2011). Collins and De Luca, 1993, introduced a new method known as stabilogram diffusion analysis that provides a quantitative statistical measure of the apparently random variations of COP trajectories recorded during quiet upright stance in humans (Collins & De Luca, 1993) (Peterka, 2000).

In a research performed by Karlsson & Frykberg, 2000, different COP measurements were compared, including the standard deviation of the COP and it was concluded that it seems to quantify different aspects of human standing. It also strongly correlated with standard deviation of the horizontal ground reaction force and the mean velocity of the COP (Karlsson & Frykberg, 2000). In another research, done by Stemplewski et al, 2011, evaluating parameters for balance in elderly in 30 second trials, showed that only average velocity of COP displacement may have a potential application value. High internal consistency and stability of results showed that it can be used for actual status measures as well as evaluation of possible changes in time. The use of the other parameters (connected to spatial distribution of COP displacement) is questionable unless the results of greater number of trials (from 6 to 13) would be averaged. Although Lafond et al, 2004, showed the higher reliability of a 120 second trial, but standing still for prolonged time (as well as an increased number of trials) may be difficult for the elderly (e.g. possibility of attention distraction or movement) especially in case of examination of unhealthy or impaired people (Stemplewski, Maciaszek, Osiński, & Szeklicki, 2011) (Lafond, Corriveau, Hébert, & Prince, 2004).

Many examples of pathologies result in postural dysfunction which is consequently seen in different variations of COP displacement during activities or even quiet standing. Important to know is that experimental protocols associated with dynamic posturography are considerably more hazardous and physically taxing than those involved in static posturography (Collins & De Luca, 1993). In a study that examined patients after neurogenic claudication, position of COP after neurogenic claudication immediately shifted toward the symptomatic side, and then returned to the initial area (before neurogenic claudication) after 20 minutes of rest. Patients with hemiparesis after stroke also tend to fall to the paretic side. In healthy subjects, COP-AP shifts forward after walking as compared with COP-AP before walking (Sasaki, Senda, Katayama, Ota, & Matsuyama, 2013). The research measuring COP movement after ACL surgery observed that impairment was especially visible in anterior-posterior direction (Kubisz, Werner, Bosek, & Weiss, 2011). Other researches found that area and total length of head and COF movements decreased with increasing age, and were significantly greater in children under 12 years than in adults. The ratio of the antero-posterior to lateral movement of COF was also larger (Sakaguchi, Taguchi, Miyashita, & Katsuno, 1994) (Oba, Sasagawa, Yamamoto, & Nakazawa, 2015). Collins et al, 1993, confirmed with his stabilogram diffusion analysis that the anteroposterior diffusion coefficients were greater than the respective mediolateral coefficients. This asymmetry can be attributed largely to the geometry of the lower limb. The ankle or tibiotarsal joint is, for example, mainly a simple hinge joint which allows rotation (plantarflexion/dorsiflexion) in the sagittal plane. Thus, from a passive mechanical standpoint, upright bipedal stance is considerably more stable in the frontal plane than in the sagittal plane. Also, the magnitudes of the diffusion coefficients were highly variable amongst young healthy subjects (Collins & De Luca, 1993).

3.5 STABILITY & MOBILITY

Mechanical definition of stable states: "capable of returning to equilibrium or original position after having been displaced". Stability is thus the capacity of an object to return to equilibrium or to its original position after being displaced (McGinnis, 2004).

Posture and stability are coupled mechanically. Posture can be defined as the rotational and translational positions of adjoining body segments and their orientation relative to gravity. We define stability as the ability to control COG amplitude and velocity of displacement while remaining standing. Body-segment alignment or postural changes affect COG location, which may alter stability. Generally, smaller amplitudes and velocities of displacement of the COG yield greater stability (Danis, Krebs, Gill-Body, & Sahrmann, 1998). The stability of an object is affected by the height of the centre of gravity, the size of the base of support (BOS), and the weight of the object (McGinnis, 2004). It is generally considered that the lower centre of gravity in women gives them better balance than men (Knudson, 2003).

The BOS is the area within the lines connecting the outer perimeter of each of the points of support, it's a two-dimensional area formed by the supporting segments of areas of the body. A large BOS provides greater stability because there is greater area over which to keep the bodyweight (McGinnis, 2004) (Knudson, 2003).

Stability is directional. An object can be more stable in one direction than in another. The posture of the body in stance or during motion determines the position of the centre of gravity relative to the BOS. Since gravity is the major external force our body moves against, the horizontal and vertical positions of the centre of gravity relative to the BOS are crucial in determining the stability/ mobility of that posture. If the line of gravity falls outside the BOS, the gravitational torque tends to tip the body over the edge of the BOS (Knudson, 2003).

It is not the size of the BOS that affects stability, but the horizontal distance between the *line of gravity* and the *edge of the base* of support in the direction that the toppling force is pushing or pulling (McGinnis, 2004). Also, the vertical distance or height of the centre of gravity affects the geometric stability of the body. When the position of the centre of gravity is higher, it is easier to move beyond the BOS than in postures with a lower centre of gravity (Knudson, 2003).

Vertical displacement explains why COG height affects stability. The higher the centre of gravity, the smaller this vertical displacement, thus the smaller the change in potential energy and the smaller the amount of work done. So a block with a lower centre of gravity is more stable because more work is required to topple it. If the distance from the line of gravity to the edge of the BOS about which toppling will occur (the moment arm of the weight) is increased, the vertical displacement the centre of gravity goes through before the object topples also increases, so the object is more stable. The most stable stance or position an object or person can be in is the one that minimizes potential energy (McGinnis, 2004).

The human body is not rigid, and balance is a person's ability to control their body position relative to some base of support. COG position, BOS and therefore balance can change with body segment positioning or posture by limb movements. Humans can thus control their stability by changing their stance and body position. This ability is needed in both static equilibrium conditions (e.g. handstand on a balance beam) and during dynamic movement (e.g., shifting the centre of gravity from the rear foot to the forward foot). In many sports and human movement activities, the athletes or performers do not want to be moved from a certain stance or position, they want to be in a very stable position (wrestler, basketball players…). In other sports, success may be determined by how quickly an athlete is able to move out of a position (sprinter, swimmer, downhill skier…). Many sports use the "shoulder width apart" cue for the width of stances because this base of support is a good compromise between stability and mobility. Wider BOS would increase potential stability but put the limbs in a poor position to create torques and expend energy, creating opposing friction forces to maintain the BOS.

These adjustments should be based on mechanical principles (Knudson, 2003) (McGinnis, 2004).

Stabilisation of the upright posture is a typical example of many unstable tasks, which must be solved in everyday life and in more demanding sport or dance gestures. These situations are characterised by repulsive forces which tend to push the system away from the intended equilibrium position. (Casadio, Morasso, & Sanguineti, 2005). In physical rehabilitation and medicine, crutches, canes, walkers, and so on, are used to increase the BOS and stability of the injured, sick, or infirm (McGinnis, 2004).

In mechanics, stability is a well-defined concept, namely the ability of a loaded structure to maintain static equilibrium even at (small) fluctuations around the equilibrium position. If stability does not prevail, an arbitrarily small change of the position is sufficient to cause “collapse”, i.e. the structure moves further away from equilibrium (Bergmark, 1989).

4 BODY STRUCTURE

Movements such as throwing a ball, running, and jumping require interactions between bones and muscles. Together, the bones, muscles, and joints form an integrated system called the musculoskeletal system (Tortora & Nielsen, 2012). The bodies of most terrestrial creatures are a concatenation of mechanically rigid segments. The consequence of this mechanical structure is that muscular and external forces acting upon any one segment will affect, through inertial coupling forces, the motions of most if not all of the segments (Nashner & McCollum, 1985).

Muscle tissue and connective tissue form the structural units of the musculoskeletal system. The specific connective tissues important to the structure of the musculoskeletal system are bone, cartilage, ligament, and tendon. Muscles may be thought of as the active elements of the musculoskeletal system, whereas connective tissues are passive elements (McGinnis, 2004).

The skeletal system forms the framework of our body.

4.1 SKELETAL SYSTEM – THE FRAMEWORK

Without bones, you would be unable to perform movements such as walking or grasping. The slightest blow to your head or chest could cause fatal damage to your brain or heart. The skeletal system performs several basic functions, including (Tortora & Nielsen, 2012):

- Support. The skeleton serves as the structural framework for the body by supporting soft tissues and providing attachment points for the tendons of most skeletal muscles.
- Protection. The skeleton protects the most important internal organs from injury. For example, cranial bones protect the brain, vertebrae (backbones) protect the spinal cord, and the rib cage protects the heart and lungs.
- Assistance in movement. Most skeletal muscles attach to bones; when they contract, they pull on bone to produce movement.

Bones can serve as a library of information about the human body. They serve as an enduring record of an individual’s life because bones do not deteriorate following death like soft tissues do. For example, age, size, stature, gender, health, and race can all be determined by examining the skeleton. The shape of a given bone also reveals a great deal of information about its functional role in the body, such as its physical strength and the type of forces it experienced as it was moved by muscles. Each little bump, groove, hole, projection, and ridge on a bone has a story to tell (Tortora & Nielsen, 2012).

Bones of the adult skeleton are grouped into two principal divisions:

- ♦ axial skeleton (skull bones, auditory ossicles, hyoid bone, ribs, sternum and the vertebral column)
- ♦ appendicular skeleton (bones of the upper and lower limbs)

The axial skeleton is the skeletal axis, or core pillar of the body, and helps protect the internal organs, while primary function of the appendicular skeleton is movement.

There is one major difference between the upper and lower limbs. The pelvic girdles of the lower limb are firmly anchored to the vertebral column via a strong ligamentous joint, but the pectoral girdles of the upper limb do not form any joints with the vertebral column; they are only weakly joined to the axial skeleton via the junction of the clavicle (collar bone), where clavicle transmits mechanical force from the free upper limb to the trunk via sternum. This primitive feature of all land vertebrates marks the major functional difference in the limbs; the hind limbs (our legs) are the locomotor limbs, and the forelimbs (our arms) are the steering column. When humans took advantage of this primitive difference in limb structure and function and raised the more mobile non-locomotor limb off the ground, we took advantage of its tremendous range of mobility to use the upper limb in many diverse ways (Tortora & Nielsen, 2012).

Forces from the upper body are transferred from the chest to the pelvis (with the exception of the latissimus dorsi muscles which act from the humerus to the lumbar back), either directly by means of active components - the abdominal pressure and the muscles - or via the spine and further down to the pelvis by means of active as well as passive elements - bone, ligaments etc. The main components for transfer of the tensile forces are the muscles (Bergmark, 1989).

4.1.1 Vertebral column

The vertebral column, also called the *spine, backbone,* or *spinal column,* makes up about two-fifths of the total height of the body. The vertebral column functions as a strong, flexible rod with elements that can move forward, backward, and sideways, and can rotate. It encloses and protects the spinal cord, supports the head, and serves as a point of attachment for the ribs, pelvic girdle, and muscles of the back and upper limbs. The five regions of the vertebral column are cervical, thoracic, lumbar, sacral, and coccygeal. The cervical, thoracic, and lumbar vertebrae are movable, but the sacrum and coccyx are not.

The spine is a complex mechanical structure complete with levers (vertebrae), pivots (facets and disks), passive restraints (ligaments), and actuators (muscles). The vertebral column complex consists of the primary axial load-bearing structures of the vertebral bodies and the intervening intervertebral disks. The ventral column is subsequently tied to the dorsal column at each segment through the pedicles. The laminae function as the roof to complete the bony spinal canal. The facet joints limit rotation, flexion, extension, lateral bending, and translation. The muscles and ligaments also function to limit torso movement while contributing to the axial load-bearing capacity at the same time (Kowalski, Ferrara, & Benzel, 2005).

The curve of the vertebral column of a fetus exhibits one long curve that is convex posteriorly; secondary curves develop in infancy (Levangie & Norkin, 2011). When viewed from anterior or posterior, a normal adult vertebral column appears straight. But when viewed from the side, it shows four slight bends called normal curves. Relative to the front of the body, the *cervical* and *lumbar curves* are convex (bulging out), and the *thoracic* and *sacral curves* are concave (cupping in). The curves of the vertebral column increase its strength, help maintain balance in the upright position, absorb shocks during walking, and help protect the vertebrae from fracture. The thoracic and sacral curves are called *primary curves* because they retain the original curvature of the embryonic vertebral column. The cervical and lumbar curves are known as *secondary curves* because they begin to form later, several months after birth. All curves are fully developed by age 10. However, secondary curves may be progressively lost in old age (Tortora & Nielsen, 2012).

The lumbar spine in the child has an exaggerated lumbar curve, or excessive lordosis. This accentuated curve is caused by the presence of large abdominal contents, weakness of the abdominal musculature, and the small pelvis characteristic of children at this age. During adolescence, posture changes because of hormonal influence with the onset of puberty and musculoskeletal growth (Magee, 2014).

Tense ligaments not only restrict the range of motion but also direct the movement of the articulating bones with respect to each other. Muscle tension reinforces the restraint placed on a joint by its ligaments, and thus restricts movement (Tortora & Nielsen, 2012). The strength characteristics of the various ligaments differ from ligament to ligament as well as from region to region. The effectiveness of a ligament is determined by its intrinsic morphology and the length of the moment arm through which it acts. Thus, a weaker ligament with a longer moment arm may be just as effective as a stronger one acting through a shorter moment arm (Kowalski, Ferrara, & Benzel, 2005).

Clinical stability of the spine is the ability of the spine under physiologic loads to limit patterns of displacement so as not to damage or irritate the spinal cord or nerve roots and, in addition, to prevent incapacitating deformity or pain due to structural changes. Any disruption of the spinal components (ligaments, discs, facets) holding the spine together will decrease the clinical stability of the spine (White & Panjabi, 1978).

Whenever you are struck by the grace and sensuality of someone's movement, you are appreciating a healthy spine. It depends on a capacity to stabilize the body without closing it with tension (Bond, 2006). The positioning of skeletal structures directly influences adjacent structures. The most recognized postural chain occurs throughout the spine (Page, Frank, & Lardner, 2010).

The stiffness of the vertebral column is the column's ability to resist an applied load. Stiffness can be represented graphically by the slope of the stress-strain curve. The steeper the slope of the curve, the stiffer the structure. The complexity of the column has made accurate determinations of both the stiffness of the column as a whole and the contributions of various structures to stiffness very difficult to obtain. Motion segments, consisting of two adjacent vertebrae and the intervening soft tissue, determine stiffness. Neutral zone: is the range of motion through which the spine can be displaced from a neutral position to the point at which elastic deformation begins when a small load is applied. Panjabi has suggested that the existence of a large neutral zone indicates instability. Instability can be considered as a lack of stiffness, and an unstable structure or one that is not in an optimal state of equilibrium. The column's ability to resist loads varies among spinal regions and depends on the type, duration, and rate of loading; the person's age and posture; the condition and properties of the various structural elements (vertebral bodies, joints, disks, muscles, joint capsules, and ligaments); and the integrity of the nervous system (Levangie & Norkin, 2001).

4.1.2 **Cervical part**

The cervical vertebrae (C1–C7) are the most variable of the vertebrae. The cervical vertebrae form a delicate column of bones that vary considerably in the range of mobility at their joint surfaces. The vertebral bodies of cervical vertebrae are smaller than those of thoracic vertebrae. The first cervical vertebra (C1), the *atlas*, supports the head, while the second cervical vertebra (C2), called the axis, has a bony process (*dens axis*) for atlas, to form a pivot on which the atlas and head rotate (Tortora & Nielsen, 2012).

4.1.3 **Thoracic part**

Thoracic vertebrae (T1–T12) are considerably larger and stronger than cervical vertebrae and become progressively larger from superior to inferior. The most distinguishing feature of thoracic vertebrae is that they articulate with the ribs. Movements of the thoracic region are limited by thin intervertebral discs and by the attachment of the ribs to the sternum (Tortora & Nielsen, 2012). Thoracic spine is the least mobile segment of the entire spine but, at the same time, it is its most stable segment (Kolar, 2013). Probably the two most important functions are ventilation of the lungs (through coupling mechanism of the rib cage, muscles of ventilation and abdomen) and protection of inner organs (Levangie & Norkin, 2001).

4.1.4 **Lumbar region**

One of the primary functions of the lumbar region is to provide support for the weight of the upper part of the body in static as well as in dynamic situations. The lumbar vertebrae (L1–L5) with corresponding disks are the largest and strongest of the unfused vertebrae in the vertebral column because the amount of body weight supported by the vertebrae increases toward the inferior end of the backbone. The compressive load that must be sustained by the lumbar structures is altered by changes in the lumbar curvature or arrangement of body segments. Changes in position of body segments will change the location of the body's centre of gravity and thus change the forces acting on the lumbar spine. In the normal standing posture the line of gravity passes through the combined axis for the lumbar vertebrae and therefore no net gravitational torque exists. Any deviations of the line of gravity will lead to torque production. The muscle contractions required to oppose the gravitational torque create additional compression on the vertebrae as well as torsional and shear stresses (Levangie & Norkin, 2001) (Tortora & Nielsen, 2012).

4.1.5 **Importance of sacral region**

Stability of the sacroiliac joints is extremely important because these joints must support a large portion of the body weight. In normal erect posture the weight of head, arms, and trunk is transmitted through the fifth lumbar vertebra and lumbosacral disk to the first sacral segment. The force of the body weight creates a nutation torque on the sacrum. Concomitantly, the ground reaction force creates a posterior torsion on the ilia. The counter torques of nutation and counternutation of the sacrum and posterior torsion of the ilia are prevented by the ligamentous tension and fibrous expansions from adjacent muscles that reinforce the joint capsules and blend with the ligaments. The sacroiliac joints and symphysis pubis are closely linked functionally to the hip and joints and therefore affect and are affected by movements of the trunk and lower extremities (Levangie & Norkin, 2001). The average lumbosacral angle in optimal erect posture is about 30° (Levangie & Norkin, 2011). A presence or absence of elastic and flexible sacroiliac joints affects the movement of the entire body (Bond, 2006). The sacrum serves as a strong foundation for the pelvic girdle.

4.1.6 **Pelvis**

The pelvis and the spine form a functional movement unit. The pelvis serves as the base that transfers movement from the lower extremities to the trunk. It has a direct influence on the structure and the curvature of the lumbar spine (Kolar, 2013) (Bond, 2006). The joints of the pelvis are linked to the hip and vertebral column in non-weight-bearing as well as in weight-bearing postures (Levangie & Norkin, 2001).

The pelvis plays an essential role in physiological balance of body posture. The position of the pelvis reflects deviations from extremities as well as the trunk. Pelvic anteversion and retroversion present the most common disturbances. The position of the pelvis in the anterior-posterior direction is dependent on the balance between the paravertebral muscles and the muscles that influence intra-abdominal pressure – the abdominal muscles, pelvic floor muscles, and also the diaphragm. Particularly important is muscle balance of the muscles with attachments to the pelvis that influence the lower extremities – ischiocrural muscles and hip flexors (iliacus, rectus femoris, Sartorius, tensor fascia latae). During a faulty angle of the pelvis (especially during pelvic anteversion), the pelvic floor muscles do not react adequately to the increased intra-abdominal pressure elicited by the contraction of the diaphragm during inspiration and postural stabilization. The result is an increased activity of the paravertebral musculature (Kolar, 2013). For example, Li et al, 1996, found in their study that *hamstring muscle* stretching (1) will not alter standing lumbar and pelvic postures, (2) will produce greater forward bending as a result of increased motion at the hips, and (3) may alter the pattern of lumbar and hip motion during forward bending, all possibly to multiple factors (muscle length, lumbosacral angles, postural awareness, motor programming) (Li, McClure, & Pratt, 1996).

Sitting or standing with a backward or forward pelvic tilt for extended periods of time puts uneven pressure on the lumbar disks, unduly stretches the sacroiliac joints, stresses spinal muscles, and comprises the curves in the upper spine and neck. A gentle curve is the neutral position for the lumbar spine (Bond, 2006). The structural changes of the entire body schema are parallel with other changes in the movement system. The most serious include changes in the morphological structures of the muscle fibre (Kolar, 2013).

The results of Toppenberg & Bullock 1986 study, revealed no significant relationship between muscle lengths and pelvic inclination. It was suggested that other factors (such as the structure of the sacrum or the lumbo-sacral angle), which were not included in the study, may account for the position of the pelvis in the sagittal plane. Association between hamstring muscle length and thoracic kyphosis may exist in certain pathological conditions (Scheuermann's disease), and this study showed that in the *normal adolescent female* population, there is no significant relationship between hamstring length and the magnitude of the curve in the thoracic region. In normal, hamstring length was not found to be an important predictor of thoracic kyphosis (Toppenberg & Bullock, 1986).

Loads the vertebral column is subjected to, are: axial compression, tension, bending, torsion, and shear stress – not present only during normal functional activities, but also at rest (Levangie & Norkin, 2001):

- Axial compression - (force acting through the long axis of the spine at right angles to the disks) occurs due to the force of gravity, ground reaction forces, and forces produced by the ligaments and muscular contractions. Most of the compressive forces is resisted by the disks and vertebral bodies, but the arches and zygapophyseal joints share some of the load in certain postures and during specific motions. Depending on the posture and region of the spine, the zygapophyseal joints carry from 0% to 33% of the compression load. The spinous processes also may share some of the load when the spine is in hyperextension. When the disks are subjected to a constant load by forces that are not large enough to cause permanent damage, the disks exhibit creep. Under sustained compressive loading such as incurred in the upright posture, the rise in swelling pressure causes fluid to be expressed from the nucleus pulposus and the annulus fibrosus. The amount of fluid expressed from the disk depends both on the size of the load and the duration of its application. When the compressive forces on the disks are decreased in the recumbent posture or absent in weightlessness, the disk imbibes fluid back from the vertebral body. The recovery of fluid that returns the disk to its original state explains why a person getting up from bed is taller in the morning than in the evening. It also explains why an astronaut returning from weightlessness of space is taller on his return than on his departure. Running is a form of dynamic loading that decreases disk height more rapidly than static loading. The height of the vertebral column is a widely used indicator of cumulative disk compression. In the elderly the amount of creep that occurs is greater than in the young and the recovery from creep and hysteresis is slower.

- Bending - Causes both compression and tension on the structures of the spine. When bending to one side, the structures on that side (portion of disk, ligaments, and muscles) are subjected to compression, while on the other to tension. Creep occurs when the vertebral column is subjected to a sustained loading such as might occur in either the fully flexed postures commonly assumed in gardening or in the fully extended postures assumed in painting the ceiling. The resulting deformation (elongation of compression) of supporting structures leads to an increase in the ROM beyond normal limits and places the vertebral structures and the risk of injury.
- Torsion - Forces are created during axial rotation that occurs as a part of the coupled motions that take place in the spine. Torsional stiffness is provided by the outer layers of both the vertebral bodies and intervertebral disks and by the orientation of the facets. The risk of rupture of the disk fibres is increased when torsion, heavy axial compression, and bending are combined.
- Shear - Forces act on the mid-plane of the disk and tend to cause each vertebra to undergo translation.

Vertical loading of the lumbar spine (axial compression) occurs during upright (standing or sitting) postures. Within the vertebra itself, compressive force is transmitted by both the cancellous (spongy) bone of the vertebral body and its cortical bone shell (Norris, 2008). The great hydrostatic pressure that is set up in the nucleus pulposus under load causes tangential forces that act not only on the annulus fibrosus, but also on the adjoining bone (Bartelink, 1957).

So long as a person is upright, even if he carries a heavy weight in his hands, the pressure upon the spine is not more than the sum of the upper trunk and the weight (Bartelink, 1957). During standing, 12% to 25% of axial compression forces are transmitted between adjacent vertebrae by the facet joints; the intervertebral disc absorbs the rest of the force. The annulus fibrosus of a healthy disc resists buckling; even if a disc’s nucleus pulposus has been removed, its annulus alone can exhibit a load bearing capacity similar to that of the fully intact disc for a brief period. When exposed to prolonged loading, however, the collagen lamellae of the annulus eventually buckle. If the pressure at the L3 disc for a 70kg standing subject is 100%, supine lying reduces the pressure to 25% and the sitting posture increases intradiscal pressure to 140%. Deformation of the disc occurs more rapidly at the onset of axial load application, the majority of the deformation occurring within 10 min of onset (Norris, 2008).

Takahashi et al. showed that upright walking creates the highest epidural pressure, and that pressure peaks intermittently during the double supporting phase corresponding to maximum forward tilt of the pelvis (leads maximum lumbar lordosis). The increase of epidural pressure at simple walking was higher than walking with lumbar flexion (Sasaki, Senda, Katayama, Ota, & Matsuyama, 2013). Devoid of its musculature, the skeleton and the spine are inherently unstable.

Without the guy wires of soft tissues, an upright skeleton, no matter how perfectly aligned, would quickly collapse into a heap (Bond, 2006).

4.2 MUSCLES – MOVE THE FRAMEWORK

One essential component of the machinery of the human body is muscular tissue. Through sustained contraction or alternating contraction and relaxation, muscular tissue has four key functions: producing body movements, stabilizing body positions, storing and moving substances within the body, and generating heat. Muscular tissue has four special properties that enable it to perform these functions: electrical excitability, contractility, extensibility and elasticity. There are three types of muscular tissue: skeletal, cardiac, and smooth. Although the three types of muscular tissue share some properties, they differ from one another in their microscopic anatomy, location, and how they are controlled by the nervous and endocrine systems (Tortora & Nielsen, 2012).

Muscular tissue directly involved in maintenance of upright stance is the skeletal muscle tissue.

4.2.1 Skeletal muscle tissue

Skeletal muscle tissue is so named because the function of most skeletal muscles is to move bones of the skeleton. (There are a few that attach to structures other than bone, such as the skin or even other skeletal muscles). Skeletal muscle tissue works primarily in a *voluntary* manner; its activity can be consciously (voluntarily) controlled. Muscle contractions may be either isotonic (concentric and eccentric) or isometric. In an isometric contraction the tension generated is not enough to exceed the resistance of the object to be moved and the muscle does not change its length. These contractions are important for maintaining posture and for supporting objects in a fixed position. Although isometric contractions do not result in body movement, energy is still expended. Isometric contractions are important because they stabilize some joints as others are moved (Tortora & Nielsen, 2012).

Skeletal muscle fibres vary in their content of myoglobin, the red protein that binds oxygen in muscle fibres. Those with a high myoglobin content are called *red muscle fibres*, while those that have a low myoglobin content are called *white muscle fibres*. Red muscle fibres also contain more mitochondria and are supplied by more blood capillaries than white muscle fibres. Skeletal muscle fibres also contract and relax at different speeds, and can be categorized as either slow or fast depending on how rapidly the ATPase in their myosin heads hydrolyses ATP. In addition, the metabolic reactions that skeletal muscle fibres use to generate ATP vary, as does the length of time it takes them to experience fatigue (inability of a muscle to maintain force of contraction after prolonged activity). All of these structural and functional characteristics are taken into account in classifying a skeletal muscle fibre as one of three main types: slow oxidative fibres (SO), fast oxidative-glycolytic fibres (FOG), and fast glycolytic fibres (FG) (Tortora & Nielsen, 2012).

	SLOW OXIDATIVE (SO) OR TYPE I FIBERS	FAST OXIDATIVE-GLYCOLYTIC (FOG) OR TYPE IIa FIBERS	FAST GLYCOLYTIC (FG) OR TYPE IIb FIBERS
STRUCTURAL CHARACTERISTICS			
Fiber diameter	Smallest	Intermediate	Largest
Myoglobin content	Large amount	Large amount	Small amount
Mitochondria	Many	Many	Few
Capillaries	Many	Many	Few
Color	Red	Red	White (pale)
FUNCTIONAL CHARACTERISTICS			
Capacity for generating ATP and method used	High capacity, by aerobic cellular respiration	Intermediate capacity, by both aerobic cellular respiration and anaerobic cellular respiration (glycolysis)	Low capacity, by anaerobic cellular respiration (glycolysis)
Rate of ATP use	Slow	Fast	Fast
Contraction velocity	Slow	Fast	Fast
Fatigue resistance	High	Intermediate	Low
Location where fibers are abundant	Postural muscles such as those of the neck	Lower limb muscles	Upper limb muscles
Primary functions of fibers	Maintaining posture and aerobic endurance activities	Walking, sprinting	Rapid, intense movements of short duration

Figure 2: presenting different fibre types with the distribution of primary functions among fibres (Tortora & Nielsen, 2012).

Most skeletal muscles are a mixture of all three types of skeletal muscle fibres. The proportions vary somewhat, depending on the action of the muscle, the person's training regimen, and genetic factors. For example, the continually active postural muscles of the neck, back, and legs have a high proportion of SO fibres. Muscles of the shoulders and arms, in contrast, are not constantly active but are used briefly now and then to produce large amounts of tension, such as in lifting and throwing. These muscles have a high proportion of FG fibres. Leg muscles, which not only support the body but are also used for walking and running, have large numbers of both SO and FOG fibres (Tortora & Nielsen, 2012).

The skeletal muscle fibres of any given motor unit are all of the same type. However, the different motor units in a muscle are recruited in a specific order, depending on need. For example, if weak contractions are enough to perform a task, only SO motor units are activated. If more force is needed, the motor units of FOG fibres are also recruited. Finally, if maximal force is required, motor units of FG fibres are also called into action along with the other two types. Activation of various motor units is controlled by the brain and spinal cord (Tortora & Nielsen, 2012). For each muscle, there is a pool (or group) of motor neurons which are activated during a voluntary muscle contraction. The number of muscle fibres in a certain motor unit and the diameter of these fibres determine the size of the motor unit or the magnitude of its contribution to the muscle force created. The number of muscle fibres within a motor unit is not constant. Most muscles have large numbers of smaller motor units and smaller numbers of larger motor units. The distribution of the motor unit sizes of a muscle determines how precisely its force can be controlled; the smaller the motor unit, the more precise its force and function (Adel & Stashuk, 2013).

An innervated muscle fibre is activated when the currents created by the activity of its neuromuscular junction create a transmembrane action potential that then propagates in both directions along the muscle fibre away from the neuromuscular junction initiating and coordinating contraction of the fibre. In other words, action potentials propagate along the axon of a motor neuron to activate the muscle fibres of a motor unit. The currents creating the action potentials of the activated muscle fibres linearly contribute to a spatially and temporally dynamic electric field created in the volume conductor in and around a muscle. The strength and spatial and temporal complexity of the created electric field is determined by the number of motor units active and their size and spatial extent. Electrodes placed in this electric field can be used to detect a time changing voltage signal (i.e. an EMG signal) (Adel & Stashuk, 2013).

Even while at rest, a skeletal muscle exhibits muscle tone, a small amount of tautness or tension in the muscle due to weak, involuntary contractions of its motor units. Skeletal muscle contracts only after it is activated by acetylcholine released by nerve impulses in its somatic motor neurons. Hence, muscle tone is established by neurons in the brain and spinal cord that excite the muscle's somatic motor neurons. To sustain muscle tone, small groups of motor units are alternately active and inactive in a constantly shifting pattern. Muscle tone keeps skeletal muscles firm, but it does not result in a force strong enough to produce movement. For example, when you are awake the muscles in the back of the neck are in normal tonic contraction. They keep the head upright and prevent it from slumping forward on the chest. Muscle tone also is important in smooth muscle tissues, such as those found in the gastrointestinal tract, where the walls of the digestive organs maintain a steady pressure on their contents. The tone of smooth muscle fibres in the walls of blood vessels plays a crucial role in maintaining blood pressure (Tortora & Nielsen, 2012).

Although a bone has growth plates that allow it to extend in a longitudinal direction, the length associated with skeletal muscle growth is usually derived from the addition of sarcomeres to the muscle fibres, primarily in the region of the myotendinous junction. If a muscle-tendon unit is stretched, additional sarcomeres are typically added at the region of the myotendinous junction (Whiting & Zernicke, 2008).

Fascicular arrangement affects a muscle's power and range of motion. As a muscle fibre contracts, it shortens to about 70 percent of its resting length. Thus, the longer the fibres in a muscle, the greater the range of motion it can produce. However, the power of a muscle depends not on length but on its total cross-sectional area. Therefore, because a short fibre can contract as forcefully as a long one, the more fibres per unit of cross-sectional area a muscle has, the more power it can produce. Fascicular arrangement often represents a compromise between power and range of motion. Pennate muscles, for instance, have a large number of short fibred fascicles distributed over their tendons, giving them greater power but a smaller range of motion. In contrast, parallel muscles have comparatively fewer fascicles, but they have long fibres that extend the length of the muscle, so they have a greater range of motion but less power (Tortora & Nielsen, 2012). Our vertically arranged muscles enable us to move, while the horizontal ones support our internal organs and help us manage our interaction with our environment (Bond, 2006).

In the study of muscles, it is common to describe the actions that individual muscles produce at their associated joints. It is important to recognize what movements muscles are capable of producing at the joints they cross, but it is equally important to realize that muscles never work in isolation. The movements attributed to muscles are possible only for a certain range of the joint's movement, or occur in combination with the actions of other muscles.

4.2.2 **Additional factors**

Feet are also crucial to postural health as well as steady breathing, core containment, or pelvic mobility; as goes the foundation, so goes the building. Other than knee trauma, most imbalances in knees are due to poorly supportive feet or restricted motion in the hips. The orientation of the knees is usually determined by the rotation of the thighs, which, in turn, is influenced by the pelvis (Bond, 2006).

Your expressive head motions are made by tiny muscles known as the suboccipitals, which connect the base of your skull to your upper two neck vertebrae. These muscles lie underneath trapezius and other larger neck muscles. The suboccipitals have more motion sensors than any other part of the body, which gives them an important role to play. While your inner ear keeps your head upright, the suboccipitals keep your head aligned with your body. Because of fascial links between your face and neck, any tension in your jaw, nose, or eyes can harden and immobilize the suboccipital muscles, undermining your balance and preventing healthy posture. The muscles that open and close your jaw pull on the skull and the neck vertebrae. Strain in the jaw muscles is transferred to your neck and relays down your throat into your shoulders, diaphragm, and pelvic floor. Jaw tension can also transmit strain to the temporal bone and inner ear, interfering with balance (Bond, 2006).

5 MOVEMENT CONTROL

The fact that we as humans are bipeds and locomote over the ground with one foot in contact (walking), no feet in contact (running), or both feet in contact (standing) creates a major challenge to our balance control system. Because two-thirds of our body mass is located two-thirds of body height above the ground we are an inherently unstable system unless a control system is continuously acting (Winter D. A., 1995).

Postural control, which can be either static or dynamic, refers to a person's ability to maintain stability of the body and body segments in response to forces that threaten to disturb the body's structural equilibrium. The control of posture is complex and is part of the body's motor control system (Levangie & Norkin, 2001). Although we sometimes think we are standing still, our nerves and muscles are making hundreds of tiny adjustments per second to orient our unstable frames against the pull of gravity (Bond, 2006).

By considering the standing body as an inverted pendulum, in this simple model, the upright posture is unstable equilibrium point of saddle-type, with stable and unstable modes, i.e., stable and unstable manifolds. Feedback control is thus indispensable for stabilizing the upright equilibrium (Yamamoto, et al., 2015). Maintaining an erect posture takes surprisingly little energy, however, as a result of constant motion brought about by postural control. This motion (postural sway) depends on kinesthesis, or motion sense, which enables us to detect the position of our body parts through organs of proprioception, vision, the vestibular apparatus in the inner ear, and skin receptors (Norris, 2008).

Thesis presented by Tokuno, 2007, demonstrated that human standing posture is controlled via an overall enhancement of cortical excitability, concurrently with an ongoing sway-dependent modulation of spinal and corticospinal processes. The constantly changing neural inputs to the motoneurone pool may give insight into the influence of postural sway to the neuromuscular responses to an unexpected perturbation (Tokuno, 2007).

Sensory information, or 'sensory cues', (any information coming from your senses, such as vision and touch) needs to be evaluated by your nervous system. Evaluation of these cues involves complex memory, reasoning and emotional processes, and must include consideration of the potential consequences of a response (Butler & Moseley, 2013). Because postural stability requires cognitive resources to process somatosensory input, any additional process that uses those resources can reduce a person's ability to maintain postural stability. All of this information is evaluated and processed in the CNS to create the necessary motor output commands to maintain postural stability. This entire process occurs constantly and automatically in a loop (Page, Frank, & Lardner, 2010).

5.1 NERVOUS SYSTEM

When we look at progress made in technology and computers, a combination of factors makes phenomenal advances in computing power possible, especially the ever-increasing sophistication of the microcircuitry, which increases speed and processing power, allows better integration, and provides a large number of programming pathways. However, even the most advanced supercomputers pale in comparison with the sophisticated circuitry and functionality of the machine that created them—the human nervous system (Tortora & Nielsen, 2012).

The nervous system differs from other body systems because many of its cells are extremely long. The longest axons are almost as long as you are tall, extending from your toes to the lowest part of your brain. Broadly speaking, the nervous system can be organized both anatomically and functionally. All complex tasks human body can produce can be grouped into three basic functions: sensory (input), integrative (control), and motor (output) (Tortora & Nielsen, 2012).

5.1.1 Sensory system

In everyday activities we depend on signals coming from our moving bodies to be able to respond to the space around us and react rapidly in changing circumstances (Proske & Gandevia, 2012).

A sensation is the conscious or subconscious awareness of changes in the external or internal conditions of the body. A perception is the conscious awareness and interpretation of a sensation. Perceptions are integrated in the cerebral cortex (Tortora & Nielsen, 2012). Injured peripheral nerves can result in a wide variety of sensations. Thanks to modern neuroscience, most of these seemingly odd sensations are no longer a mystery. Many common syndromes such as tennis elbow, plantar fasciitis and carpal tunnel syndrome are likely to involve peripheral nerves (Butler & Moseley, 2013).

The senses can be grouped into two classes (Tortora & Nielsen, 2012):

- General senses:

Somatic: tactile sensations (touch, pressure, vibration, itch, and tickle); thermal sensations (warm and cold); pain sensations; and proprioceptive sensations, which allow perception of both the static (non-moving) positions of limbs and body parts (joint and muscle position sense) and movements of the limbs and head

Visceral senses: provide information about conditions within internal organs, such as pressure, stretch, chemicals, nausea, hunger, and temperature.

- Special senses: smell, taste, vision, hearing, and equilibrium (balance).

Classification of Sensory Receptors

BASIS OF CLASSIFICATION	DESCRIPTION
MICROSCOPIC FEATURES	
Free nerve endings	Bare dendrites associated with pain, thermal, tickle, itch, and some touch sensations
Encapsulated nerve endings	Dendrites enclosed in a connective tissue capsule for pressure, vibration, and some touch sensations
Separate cells	Receptor cells synapse with first-order sensory neurons; located in the retina of the eye (photoreceptors), inner ear (hair cells), and taste buds of the tongue (gustatory receptor cells)
TYPE OF STIMULUS DETECTED	
Photoreceptors	Detect light that strikes the retina of the eye
Mechanoreceptors	Detect mechanical stimuli; provide sensations of touch, pressure, vibration, proprioception, and hearing and equilibrium; also monitor stretching of blood vessels and internal organs
Thermoreceptors	Detect changes in temperature
Osmoreceptors	Sense the osmotic pressure of body fluids
Chemoreceptors	Detect chemicals in mouth (taste), nose (smell), and body fluids
Nociceptors	Respond to painful stimuli resulting from physical or chemical damage to tissue
RECEPTOR LOCATION AND ACTIVATING STIMULI	
Exteroceptors	Located at or near body surface; sensitive to stimuli originating outside body; provide information about *external* environment; convey visual, smell, taste, touch, pressure, vibration, thermal, and pain sensations
Interoceptors	Located in blood vessels, visceral organs, and nervous system; provide information about *internal* environment; impulses produced usually are not consciously perceived but occasionally may be felt as pain or pressure
Proprioceptors	Located in muscles, tendons, joints, and inner ear; provide information about body position, muscle length and tension, position and motion of joints, and equilibrium (balance)

Figure 3: classification of sensory receptors (Tortora & Nielsen, 2012).

Two systems, *visual* and *proprioceptive* (the vestibular system + somatosensory system) are important in providing sensory information for postural control and provide information for constructing an internal body model that represents the different body segments relative to the surrounding environment (Enoka, 1994) (Hirata, et al., 2013).

The information necessary to control movement is provided by the visual sense of eye position with respect to surrounding surfaces involved in planning our locomotion and in avoiding obstacles along the way, the vestibular sense of head orientation in inertial-gravitational space is our ‘gyro’, which senses linear and angular accelerations, and the somatic sense of body segment positions relative to one another and to the support surface. The execution of a motor task and adjustment of pressure to maintain their COP (in relation to the centre of mass of their bodies and general coordination systems), frequently requires a combination of motion information from several senses. During stance, knowledge of eye and head movements derived from somatic and vestibular inputs is required to interpret visual motion inputs correctly (Winter D. A., 1995) (Nashner & McCollum, 1985) (Han, Lee, & Lee, 2013).

Computational models indicate that healthy subjects rely mainly on somatosensory information (70%) to control their balance during quiet standing, using only 10% and 20% of visual and vestibular information respectively (Hirata, et al., 2013). Han et al., 2013, performed a study with vibration stimulation on the belly of anterior tibialis and gastrocnemius, and established that somatosensory stimulation can decrease postural sway in normal subjects when their eyes are closed, which suggests that visual information is an important element and that vibration, particularly without visual information, helps to improve postural balance by stimulating the proprioceptors of the body. It is thought that vibration may have a positive effect in maintaining static balance by activating the proprioceptors (Han, Lee, & Lee, 2013).

During limb movement and changes in position, the tissues around the relevant joints will be deformed, including skin, muscles, tendons, fascia, joint capsules, and ligaments. All these tissues are innervated by mechanically sensitive receptors, and their density varies across muscles and regions of the body (Proske & Gandevia, 2012). The receptors which lie in the depth of the organism are adapted for excitation consonantly with changes going on in the organism itself, particularly in its muscles and their accessory organs (tendons, joints, blood-vessels, etc.). Since in this field the stimuli to the receptors are given by the organism itself, their field may be called the *proprio-ceptive* field (Sherrington, 1906).

Proprioceptive sensations, also referred to as *proprioception*, allow us to know where our head and free limbs are located and how they are moving even if we are not looking at them, so that we can walk, type, or put a shirt on without using our eyes. Proprioceptive sensations arise in receptors called proprioceptors. Those proprioceptors embedded in muscles (especially postural muscles) and tendons inform us of the degree to which muscles are contracted, the amount of tension on tendons, and the positions of joints (Tortora & Nielsen, 2012).

Three types of musculoskeletal proprioceptors are (Tortora & Nielsen, 2012) (Proske & Gandevia, 2012):

- *Muscle spindles* (intrafusal fibres) – within skeletal muscles, monitor changes in the length of skeletal muscles and participate in stretch reflexes. By adjusting how vigorously a muscle spindle responds to stretching of a skeletal muscle, the brain sets an overall level of muscle tone.
- *Tendon organs* – located within tendons at the junction of a tendon and a muscle, protect tendons and their associated muscles from damage due to excessive muscle tension.
- *Kinaesthetic receptors* - free nerve endings and type II cutaneous mechanoreceptors (*Ruffini corpuscles*) in the capsules of synovial joints respond to pressure. Small lamellated *(Pacinian)* corpuscles in the connective tissue outside articular capsules respond to acceleration and deceleration in the movement of joints. Joint ligaments contain receptors similar to tendon organs that adjust the adjacent muscles when excessive strain is placed on the joint.

Kinaesthetic awareness, or movement sense, includes the detection of both joint displacement and change in velocity (i.e. acceleration). It is commonly assessed by measuring the threshold to detection of passive motion: individuals simply state when they feel that movement has begun. One cannot act to correct imbalance until one is aware that there is an imbalance. The awareness can be conscious or unconscious, however, and the corrective action likewise can be intentional or automatic (Norris, 2008).

Kinaesthesia is behavioral in nature, and it places an emphasis on the body's motions, as well as incorporates routine or habitual behaviors to improve movements. Both hand-eye coordination and muscle memory involve kinaesthesia — the more you perform certain actions, such as during sports, the better at them you will become. Comparatively, proprioception has more to do with body position, and focuses on the cognitive awareness of the body in space (Bennington, 2013).

Much of this knowledge about position and movement of the limbs and trunk is provided by sensations arising in proprioceptors. The information they provide allows us to manoeuvre our way around obstacles in the dark and be able to manipulate objects out of view (Proske & Gandevia, 2012). If the trunk is moving slowly, a subject feels tissue tension at the end range and is able to stop a movement short of the full end range – thereby protecting the spinal tissues from overstretching. However, rapid trunk movements can build up sufficient momentum to push the spine to the full end range, thereby stressing the spinal tissues. These activities can lead to excessive flexibility and a reduction in passive stability of the spine (Norris, 2008).

The study by Bullock-Saxton, 1993, consisting of groups of normal, pregnant and back pain subjects, in the ages of 18-19 years, demonstrated no significant difference between the separate sets of measures of lumbar curvature, thoracic curvature and pelvic tilt, over a period of two years. It has shown that on a particular day, a person assumes a consistent postural alignment (in terms of spinal curvature and pelvic inclination) when asked to stand comfortably erect. This means that if changes in spinal curvature are observed in a patient during the normal treatment period, they can be attributed to specific changes occurring within that patient. The knowledge that this applies to those suffering from low back pain as well as those who are symptom free and also to those whose physique has changed from their normal body proportions, as in the case of the pregnant subjects, is important in patient management. Apparently, a person's awareness of what constitutes, for them, a comfortable erect posture is sufficiently strong and consistent that they are able to assume a similar posture repeatedly (Bullock-Saxton, 1993).

Proprioceptive sensations are mysterious because we are largely unaware of them. They are distinguishable from exteroceptors such as the eye and the ear in that they are not associated with specific, recognizable sensations. Yet, when we are not actually looking at our limbs, we are able to indicate with reasonable accuracy their positions and whether they are moving. Part of the explanation for this lack of identifiable sensations relates to the predictability of proprioceptive signals. We are aware that we are making a willed movement and so anticipate the sensory input that it generates. A general concept in sensory physiology is that what we feel commonly represents the difference between what is expected and what has actually occurred. On that basis, if a movement goes to plan and there is no mismatch between the expected signals and those actually generated, no definable sensation is produced, yet the subject knows precisely the location of their limb. It is possible to generate an artificial proprioceptive signal using muscle vibration. Vibration produces sensations of limb displacement and movement, leading the subject to express astonishment at the unwilled nature of the sensations. This suggests that the will to move and the subsequent proprioceptive sensations are intimately linked (Proske & Gandevia, 2012). Because proprioceptors adapt slowly and only slightly, the brain continually receives nerve impulses related to the position of different body parts and makes adjustments to ensure coordination (Tortora & Nielsen, 2012).

However, like the proprioceptive system, the vestibular system of the inner ear also has specialized hair receptors that give feedback about the head's position and changes in its position contributing to a range of conscious sensations as well as the guidance of movement and posture (Proske & Gandevia, 2012) (Nashner & McCollum, 1985) (McGinnis, 2004). There are two types of equilibrium or balance. Static equilibrium refers to the maintenance of the position of the body (mainly the head) relative to the force of gravity. Body movements that stimulate the receptors for static equilibrium include tilting the head and linear acceleration or deceleration, such as when the body is being moved in an elevator or in a car that is speeding up or slowing down. Dynamic equilibrium is the maintenance of body position (mainly the head) in response to sudden movements such as rotational acceleration or deceleration. The receptor organs for equilibrium include the saccule, utricle, and semicircular ducts, and are collectively referred to as the vestibular apparatus. Various pathways among the vestibular nuclei, cerebellum, and cerebrum enable the cerebellum to play a key role in maintaining static and dynamic equilibrium. The cerebellum continuously receives updated sensory information from the utricle and saccule. It monitors this information and makes corrective adjustments. Essentially, in response to input from the utricle, saccule, and semicircular ducts, the cerebellum continuously sends nerve impulses to the motor areas of the cerebrum. This feedback allows correction of signals from the motor cortex to specific skeletal muscles to smooth movements and coordinate complex sequences of muscle contractions to help maintain equilibrium (Tortora & Nielsen, 2012).

Vision or the act of seeing, is extremely important to human survival. More than half the sensory receptors in the human body are located in the eyes, and a large part of the cerebral cortex is devoted to processing visual information (Tortora & Nielsen, 2012). Vision is an important source of information in elderly people when maintaining balance. Visual information cannot completely compensate for the lack of information from the feet. Healthy obese, when compared with normal weight subjects, have increased postural sway, which becomes more evident with absence of visual information (Hirata, et al., 2013). Another research showed that shutting off visual stimuli proved to have a much higher impact on the posture control system disorders in subjects after the ACL reconstruction. The analysis of the results showed that the visual control system supports mechanical receptors in improving the posture control. Furthermore, this system works in conjunction with oscillating head movements. When standing freely with eyes open head movements are minimal. They increase in amplitude and frequency when eyes are closed (Kubisz, Werner, Bosek, & Weiss, 2011). Predilection (predetermined) positioning of the head, which is physiological only in the new-born developmental stage, can persist into later months, which leads to an abnormal postural deficits in childhood. At a later age, we observe a deficit in the assessment of sensory input – especially the assessment of proprioceptive and vestibular information, in which a patient with a tilted head position perceives, for example, that their head is straight and displays a limited range of visual field, including perception (Kolar, 2013).

Visual, proprioceptive, and vestibular systems are critical sources of afferent information that influence the control of stability. Unpublished research has shown that individuals *without* vestibular impairment efficiently maintain equilibrium in quiet standing with minimal muscular activation, metabolic cost, and joint loading. Individuals *with* vestibular hypofunction are reported to be less stable than individuals without impairment. The loss of unilateral vestibular function, however, has been reported to cause an increase in body sway when there are coexisting impairments in both the visual and somatosensory systems. In study done by Danis et al, 1998, both the subjects with vestibular hypofunction and the subjects without impairment demonstrated a slightly extended trunk and head during standing with feet apart and eyes open, however, the subjects with vestibular hypofunction had higher ranges for the following joint angles in both standing positions: pelvic flexion and extension, head flexion and extension, and pelvic and trunk lateral side bending. Also, during quiet standing with feet apart, the subjects with vestibular hypofunction had an unequal weight distribution compared with the subjects without impairment, they stood with more weight on the left lower extremity. Compensation for this asymmetry may have caused increased body sway (Danis, Krebs, Gill-Body, & Sahrmann, 1998).

The information from sensory systems is organized to generate muscle forces aiming to stabilize the body oscillations and maintain balance. In the presence of disease, some of these sensory systems might be impaired, requiring the ability to increase the contribution of unaffected areas and sensory systems for maintenance of postural orientation. The sensory reweighting hypothesis suggests that when controlling balance, the central nervous system can dynamically adjust the relative contribution (gain) of each sensory input involved, according to the contextual changes in the environment and therefore, modify postural responses. Healthy subjects are capable of reweighting the sensory information in order to maintain balance (Hirata, et al., 2013).

Increased body sway in infants at the transition age reflects an *adjustment* to using sensory information to control posture in the new postural position. That is, learning to walk requires a *recalibration* of sensorimotor control of posture. Infant postural development is more than just reducing sway. There is a change in the nature of sway toward lower frequency and slower, less variable velocity and sensory information is used more efficiently in estimating posture. Researchers realized that children under the age of 7.5 years cannot reweight sensory inputs and rely more on vision. Adults are capable of very precise reweighting of sensory information when necessary. If one sensory system provides unreliable information, the postural control systems of adults can decrease the emphasis on information from this system and increase emphasis on information from the other, more reliable system. Older adults appeared to be again more dependent on visual information (sensory reweighting to visual). It is not surprising, that an inability to react quickly to a balance threat is problematic for older adults. Older adults sway more than young adults, especially when somatosensory information is perturbed or the balance task becomes more difficult (Enoka, 1994).

Sensory conflict occurs fairly often in daily living. The visual system often tricks us when we observe the movement of one vehicle relative to another. When we observe an adjacent bus or train from our own vehicle we often perceive that we are moving rather than the adjacent vehicle. Or in the movement of the deck of a boat we can get conflicting information especially if we are below decks and cannot see the horizon as a reference (Winter D. A., 1995). When inputs are altered or absent, the control system must respond to incomplete or distorted data and thus the person's posture may be altered and stability compromised. Altered or absent inputs may occur either in the absence of the normal gravitational force in weightless conditions during space flight, or when someone has decreased sensation in the lower extremities. Examples include astronauts after returning from space with changes attributed to reweighting of vestibular inputs, "sleepy feet", or after injury or peripheral nerve damage (Levangie & Norkin, 2001).

Research suggest that generally poorer balance in patients with multiple sclerosis could be a result of an impaired vestibular system or degraded somatosensory feedback since the disease contributes to delayed visual, auditory and somatosensory evoked potentials along with possibility of secondary effects on balance e.g. due to increased fatigability. Impaired balance is in part due to a decrease in the somatosensory feedbacks from the soles (Borg, Finell, Hakala, & Herrala, 2007).

After injury, movement or even just a sustained posture may ignite an injured nerve which keeps ringing like a car alarm (Butler & Moseley, 2013). Hirata, et al., 2013, observed that the pain intensity was positively correlated with increased postural sway (COP range in the medial-lateral direction) while standing on firm surface when visual input is not available. Larger oscillations are indicators that, the higher the pain intensity, the less efficient is the postural control applied to restore an equilibrium position while standing. This lack of effectiveness make the patients more prone to fall if immediate actions fail to restore the balance. In further research it was found that anaesthetizing the knee joint of knee osteoarthritis patients does not improve balance or knee proprioception, although it increases the maximum quadriceps strength one hour after a (bupivacaine) injection supporting the notion that pain inhibits muscle activation and torque (Hirata, et al., 2013).

Schilling, 2009, concluded that subjects with peripheral neuropathy and diabetic peripheral neuropathy appeared less steady made sense in terms of the underlying postural control system. Low nerve conduction velocities mean more delay in the feedback control system used to maintain balance. It is well known that as delay is increased in a linear feedback control system, the stability margin decreases (Schilling, et al., 2009). Another report described the sway of COP during quiet standing on a force plate after the occurrence of neurogenic claudication (NC). Results show that the sway of COP increases after NC due to neurological deficits. NC induced by lumbar stenosis leads to muscular weakness, sensory disturbance and/or pain. The time to COP recovery is longer than the time required for subjective recovery from symptoms. Thus, postural sway after NC depends not on symptoms (degree of pain), but rather on neurological signs (Sasaki, Senda, Katayama, Ota, & Matsuyama, 2013).

Dynamic joint stability (i.e. the body’s ability to constantly make unconscious micro corrections to keep a joint stable) occurs via reflexes at the spinal level. The ideal situation for back stability is that you have such closed-loop efferent signals constantly going out to your stability muscles (Norris, 2008).

The major goals of postural control in the erect position are to control the body’s orientation in space; maintain the body’s COG over the BOS, and stabilize the head with respect to the vertical so that the eye gaze is appropriately oriented. Maintenance and control of posture depends on the integrity of the CNS, visual system, vestibular system, and the musculoskeletal system. In addition, postural control depends on information from receptors located in and around the joints (joint capsules, tendons, and ligaments) as well as on the soles of the feet. The CNS must be able to detect and predict instability and must be able to respond to all of this input with appropriate output to maintain the equilibrium of the body. Furthermore, the joints in the musculoskeletal system must have a range of motion that is adequate for responding to specific tasks, and the muscles must be able to respond with appropriate speeds and forces (Levangie & Norkin, 2001).

Volitional control of a motor unit occurs only through the synapses between the motor neuron and the neurons whose fibres descend from the higher-order structures in the central nervous system. The other synapses transmit neural impulses that may augment or detract from the desired volitional response. Through feedback from the proprioceptors, the proper intensity of the volitional neural impulse occurs at the motor neuron synapses with the neurons whose fibres descend from the central nervous system. This process of constant feedback and control determines the behaviour of a motor unit (McGinnis, 2004).

One can, with intentional movements, know precisely what one is doing, without seeing or consciously feeling what is going on. But this is only because they are intentional movements and one has the prior introspective knowledge that one intends to be performing these movement, and the prior sense-knowledge that these movements are within one's capabilities (Locke, 1967). The commonly used term *neuromuscular* refers to the interdependence of the sensory and motor systems, especially regarding the effects of the CNS on the muscular system, which controls the skeletal system. Muscles often act as movers as well as stabilizers during functional movement; therefore, neuromuscular control can be defined as the unconscious activation of muscular stabilizers to prepare for and respond to joint movement and loading for functional joint stability. These stabilizing mechanisms occur both globally through postural stabilization and locally through functional joint stabilization (Page, Frank, & Lardner, 2010).

5.2 MEASURING MUSCLE ACTIVITY - EMG

Voluntary muscle contractions are initiated when the central nervous system recruits motor units by activating their motor neurons, which in turn, via their neuromuscular junctions, activate their muscle fibres. The currents creating the action potentials of the activated fibres of recruited motor units summate to create dynamic electric fields in the volume conductor in and around muscles. Electrodes placed in these electric fields detect time changing voltage signals which are the electromyographic (EMG) signals (Adel & Stashuk, 2013). EMG is an experimental technique concerned with the development, recording and analysis of myoelectric signals. Unlike the classical neurological EMG, where an artificial muscle response due to external electrical stimulation is analysed in static conditions, the focus of kinesiological EMG can be described as the study of the voluntary neuromuscular activation of muscles within postural tasks, functional movements, work conditions and treatment/training regimes (Konrad, 2006).

The EMG instrument picks up weak electrical signals generated during muscle action. During muscle contraction, small part of electrical energy leaves the muscle and migrates through surrounding tissue. Some of this energy becomes available for monitoring at the surface of the skin. The tasks of an EMG machine are as follows (Schwartz & Andrasik, 2003):

1. To receive the very small amount of electrical energy from the skin
2. To separate emg energy from other extraneous energy on the skin, and to greatly magnify the emg energy
3. To convert this amplified emg energy into information or feedback that is meaningful to the user

The EMG signal is based upon action potentials at the muscle fibre membrane resulting from depolarization and repolarization processes.

Characteristics of the electromyographic signal (Robertson, Caldwell, Hamill, Kamen, & Whittlesey, 2004) (Konrad, 2006) (Kasman & Wolf, 2002):

> In the mildest muscle contraction, a single motor unit may be activated. This is recorded at the surface as the motor unit action potential, followed by electrical silence until the unit's next firing. As the desired force increases, other motor units may be recruited and fire at ever increasing frequency. At any point in time, the EMG signal is a composite electrical sum of all of the active motor units. A large peak in the EMG signal might be the result of the activation of two or more motor units separated by a short interval. The amplitude of the surface-recorded EMG signal varies with the task, the specific muscle group under study, and many other features. As the intensity of contraction increases, both the EMG amplitude and force increase in a predictable and linear manner.

The voltage signal detected when measuring the dynamic electric field created in the volume conductor surrounding a muscle fibre by the currents that flow to create and propagate a muscle fibre action potential, is called a muscle fibre potential (MFP). In turn, the detected voltage signal associated with the firing of a motor unit is called a motor unit potential (MUP). A MUP is actually the sum of the MFPs of it muscle fibres. The train of detected MUPs created by the repeated firing of the same motor unit is referred to as a motor unit potential train (MUPT).

Thus, a motor unit can be represented by its MUPT or by a MUP template; which is an estimate of its typical or expected MUP shape. The detected MUPTs created by all of the active motor units during a muscle contraction summate to comprise a detected EMG signal. Thus, a detected EMG signal contains contributions from all of the muscle fibres active during a muscle contraction. In kinesiological studies the MUPs are electrically superposed and observed as a bipolar signal with symmetric distribution of positive and negative amplitudes (mean value equals to zero). This is called an interference pattern (Konrad, 2006) (Adel & Stashuk, 2013).

Due to different distances between a detection electrode surface and the individual muscle fibres of a motor unit, the size and frequency content of the MFP contributions of the various fibres to the MUPs generated by a motor unit vary among the different fibres of the motor unit. There is an inverse relationship between both the amplitude and high frequency content of MFPs, and the distance between the contributing muscle fibre and the electrode detection surface such that muscle fibres that are closer to the detection surface contribute larger and higher frequency content MFPs. In addition, the peaks of individual MFP contributions occur at different times, indicating that their associated muscle fibre action potentials are not synchronously propagating past or "arriving" at the electrode detection surface. The difference in their arrival times is referred to as their *temporal dispersion*. Temporal dispersion is caused by the different conduction distances between the neuromuscular junctions (NMJs) of the fibres of a motor unit and the electrode detection surface and the different muscle fibre action potential conduction velocities of the fibres of a motor unit. The number of muscle fibres contributing significant MFPs to a MUP and their respective temporal dispersions will determine the size and complexity of a detected MUP. The stability of the MUPs of a motor unit refers to how similar its detected MUPs are across multiple motor neuron discharges. MUP stability is primarily dependent on the consistency of the times required by the NMJs of a motor unit to initiate a muscle fibre action potential on their respective muscle fibre and the consistency of the propagation velocities of the initiated muscle fibre action potentials (Adel & Stashuk, 2013).

5.2.1 **Electrodes and signal detection**

One way of envisaging an EMG electrode is to compare it to a receiving antenna. For telecommunications, dynamic electromagnetic signals propagate throughout air and an antenna detects these signals. Air in this case is analogous to the volume conductor throughout which currents spread. An EMG electrode acts as an antenna detecting, in this case, dynamic voltage signals generated by the activity of muscle fibres from which currents propagate throughout the volume conductor surrounding the muscle fibres and muscles. Electrodes used to detect EMG signals are actually transducers that allow the electric fields created in the volume conductor surrounding muscle fibres by the ionic currents associated with muscle contraction to be detected and amplified using standard instrumentation amplifiers which are dependent on electronic currents. EMG signals can be detected using a bipolar electrode configuration; measuring the voltage difference using two, or more, active electrodes, or a monopolar electrode configuration; with one reference (passive) electrode and one active electrode. In general, an EMG signal can be detected using a surface or intramuscular electrode configuration. Accordingly, there are two classes or types of EMG signals, surface and intramuscular EMG signals, respectively (Adel & Stashuk, 2013).

On its way from the muscle membrane up to the electrodes, the EMG signal can be influenced by several factors altering its shape and characteristics. They can basically be grouped in (Kasman & Wolf, 2002) (Konrad, 2006) (Adel & Stashuk, 2013):

- Intrinsic factors (the number of active motor units, the fibre type composition of the muscle, the amount of blood capable of flowing through the muscle during the contraction, the diameters, depths and locations of the active fibres)
- Physiological cross talk (signal from neighbouring muscles)
- External electrical noise or artifact (direct interference of power hum, typically produced by incorrect grounding of other external devices)
- Electrode and amplifiers (electrode and reference electrode size and position, avoiding motor points that can be detected by low frequency stimulus power generators producing right angled impulses, interelectrode distance, amplifier sampling rate)

Surface EMG electrodes are placed on the skin overlying a muscle. Typically, bipolar electrode configurations with surface areas approximately equivalent to that of a 1 cm by 3 cm rectangle and with approximately 1 cm spacing, and a differential amplification are used for kinesiological EMG measures. EMG-amplifiers act as differential amplifiers and their main purpose is the ability to reject or eliminate artifacts. The differential amplification detects the potential differences between the electrodes and cancels external interferences out. Because surface electrodes are placed on the skin overlying a muscle, whose muscle activation related electric fields they are detecting, the various distances between specific motor units and the muscle fibres of those motor units to the electrode detection surface(s) are large and relatively equal. As such, the motor unit potentials of different motor units are composed of primarily of low frequency components (50 to 200Hz) and quite similar in shape and it is difficult to discriminate between the activities of different motor units (Adel & Stashuk, 2013) (Konrad, 2006).

Because a motor unit consists of many muscle fibres, the electrode pair "sees" the magnitude of all innervated fibres within this motor unit - depending on their spatial distance and resolution. Typically, they sum up to a triphasic motor unit action potential, which differs in form and size depending on the geometrical fibre orientation in ratio to the electrode site. An unfiltered (exception: amplifier bandpass) and unprocessed signal detecting the superposed MUAPs is called raw EMG Signal. When the muscle is relaxed, a more or less noise-free EMG baseline can be seen. The averaged baseline noise should not be higher than 3 – 5 microvolts, 1 to 2 should be the target. By its nature, raw EMG spikes are of random shape, which means one raw recording burst cannot be precisely reproduced in exact shape. Before a signal can be displayed and analysed in the computer, it has to be converted from an analog voltage to a digital signal (A/D conversion) with a proper sampling frequency (Konrad, 2006). The surface EMG device measures voltage, which when properly recorded, represents the relative level of instantaneous *muscle recruitment* but not force, strength or fatigue (Kasman & Wolf, 2002).

One major drawback of any EMG analysis is that the amplitude (microvolt scaled) data are strongly influenced by the given detection condition: it can vary greatly between electrode sites, subjects and even day to day measures of the same muscle site. One solution to overcome this "uncertain" character of micro-volt scaled parameters is the *normalization* to a reference value, e.g. the maximum voluntary contraction (MVC) value of a reference contraction. The basic idea is to "calibrate the microvolts value to a unique calibration unit with physiological relevance", the "percent of maximum innervation capacity" in that particular sense. Other methods normalize to the internal mean value or a given trial or to the EMG level of a certain submaximal reference activity. The main effect of all normalization methods is that the influence of the given detection condition is eliminated and data are *rescaled from microvolt to percent* of selected reference value. It is important to understand that amplitude normalization does not change the shape of EMG curves, only their Y-axis scaling. Benefit of MVC-normalization is the rescaling to percent of a reference value is unique and standardized for all subjects within a study. But, the MVC concept can only be used in studies done with healthy and trained subjects (Konrad, 2006).

In one study for example, surface EMG measurements were amplitude normalized to two standardized activities designed to elicit a stable submaximal voluntary contraction. This was performed because normalization to a maximal voluntary contraction reportedly is unreliable, reducing the ability to detect small changes in levels of motor activity during the performance of postural tasks (O'Sullivan, et al., 2002).

6 MAINTAINING THE UPRIGHT STANCE

The study of any particular posture includes kinetic and kinematic analyses of all body segments. Humans and other living creatures have the ability to arrange and to rearrange body segments to form a large variety of postures, but maintenance of erect bipedal stance is unique to humans (Levangie & Norkin, 2001).

The control of balance is a key aspect of mobility across the human life span from young children learning to stand and walk to elderly adults who may require the assistance of a cane or a walker. Postural control consists of both postural steadiness associated with the ability to maintain balance during quiet standing, and postural stability that is associated with the response to applied external stimuli and volitional postural movements. The postural control system makes use of information from the visual, vestibular, and somatosensory systems (Schilling, et al., 2009). The body maintains its COG on the BOS against internal and external forces through the interaction of sensory input, motor responses, and cognitive processes. Normal balance is characterized by the body's ability to maintain its COG within postural sway using information and motor responses (Han, Lee, & Lee, 2013).

Bond, 2006, mentions six body regions involved in creating open or closed stability, depending on how those regions are used. The posture zones include your breathing muscles, abdomen, pelvic floor, hands, feet, and head. The first three of these areas are structures that contain your body's core and through which you can stabilize yourself internally. The last three help you orient to and relate with the world. The six regions are connected anatomically, so activity – tension or release – in any one area always affects the others (Bond, 2006).

A biped standing perfectly erect is in a state of metastable equilibrium with respect to gravity. No active muscular control is required, since the centre of mass of each body segment is located precisely above its support. The task of postural adjustments is to return the body to erect equilibrium in the event of perturbation (Nashner & McCollum, 1985).

Normal body structure makes an ideal posture impossible to achieve, but it is possible to attain a posture that is close to the ideal. In normal optimal standing posture, the line of gravity falls close to, but not through, most joint axes. Therefore, in the normal optimal standing posture the gravitational torques are small and can be balanced by counter torques generated by passive ligamentous tension, passive muscle tension, and a minimal amount of muscle activity. The body segments in the normal optimal posture are in or near vertical alignment; the compression forces are distributed optimally over the weight-bearing surfaces of the joints; and no excessive tension is exerted on the ligaments or required by muscles. Slight deviations from the optimal posture are to be expected in a normal population because of the many individual variations found in body structure. If faulty postures are habitual and assumed continually on a daily basis, the body will not recognize these faulty postures as abnormal and over time structural adaptations will occur (Levangie & Norkin, 2001) (Nashner & McCollum, 1985).

Vladimir Janda's thinking was that the basic function of human locomotor system is to move as it has generally been accepted that locomotion for the lower extremity and prehension for the upper extremity present the basic reflex movement patterns. He continues by stating that gait can be considered as the principle movement pattern where at least 85% of time, during gait pattern, is spent on one leg. Concluding, muscles controlling one leg balance have the dominant postural function (Janda, 1983).

6.1 A PARADIGM SHIFT

Paradigms are to be universally recognized scientific achievements that for a time provide model problems and solutions to a community of practitioners. It consists of two characteristics; achievement is sufficiently unprecedented to attract an enduring group of adherents away from competing modes of scientific activity, and simultaneously, it is sufficiently open-ended to leave all sorts of problems for the redefined group of practitioners to resolve (Kuhn, 1970).

There are two major perspectives on postural control. One dominated the thinking of developmentalists for most of the last century. The second has received increasing attention over the last quarter century. The perspective that guided work on postural control for most of the 20th century is called the reflex hierarchy approach. The reflex hierarchy approach sees posture as a reflex response to sensory inputs to motor centres in the central nervous system. This is rooted in the works of Sherrington (1906) and his Cartesian approach to the matter. Magnus later applied Sherrington's work on reflexes to the study of posture on *animals* (Haywood, Roberton, & Getchell, 2012). As Rudolf Magnus stated: "Posture is an active process, and is the result of the cooperation of a great number of reflexes, many of which have a tonic character", while also saying that many parts of the central nervous system contribute to the function of posture (Magnus, 1926).

The reflex hierarchy perspective was well accepted for most of the 20th century but ultimately was found wanting in regard to several aspects of behaviour (Haywood, Roberton, & Getchell, 2012):

- First was the tendency to view posture as static, as a summation of antigravity stretch *reflexes* used to maintain balance. Recent research, however, has suggested that the mechanism controlling posture and the mechanisms controlling movement are tightly integrated rather than separate systems.
- Reflex hierarchy perspective focused on *gravity* as the single outside force with which postural control must contend. It is now evident that self-generated reactive forces are also a factor in the maintenance of equilibrium.
- A third complication for the reflex hierarchy perspective is that many postural responses involve most of the body. A reflex is typically defined as a local response to a specific sensory input. Yet, to achieve postural control many joints otherwise free to move must be maintained at a specific angle, and maintaining equilibrium often involves *anticipating* the forces that will act on the body or a body part. Cordo and Nashner (1982) established that postural activity precedes action, anticipating the need to counterbalance the forces generated in carrying out a task. This finding clearly does not fit the model of posture as a set of reflex responses. One reason why the reflex hierarchy perspective is insufficient for explaining all aspects of postural control is that it was rooted in studies of animal behaviour performed under unnatural conditions.

The emergence of systems theory late in the 20th century provided a new perspective on posture. Nikolai Bernstein was one of the first who introduced the notion of postural synergy, the combination of control signals to multiple muscles to assure stability of either a limb or the whole body in anticipation of a perturbation. While the reflex hierarchy approach focused on a specific stimulus for a specific reflex neurological loop, a *systems approach* recognizes that even infants use multimodal perceptual information to maintain equilibrium. Gravity is not the only force monitored, but also reaction forces to surfaces as well as self-generated forces resulting from movement. From the systems perspective, posture is synonymous with the control and flexible use of all the forces acting on a body. This view is in contrast to the traditional approach, which regards posture as the response to gravity used to achieve stability (Haywood, Roberton, & Getchell, 2012).

Posture is defined as the synergistic contraction of muscles and the organization of sensory information that permits stability and alignment of the body on a BOS (Bertoti, 1988). When researchers shifted from the reflex hierarchy theory to systems theory, they freed themselves to study postural control in more natural environments and with more natural tasks (Haywood, Roberton, & Getchell, 2012).

Soames & Atha, 1981, observed that antigravity muscular activity in standing is generally low and often absent, and that the myograms from the muscles of the right and left sides of the body differed appreciably, the two sides rarely working together. Some sudden and united bursts of antigravity muscle activity were observed. It was concluded that the view that postural control in quiet standing is continuously mediated in a simple way by stretch reflex mechanisms is probably not valid, and that other mechanisms for controlling posture remain to be identified (Soames & Atha, 1981). Reason for this might be in the explanation provided by Collins et al, 1993. In the past, it was generally believed that afferent signals (visual, vestibular, somatosensory) were utilized to regulate and continually modify the activity of the musculature during quiet standing. Analyses performed by Collins et al, 1993, indicate that in addition to this closed-loop feedback mechanisms, the postural control system also employs open-loop control schemes, the output of which may take the form of descending commands to different postural muscles. Since skeletal muscles are incapable of producing purely constant forces, these open-loop activation signals result in small mechanical fluctuations at various joints of the body. The present work suggests that these fluctuations and their associated drift effects are left unchecked by the postural control system until they exceed some systematic threshold, after which corrective feedback mechanisms are called into play. This open-loop/closed-loop control strategy, which allows a certain amount of "sloppiness" in balance control, may have evolved to take account of the inherent time delays of feedback loops and to simplify the task of integrating vast amounts of sensory information when the system is not in jeopardy of instability (Collins & De Luca, 1993).

6.2 NEUROMUSCULOSKELETAL MODEL OF FUNCTIONAL MOVEMENT

Vladimir Janda (1928 – 2002) noted that due to the interactions of the skeletal system, muscular system, and CNS, dysfunction of any joint or muscle is reflected in the quality and function of others, not just locally but also globally. He often spoke of muscle slings (*or chains*), groups of functionally interrelated muscles. Because muscles must disperse load among joints and provide proximal stabilization for distal movements, no movement is truly isolated. There are three interdependent chains—the articular, muscular, and neurological chains (Page, Frank, & Lardner, 2010):

- Articular chains maintain posture and movement throughout the skeletal system. They result from the biomechanical interactions of different joints throughout a movement pattern. Further divided into:

- Postural chains are the position of one joint in relation to another when the body is in an upright posture. Postural chains influence positioning and movement through structural and functional mechanisms. Structural mechanisms describe the influence of static skeletal positioning on adjacent structures, while functional mechanisms describe the dynamic influence that the position of keystone structures (the pelvis and scapulae) has on muscles attaching to those structures. Structural chains are influenced by static joint position, while functional chains are influenced by muscle activity around joint structures.
- Kinetic chains are most commonly recognized as the concepts of open kinetic chain and closed kinetic chain activities, in which focus is on movement of the joints. These kinetic chains are easily identified through biomechanical assessments.

♦ Muscular chains provide movement and stabilization through muscular synergists, slings, and fascial chains. They are groups of muscles that work together or influence each other through movement patterns. Divided into three subtypes:

- A synergistic muscle works with another muscle (agonist) to produce movement or stabilization around a joint. Synergists may include secondary movers, stabilizers, or neutralizers.
- In contrast to synergists that work together locally for isolated joint motion, muscle slings (also referred to as *muscle loops*) are global, providing movement and stabilization across multiple joints.
- Myofascial chains - fascia serves as a vital link to multiple muscles acting together for movement as well as connects the extremities through the trunk.

♦ Neurological chains provide movement control through protective reflexes, neurodevelopmental motor progression, and the sensorimotor system:

- Protective Reflexives - arguably, the most important neuromuscular chains in the human body provide critical reflexes for function and protection.
- Sensorimotor chains - in controlling movement, feedback and feed-forward mechanisms provide a chain reaction of neuromuscular events. This provides both local and global dynamic stabilization of joints through muscular chains.
- Neurodevelopmental motor patterns - there are two groups of muscles regulated throughout the body by the CNS: the tonic muscle system and the phasic muscle

system. They are separated phylogenetically by their neurodevelopmental progression.

Collectively, these three chains form a neuromusculoskeletal model of functional movement. Poor posture is a chain reaction occurring throughout the spine, from the position of the pelvis to the position of the head (Page, Frank, & Lardner, 2010).

6.2.1 **Tonic & phasic muscles**

Tonic system muscles are older phylogenetically and are dominant. They are involved in repetitive or rhythmic activities and in the withdrawal reflex in the upper and lower extremities. Their function is predominantly that of flexion. *Phasic* system muscles, on the other hand, are more predominant in extension movements. The phasic muscles are younger phylogenetically and typically work against gravity, acting as postural stabilizers (Page, Frank, & Lardner, 2010). Changes in the body posture are associated with conservative control system (tonic) and the ability to retain balance with the operative (phasic system) (Zatsiorsky & Duarte, 2000). For example in the ankle part of postural control, the whole triceps surae group is involved in the plantar flexor activity, but m. gastrocnemius may have an especially important role for the phasic control of balance (Borg, Finell, Hakala, & Herrala, 2007).

The proper balance of these two systems is demonstrated in normal gait and posture.

Physiologically, tonic and phasic muscles refer to the predominant metabolic fibre type; while neurologically, tonic and phasic muscles refer to their classification in neurodevelopmental movement patterns. Therefore, neurodevelopmental descriptions of muscle refer to the tonic and phasic systems of muscles as opposed to the tonic and phasic characteristics of individual muscle fibre types. Note that the tonic-phasic classification system is not rigid because of each person's variability in neurological control. The tonic and phasic muscle systems do not function individually; rather, they work together through coactivation for posture, gait, and coordinated movement. This is what is meant by the concept of muscle balance: an interaction of the tonic and phasic systems for optimal posture and movement. This interaction provides centration of joints during movement, creating a balance of muscular forces to maintain joint congruency through movement (Page, Frank, & Lardner, 2010).

6.3 STABLE POSTURE

Despite the instability caused by a small BOS and a high COG (approximately at the second sacral segment), maintaining stability in the static erect posture requires very little energy expenditure in the form of muscle contraction. Humans are relatively unstable compared with quadrupeds, which have a larger BOS and lower centre of gravity. The bones, joints, and ligaments are able to provide the major torques needed to counteract gravity and frequent changes in body position assist in promoting circulatory return (Norris, 2008) (Levangie & Norkin, 2001).

Maintaining our upright stance is a process of perpetual motion. There is no such thing as standing still, or even sitting still, because the structural design of the body is inherently unstable. In the first place, the larger masses of the body are poised high above the narrow BOS provided by the feet. Second, the body's framework – the bony skeleton – is segmented, and the rounded edges of the interfaces between neighbouring bones configure our joints for mobility rather than stability (Bond, 2006). At first glance, the control of human standing posture appears to be a relatively simple task. In reality however, maintaining an upright stance is rather complex. This inherently unstable system requires the successful integration of several commands, including receiving sensory inputs from the visual, vestibular, and somatosensory systems, processing the sensory feedback within the central nervous system, and taking appropriate actions with the musculoskeletal system, for postural stability to be achieved. Any disruptions or deteriorations to these *neuromuscular processes*, through aging or disease, can have drastic consequences on the ability to maintain a standing posture (Tokuno, 2007) (Schilling, et al., 2009) (Winter D. A., 1995) (Danis, Krebs, Gill-Body, & Sahrmann, 1998).

Danis et al, 1998, showed that whole-body movement patterns control posture in persons with vestibular hypofunction and in persons without impairment during standing with feet together and eyes closed (Danis, Krebs, Gill-Body, & Sahrmann, 1998).

From the aspect of postural functions, we distinguish the following (Kolar, 2013):

1. Postural stability
2. Postural stabilization
3. Postural reactability

6.3.1 **Postural stability**

In a static position, the body as a whole does not change its position in space. However, every static position (erect standing, sitting, etc.) implicitly contains dynamic processes. Attaining a steady position is not a static occurrence, but rather a certain course or a process that "resists" the natural volatility of the movement system, which is a necessary premise for movement. Therefore, it is not a single attempt at attaining a static position, but a continuous "attaining" of a static positon. The ability to attain a body posture that does not allow for unintentional or uncontrolled falling is called postural stability. Stability is influenced by both biomechanical and neurophysiological factors. The area of support belongs to the biomechanical factors (Kolar, 2013).

If, during static loading, the vector of gravitational force does not project into the support base, this principle is violated. In such a case, the ligaments and muscles must maintain rotational moment or a significant muscle force in order to maintain balance. Unbalanced standing is at first corrected for by higher muscle activity with accompanied hypertonia of corresponding muscles and later by pain and even later by the development of deformity (Kolar, 2013).

6.3.2 **Postural stabilization**

Postural stabilization is understood to be an active (muscular) holding of body segments against the activity of external forces controlled by the CNS. This muscle activity holds body segments (active segment holding) against the action of external forces (especially gravitational force). During static conditions (in standing, sitting, etc.), a relative tightness of joints is achieved via muscular activity, which is coordinated by the activity of agonists and antagonists (co-activation activity). This activity also allows for resisting gravitational force in a given position. The tightening of body segments enables the achievement of an erect posture and locomotion of the body as a whole (an analogy can be seen in the experiments when we are trying to erect a wooden wand and a chain or a board and a net). Without coordinated muscle activity our skeleton would collapse – hence postural stabilization. Postural stabilization does not only act against gravity, but it participates in all movements, even movements involving only the lower or upper extremities (Kolar, 2013).

6.3.3 Postural reactability

With each movement of a body segment during a demanding activity (i.e. lifting and carrying a heavy object, movement of an extremity against resistance and without resistance, push-off/rebound effort, ball throw, etc.), a muscle contraction is necessary to overcome the resistance generated. This is transferred into force moments in the lever segment system of the human body and elicits reactionary muscle forces in the whole movement system. This reaction stabilization function is called postural reactability. The biological purpose of this force is to increase firmness of individual movement segments (joints) to obtain the most stable punctum fixum and allow joints segments to overcome the effects of external forces. Punctum fixum thus means that one of the insertional muscle parts is tightened (by the influence of the tightening activity of other muscles), so that the other insertional part of the muscle can carry out movement in a joint. This we then call a punctum mobile. The tautness in connected segments can be, to a certain extent, altered and it is possible to link together several anatomically given segments into one unit. The necessary tautness of connected links is achieved by the coordinated activity of agonists, antagonists, and other muscle groups. It is clear, that with movement of the trunk through the help of extremities, a certain degree of freedom in the joints of the extremities is necessary. On the other hand, the thorax cannot be formed by a number of loosely linked segments; it must form a relatively firm unit. This can be illustrated again by the chain analogy: if we pull a string attached to one of its links, the whole chain will be distorted (Kolar, 2013).

No purposeful movement (including movement of the extremities) can be carried out without insertional muscle stabilization, meaning securing tightness in the joint segment at the insertional region. For example, it is not possible to achieve flexion in the hips without the stabilization of the spine and pelvis; the insertional origins of the hip flexors – rectus femoris, iliopsoas, sartorius. With movement in a segment (for now in the hip joint), the spinal extensors and their antagonists are linked. These antagonists are not only the abdominal muscles, as it is usually noted, but primarily intra-abdominal pressure regulated by the muscles of the abdominal cavity (abdominal muscles, diaphragm, pelvic floor). The interplay between the spinal extensors and intra-abdominal pressure forms a fixed point in the region of lumbar spine and pelvis. Under physiological conditions, the joints of the lumbar spine are in a centrated position during hip flexion, there must be no movement and decentration at the insertional region. Muscle activity in the stabilizing segment generates activity in other muscles in which the insertions are connected. These then allow stability in other joint segments and that is how muscle activity in the movement system is "chained" (Kolar, 2013).

Repeatedly, it has been experimentally observed that the activation of the diaphragm, pelvic floor, abdominal and back muscles (thus muscles that ensure trunk stability to allow for movement of extremities) precede movement activity of the upper and lower extremities. In studies, joint activation of the diaphragm, transversus abdominis, pelvic floor and multifidi during postural activity is cited. Every movement in the segment is transferred in this way into the whole posture. Every movement manoeuvre includes transfer of stabilization into the insertionally roped regions and, therefore, into the whole body. Chest wall, abdomen, brachial and lumbosacral plexuses and, naturally, the spine form a mutual "firm frame", which is the requirement for all movement activity (Kolar, 2013).

A person's ability to maintain the erect posture may be affected by altered outputs such as the inability of the muscles to respond appropriately to signals from the CNS, as in paresis, paralysis, atrophied muscles or any other neuromuscular disorder (Levangie & Norkin, 2001).

6.4 POSTURAL SWAY

When humans are asked to stand normally, they are not completely motionless. Rather, small amounts of body movement, termed postural sway, can be observed (Tokuno, 2007).

One giant sequoia (*Sequoiadendron giganteum*), known as General Sherman, is the world's largest tree, while a redwood (*Sequoia sempervirens*) called Hyperion is the tallest with 115,7m (Szalay, 2013). Sequoia trees, located in Sierra Nevada, California, grow tall and wide-crowned as a measure of competition with other trees, racing upward, reaching outward for sunlight and water. And a tree doesn't stop getting larger—as a terrestrial mammal does, or a bird, their size constrained by gravity—once it's sexually mature. A tree too is constrained by gravity, but not in the same way as a condor or a giraffe. It doesn't need to locomote, and it fortifies its structure by continually adding more wood. Given the constant imperative of seeking resources from the sky and the soil, and with sufficient time, a tree can become huge and then keep growing. Giant sequoias are gigantic because they are very, very old (Quammen, 2012). The winds that make other much smaller trees visibly sway are not strong enough to move these.

Upright standing in humans is never motionless at any age. We sway when standing, although the movement might not be noticeable to the naked eye (Haywood, Roberton, & Getchell, 2012).

The total body mass can be assumed to be concentrated at the COG without an alteration of the body's translational inertia properties. In quiet standing, the whole-body COG is in constant motion. The locations of the joint centre and the COG determine the rotatory moment of the body and its extremities. Gravity produces rotatory movements via external mechanical force imposition (Danis, Krebs, Gill-Body, & Sahrmann, 1998). Normal postural sway consists of a small continuous motion in the sagittal plane. This oscillation of the COG results from alternating muscle activity - possibly a relief mechanism to reduce lower-limb fatigue and to aid blood flow. Excessive postural sway generally reveals poor balance and stability, a situation commonly seen in elderly and inactive people. Heavy people also may exhibit greater body sway, as may tall people. Training usually can reduce postural sway. In elderly people, strength training may improve stability and limit postural sway. Following ankle injury, postural sway increases, but balance and coordination training can return body sway to normal values (Norris, 2008).

Simultaneous manipulation of visual and feet proprioceptive information (soft foam surface) increased postural sway range in both young and elderly individuals (Hirata, et al., 2013). Sasaki et al., 2013, included high BMI as a significant factor in increased postural sway of patients with lumbar spinal stenosis, along with stenotic signs. High body mass has a strong association with increasing postural sway. The causes of increased body mass' influence on postural sway have been reports as adaptation and desensitization of plantar cutaneous receptors, diminished proprioception in the knee and ankle joints, and increased ankle torque. Increased body mass also affects the spine (Sasaki, Senda, Katayama, Ota, & Matsuyama, 2013).

Adult sway during quiet standing has two components; these two components likely reflect two different control mechanisms. There is a slow drift that might be attributed to small errors in estimating postural state and a fast-damped oscillation that might reflect control of body sway over the BOS. In the latter case the body is somewhat like an inverted pendulum of a clock, wherein there is weight at a distance from the point of rotation. Adult sway increases during the performance of a challenging task but decreases when additional sensory information is provided (Levangie & Norkin, 2011).

Zatsiorsky and Duarte proposed a rambling and trembling hypothesis where, 1) CNS specifies an intended position of the body. The intended position is specified by a reference point on the supporting surface with respect to which body equilibrium is instantly maintained, 2) the reference point migrates and can be considered a moving attraction point, 3) the body sways because of two reasons: the migration of the reference point and the deviation away from the reference point, 4) when the deflection is not too large, the restoring force is due to the "apparent intrinsic stiffness" of the muscles (Zatsiorsky & Duarte, 2000).

6.4.1 **Inverted pendulum**

The model of inverted pendulum has been often used as a way to simulate body behaviour in biomechanical approach to analysis. Inverted pendulum models can be used to explore how the central nervous system (CNS) controls balance. Especially in the kinetics of human movement we see the integrated control evident at each joint and in entire limbs. The CNS is totally aware of the problems of controlling a multisegmental system and the interlimb coupling that can facilitate balance control. Here biomechanical analyses are extremely valuable in identifying the goals and synergies of the CNS and pinpointing the total limb or body synergies that accomplish those goals (Winter D. A., 1995). The inverted pendulum model assumes that the body behaves as a rigid object above the ankle (Soha, Szabó, & Budai, 2012).

Recent studies have revealed double-inverted-pendulum-like behaviours during quiet standing (Yamamoto, et al., 2015). When standing quietly, human upright stance is typically approximated as a single segment inverted pendulum, pivoting around the ankle. In contrast, investigations which perturb upright stance with support surface translations or visual driving stimuli have shown that the body behaves like a two-segment pendulum, displaying both in-phase and anti-phase patterns between the upper and lower body. Similar to perturbed stance, quiet stance has simultaneously co-existing in-phase and anti-phase patterns (Creath, Kiemel, Horak, Peterka, & Jeka, 2005).

Postural sway during human quiet standing is often quantified by measuring the motion of the COP, namely the point of application of the ground reaction force vector. COP shift profiles are closely related to the sway of the COM during quiet standing. Thus, motion of the standing body can be estimated from COP patterns with an acceptable accuracy either in the context of the single inverted pendulum model or the double pendulum model with hip and ankle joints. Characterizing COP motion is of critical importance for understanding neural mechanisms of postural control as well as for better diagnosing severity of neurological diseases with postural instability (Yamamoto, et al., 2015) (Schilling, et al., 2009). In studies of the elderly there have been reports of increased amplitude of COP and higher frequency content of the COP signals (Winter D. A., 1995).

Model of inverted pendulum relates the controlled variable COM with the controlling variable COP. If the body behaves like an inverted pendulum, body COM is regulated through movement of the COP under the feet (Casadio, Morasso, & Sanguineti, 2005). Winter et al, 1998, proposed that restoration torque is set by the joint stiffness model, where it assumes that muscles act as springs producing appropriate joint moment, to cause the COP to move in phase with the COM as the body sways about some desired position. Thus CNS setting of joint stiffness, through appropriate muscle tone (at specific balance control sites such that the stiffness constant is sufficient to control the large inertial load against the gravitational forces that attempt to topple the pendulum system) is a simple way of controlling body COM during quiet standing (Winter D. , Patla, Prince, Ishac, & Perczak, 1998). Although receiving criticism for his model, Winters' direct estimate of ankle stiffness is supposedly sufficient to control posture during quiet standing. Muscle stiffness is controlled by muscle tone, which is a summation of recruited muscle twitches in the balance control muscles (Winter D. A., Patla, Rietdyk, & Ishac, 2001).

As has been argued by Loram et al, the compliance of the tendon makes it difficult, or even impossible from study of Morasso and Sanguineti, to maintain posture and mechanical stability of the system with ankle musculature when there is no anticipatory control input using a simple stiffness control. A constant adaptive muscle control is thus needed. Since during quiet standing one is leaning a bit forward, the main stabilizing action is maintained by the plantar flexors (pulling the body backwards against gravity). Studies have revealed that quiet standing involves a complex muscular dynamics in order to stabilize the basically unstable human inverted pendulum. Soleus and gastrocnemius move paradoxically, shortening when the body sways forward and lengthening when the body returns. This confirms that intrinsic ankle stiffness is too low to stabilize human standing. Moreover, it shows that the increase in active tension is associated with muscle shortening. This pattern cannot be produced by muscle stretch reflexes and can only arise from the anticipatory neural control of muscle length that is necessary for balance (Morasso & Sanguineti, 2002) (Borg, Finell, Hakala, & Herrala, 2007) (Loram, Maganaris, & Lakie, 2004).

AP swayings part can be quite well modelled using the human inverted pendulum model (Borg, Finell, Hakala, & Herrala, 2007). It was revealed through research that the COP amplitude is slightly larger than the COM in both the AP or ML directions, to ensure that the COM is maintained in the ideal location within the BOS. This is consistent with the inverted pendulum model, which predicts that the COP tracks the COM and oscillates either side of the COM to stabilize it around some central position. No significant AP differences were found between any of the stance width positions because the BOS in the AP direction remained constant. However, in the ML direction both the sway (COM) and COP amplitudes decrease significantly as stance width increases (Winter D. , Patla, Prince, Ishac, & Perczak, 1998) (Tokuno, 2007). The adult human body could behave as a two-link pendulum where the links could oscillate in-phase as a single-segment system or anti-phase as a double pendulum. It has been clarified that each of COP-ML and COP-AP patterns contain three characteristic frequency components: a slow (either non oscillatory or oscillatory) component, a fast damped oscillatory component, and a very fast oscillatory component representing the anti-phase coordinated trunk-leg movement (Yamamoto, et al., 2015) (Creath, Kiemel, Horak, Peterka, & Jeka, 2005). There are numerous metrics or features of quiet standing sway that have been measured and statistically analysed including time-based, time and frequency-based (hybrid), and frequency-based characteristics. With so many quiet standing sway characteristics under consideration, there is no clear consensus as to which single metric or subset is most appropriate for describing the steadiness of young, old, healthy and unhealthy individuals (Schilling, et al., 2009) (Schubert, Kirchner, Schmidtbleicher, & Haas, 2012).

Zatsiorsky and Duarte termed the slow and the fast components (average 0.16 Hz and 0.67 Hz, respectively, for their experimental subjects) as "rambling" and "trembling", respectively. The rambling component reveals the motion of a moving reference point (a set point or attracting point) with respect to which the body's equilibrium is instantly maintained. The trembling component reflects body oscillation of COP around the reference point trajectory with restoring force similar to an elastic one, possibly due to intrinsic properties of muscles (Yamamoto, et al., 2015) (Zatsiorsky & Duarte, 1999). Creath et al, 2005, showed that the trunk and the leg segments during quiet standing exhibited antiphase oscillation particularly in the frequency above 1 Hz (1.0–5.0 Hz), which was predominantly related to the mechanical characteristics of a double-inverted-pendulum-model of the standing body (Yamamoto, et al., 2015) (Creath, Kiemel, Horak, Peterka, & Jeka, 2005). When quietly standing, humans naturally sway at a mean frequency of 0.27-0.45 Hz. These small oscillations are associated with angular changes of approximately 1.0-1.5° at the ankle, knee and hip joints and result in the body's COM to horizontally displace 4-18 mm (Tokuno, 2007) (Winter D. , Patla, Prince, Ishac, & Perczak, 1998), while movements around the knee joint are significantly smaller than the movement involving the ankle joint (Hirata, et al., 2013). Constant swaying motion (postural sway, sway envelope), can extend up to 12° in the sagittal plane and 16° in the frontal plane. The inertial forces that may result from this swaying motion usually are not considered in the analysis of forces for static postures (except for dynamic – running, walking, jogging…) (Levangie & Norkin, 2001). In another study, during normal standing, the subject's COG swayed forwards and backwards involuntarily by 20 mm (Di Giulio, Maganaris, Baltzopoulos, & Loram, 2009).

As a consequence of a theoretical assumption regarding the posture stability model which compares a human being to an inverted pendulum, a need of the assumption concerning so called limits of stability (LOS) arises. The LOS mark the area in which a vertical projection of the COM may relocate without losing the balance of the body (Nashner & McCollum, 1985). In other words, the limits of stability constitute a potential scope of angular sway of the body from the perpendicular. According to the inverted pendulum theory presenting human body stability explanation, the bigger scope of potential sway is, the better stability becomes and the lower is the risk of fall (Stemplewski, Maciaszek, Osiński, & Szeklicki, 2011).

6.5 POSTURAL RESPONSES

While standing, the body sways constantly, requiring continuous correction of its position to maintain stability (Hirata, et al., 2013). We organize our posture in two ways: by orienting our body in space and by stabilizing it so we can move without falling (Bond, 2006).

A perturbation is any sudden change in conditions that displaces the body posture away from equilibrium. It can be either sensory (altered visual input) or mechanical (involve direct changes in the relationship of COG to the BOS). The postural responses to perturbations caused by either platform movement or by pushes and pulls are reactive or compensatory responses in that they are involuntary reactions (referred to as synergies or strategies) (Levangie & Norkin, 2001).

Nashner, 1985, explained in his own way; normal subjects contract muscles in relatively stereotyped *patterns*, which he refers to as muscle synergies. These muscle synergies tend to move the ankle and hip joints while maintaining the knee in its equilibrium position. To generate the appropriate postural movement in response to a perturbation, the system determines the region into which it has been displaced and then selects the control strategy appropriate to that region. Strategy is a more global term than synergy and includes not only the muscle contractile pattern used to execute an action but also the sensory interactions relating the action to the external environment (Nashner & McCollum, 1985).

During human quiet standing, the passive stiffness of the ankle joint, arising from visco-elasticity of the muscle-tendon-ligament system, is lower than the growth-rate of the gravitational toppling torque, leaving an upright unstable equilibrium of saddle type which is characterized by a topology of a system's phase space spanned by the position and the velocity providing a convergent motion toward the equilibrium in one direction (a stable manifold) and a divergent motion away from the equilibrium in a different direction like a mountain pass (an unstable manifold). Thus the upright standing posture requires to be stabilized by suitable active control strategies (Asai, et al., 2009).

There are many factors that potentially affect the postural control system and may lead to an increased risk of falling. These include health or medical conditions such as diabetes, peripheral neuropathy, stroke, multiple sclerosis, Parkinson's disease, and obesity. One of the most important determinants for the risk of falling is age. As humans age, they experience reduced tactile and joint position sensitivity and increased reaction time, as well as reduced muscle mass (Schilling, et al., 2009). Misalignments in position of the centre of total body mass can be corrected by postural movements which exert one force or a combination of torque, vertical, and horizontal forces against the support surface (Nashner & McCollum, 1985). When the amplitude of the sway is sufficiently large, the centre of gravity of the subject moves outside the BOS in which case remedial action, such as movement of the feet or arms, is required to maintain balance. Consequently, very large values of the quiet standing index can be associated with a reduction in steadiness (Schilling, et al., 2009).

The responses of the motor system to maintain postural stability are known as *automatic postural responses*. These responses are mediated on a subcortical level, mainly in the cerebellum. They occur on the subconscious level before voluntary movement and are not modifiable by conscious effort. These automatic postural reactions are divided into three characteristic balance strategies: the ankle, hip, and step strategies. These three strategies are activated progressively to restore the alignment of the COG and BOS (Page, Frank, & Lardner, 2010) (Levangie & Norkin, 2001) (Nashner & McCollum, 1985):

- Ankle Strategy - The ankle plays a central role in postural correction. Small changes to the COG are corrected through the ankle to reposition the COG over the BOS. This strategy commonly occurs when a person stands on altered support surfaces such as foam pads. The correction occurs distally to proximally while the head and hips move synchronously. This response is also known as an *inverted pendulum.*

Because the LOG is anterior to the ankle joint, gravity is continuously pulling the tibia anteriorly. This would result in enough dorsiflexion to unbalance the body were it not for constant opposing resistance provided by muscle action from the soleus. The LOG passes in front of the knee joint axis (but behind the patella), forcing the femur anteriorly and creating an extension torque resisted by the posterior knee structures (Norris, 2008).

- Hip Strategy - Larger changes to the COG are corrected through a multisegmental strategy at the hips. The correction occurs proximally to distally as the head and hips move asynchronously. This strategy is used when standing on small support surfaces.

Hip strategy consists of discrete bursts of muscle activity on the side of the body opposite to the ankle pattern (Levangie & Norkin, 2001).

- Step Strategy - When unable to reposition the COG with the ankle or hip strategy, the body repositions the BOS under the COG by taking a step.

Additional strategies include *head stabilizing strategy* which occurs in anticipation of the initiation of internally generated forces and are used during sustained movement of the body such as walking (Levangie & Norkin, 2001). Age related changes can affect the strategy used. Compared with young adults older adults tend to use the hip strategy more often (Enoka, 1994).

Reactive (compensatory) responses occur as reactions to external forces that displace the body's COG. Proactive (anticipatory) responses occur in anticipation of internally generated destabilizing forces such as raising one's arms to catch a ball or bending forward to tie one's shoes. During standing, flexion moments are created at the neck and head, cervical, thoracic and lumbar spine, hip and ankle. To counteract these moments, the neck, back and hip extensors together with ankle plantarflexors may have to contract (Levangie & Norkin, 2001).

The ankle strategy persists during small perturbations consisting of low-amplitude, low-velocity or low frequency stimuli. With larger perturbations, the hip strategy predominates. Other factors such as the length of the support surface, central set and neurological pathologies influence the prevalence of the ankle or hip strategy. These results have led to a conceptual framework in which postural responses are chosen from a continuum of ankle-hip strategy mixtures, with the "pure" strategies at opposite extremes. The generally accepted idea is that these basic patterns are centrally selected from a set of motor programs, arising from high-level neural strategies and implemented by complex sensorimotor control processes to most effectively counteract the physical characteristics of the perturbation. Central selection, however, may not be the primary determinant of the postural response strategy. From a biomechanical perspective, these patterns arise from the dynamics of a multi-link inverted pendulum. Early attempts to characterize a biomechanical influence simplified the problem of controlling an inverted pendulum by analysing gravitationally driven, non-inverted pendulums with properties based upon anthropometric measures of the human body (Creath, Kiemel, Horak, Peterka, & Jeka, 2005).

Danis et al, 1998, explains the reason for using step strategy through one example from their research: the reason that weight shift became more symmetrical in the subjects with vestibular hypofunction during standing with feet together may have been their *attempt to deal with a more challenging position*. By narrowing the BOS, individuals may be more likely to sway and to take a step. Distributing body weight more evenly in this position may allow upright stance to be maintained without stepping. With a larger BOS (e.g. during standing with feet apart), the medial and lateral limits of stability extend from the outer edge of one foot to the outer edge of the other foot. When the BOS is narrowed, the limits of stability decrease. If body weight is borne primarily on one lower extremity, the BOS becomes even smaller. Remaining stable during standing with feet together, therefore, may be easier with a more symmetrical distribution of body weight (Danis, Krebs, Gill-Body, & Sahrmann, 1998).

The upright body does not behave like a limit cycle, even when oscillatory stimuli are imposed. Upright stance control is essentially a stable, fixed point influenced by noise, with simultaneous co-existing modes, in both the quiet and perturbed state. Even though body mechanics alone can account for two different patterns as a function of frequency, a solely mechanical explanation cannot explain the coordinative changes corresponding to different types of perturbations, such as an increase in the amplitude of a support surface perturbation. For example, a mechanical view would predict an approximately linear response: larger amplitude perturbations would be matched by larger amplitudes of the ankle pattern, rather than the well-documented predominance of a hip strategy with increasing perturbation amplitude. Therefore, it is likely that the central selection of a motor program combines with mechanics in the expression of these synergies (Creath, Kiemel, Horak, Peterka, & Jeka, 2005).

In a study done by Casadio et al, 2005, in all the subjects where disturbance was introduced by the platform, although clearly perceived, did not disrupt the background sway patterns. The response is stereotypically characterised by three distinct phases (Casadio, Morasso, & Sanguineti, 2005):

- Immediate ‘‘mechanical’’ response in the same direction of the disturbance (forward shift of the COP for a toes-up disturbance and backward shift of the COP for a toes-down disturbance) related to the mechanical impedance of the ankle,
- ‘‘Biomechanical’’ response in the opposite direction which corresponds to the incipient backward fall of the body,
- Voluntary ‘‘neural’’ response which recovers the dynamic stability characteristic of quiet standing. Thus, the range of body sways which must be counteracted by the mechanical properties of the ankle muscles goes from a few hundredths of a degree up to 1°.

Casadio et al, 2005, states that in general the measured ankle stiffness tends to decrease as the amplitude of the test disturbance increases with their data suggesting that the margin of ankle stiffness modulation is substantial, although short of the critical level. In that case, a synergetic action is provided by ‘‘unlocking’’ the hip joint and translating the focus of attention from a partially locked ankle to the hip joint (Casadio, Morasso, & Sanguineti, 2005). Under more strenuous conditions, such as when support surface perturbations are imposed, multiple coordination patterns are observed. The ankle strategy applies in quiet stance and during small perturbations and predicts that the ankle plantar flexors/ dorsi flexors *alone* act to control the inverted pendulum. In more perturbed situations or when the ankle muscles cannot act a hip strategy would respond to flex the hip, thus moving COM posteriorly, or to extend the hip to move the COM anteriorly (Winter D. A., 1995) (Creath, Kiemel, Horak, Peterka, & Jeka, 2005). The coexistence of in-phase and anti-phase patterns during quiet stance suggests that the ankle and hip strategies are *not* extremes along a behavioral continuum of mixed strategies. They are "simultaneously co-existing excitable modes", both always present, but one of which may predominate depending upon the characteristics of the available sensory information, task or perturbation (Creath, Kiemel, Horak, Peterka, & Jeka, 2005). It is becoming a common view that the ankle and hip strategy are implemented not only in response to perturbations, but also during quiet stance along with a mixed strategy (Yamamoto, et al., 2015).

6.6 MUSCLES USED IN LOWER LIMBS DURING QUIET STANDING

The laws of physics dictate that the line of gravity (LOG) must pass with the body's BOS to maintain stability. The closer the body segments are to the LOG, the less torque there is around a joint. Where the LOG passes through the joint axis, no torque is created around that joint at all. If the LOG passes some distance from the joint axis, gravitational torque would tend to move the body segment toward the line of gravity were the segment not counterbalanced by elastic recoil of soft tissue and muscle action. With the LOG anterior to the joint axis, the proximal segment of the body connected to the joint tends to move anteriorly; posterior motion tends to occur when the LOG is posterior to the joint axis (Norris, 2008).

The time course of the COP during human quiet standing, corresponding to body sway, is a stochastic process, influenced by a variety of features of the underlying neuro-muscular-skeletal system, such as postural stability and flexibility (Yamamoto, et al., 2015). More sophisticated analysis may be performed using radiography, photography, EMG, electrogoniometry, force plates, or three-dimensional computer analysis. Monitoring of muscle activity patterns through EMG and determinations of muscle peak torque and power outputs are used to study postural responses during perturbations of upright postural stability (Levangie & Norkin, 2001).

Experimental data with healthy subjects produced by Hirata, et al., 2013, indicated that somatosensory information from the lower limb is the most important information to posture control (Hirata, et al., 2013). Di Giulio et al, 2009, further states that humans can stand using sensory information solely from the ankle muscles. During quiet standing, sway of the entire body is correlated highly with ankle joint rotation and this explains why muscles crossing the ankle joint are able to provide sensory information necessary to maintain upright standing. Generating sufficient tension in the calf muscles to maintain balance results in changes in muscle length which are paradoxical with respect to bodily sway i.e. when the body sways forward the muscle fibres are actively shortened to maintain balance. Recruitment of agonist behaviour may depend on how far forward from the ankles an individual maintains the COG (Di Giulio, Maganaris, Baltzopoulos, & Loram, 2009).

According to Nashner, 1985, muscles taking a dominant role in postural movements are (Nashner & McCollum, 1985):

- anterior tibialis (ankle dorsiflexion)
- gastrocnemius (plantarflexion)

Soleus and gastrocnemius, often considered together, have traditionally been considered the source of muscle proprioceptive information signalling changes in body position, with soleus as the main agonist regulating quiet standing. It is normally accepted that soleus and gastrocnemius, plantar flexors of the ankle, act as active agonists and, because the foot is constrained on the ground, these muscles prevent forward toppling of the body whose centre of gravity is maintained in front of the ankle joint (Di Giulio, Maganaris, Baltzopoulos, & Loram, 2009). Electromyographic studies have demonstrated that soleus and gastrocnemius activity is fairly continuous in normal subjects during erect standing. This activity suggests that these muscles are exerting a minimal but constant torque about the ankles to oppose the gravitational dorsiflexion moment that exists at the ankle. Ankle joint muscles that have shown inconsistent activity in EMG recordings during standing are the tibialis anterior, peroneals, and tibialis posterior. These muscles have primary actions other than plantarflexion at the ankle joint. Therefore, it is probable that these muscles are helping to provide transverse stability in the foot during postural sway rather than acting to oppose the gravitational moment at the ankle joint (Levangie & Norkin, 2001) (Soames & Atha, 1981) (Gray, 1969). In one research using intramuscular EMG during standing, the activity of motor units in the soleus muscle was quite consistent, whereas the activity of medial gastrocnemius motor units was much more intermittent. Lateral gastrocnemius motor units showed little to no activity in standing balance. This was associated with motor unit recruitment thresholds being 20 –35 times higher in the lateral gastrocnemius compared to the soleus and medial gastrocnemius muscles. They also noted that the rate of motor unit discharge was much more variable in the medial gastrocnemius in standing compared to activity of soleus motor units (Heroux, Luu, Dakin, Inglis, & Blouin, 2014). Intermittent activity was also noted in other research, where motor units did not discharge continuously throughout standing. They were recruited within individual, forward sways and intermittently, with a modal rate (Vieira, Loram, Muceli, Merletti, & Farina, 2012).

- ♦ gastrocnemius and hamstrings (knee flexion)

Little or no activity is required to maintain the knee in extension in the optimal erect posture. However, a small amount of activity has been identified in the hamstrings (Levangie & Norkin, 2001).

- ♦ quadriceps – rectus femoris head (knee extension)
- ♦ quadriceps, abdominals (hip flexion)

EMG studies have shown activity of the iliopsoas muscle during standing, and it is possible that the iliopsoas is acting to create a balancing flexion moment at the hip (Levangie & Norkin, 2001) (Basmajian, 1978).

Quadriceps actively stabilizes knee joint during extension. Quadriceps belong to a part of anti-gravity muscle group. Their permanent but low tension is necessary for keeping a balanced vertical body posture (Kubisz, Werner, Bosek, & Weiss, 2011). If the gravitational extension moment at the hip were allowed to act without muscular balance, as in a so-called relaxed standing posture, hip hyperextension ultimately would be checked by passive tension in the iliofemoral, pubofemoral, and ischiofemoral ligaments. The relaxed standing posture does not require any muscle activity at the hip but causes an increase in the tension stresses on the anterior hip ligaments. The relaxed standing posture may also increase the magnitude of the gravitational torque at other joints in the body (Levangie & Norkin, 2001).

- ♦ hamstrings, paraspinals (hip extension)

EMG studies have shown that the longissimus dorsi, rotatores, and neck extensor muscles exhibit intermittent electrical activity during normal standing. This evidence suggest that ligamentous structures are unable to provide enough force to oppose all gravitational moments acting around the joint axes of the vertebral column (Levangie & Norkin, 2001) (Morris, Benner, & Lucas, 1962).

If a subject voluntarily adopts a forward or backward postural lean, what is the response of our *hip* motor patterns to this perturbation? Forward lean results in an enhanced response of the posterior muscles at all three joints, a characteristic anterior weight shift pattern of dorsal muscle activation that begins with the distal gastrocnemius muscle, which is followed by the hamstrings and the lumbar paravertebrals. The *hip* is therefore biased with a larger extension moment; the knee is biased in the flexor direction; the ankle is toward more plantarflexion. The backward lean trial showed exactly the opposite response at all three joints, where posterior weight shift is countered by a ventral muscle response that begins distally with the tibialis anterior and then involves the quadriceps and finally the abdominal muscles. Therefore, the muscle group opposite the direction of the weight shift or perturbation is responsible for maintaining postural stability. A medial weight shift activates lateral muscles for stabilization, while a lateral weight shift activates medial muscles (Page, Frank, & Lardner, 2010) (Winter D. A., 1995).

Winter, 1995, discovered that to cause the net COP to move to the right any one of the following muscle activations could be the cause: left ankle evertors, right ankle invertors, left hip adductors, right hip abductors. The movement of net COP to the right would cause a lateral acceleration of the COM to the left. Theoretically, the same magnitude of torque acting at any one of these four joints would have the same results. However, due to the biomechanics and anatomy of the ankle and hip joints this theoretical situation never occurs. First, the ankle invertors and evertors cannot act independently. All the evertors (peroneii) and all the invertors (tibialis anterior and posterior, extensor digitorum longus, and hallucis longus) are also plantarflexors and dorsiflexors. The AP control of balance requires collaboration between right and left plantarflexors and dorsiflexors. The COP under each foot will move back and forth in almost complete synchronization; however, any ML component by the invertors/evertors will move the COP under both feet in the same medial or lateral direction. For example, if both left and right peroneii are active to cause the COPs to move anteriorly they will also cause the both COPs to move medially. There is a second reason that the invertors/evertors could not act when large balancing moments were required. Because of the small width of the foot the maximum moment that could be generated by either invertors or evertors would be about 10 Nm. Anything above 10 Nm would cause the foot to roll over on its medial or lateral borders. However, the hip abductors/ adductors are not so constrained. Each of these muscle groups could generate in excess of 100 Nm in emergencies (Winter D. A., 1995).

Therapists, who studied the postural effect of horseback riding (hipotherapy) on children with spastic cerebral paralysis, reported that hypertonicity, especially extensor muscle hypertonus and hip adductor muscle spasticity, was decreased after therapy, contributing to improvement in achievement of functional movements such as sitting, stance, and walking (Bertoti, 1988).

Studies of balance and posture during quiet or perturbed standing have identified the dominance of the ankle muscles (plantarflexors/dorsiflexors) in the AP direction and hip abd/adductor muscles in the ML direction. In the ML direction, COP-Left is controlled by the left ankle invertors/evertors, COP-Right, is under the control of the right ankle invertors/evertors (Winter D. A., 1995). The COP is controlled by ankle plantarflexors/ dorsiflexors torque in the sagittal plane and hip abductor/adductor torque in the frontal plane (Winter D. , Patla, Prince, Ishac, & Perczak, 1998). The biomechanics of these changes has shown that vertical reaction forces under the left foot and vertical reaction forces under the right foot change completely out of phase and that an increased load on one limb is marked by an equal and opposite unload on the opposite limb. For example the right hip abductors could become more active and increase the right limb load from 49 to 52%; this would result in an instantaneous unloading of the left limb from 52 to 49%. Biomechanically this same change could have been achieved by increased activity in the left hip adductors (Winter D. A., 1995).

Balanced standing on two legs is very unpleasant and tiring. Normally, after a while, we transfer the weight of the body to one leg using the other for support.

6.7 MUSCLES USED TO STABILIZE THE SPINE

At first sight it seems unreasonable to assume any pressure transfer through the trunk other than by the spine, because all the structures are soft. However, soft material can be arranged in such a way that use is made of its tensile strength, rather than its rigidity, to transmit pressures - for instance a football. There exists an additional support for the body outside of the spine. This support is the tensed abdomen, the tension appearing through reflex contraction of certain muscles (Bartelink, 1957).

Mechanically, the spine is like a stack of blocks separated by small cushions. Stability of the spine is primarily a function of ligaments and muscles, which act like the guy wires that stabilize a tower or the mast of a boat. These muscles are short and long and often must simultaneously stabilize and move the spine. Biomechanics research using computer models and EMG are trying to understand how muscles and loads affect the spine (Knudson, 2003). The problem with this model is that a stack of blocks doesn’t move. For a model that is more in accord with the fluid nature of the body we can use a geodesic dome design principle engineered by American architect Buckminster Fuller (he mostly popularized this principle, but didn't invent it). Using pliable materials, Fuller used tension rather than compression to sustain his structures and named his design system tensegrity (*tension integrity*). If we apply Fuller's model to our bodies, we can see that it is the tensional force of our softer tissues that keeps us erect, not the compressional strength of our bones. Floating within a sea of fluid tissues, bones are internal spacers for the body rather than beams that resist compression. The length and tension of connective tissue adapts to the changing orientation of the bones and distributes gravitational forces through our bodies as we move (Bond, 2006) (Page, Frank, & Lardner, 2010). To achieve postural balance, co-activation of the extensor and flexor muscle systems in needed. On one side, there are spinal extensors (primarily deep extensors), on the other side, there are deep cervical flexors and muscles that form and regulate intraabdominal pressure (diaphragm, abdominal and pelvic floor muscles) (Kolar, 2013).

Efficiency of motion and stresses imposed on the spine are very much determined by the posture maintained in the trunk as well as trunk stability. The spine is stabilized by three systems, including a passive musculoskeletal system, an active musculoskeletal subsystem, and the neural feedback system. The passive subsystem includes the vertebrae, facet articulations, joint capsules, intervertebral disks, and spinal ligaments. The active system includes the muscles and tendons that stabilize the spine, and the neural subsystem provides control (Hamill & Knutzen, 2008).

Rotators and lateral flexors of the back and thorax are:

- ♦ External oblique: global, bilateral action in the upper part induces flexion and unilateral action flexion - rotation of the thoracic cage.
- ♦ Internal oblique: global, bilateral action induces flexion and unilateral action flexion-lateral bending of the thoracic cage.

If lateral flexion occurs, from erect standing, the force of gravity will continue the lateral flexion movement and the contralateral muscles will be required to balance the gravitational moment and control the movement by contracting eccentrically (Levangie & Norkin, 2001).

Contraction of the flexor muscles causes compression forces on the vertebral column. Forward flexion of the trunk from the erect standing posture does not require any action of the trunk flexors because the gravitational force will pull the trunk forward. However, any activity that involves pushing, pulling, or lifting will initiate an immediate isometric contraction of the flexors to stabilize the ribs and pelvis and, indirectly, the vertebral column. The flexor muscles are not active during normal erect standing. However, they are considered essential for balancing the pull of the back extensor and the hip flexor muscles in dynamic situations and for keeping the pelvis in a normal position. When either the back extensor or hip flexor muscles act unopposed, they cause an anterior tilting of the pelvis in the sagittal plane (anterior pelvic tilt) and an increase in extension in the contiguous lumbar spine. Also, the abdominal muscles perform the function of protecting and supporting the viscera (Levangie & Norkin, 2001).

Extensors of the spine:

- Splenius: capitis, cervicis.
- Sacrospinalis / erector spinae: lateral group of iliocostalis, intermediate group longissimus, medial group of spinalis (extend the upper lumbar and the thoracic spine), latissimus dorsi.
- Deep to erector spinae are *transversospinales* (attach to the transverse, spinous and articular processes of vertebra): semispinalis thoracis, semispinalis cervicis, semispinalis capitis, multifidus, rotatores, interspinales, and intertransversarii.

A higher percentage of type 1 fibres has been found in the longissimus and multifidus muscles at thoracic levels in comparison to the same muscles in the lumbar region. This finding is related to the need for more or less continual low level of activity in the thoracic muscles to counteract the flexion moment that exists in the thoracic region during erect stance (line of gravity falls anterior to thoracic spine and either through or posterior to the lumbar spine) (Levangie & Norkin, 2001).

- Vertebral column: trapezius, latissimus dorsi, rhomboid major, minor, levator scapulae.
- Fascia: thoracolumbar fascia.
- Thorax: Intercostal muscle (external, internal, innermost), subcostalis, transversus thoracis, levatores costarum, serratus (posterior, inferior, superior), thoracic diaphragm.
- Thoracic cavity: pectoralis major, pectoralis minor, subclavius, serratus anterior, and sternalis.
- Fascia: pectoral fascia, clavipectoral fascia.

All the muscles can produce extension of the spine and can increase the lumbar curve. Conversely, the contraction of the flexor muscles decreases the lumbar curve. The extensor muscles are responsible for controlling forward flexion of the vertebral column in the standing position. The gravitational moment will produce forward flexion, but the extent and rate of flexion is controlled partially by eccentric contraction of the extensors and partially by the thoracolumbar fascia and posterior ligamentous system. The thoracic and lumbar extensors act eccentrically until approximately two-thirds of maximal flexion has been attained, at which point they become electrically silent. This is called the flexion-relaxation phenomenon (Shirado, Ito, Kaneda, & Strax, 1995) (Colloca & Hinrichs, 2005) (Levangie & Norkin, 2001). The extensors lie parallel to the vertebral column and thus, like the abdominals, exert a compression force on the column during contractions.

Equally important are pelvic floor muscles, also known as pelvic diaphragm (Herschorn, 2004) (Levangie & Norkin, 2001):

- Levator ani (iliococcygeus, pubococcygeus)
- Coccygeus

Voluntary contractions of the levator ani muscles help to constrict the openings in the pelvic floor (urethra and anus) and prevent unwanted micturition and defecation (stress incontinence). Involuntary contractions of these muscles occur during coughing or holding one's breath when the intra-abdominal pressure is raised. In women, these muscles surround the vagina and help to support the uterus. The coccygeus muscle assists the levator ani in supporting the pelvic viscera and maintaining intra-abdominal pressure (Levangie & Norkin, 2001).

It is important to distinguish between the muscles of the pelvic floor and those immediately surrounding it. Activity in the perineum itself does not change the inclination of the pelvis, but because the bones defining the pelvic floor are attached to muscles of the buttock and thighs, tension in these muscles does affect the orientation of the pelvic floor (Bond, 2006).

Spinal extensors are always engaged during spinal stabilization (reinforcement). Their activation occurs in the following sequence (timing) (Kolar, 2013):

1. Deep extensors are engaged and only situations requiring greater muscle demands lead to the contraction of the superficial muscles.
2. Their function is balanced by a flexion synergy that comprises the deep neck flexors and the synergy between the diaphragm, abdominal muscles and the pelvic floor muscles.

We can categorize muscles into two non-distinct groups: muscles that primarily stabilize a joint and approximate the joint surfaces are known as stabilizers or postural muscles, and muscles primarily responsible for movement (those that develop angular rotation more effectively than the stabilizers), are called mobilizers or task muscles. Stability muscles tend to be more deeply placed in the body and are usually monoarticular (one-joint) muscles, whereas mobilizers are superficial and are often biarticular (two-joint) muscles. For example, in the leg, the rectus femoris is classified as a mobilizer, whereas the other quadriceps muscles are stabilizers. Stabilizer function is more slow-twitch (type 1) or physiologically tonic in nature, whereas the mobilizers tend toward fast-twitch (type 2) action. This physiology suits the functional requirements of the muscles, enabling mobilizers to contract and develop maximal tension rapidly but also to fatigue quickly. The stabilizer muscles build tension slowly and perform well at lower tensions over longer periods, being more fatigue resistant. Take as an example the calf muscles. The gastrocnemius is classified as a mobilizer, powering us away from the blocks in sprint. The soleus muscle is a stabilizer, being responsible for *postural body sway in standing* (Norris, 2008).

Stabilizers can be subdivided into primary and secondary types (Norris, 2008):

- Primary stabilizers (e.g. multifidus, transversus abdominis, and vastus medialis oblique) have very deep attachments, lying close to the axis of rotation of the joint. In this position, they are unable to contribute any significant torque but will approximate the joint. In addition, many of these smaller muscles have important proprioceptive functions. For example, the intertransversarii muscles lying between the spinous processes both have a dense concentration of muscle spindles indicating a significant proprioceptive function.
- Secondary stabilizers (e.g. gluteals and oblique abdominals) are the main torque producers, being large monoarticular muscles attaching via extensive aponeuroses. Their multipennate fibre arrangement makes them powerful and able to absorb large amounts of force through eccentric action (Norris, 2008).

Stabilizer muscles are better activated at low resistance levels – about 30% to 40% of the maximum voluntary contraction – whereas mobilizer muscles are generally better activated above this level. The structure and functional characteristics of the two muscle categories make the stabilizers better equipped for postural holding and antigravity function (Norris, 2008). With electromyographic studies of the abdominal wall during weight lifting it was found that the rectus abdominis muscles, which are mainly concerned in longitudinal pull, do not contract, but suggested that perhaps the main action responsible for raising the intra-abdominal pressure is supplied by the transverse abdominal muscles which do not have a significant vertical component (Bartelink, 1957).

Because postural alignment reflects changes in muscle length, it is usually the first form of assessment in use to determine muscle imbalance. The body moves continually around the optimal position in a process called body sway, and back stability is an essential component of this mechanism (Norris, 2008). Numerous muscles contribute to stability and provide mobility for the vertebral column. The simplest classification of the vertebral muscles is on the basis of function, in which case there are forward flexors, lateral flexors, rotators, and extensors. Generally, the forward flexors are located anteriorly, the extensors posteriorly, and the lateral flexors and rotators on either side of the vertebral column. Muscles that attach to the pelvis and span a maximum number of vertebrae are most efficient for providing lateral stability for the lumbar vertebral column. Efficiency increases as the muscles are positioned more laterally because of the increased moment arm of the muscle action lines. In addition to the muscles and ligaments, the thoracolumbar fascia has been identified as playing a role in the stability of the vertebral column (Levangie & Norkin, 2001).

6.7.1 **Global and local system of stabilization**

In 1989, Bergmark introduced a classification scheme that divides the muscle systems equilibrating the *lumbar* spine into global and local. Global muscles are superficial, fast-twitch muscles. They have a tendency to shorten and tighten. Local muscles, on the other hand, are slow-twitch, deep stabilizers that are prone to weakness. Bergmark described the local system as muscles inserting or originating at lumbar vertebrae and the global system as muscles originating on the pelvis and ribs. There is some overlap between the two systems, with portions of individual muscles exhibiting characteristics of both systems. While mostly structurally based, Bergmark's classification scheme also has some functional (neurological) components related to motor control, lending itself to the control model of lumbar stability (Page, Frank, & Lardner, 2010).

Bergmark proposed that the muscles controlling the trunk could be classified into two groups. The first group includes muscles attached directly to the lumbar vertebrae that can provide spine segmental stability (lumbar multifidus, transversus abdominis, and internal oblique muscles are part of this group). The second group consists of large torque-producing muscles with no segmental attachment to the lumbar spine. These muscles control gross trunk movement and provide general trunk stability (include the rectus abdominis, external oblique, and thoracic erector spinae muscles) (O'Sullivan, et al., 2002).

- All muscles which have their origin or insertion at the vertebrae, with the exception of the psoas, are defined as belonging to the local system. The local system is used to control the curvature and to give sagittal and lateral stiffness to maintain mechanical stability of the lumbar spine. The *psoas* muscle is not included in the local system as its mechanical role obviously is global (flexor of the hip joints) (Bergmark, 1989).
- The global system consists of the active components, i.e. the muscles and the intra-abdominal pressure, which transfer the load directly between the thoracic cage and the pelvis. The muscles included are: the *global erector spinae muscles*, the *internal and external obliques*, the *rectus abdominal* muscles and the lateral parts of the *quadratus lumborum* muscles (inserted at the twelfth ribs) (Bergmark, 1989).

The line of action of the force from the global system, which will be counteracted by the local system, must always pass forward of or through the midpoint of the most anterior lumbar disk. Otherwise this force would extend the lumbar spine with no possibility for the muscles of the local system to reinforce it without causing further extension. In other words: equilibrium could not be satisfied (with given curvature of the lumbar spine). The global system can be said to respond to changes of the line of action of the outer load, whereas the local system responds to changes of the posture of the lumbar spine. Both systems respond to changes of the magnitude of the outer load. Naturally, the global system also is used to change the position of the thoracic cage in relation to the pelvis. In order to avoid excessive local muscle stress, increased vertical loading on the spinal system must be met by decreased magnitude of the relative lumbar lordosis. Also a small flexion of the lumbar spine seems to be needed in order to minimize the maximum local muscle stresses at the upper and lower lumbar levels. The main role of the global system appears to be to balance the outer load so that the resulting force transferred to the lumbar spine can be handled by the local system. Thus large variations of the distribution of the outer load should give rise to only small variations of the resulting load on the lumbar spine. The local system, therefore, is essentially dependent on the magnitude (not the distribution) of the outer load and of the posture (curvature) of the lumbar spine. In reality the load probably is shared between short and long *multifidi* muscle fibres. The multifidi muscles extend the lumbar spine. As they insert at the spinous processes and the fibres are essentially parallel to the vertebral column, there is only a minor influence in the lateral direction. The mechanical role of the *multifidi* muscles is therefore more emphasized on transfer of forces and to act as a mover, thus controlling the lordosis, while the *intertransversarii* and the *interspinales* muscles will, in spite of their comparatively small muscle force but due to their short length, give an increased stiffness and thus extrinsic mechanical stability to the spine (Bergmark, 1989).

The global *erector spinae* muscles are by far the most important back-muscles both as regards equilibrium and stability of the spine. Because of the S-shaped sagittal projection of the spine, local muscles are necessary to maintain sagittal equilibrium of the spinal system. During normal standing the spinal motion segments are supposed to be in or close to - their neutral positions and the moments carried passively therefore are much smaller than the moments which are carried by the local muscles. Best suited to carry the local moments are the interspinales, the multifidi muscles and the spinalis muscle (in the upper lumbar region) as they have the longest lever arms in the sagittal plane (Bergmark, 1989). The mechanical role of the global erector spinae muscles is to extend the trunk and stabilize the spinal system in the sagittal and lateral directions. Unilateral activity will induce lateral bending and extension of the thoracic cage. The *lumbar erector spinae* muscle fibres also extend the spine, but in a less efficient way because of the shorter sagittal lever arms compared to the *multifidi* muscles. Unilateral activity gives the combined mechanical function of extension and lateral bending of the lumbar spine. Bilateral action extends the *lumbar* spine and stabilizes the spine mainly in the lateral direction (Bergmark, 1989). The lumbar multifidus muscle is unique in its ability to enhance lumbar segmental stability while dynamically stabilizing the sacroiliac joint through its control of sacral nutation. The transversus abdominis and internal oblique muscles provide a stabilizing influence on the lumbar spine *via* the thoracolumbar fascia and control of intraabdominal pressure. The anteroinferior portion of the internal oblique and transversus abdominis muscles is capable of generating compression and hence of increasing the stability of the sacroiliac joints (O'Sullivan, et al., 2002).

Four muscle groups may give lateral support to the spine: the *intertransversarii* muscles, the *quadratus lumborum*, the *transverse abdominal muscles* and the *local erector spinae* muscle fibres. Minor support also may come from the internal oblique muscles via the lateral raphe and the thoracolumbar fascia. The main local lateral support is assumed to come from the intertransverse, the quadratus lumborum and the local erector spinae muscle fibres. The local part of the quadratus lumborum muscles stabilizes the spine in the lateral direction. Unilateral action induces lateral bending of the lumbar spine. The mechanical role of the global part of the quadratus lumborum muscles, which act between the pelvis and the twelfth ribs, is to counteract activity in the diaphragm. Thoracolumbar fascia also gives the spine lateral support and can only to a minor extent be expected to passively resist a flexion moment acting on the trunk. The importance of this is small when also direct local lateral support is present (Bergmark, 1989).

Individual muscles of the abdominal wall have different functions with regard to supporting upright postures, highlighting the fact that these muscles do not act as a homogeneous group (O'Sullivan, et al., 2002). The way the *transversus abdominis* blends into the lumbar fascia is key to its role in stabilizing the lower back. Within the lumbar fascia on both sides of the spine are five *multifidi* muscle bundles that run between individual lumbar vertebrae. When the transversus abdominis activates the lumbar fascia, the multifidi are stimulated to control the lumbar segments. This means that although the transverse abdominis is a broad expanse of muscle, its action on the lumbar spine is very specific. Studies show that the TA contracts to stabilize your body before you use your arms or legs. Sustained contraction of the TA at about 10 to 25% is enough to support lower back and can prevent the pain. This means that for healthy posture the muscle should be mildly active whenever your body is upright and moving (Bond, 2006). O’Sullivan et al., 2002, observed through the EMG that the activation of the *superficial lumbar multifidus, internal oblique, and thoracic erector spinae* muscles decreased in passive sitting and passive standing postures, but increased in erect postures, indicating a postural stabilizing role for these muscles. There was also a concurrent increase in rectus abdominis activation observed during sway standing as compared with erect standing. These findings suggest a close relation between the adoption of passive postures and reduction in activity of the lumbo-pelvic stabilizing muscles (O'Sullivan, et al., 2002).

Age and activity affect the mechanical properties of all connective tissues. Bone, cartilage, tendon, and ligament strengths increase with regular cycles of loading and unloading. Usually this strength increase is due to an increase in size of the tissue cross section, but the stiffness and ultimate strength of these tissues may also increase, an indication that size alone is not responsible for the strength increase. Inactivity and immobilization result in decreased strength of these tissues and a shortening of the ligaments and tendons. All of these connective tissues show an increase in ultimate strength with age until the third decade of life, after which strength decreases (McGinnis, 2004).

7 FAULTY POSTURE

Although there are sometimes structural reasons that prevent balanced posture and good use of the body, most of us are guilty of misusing our body machinery due to habit. As with all habits, there postural ones seem to be such a large part of our make-up that change appears impossible, difficult, or unnecessary (Bond, 2006). Unless normal postural and movement components develop, abnormal development is manifested as various compensations, clinically seen as postural deviations, asymmetries, or deformities (Bertoti, 1988).

In faulty body posture, the distribution of pressure acting on the joint surfaces is not balanced, which negatively influences their function. Anatomical disharmony (sacral dysplasia, femoral anteversion or valgus, kyphotization of vertebral bodies after a course of Scheuermann's disease, etc.), whether neurological or functional (abnormal postural development, cultural and aesthetic factors that influence body posture, etc.), leads to the disruption of stability and complications (Kolar, 2013).

It has been proposed that different postures that superficially appear similar may lead to altered muscle activation. Postural training works on the assumption that an optimally aligned skeletal system reduces stress in its structures. Commonly adopted relaxed postures often are passive in nature, with a predisposition toward sway standing and slump sitting. It is proposed that these postures rely on the passive lumbopelvic structures for the maintenance of an upright position against gravity. As a result, the requirement for muscle activity is diminished. It has been reported clinically that these passive postures frequently exacerbate low back pain and that the adoption of these postures is associated commonly with motor dysfunction of spine-stabilizing muscles such as the lumbar multifidus muscle and the deep abdominal musculature (O'Sullivan, et al., 2002). Goel and co-workers used combined 3D finite element model; muscle model compared to ligament model. Muscles decrease stress in vertebral body, causing no increase in intradiscal pressure. Load bearing of the facets increased in the muscle model compared to ligamentous. Gardner-Morse and associates found that muscles played a significant role in maintaining the stability of the lumbar spine during loading and motion and that they appear to act as "stabilizing springs" (Levangie & Norkin, 2001). Sustaining a slouched posture for as little as 10 minutes creates relaxation in the muscles of the back, but the load of the body is then placed on the ligaments, discs and joints (Pynt & Higgs, 2010).

While sitting involves more lumbar flexion than standing, it is unclear how much flexion this should involve. Spinal posture requires sufficient muscle activation to aid postural stability, without excess muscle activation causing fatigue and exerting large compressive spinal loads. There is considerable evidence of increased superficial muscle activation among low back pain subjects in low load tasks. A recent study suggested that even pain-free subjects may find assuming neutral postures difficult without manual or verbal feedback. Since subjects with low back pain may have deficits in proprioception, and alterations in their body schema, it might be even more difficult for low back pain patients to assume and maintain prescribed neutral spinal postures. Rehabilitation which involves retraining of neutral spinal postures has been shown to improve low back pain outcomes (O'Sullivan, McCarthy, White, O'Sullivan, & Dankaerts, 2012).

7.1 POSTURAL DISTURBANCES

Optimal posture combines both minimal muscle work and minimal joint loading. The combination of these two factors is important – where optimal posture is lost (e.g., in slouched standing), the muscle activity is clearly reduced, but there is a significant increase in joint loading. Joint loading should be minimized over time – articular cartilage gains its nutrition through intermittent loading, and an even distribution of force is preferable to point pressure. Contact pressure is directly proportional to the transmitted force but inversely proportional to area. Distributing force over a larger area by optimizing segmental alignment, therefore, reduces joint surface compression and lessens the risk of degenerative changes to a joint. The aim of any posture should be to reduce total energy expenditure and lessen stress on the supporting body structures (Norris, 2008).

Bad posture is a bad habit and, unfortunately, is all too common. Postural faults have their origin in the misuse of the capacities provided by the body, not in the structure and function of the normal body. If faulty posture were merely an aesthetic problem, the concerns about it might be limited to those regarding appearance. However, postural faults that persist can give rise to discomfort, pain, or disability. The range of effects, from discomfort to incapacitating disability, is often related to the severity and persistence of the faults. The high incidence of postural faults in adults is related to this tendency toward a highly specialized or repetitive pattern of activity (Kendall, McCreary, Provance, Rodgers, & Romani, 2005).

Functional pathology of the motor system describes impaired function of structures rather than damage to structures. Traditionally, clinicians have taken a more structural approach, relying on their knowledge of anatomy and biomechanics in a purely orthopaedic approach to chronic musculoskeletal pain. In contrast, the functional approach recognizes unseen mechanisms related to the function of the neuromuscular system (Page, Frank, & Lardner, 2010).

Postural disturbances according to origin, with emphasis on the functional (Kolar, 2013):

1. Anatomical - innate or acquired
2. Neurological - neurological syndromology
3. **Functional** - Impairment of the stabilizing function of postural muscles during movement and static positions, which is most commonly examined via tests and assessment of an impaired distribution of muscle tone, which is most significantly projected into the body posture.

7.1.1 Functional postural disturbances

Main reasons for functional muscle disturbance with postural consequence are as follows:

1. Central coordination disturbances (CCD) during postural development

During the physiological development of a child, balance appears between muscles with antagonistic function, which allows for holding joint positions in a so called neutral position (centrated position). This occurs only in a healthy central nervous system. We speak of an ideal posture. In postural developmental dysfunctions, a deficit in the functional joint position always occurs – anteversion of pelvis, forward head, inspiratory position etc. Changes during development consider the infants and include abnormal motor development which can become fixed and presents the foundation for postural behaviour in later age (Kolar, 2013).

2. The way in which our stereotypical movements have been evolved, strengthened and modified, often in the context of individual's psychological state

During motor learning, it is important for a posturally correct and secured movement to evolve. The movement should be so efficiently developed that truly only the muscles that execute and posturally stabilize this movement participate in such movement. Under such ideal assumptions, the movement occurs during the correct positioning of a joint, which we denote as centrated (neutral). This leads to an optimal loading of the joint and ligamentous structures. This principle can be observed during postural development under the presumption of physiological development of the brain and during reflex locomotion – i.e. an "ideal postural pattern". An example is the breathing stereotype in which the accessory breathing muscles function primarily (Kolar, 2013).

Unilateral or incorrectly performed movement loading, most commonly caused by occupations, is one of the reasons for evoked changes in the muscle tone and thus the formation of faulty postural behaviour. Therefore, muscle tightness and muscle inhibition occurs. This is typical in athletes who begin unilateral loading prematurely or are routinely incorrectly directed in practices. Cultural or ethic influences also markedly determine our postural presentation. For example, women are ashamed of a protruding stomach, and therefore, they draw it in or how it is fashionable to wear high heels. In addition, psychological states result in postural changes, seen in different emotional states when body changes the muscle tone through its influence of the limbic system (Kolar, 2013).

Non-physiologic hypertonus linked to the formation of muscle imbalances occurs primarily during a longstanding stressful demand. The characteristics for this hypertonus include (Kolar, 2013):

- Limited to a given region, but not to a muscle group
- Ease of transition between hypertonic and normal tonic regions (the transition is difficult to detect via palpation)
- Localized primarily in the neck musculature and shoulder girdle and into the lumbosacral plexus and pelvic region;
- Manifestation of changes in the muscle tone in the method of a breathing stereotype (breathing is more costal, accessory muscles are more involved and expiration is not fully completed).
- Vegetative manifestations are present (perspiration, dermography, cold distal appendages)

3. Dysfunction in nociceptive control

The next cause of changes in postural functions is related to nociceptive stimulation and the subsequent reaction. When a pathological situation develops in an organism, nociceptive information is formed. Information about damage is not a mere interpretation of a state, but acts as a “trigger” of defense mechanisms. As a reaction, activities develop with the purpose to prevent damage to a structure or at least to minimize the injury. The motor system’s own part in the control of nociception lies in reflex reprogramming, meaning in influencing the output of motor information. An emergency saving program is formed. Automatically, changes in muscle function develop – muscle hypertonus and inhibition – which are components of autoregulatory process. Changes in tone related to this peripheral (reflex) cause may affect the whole muscle group, a single muscle, or, more frequently, only a part of a muscle – in such case, the trigger point. Unilateral overloading is the result of all sources leading to the changes in postural functions, which during long term duration leads to the formation of morphological impairments (acquired spondylolisthesis, degenerative joint changes, etc.) (Kolar, 2013).

Good body posture is projected into the muscle tone (muscle balance or imbalance) and central control mechanisms including psychological state, ligament conditions, and anatomical relationships are all reflected in posture. Posture also reflects reactions to pathological states within the organism. During a physiological situation, individual movement segments are centred so that the *postural tone* in the muscles (especially the superficial muscles) is minimal. All excessive (whether globally or locally) muscle tone has a significant outcome value. It is practically impossible for increased resting postural tone not to be a source or a consequence of a patients complications (including internal dysfunctions). Muscle tone in standing also speaks to the overall relaxation capabilities of a patient (Kolar, 2013).

Good body mechanics requires that range of joint motion be adequate but not excessive. Normal flexibility is an attribute; excessive flexibility is not. A basic principle regarding joint movements can be summarized as follows: the more flexibility, the less stability; the more stability, the less flexibility. A problem arises, however, because skilled performance in a variety of sport, dance, and acrobatic activities requires excessive flexibility and muscle length. Although "the more, the better" may apply to improving the skill of performance, it may adversely affect the well-being of the performer (Kendall, McCreary, Provance, Rodgers, & Romani, 2005). Normal posture is maintained by balanced, strong, and flexible muscles, intact ligaments, freely moving fascia, healthy, properly functioning joints, a balanced line of gravity and good postural habits. Changes in postural alignment may be secondary to structural malformation, joint degeneration, bone deterioration, joint instability, change in the centre of gravity, poor postural habits, or pain. Faulty alignment creates unnecessary stress and strain on the individual, creating either excessive elongation or adaptive shortening of muscles (Gross, Fetto, & Rosen, 2009). Maintaining a habitually closed posture induces fascia to produce more fibre which causes overlapping fascial sheaths to adhere to one another. This is how poor posture becomes chronic (Bond, 2006). Bad posture can also develop for example, in the case of a child with cerebral palsy due to lengthy surgical history who also had apparently longstanding postural habits and compensations (Bertoti, 1988).

Interpretation of any postural changes over time relies on an appreciation that during a reasonably limited period, the person's perception of comfortable erect posture remains sufficiently constant that they can consciously stand with the same degree of spinal curvature when asked to assume such a position, even on occasions separated by a month or a year. Unless they can, there is no reliable basis on which to make a judgement about normalcy or abnormality, or about progressive improvement or deterioration of posture over time (Bullock-Saxton, 1993).

There are four classical abnormal posture types. In the lordotic posture, the main feature is excessive anterior pelvic tilt. It may result from increased weight of the abdomen, as in pregnancy, or extreme obesity, poor posture, rickets, osteoporosis, or tuberculosis of the spine (Tortora & Nielsen, 2012). Anterior displacement of the pelvis characterizes the swayback, whereas the flat back posture has slight posterior pelvic tilting and loss of lumbar lordosis. In the kyphotic posture, the thoracic curve is excessive (Norris, 2008). Example include round back, hump back (gibbus), flat back (decreased pelvic inclination -20°), and dowager’s hump. Additional deformity is scoliosis, it’s a lateral bending of the vertebral column, usually in the thoracic region. The most common of the abnormal curves, scoliosis may result from congenitally (present at birth) malformed vertebrae, can be also postural, idiopathic, after chronic sciatica (pain in the lower back and lower limb), paralysis of muscles on one side of the vertebral column, poor posture, or one leg being shorter than the other (Magee, 2014).

Other deformities surrounding spine include:

- kypholordotic posture (combination of excessive kyphosis and lordosis)
- barrel chest (sternum projects forward and upward, appears to be in a constant inspiratory position, associated with weakening of the postural potential of the diaphragm (Kolar, 2013))
- open scissors syndrome
- pectus excavatum (congenital deformity, sternum projects forward and downward, impairs the effectiveness of breathing by restricting ventilation volume)
- pectus excarinatum (congenital deformity, sternum is pushed posteriorly by an overgrowth of the ribs, heart may be displaced, causes depression of sternum during inspiration)

- Pelvic deformities (pelvic tilt, shift, torsion, rotation, outflare or inflare)

Kyphosis or lordosis become problems when extreme curvatures are so set by habitual muscular tension and accompanying fascial adhesion that the spine loses resilience and adaptability. The curves themselves are beneficial. They are dysfunctional only when they become extreme or too stiff to move (Bond, 2006).

Unbalanced standing is at first corrected by higher muscle activity accompanied by hypertonia, then pain appears and, later, a deformity forms. The necessity of excessive muscle activity occurs not only in standing, but also during any other movement (for example, when lifting a heavy object). The balance deficit is corrected not only structurally, but also centrally (sensory postural presentation) and so the patient perceives any postural correction as unnatural and, in the corrected posture, feels as if not standing straight (Kolar, 2013). Many changes in tissues are just a normal part of being alive and don't have to hurt. What's more, these changes don't necessarily have to stop anyone leading a very functional and active life. It is very likely that an x-ray of an older person's spine will reveal changes which could be described as arthritic or degenerative. Yet they can still function very well. Pains from bites, postural pain and sprains are simple 'everyday' pains that can be easily related to changes in tissues. The brain concludes that the tissues are under threat and that action is required, including healing behaviours. An added benefit is that memories of the pain will hopefully protect you from making the same mistake twice (Butler & Moseley, 2013).

Painful conditions associated with faulty body mechanics are so common that most adults have some first-hand knowledge of these problems. Painful low backs have been the most frequent complaints, although cases of neck, shoulder, and arm pain have become increasingly prevalent. With the current emphasis on running, foot and knee problems are common. When discussing pain in relation to postural faults, questions are often asked about why many cases of faulty posture exist without symptoms of pain, and why seemingly mild postural defects give rise to symptoms of mechanical and muscular strain. The answer to both depends on the constancy of the fault. A posture may appear to be very faulty, yet the individual may be flexible and the position of the body may change readily. Alternatively, a posture may appear to be good, but stiffness or muscle tightness may so limit mobility that the position of the body cannot change readily. The lack of mobility, which is not apparent as an alignment fault but which is detected in tests for flexibility and muscle length, may be the more significant factor. Basic to an understanding of pain in relation to faulty posture is the concept that the cumulative effects of constant or repeated small stresses over a long period of time can give rise to the same kind of difficulties that occur with a sudden, severe stress. Cases of postural pain are extremely variable in the manner of onset and in the severity of symptoms. In some cases, only acute symptoms appear, usually as a result of an unusual stress or injury. Other cases have an acute onset and develop chronically painful symptoms. Still others exhibit chronic symptoms that later become acute (Kendall, McCreary, Provance, Rodgers, & Romani, 2005). Chronic pain is often associated with multiple factors, such as fatigue or certain postures or activities (Magee, 2014). Movement often makes it worse and nerves are more comfortable in some positions than in others. When a nerve is sensitive, we favour postures that tend to avoid putting mechanical load on the affected nerve, e.g. by raising shoulder up, bending spine sideways or poking head forward (Butler & Moseley, 2013). Low back pain is a common musculoskeletal disorder, with many different contributing factors including provocative spinal postures. Therefore, addressing provocative spinal postures is commonly advocated in management of health (O'Sullivan, McCarthy, White, O'Sullivan, & Dankaerts, 2012).

Musculoskeletal system is the largest energy user in the body by a large margin, and when we misuse it and waste energy we are also loading a burden of strain onto areas (whether feet, knees, pelvic joints, spine, or neck) that will ultimately demonstrate disapproval of being misused by becoming tired, painful, and dysfunctional. As our joints and muscles start to complain, we too may also find ourselves becoming tired, pained, and less functional (Bond, 2006).

7.2 MUSCLE IMBALANCE

There are two schools of thought on muscle imbalance: one that believes in a biomechanical cause of muscle imbalance resulting from repetitive movements and posture and one that believes in a neurological predisposition to muscle imbalance. The traditional view of muscle imbalance relates to biomechanics. The biomechanical cause of muscle imbalance is the constant stress that muscles experience due to prolonged postures and repetitive movements. On the other hand, Dr. Vladimir Janda suggested that the nervous system plays a key role in pain pathogenesis and maintenance, and that muscle imbalance is systematic and predictable involving the entire body. Janda defined functional pathology as impairment in the ability of a structure or physiological system to perform its job; this impairment often manifests in the body through reflexive changes (Page, Frank, & Lardner, 2010). The mixture of tightness and weakness in muscle imbalance alters body segment alignment and changes the equilibrium point of a joint. Normally the equal resting tone of agonist and antagonist muscles allows the joint to assume a balanced resting position, with the joint surfaces evenly loaded and the joint's inert tissues not excessively stressed. However, if the muscles on one side of a joint are tight and the opposing muscles are lax, the joint will be pulled out of alignment toward the tight muscle. This alteration in alignment throws weight-bearing stress onto a smaller region of the joint surface, increasing pressure per unit area. Furthermore, the inert tissues on the shortened (closed) side of the joint will contract over time. Avoidance of end-range posture that load the soft tissues excessively may reduce short-term pain as well as long-term pain caused by overuse (Norris, 2008).

Muscle balance can be now defined as a relative equality of muscle length or strength between an agonist and an antagonist; this balance is necessary for normal movement and function. Muscle balance may also refer to the strength of contralateral (right versus left) muscle groups. Muscle balance is necessary because of the reciprocal nature of human movement, which requires opposing muscle groups to be coordinated (Page, Frank, & Lardner, 2010). When a person develops elongated or shortened muscles, he or she may not develop symptoms immediately. It may take many years of stress and strain for problems to reach clinical recognition (Gross, Fetto, & Rosen, 2009). Adequate balance, timing, and recruitment of the musculature are imperative for smooth and efficient movement patterns. Imbalance or impairment in recruitment and coordination of muscles in any part of the kinetic chain manifests as faulty patterns and inefficient energy expenditure (Page, Frank, & Lardner, 2010). If one body segment moves forward, for example, another must move backward to keep the body's line of gravity within the BOS (Norris, 2008). In the spine, restriction in any one of the curvatures creates compensatory tension in muscles and fascia of the curves above or below (Bond, 2006). The body's attempts to compensate for imbalance cause an impairment in movement, or movement dysfunction. This impairment generally exacerbates the problem and can lead to serious disability, often leading to postural changes due to alterations in resting muscle tone (Page, Frank, & Lardner, 2010) (Norris, 2008).

Muscles may become unbalanced as a result of adaptation or dysfunction. Such muscle imbalances can be either functional or pathological (Table 1). These types of imbalances are most common in athletes and are necessary for function. Functional muscle imbalances occur in response to adaptation for complex movement patterns, including imbalances in strength or flexibility of antagonistic muscle groups (Page, Frank, & Lardner, 2010).

Functional imbalance	Pathological imbalance
Atraumatic	With or without trauma
Adaptive change	Adaptive change
Activity specific	Associated with dysfunction
No pain	With or without pain

Table 1: comparison between functional and pathological imbalance (Page, Frank, & Lardner, 2010).

When muscle imbalance impairs function, it is considered to be pathological. Pathological muscle imbalance typically is associated with dysfunction and pain, although its cause may or may not result from an initial traumatic event. Pathological imbalance may also be insidious; many people have these muscle imbalances without pain. Ultimately, however, pathological muscle imbalance leads to joint dysfunction and altered movement patterns, which in turn lead to pain. Note that this muscle imbalance continuum may progress in either direction; muscle imbalance may lead to altered movement patterns and vice versa (Page, Frank, & Lardner, 2010). Results by Danis et al, 1998, showed that female subjects without impairment have an anterior pelvic tilt in quiet standing (Danis, Krebs, Gill-Body, & Sahrmann, 1998). Muscle imbalance often begins after injury or pathology leads to pain and inflammation. Imbalance may also develop insidiously from alterations in proprioceptive input resulting from abnormal joint position or motion. These two conditions lead muscles to either tighten (hypertonicity) or weaken (inhibition), creating localized muscle imbalance. This imbalance is a characteristic response of the motor system to maintain homeostasis. Over time, this imbalance becomes centralized in the CNS as a new motor pattern, thus continuing a cycle of pain and dysfunction (Page, Frank, & Lardner, 2010).

Lifestyle in today's society often contributes to muscle imbalance as well as it’s compounded by stress, fatigue, and insufficient movement through regular physical activity as well as a lack of variety of movement, noted in repetitive movement disorders. Cultural patterns of modern civilization add to the stresses on the basic structures of the human body by imposing increasingly specialized activities (Page, Frank, & Lardner, 2010) (Kendall, McCreary, Provance, Rodgers, & Romani, 2005). It was suggested that repeated movements or sustained postures can lead to adaptations in muscle length, strength, and stiffness; in turn, these adaptations may lead to movement impairments. Muscles grow longer or shorter as the number of sarcomeres in series increases or decreases, respectively. These muscle adaptations can result from everyday activities that alter the relative participation of synergists and antagonists and eventually affect movement patterns. The precision of joint motion changes when a particular synergist becomes dominant at the expense of the other synergists; this change may lead to abnormal stresses in the joint. For example, if the hamstring muscle is dominant and the gluteus muscle is weak, the result may be a repeated hamstring strain and a variety of painful hip joint dysfunctions (Page, Frank, & Lardner, 2010). The longer the slouched posture is sustained, the more the ligaments and muscles stretch. After 20 minutes of sustained stretching, the deep muscles of the back begin to spasm intermittently in an attempt to compensate for the diminished protection offered by the stretched ligaments. This muscle hyperexcitability continues and increases for the next 2 to 6 hours of rest following sustained slouched postures. Muscle hyperexcitability is accompanied by inflammation in the ligaments. It is quite likely that the sudden knifelike back pain described by some sufferers is a result of these spasms of the deep spinal muscles (Pynt & Higgs, 2010). Over time, changes in force per unit area cause tissue adaptation. Changes in serial sarcomere number within muscles, for example, are adaptations to postural changes over time. Shortening ligaments lead to reduced range of motion, whereas lengthening ligaments reduce a joint's passive stability (Norris, 2008). For example, tightness of the hamstrings may limit the full ROM and force of knee extension (Page, Frank, & Lardner, 2010).Inherent in the concept of good body mechanics are the inseparable qualities of alignment and muscle balance. Examination and treatment procedures are directed toward restoration and preservation of good body mechanics in posture and movement. Therapeutic exercises to strengthen weak muscles and to stretch tight muscles are the chief means by which muscle balance is restored (Kendall, McCreary, Provance, Rodgers, & Romani, 2005). Static posture provides a window into the overall status of the CNS, in that the muscular system lies at the functional crossroads between the CNS and the osteoarticular system. The muscular system exerts a strong influence on the articular system and CNS and vice versa. Hence, functional pathology in any part of the sensorimotor system is reflected by alterations in function elsewhere in the system. The primary functions of muscles to produce and control motion, to stabilize, and to protect joints are regulated by the CNS (Page, Frank, & Lardner, 2010).

If a person has strong, flexible muscles, faulty postures may not affect the joints because he or she has the ability to change position readily so that the stressed do not become excessive. If the joints are stiff (hypomobile) or too mobile (hypermobile), or the muscles are weak, shortened, or lengthened, however, the posture cannot be easily altered to the correct alignment, and the result can be some form of pathology. The pathology may be the result of the cumulative effect of repeated small stresses (micro trauma) over a long period of time or of constant abnormal stresses (macro trauma) over a short period of time. These chronic stresses can result in the same problems that are seen when a sudden (acute) severe stress is applied to the body. The abnormal stresses can cause excessive wearing of the articular surfaces of joints and produce osteophytes and traction spurs, which represent the body's attempt to alter its structure to accommodate these repeated stresses. The soft tissue (e.g., muscles, ligaments) may become weakened, stretched, or traumatized by the increased stress. This postural deviations do not always cause symptoms, but over time, they may do so. The application of an acute stress on the chronic stress may exacerbate the problem and produce the signs and symptoms that initially prompt the patient to seek aid (Magee, 2014). Correcting the posture so that the correction becomes automatic is extremely difficult. It requires a combination of several factors where shortened muscles must be stretched and lengthened muscles shortened so that posture can change permanently – assuming that the tissue is not allowed to change again through poor postural alignment. If poor posture is the result of muscle weakness brought through injury (wasting or pain inhibition) - muscle strengthening, after the pain has eased, may optimize posture (Norris, 2008). Influencing the stabilization function of a muscle is not as much a question of exercising as it is commonly presumed, but rather it is a learning system. In this case, muscles cannot be exercised according to their anatomically defined origin and insertion. Goal is to affect the muscle in its actual function, in this case in the stabilization function, or co-activation by reinforcing segment(s) – with other muscles. This is a question of not only actual muscle strength, but especially its recruitment, or inclusion in a synergy. Among the muscles that are activated during a particular movement, a firm feedback (memory) is formed so that all the participating muscles form a functional unit in the end (Kolar, 2013). Healing somebody's posture cannot be a quick fix. Conventional programs usually teach to align body along a vertical line of gravity's pull, and to strengthen muscles to maintain that alignment. While it is true that most people hold their bodies behind gravity's axis, simply positioning the body more forward is merely a mechanical adjustment. It does nothing to change your perceptual relationship with gravity or the world around you. The activity of changing your perceptions is what makes changes in posture sustainable (Bond, 2006). For many cases of poor stability, progressive exercises and proprioceptive training can enhance stability and produce positive postural changes. When posture has been suboptimal for many years, however, full correction probably is not possible. Certainly improvements can be made, and these may be clinically significant (especially in relieving pain), but they will be limited (Norris, 2008).

8 BREATHING

Good – or poor – breathing habits affect every aspect of our bodies' functioning, from our mental state to our digestive efficiency. Breathing is central to our posture and to the way we move. It has huge influence on our appearance, health, mental outlook, emotional resilience, and capacity to manage stress (Bond, 2006).

Somatic motor neurons innervate skeletal muscles—the effectors of the somatic nervous system—and produce both reflexive and voluntary movements of the musculoskeletal system. When a somatic motor neuron stimulates a skeletal muscle, the muscle contracts; the effect always is excitation. If somatic motor neurons cease to stimulate a muscle, the result is a paralyzed, limp muscle that has no muscle tone. In addition, even though we are generally not conscious of breathing, the muscles that generate respiratory movements are skeletal muscles controlled by somatic motor neurons. If the respiratory motor neurons become inactive, breathing stops (Tortora & Nielsen, 2012). Generally, the activity of breathing muscles is not intended for a single purpose despite its seemingly functionally-anatomical division. Since it depends on the circumstances under which the breathing motion occurs, it is obvious that the muscles considered as primarily respiratory also participate in postural function, change the configuration of movement segments during breathing (primarily the spine) and, thus, influence body posture. Since they are characterized as communicatively strong, they can be nowadays called "respiratory-postural" muscles" and not only "respiration active" (Kolar, 2013).

The movement axis of breathing is formed by the pelvis-spine-head. Breathing movements serve for lung ventilation and, at the same time, influence postural functions and body posture. During the assessment of an alignment, co-activation of most trunk muscles with breathing is observed during simultaneous participation of the configuration of the thorax and an overall body posture and its movements. Breathing movements can be observed in three sections of the trunk (Kolar, 2013):

- Lower - abdominal, from the diaphragm to the pelvic floor
- Middle - lower thoracic between the diaphragm and the 5th thoracic vertebra
- Upper - upper thoracic, from T5 to the lower cervical spine

Respiratory movements rhythmically repeat themselves in two phases – inspiration (breathing in) and expiration (breathing out) and are divided by pre-inspiration and pre-expiration. Pre-inspiration is a short pause at the end of expiration before inspiration occurs. Expiration is linked to inhibitory activity of the posturally-locomotor system. Its effect is facilitated by an inspiratory pause (apnoea at the end of inspiration). Expiration is generally linked to relaxation and release of muscle tension. Pre-expiration is a short pause at the end of inspiration and before expiration. Inspiration has an excitatory effect on muscle activity of the posturally-locomotor system and is used for facilitation of muscle activity, i.e. during intense concentration on a certain task performed “while holding breath” (Kolar, 2013).

The muscles that act on the rib cage are generally referred to as the ventilatory muscles. The ventilatory muscles are striated skeletal muscles that differ from other skeletal muscles in a number of ways (Levangie & Norkin, 2011):

- have increased fatigue resistance and greater oxidative capacity
- contract rhythmically throughout life rather than episodically
- work primarily against the elastic properties of the lungs and airway resistance rather than against gravitational forces
- neurological control of these muscles is both voluntary and involuntary
- actions of these muscles are life-sustaining

Any muscle that attaches to the chest wall has the potential to contribute to ventilation. The recruitment of muscles for ventilation is related to the type of breathing performed. In *quiet breathing* that occurs at rest, only the *primary* inspiratory muscles are needed for ventilation. During active or forced breathing that occurs with, for example, increased activity or pulmonary pathologies, *accessory* muscles of both inspiration and expiration are recruited to help meet the increased demand for ventilation (Levangie & Norkin, 2011). Mouth breathing for example, encourages forward head posture with protrusion of the mandible and increases activity of accessory respiratory muscles (Magee, 2014) (Conti, Sakano, Ribeiro, Schivinski, & Ribeiro, 2011).

The ventilatory muscles are most accurately classified as either primary or accessory muscles of ventilation. A muscle’s action during the ventilatory cycle, especially the action of an accessory muscle, is neither simple nor absolute, which makes the categorizing of ventilatory muscles as either inspiratory muscles or expiratory muscles inaccurate and misleading (Levangie & Norkin, 2011).

8.1 PRIMARY MUSCLES OF VENTILATION

The primary muscles are those recruited for quiet ventilation. These include (Levangie & Norkin, 2011):

- diaphragm (most important)
- intercostales – internal (parasternal)
- levatores costarum (Kolar, 2013)
- scalenes (according to Kolar, 2013, mm. scaleni are accessory)

These muscles all act on the rib cage to promote inspiration. There are no primary muscles for expiration because expiration at rest is passive (Levangie & Norkin, 2011). Kolar, 2013, states the opposite and includes the following as primary muscles of expiration (Kolar, 2013):

- intercostales – internal
- sternocostal

Bond, 2006, adds a combination, writing that exhalation is caused by the elastic recoil of lung tissue, by the upward movement of the diaphragm as it relaxes, and when the body is upright, by compression of the abdomen (Bond, 2006).

8.1.1 Diaphragm

It's a sheet of muscle that is simultaneously the roof of your abdomen and the floor of your rib cage. It is one of the few places where muscle tissue lies across your body – roughly perpendicular to your vertical stance (Bond, 2006). This also makes us unique among animals, with mammals being the only class in animal kingdom with a true diaphragm (Kitaoka & Chihara, 2010).

The diaphragm is the primary muscle of ventilation, accounting for approximately 70% to 80% of the inspiration during quiet breathing. It is formed as a circular set of muscle fibres that arise from the sternum, ribs, costocartilages and vertebral bodies, and travel cephally to insert into a central tendon. The lateral leaflets of the boomerang-shaped central tendon form the tops of the domes of the right and left hemidiaphragms, which are innervated and supplied with blood from right and left sources, respectively (Hodges, Butler, McKenzie, & Gandevia, 1997) (Levangie & Norkin, 2001).

The thoracoabdominal movement during quiet inspiration is a result of the pressures that are generated by the contraction of the diaphragm, the shape of diaphragm, and angle of pull of its fibres. During tidal breathing, the muscles of the diaphragm shorten, causing the central tendon to descend. The resultant increase in thoracic size causes a decrease in pleural pressure. This negative pleural pressure causes a decrease in intrapulmonary pressure that is responsible for inspiration. If unopposed by the scalenes and the parasternals, this negative pleural pressure and the resultant decreased intrapulmonary pressure are strong enough to cause the upper chest to collapse inward during inspiration (Levangie & Norkin, 2001). As a result of gravity, in an upright individual the pleural pressure at the base of the lung base is greater (less negative) than at its apex; when the individual lies on his back, the pleural pressure becomes greatest along his back (John Hopkins University, 1995). The slight forward tilt of the pelvis in healthy sitting and standing deflects the diaphragm's pressure away from the bladder (Bond, 2006), while the forward-leaning position results in increased intra-abdominal pressure by approximating the ribs to the pelvis, making it difficult for the diaphragm to descend caudally during inspiration (Kim, et al., 2012).

No mammals can live without the diaphragm. Congenital diaphragmatic dysplasia causes death just after birth due to pulmonary hypoplasia. Traumatic diaphragmatic rupture is also fatal because the lung is compressed by abdominal organs (Kitaoka & Chihara, 2010). The contribution of diaphragm to respiration is the reason why the diaphragm is considered to be the most important muscle right after the heart (Kolar, 2013). Diaphragm also contracts in non-respiratory movements such as the expulsive effort of defecation and parturition (Hodges, Butler, McKenzie, & Gandevia, 1997).

8.2 ACCESSORY MUSCLES OF VENTILATION

The muscles that attach the rib cage to the shoulder girdle, head, vertebral column, or pelvis may be classified as accessory muscles of ventilation. These muscles assist with inspiration or expiration in situations of stress, such as increased activity or disease. When the thorax is stabilised, the accessory muscles of ventilation move the vertebral column, arm, head, or pelvis on the trunk. During times of increased ventilatory demand, the rib cage can become the mobile segment. The accessory muscles of inspiration, therefore, increase the thoracic diameter by moving the rib cage upward and outward. The accessory muscles of expiration move the diaphragm upward and the thorax downward and inward (Levangie & Norkin, 2011) (Levangie & Norkin, 2001) (Bond, 2006).

Accessory muscles are (Levangie & Norkin, 2011) (Kolar, 2013):

- Sternocleidomastoid (with cervical spine fixed moves upper rib cage superiorly, by fixating the head with trapezius)
- Pectoralis major (sternocostal part and clavicular part – depends on arm position if humerus is fixed: humeral insertion below clavicle - expiratory, insertion above clavicle - inspiratory)
- Pectoralis minor (lifts 3rd ,4th and 5th rib at forced inspiration)
- Subclavius (can raise first rib during inspiration)
- Levatores costarum (assists with inspiration in the upright position, lateral trunk flexion)
- Serratus posterior superior and inferior
- Serratus anterior (Kolar, 2013)
- Abdominals (transversus abdominis, internal oblique, external oblique and rectus abdominis)

  Transversus abdominis wraps around the abdomen like a corset and its contraction compresses the abdomen and tightens the lumbar fascia. Although the muscle extends as far up as the diaphragm, it is the contraction of the lower fibres – between pubic bone and navel – that is crucial for lower back stability. This muscles only squeezes the trunk, which distinguishes it from the muscles of the outer corset (Bond, 2006).

- Transversus thoracis / triangularis sterni (pulls the rib cage caudally, active expiration during talking, coughing, laughing, forced exhalation. Are inactive in rest and supine, active in quiet expiration in standing elderly)
- Quadratus lumborum (stabilizes diaphragm as it eccentrically contracts during phonation)
- Pelvic floor muscles (Kolar, 2013)
- Back muscles (iliocostalis pars inferior, erector spinae…)

8.3 NORMAL SEQUENCE OF CHEST WALL MOTIONS DURING BREATHING

Children tend to breathe abdominally, whereas women tend to do upper thoracic breathing. Men tend to be upper and lower thoracic breathers. In the aged, breathing tends to be in the lower thoracic and abdominal regions (Magee, 2014). There is no single way to breathe. There are many blends of abdominal and thoracic breathing, but the essential movement of normal respiration is performed by the diaphragm (Bond, 2006).

When one observes the abdomen and chest wall of a normal, healthy person during quiet breathing, the following sequence of motion usually occurs. First, the diaphragm contracts and the central tendon moves caudally. Intraabdominal pressure increases and abdominal contents are displaced such that the anterior epigastric abdominal wall is pushed outward. Once the central tendon is “fixed” or stabilized on the abdominal organs, the appositional, vertical fibres pull the lower ribs upward and outward resulting in lateral movement of the lower chest. Following lateral expansion, with continued inspiration, the parasternals, scalenes, and levatores costarum actively rotate the upper ribs and elevate the manubrosternum, resulting in an anterior motion of the upper chest. The lateral and anterior motions of the chest can occur simultaneously. Expiration during quiet breathing is passive, with recoil of the elastic components of the lungs and chest wall (Levangie & Norkin, 2001).

During physiological breathing, expansion of the lower part of the chest occurs and the sternum is moving in the anterior-posterior direction. Breathing under this circumstance involves the diaphragm and the intervertebral muscles without the help of the accessory breathing muscles. In reality, however, most of the time, a stereotype persists in which the accessory breathing muscles function primarily (pectoral muscles, scalene). These muscles activate additional muscles that must stabilize these accessory muscles, such as the suboccipital muscles. Therefore, muscles that lack any mechanical connection with the breathing movement become associated with breathing. A strong bond is formed between the muscles that are activated during a corresponding movement so that, eventually, all involved muscles form a functional unit. An individual then constantly activates these muscles as a whole, which leads to a non-purposeful loading of soft tissues and joint structures (Kolar, 2013). Poor breathing habits develop when we misuse the respiratory system to make ourselves feel stable in an unstable world, which eventually distorts posture and damages health. The more you can allow gravity to support your body, the easier it is to breathe with your diaphragm (Bond, 2006).

During increased tonic tension of the diaphragm, the abdominal muscles eccentrically recede to the inspiratory contraction of the diaphragm. If this cooperation is disrupted, the upper stabilizers of the thorax become engaged into respiration, which results in insufficient anterior spinal stabilization and overloading of the spinal extensors (Kolar, 2013).

8.3.1 Expiratory and abdominal muscles

During quiet expiration, the diaphragm passively relaxes and returns to its equilibrium position. However, during exercise or upright stance, expiration becomes an active process - the abdominal muscles contract to raise abdominal pressure, which pushes the diaphragm upward and forces air out of the lungs. During quiet breathing, the diaphragm moves a centimetre or two up and down, but during exercise, it can move more than 10 cm (John Hopkins University, 1995) (Bond, 2006).

The major function of the abdominal muscles in ventilation is to assist with forced expiration. The muscle fibres pull the ribs and costocartilages caudally, into a motion of exhalation. By increasing intra-abdominal pressure, the abdominal muscles can force the diaphragm upward into the thoracic cage, increasing both the volume and speed of exhalation (Levangie & Norkin, 2001). During active expiration, the abdominal muscles are contracted to force up the diaphragm and the resulting pleural pressure can become positive. Positive pleural pressure may temporarily collapse the bronchi and cause limitation of air flow (John Hopkins University, 1995).

Although usually considered accessory muscles of exhalation, the abdominal muscles play two significant roles during inspiration (Levangie & Norkin, 2001):

- ♦ First, the increased abdominal pressure created by lowering of the diaphragm in inspiration must be countered by tension in the abdominal musculature. Without sufficient compliance in the abdominal muscles, the central tendon of the diaphragm cannot be effectively stabilized and lateral chest wall expansion cannot occur.
- ♦ Secondly, the increased intra-abdominal pressure created by the active abdominal muscles during forced exhalation pushes the diaphragm cranially and exerts a passive stretch on the costal fibres of the diaphragm. These changes prepare the respiratory system for the next inspiration by optimizing the length-tension relationship of the muscle fibres of the diaphragm. During periods of increased ventilatory needs, the increased muscular activity of the abdominal muscles assists in both exhalation and inhalation.

During inspiration the abdominals assist with lateral chest wall expansion by providing anterior stability to the abdomen so it may act as a fulcrum for the diaphragm action thereby maintaining the zone of apposition. In the supine position, gravity provides the anterior stability of the abdominal wall. In the supine position, the abdominals are not needed and in fact, are silent on the EMG. The muscular activity of the abdominals increases during exercise as increased ventilation is needed (Levangie & Norkin, 2001). Healthy muscle tone in the abdomen both supports the spine and assists with digestion and respiration. Constant upper abdominal tension, however, prevents the diaphragm from descending and blocks the natural lift of the chest that breathing should create. Such tension can develop by habitually tightening the stomach muscles in an attempt to appear thin, by performing abdominal exercises incorrectly, or through emotional constraint or digestive problems (Bond, 2006).

8.4 INTRA-ABDOMINAL PRESSURE

Intra-abdominal pressure (IAP) is sometimes described as intratruncal pressure, although this term includes both intra-abdominal and intrathoracic pressure. Intrathoracic pressure is created during inspiration by expanding the lungs within the rib cage to coincide with a lift or other effort. Most people experience IAP in everyday life, for example, when the muscles contract reflexively to defend the abdomen from a direct blow (Norris, 2008).

Imagine the trunk as a cylinder. The top of the cylinder is formed by the diaphragm, the bottom the pelvic floor, and the walls the deep abdominals (transversus and internal oblique). The deep abdominals (transversus abdominis and internal oblique) are the most important of the abdominal muscle groups in this respect because they are visceral compressors rather than flexors. As the abdominal wall is pulled in and up, the walls of the cylinder are effectively pulled in. If a deep breath is taken, the diaphragm is lowered, compressing the cylinder from the top. If the pelvic floor (the bottom of the cylinder) is intact, the cylinder is pressurized and made more solid. In this way, it is able to resist any bending stress applied to it. A very simple example of this is a slender rod subjected to a compressive force. The straight rod is at equilibrium irrespective of the magnitude of the axial load, but loses its mechanical stability, if the compressive force exceeds a certain value (Bergmark, 1989) (Norris, 2008). Together with the muscles of the pelvic floor, they are the muscles that surround the “fluid ball“ and by their contraction create the “muscular skeleton“ much in the same way as invertebrates are able to create a support that enables them to drive forward the front end of their bodies. The abdominal fluid ball according to this reasoning would be genetically very old, and part of the reflex might even be an inborn reflex (Bartelink, 1957).

The abdominal cavity contains mainly liquid and viscous material and may be considered as a non-compressible fluid. Probably, only one of the three lateral abdominal wall muscles, *i*.e. the external or the internal oblique or the transversus muscles is needed to maintain the IAP. This liberty of choice opens the possibility for the IAP to be maintained with or without tensile forces acting between the thoracic cage and the pelvis in the abdominal wall. As these three muscles are curved, the contrary is also valid: activity in either of them provokes IAP. The mechanical role of the intra-abdominal pressure is not completely understood and is still a question focused by biomechanical researchers. In vivo experiments show a strong positive correlation between increased loading on the trunk and the magnitude of the intra-abdominal pressure (Bergmark, 1989).

Making the trunk into a more solid cylinder reduces axial compression and shear loads and transmits loads over a wider area. IAP may also help to protect the spine from excessive indirect loads (those not acting directly on the spine but through limb loading), with the muscles acting to involuntarily fix the rib cage. IAP is greater when heavy lifts are performed and when the lift is rapid (Norris, 2008). The diaphragm may contribute to postural stability by increasing pressure within the abdominal cavity, thereby maintaining the hoop-like geometry of the abdominal muscles or by hydraulically unloading the spine and increasing trunk stability (Hodges, Butler, McKenzie, & Gandevia, 1997).

The reflex contraction of the abdominal wall muscles-lasts only a very short time. What Bartelink, 1957, seen in the studied subjects was partly this reflex, but partly also the (subconscious) voluntary contraction with which they maintained the position. All these observations make it clear that there is a relationship between effort involving the trunk, especially sudden effort, and the IAP (Bartelink, 1957). The theoretical basis for the IAP mechanism is that pressure within the abdomen, acting like an inflated balloon against the pelvis and diaphragm, provides additional extensor torque to the spine; moreover, the inflated balloon acts on a torque arm that is as much as three times greater than that of the erector spinae. Contraction of the transversus abdominis and the internal oblique increases IAP, providing the *glottis is closed* (Norris, 2008) (Bartelink, 1957). According to Bergmark, the IAP theoretically has a global and a local mechanical role. The global role is to act directly on the thoracic cage or on the curved global muscles. The local action consists of the transverse force in the posterior direction acting directly on the lumbar spine thus, inducing a flexion moment, which opens the possibility for increased muscle reinforcement from sagittal local muscle action (multifidi and interspinal muscles) without changing the equilibrium conditions for the system as a whole (Bergmark, 1989).

The synchronous activity of the pelvic floor, the diaphragm and the abdominal muscles contributes to the adjustment of the intra-abdominal pressure. The pelvic tilt and especially the alignment of the thorax in relation to the pelvis are very important for the resultant force vector. Even a slight shift of the thorax forward elicits excessive activity of the superficial spinal extensors (Kolar, 2013). As the diaphragm descends, it compresses the abdominal contents, increasing IAP. The portion of the diaphragm, which is close to the inner wall of the lower rib cage, is called the zone of apposition. Continued shortening of the costal fibres of the diaphragm with deeper inhalation will decrease the zone of apposition because the superior border of the zone is pulled away from the ribs toward the central tendon. With hyperinflation, the fibres of the diaphragm may become so horizontally aligned that contraction of the fibre may pull the ribs inward in an expiratory direction (Levangie & Norkin, 2001). Contraction of the pelvic floor and abdominal muscles, particularly transversus abdominis, correlates closely with increases in IAP in a variety of postural tasks. For the contraction of abdominal muscles to elevate IAP it is necessary for the diaphragm to contract simultaneously and thus minimize displacement of the abdominal contents into the thorax. Abdominal (and also trans-diaphragmatic) pressure increases progressively during shortening and lengthening of the diaphragm. However, as abdominal pressure increases due to co-contraction of transversus abdominis, further contraction of the diaphragm occurs eccentrically (Hodges, Butler, McKenzie, & Gandevia, 1997). Using direct stimulation of the phrenic nerve, Hodges and colleagues (2005) showed intraabdominal pressure increases of 31% without TrA contraction – the increase coming from the diaphragm alone (Norris, 2008).

If your transversus abdominis is weak, you may unconsciously bear down internally instead of drawing in and up. Bearing down creates abdominal pressure that feels like, but isn't, core support. Bearing down and holding your breath when you lift things can cause a hernia (Bond, 2006). Well known symptoms of weight lifting are congestion and redness of the head and frequently expulsion of a hernia (Bartelink, 1957). A number of important criticisms have been made against the IAP mechanism when it has been presented as the only stabilizing process for the spine. First, to fully stabilize the spine during the lifting of heavy weights, the IAP would have to exceed the systolic pressure within the aorta, effectively cutting off the blood flow to the viscera and lower limbs. Competitive weightlifters have been known to black out when lifting extremely heavy weights. Second, the muscle force required to create a sufficiently high IAP is greater than the hoop pressure possible from the abdominal muscles. Third, if the rectus abdominis contracts to increase IAP, it produces a flexion torque that counteracts the antiflexion effect of IAP created as the diaphragm and pelvic floor spread apart. These criticisms of IAP have led to re-examination of its contribution to back stability. Originally, IAP was believed to reduce the compression acting on the lumbar spine by as much as 40%, but more recent studies have shown this to be only 7% (Norris, 2008).

8.4.1 Valsalva manoeuvre

It is a forced exhalation against a closed rima glottidis as may occur during periods of straining while defecating (Tortora & Nielsen, 2012).

Timing inspiration with effort can lead to use of the Valsalva manoeuvre, where the breath is held to maintain increased intrathoracic pressure. The intraabdominal pressure is greater if the breath is held following a deep inspiration (Valsalva manoeuvre) because the diaphragm is lower and the comparative size of the abdominal cavity (the cylinder) is reduced. During lifting, the pelvic floor muscles (the floor of the cylinder) contract to maintain pelvic integrity and prevent urination. The Valsalva manoeuvre is therefore appropriate for normal subjects during heavy lifting as long as it occurs only briefly. Abdominal muscle strength affects IAP – strong athletes can produce very large IAP values. However, because it can raise blood pressure to dangerous levels, it may not be desirable in subjects with poor cardiopulmonary health so heavy lifting is not recommended for this group. In principle, abdominal bracing and the Valsalva manoeuvre are identical to the process observed (a) from the perspective of pressure in the abdominal cavity and (b) from the perspective of pressure in the thoracic cavity (Kolar, 2013) (Norris, 2008). Theoretically at flexion and extension loading of the thoracic cage, the global action of the intra-abdominal pressure may decrease the compressive load acting in the spine about 1530%. In vivo experiments, however, showed that the Valsalva manoeuvre did raise the intra-abdominal pressure, but it increased rather than decreased the L3-L4 disk pressure and thus also the lumbar spine compression (Bergmark, 1989).

Price et al, 2014, studied different positions of brass musicians during performing and found that levels of abdominal muscle activity and movement of the chest and abdominal wall during the performance of an orchestral excerpt are greatest when standing and lowest when sitting. Greater abdominal wall tension when standing gives the impression that more work is required during exhalation (though less for inhalation) and they have seen that abdominal muscle activity is indeed greater. However the inward movement of the abdominal wall is smaller when standing. An important factor in respiratory biomechanics is that when standing, abdominal wall tension is 30% greater than when sitting and intraabdominal pressure is increased by 20%. When players were sitting on a flat or a sloping seat, activity in the rectus abdominis and external oblique muscles showed a 32–40% reduction in activity when compared to standing. Abdominal wall tension is greater during inspiration than expiration and rises even higher during the Valsalva manoeuvre. The reason why abdominal wall tension is greater in standing is not entirely clear, however the angle of the pelvis causes the lumbar spine to curve into lordosis which will both push the abdominal contents forward and stretch the abdominal wall through a compensatory backward tilting of the thorax to keep the centre of gravity correctly aligned over the feet (Price, Schartz, & Watson, 2014).

8.5 POSTURAL FUNCTION OF BREATHING MUSCULATURE

Many of the ventilatory muscles participate in activities other than ventilation, including speech, defecation, and the maintenance of posture. A high and complex level of coordination is necessary for these muscles to carry out these alternate activities while continuing to perform necessary function of ventilation (Levangie & Norkin, 2001).

During breathing phases, the inspiratory and expiratory muscles act in mutual synergy and cooperation. Even the pelvic floor muscles participate in breathing movements, affect the intra-abdominal pressure and, at the same time, influence the changing configuration of the *spine* during breathing. Breathing movements influences the movement of the thorax and the spine and contributes to body posture. This activity is modulated by breathing. Limited range of these movements is one of the causes of painful vertebrogenic deficits. It is found most often during postural dysfunction syndrome (Kolar, 2013) (Hodges, Butler, McKenzie, & Gandevia, 1997).

The diaphragm has a dual function, not only becomes engaged as a breathing muscle, but also significantly participates in postural activity (Kolar, 2013). The abdominal and thoracic cavities on which this muscle acts are also involved in the stability of the trunk and postural control (Hodges, Butler, McKenzie, & Gandevia, 1997). The rib cage is also an important skeletal structure to consider in the assessment of posture because of its direct influence on the position of the thoracolumbar spine. Patients with weakness of the diaphragm or deep spinal stabilizers often elevate the lower rib cage during inspiration as a compensation for breathing. Ideal posture is sacrificed in favour of maintaining respiratory integrity. Training a proper respiratory stereotype serves both breathing and spinal stability. Diaphragm has both respiratory and postural function (Page, Frank, & Lardner, 2010).

In addition to its role in breathing as described before, the diaphragm also has another feature by which it impacts posture; muscular fibres called the crura that can operate independently of the dome (Pickering & Jones, 2002) (Bond, 2006). Contraction of both the crura and the scalenes pulls the spine forward. To resist this tendency, we must engage our back muscles when we inhale. This means that the natural motion of breathing should include a very slight backward stretch of the spine with inhalation. When we exhale, the spine should relax to its neutral erectness. The resulting subtle articulation of the vertebrae pumps fluid through the vertebral discs, keeping them healthy. If your spine is stiff with chronic tension, your breathing muscles must work harder to raise your ribs and open your chest (Bond, 2006). The quality of respiration and stabilization of the spine are very closely related. A disturbance in this static and dynamic muscle synergy leads to a tension difference known as imbalance, for example a persistent presence of an overloaded thoracic musculature syndrome and a variable faulty body posture syndrome as frequent manifestations of imbalance. Also, patients with respiratory pathway obstruction present with many signs with decreased segmental mobility and changes in tone, which all significantly influence overall posture of the trunk, head and the pelvis (Kolar, 2013).

Contraction of the abdominal muscles contributes to trunk stability prior to and during movement of the limbs and this action is increased when respiratory demands increase. When a limb is moved reactive forces are imposed on the trunk acting equal and opposite to those producing the movement. The diaphragm cannot move the trunk directly to oppose these forces, but it has been proposed that its contraction contributes to trunk stability via an increase in pressure in the abdominal cavity. Hodges et al., 1997, performed an experiment measuring activity of diaphragm and abdominal muscles: when rapid flexion of the shoulder was performed voluntarily in response to a visual stimulus to move, EMG activity in the costal diaphragm increased before any activity was observed in deltoid. The onset of the increase in diaphragm EMG prior to that in deltoid suggests that this response is preprogramed by the central nervous system. The onset of transversus abdominis and diaphragm EMG occurred almost simultaneously. Also, when subjects were standing, rapid movement of either the thumb or wrist was not associated with any anticipatory EMG in the diaphragm. However, with flexion of the elbow the diaphragm contracted at the same time as for flexion of the arm at the shoulder. This suggests that the early diaphragmatic response when the whole arm moved was more likely to represent a postural adjustment, rather than simply a response associated with the request to 'move as rapidly as possible'. It also indicates that the diaphragmatic response requires a threshold magnitude of reactive forces resulting from the movement. The contraction was independent of the phase of respiration. The findings show that this preparatory contraction of the diaphragm is associated with initial shortening of its muscle fibres and occurs simultaneously with activation of transversus abdominis (Hodges, Butler, McKenzie, & Gandevia, 1997).

In cases of ventilatory deficit in the respiratory system the influence is seen in the activation of respiratory muscles in their respiratory function, which always has direct consequences on muscle stabilization function, or postural function. The muscle stabilization function influences the dynamic function of the muscles not just in the area where the muscles concentrically insert. This stabilization is also interconnected with the entire movement pattern (global biomechanical chain). Typical dysfunction is an increased activity of upper abdominal muscles accompanied by drawing in of the abdominal wall. This posture is called hourglass syndrome. With such body posture, during a postural reaction, an inverse (paradoxical) diaphragm action is present, thus punctum fixum of the diaphragm is on the centrum tendineum and, during diaphragm function the lower ribs are pulled in and move cranially with the sternum. Through the sternum, cranial movement is transferred into the upper ribs, which are further elevated by the activity of accessory breathing muscles which leads to the expansion of the upper part of the chest wall, specifically in the anterior-posterior direction. In such individuals, we can also observe paravertebral hypertonia, or hypertrophy of paravertebral muscles in the region of lower thoracic and upper lumbar spine related to the significant activity of the lumbar portion of the diaphragm. These muscles stabilize only the insertions of the diaphragm. This stabilization (of posture) is evidenced by a weakened function of the diaphragm with postural stabilization and a non-physiological type of breathing (Kolar, 2013).

Right at the intersection of ribs and spine, breathing and back tension are inextricably linked. Excessive tension in muscles along your spine prevents your ribs from pivoting; this, in turn, restricts your breathing. For healthy breathing, the ribs should move in relation to the spine; for the spine to be flexible, the breath must be unrestricted. To heal your spine, you must heal your breath, and vice versa. To heal your posture, you must heal both (Bond, 2006).

9 RESEARCH METHODOLOGY

One problem that often plagues progress in global health is the slow translation of research into practice. Oftentimes, disconnect exists between those who create the evidence base and those who are positioned to implement the research findings. The underlying problem is in the way in which the production of evidence is organized institutionally with highly centralized mechanisms, whereas the application of that science is highly decentralized. This social distance prevails because scientists are more oriented to the international audiences of other scientists for which they publish than to the needs of practitioners, policy makers, or the local public. Well-conducted research is vital to the success of global health endeavours. Not only does research form the foundation of program development and policies all over the world, but it can also be translated into effective global health programs. Research draws its power from the fact that it is empirical: rather than merely theorizing about what *might* be effective or what *could* work, researchers go out into the field and design studies that give policymakers hard data on which they can base their decisions. Furthermore, good research produces results that are examinable by peers, methodologies that can be replicated, and knowledge that can be applied to real-world situations. Researchers work as a team to enhance our knowledge of how to best address the world's problems. Ultimately, the key to a successful research project lies in iteration: the process of returning again and again to the research questions, methods, and data, which leads to new ideas, revisions and improvements (Unite For Sight, Inc., 2015) (Green, Ottoson, Garcia, & Hiatt, 2009).

9.1 PURPOSE AND AIM

The purpose of this thesis is to examine the effect of abdominal breathing on the muscle activity and changes of centre of pressure during quiet standing.

Goals in the theoretical part:

- Illustrate the concept behind the term posture.
- Explain basic human biomechanics and physics behind the forces acting on the body and forces body exerts upon its surroundings.
- Describe body structure and its elements with the emphasis on the spine as the main element for force transfer and connecting upper and lower part of the body.
- Explain the interrelation between body elements and how they maintain the upright stance.

- Explain the mechanism of breathing and its effect on the posture.

Goals in the empirical part:

- Measure the muscle activity and centre of pressure distribution during a set time window.
- Apply a defined breathing technique to observe for differences.
- Analyse and interpret the acquired data into definable and discussable information.
- On the basis of results confirm or refute the set hypotheses.
- Attain the meaning to the insights of the application.

9.2 RESEARCH QUESTIONS

With quantitative research, the process begins by defining the hypotheses which predict the expected research results and require statistical testing. On the basis of research questions, the hypotheses were set.

Q 1: What is the effect of abdominal breathing on muscle activity during quiet standing, especially on the paraspinals?

Q 2: Does the activity in paraspinal muscles during quiet standing become more rhythmical in oscillations?

Q 3: What happens with COP during quiet standing when breathing abdominally?

9.3 HYPOTHESES

H 0: Muscle activity of abdomen (muscles of abdominal wall, diaphragm and pelvic floor) and back work together to stabilize the spine during movement.

H 1: Abdominal breathing can during quiet standing reduce work of muscles, mostly of the paraspinals, which are commonly overused to maintain body upright.

H 2: Activity in paraspinal muscles during quiet standing when breathing abdominally becomes more rhythmical, with more and steady oscillations.

H 3: COP movement during quiet standing when breathing abdominally increases more in the Y axis than in the X axis.

9.4 METHODS AND TECHNIQUES

Although used interchangeably, there is a difference between technique and a method, where technique is the way or manner in which a method is applied or deployed.

In the theoretical part of this thesis we used the qualitative methods, while in the empirical part we used the quantitative methods of research.

Qualitative method was based on the descriptive procedure of basic research, involving primary and secondary sources, where we used the following methods and tools:

- Analytical approach
- Method of compilation
- Method of description
- Method of comparison

For quantitative research we had used:

- Experimental research
- Applied research
- Method of correlation (relational study)
- Descriptive research and statistics

In acquirement of data were used primary methods of research with study of primary sources (conducting a laboratory setting experiment), as well as secondary researches with study of secondary sources (examination of books, medical issues, journals and articles including other studies).

9.5 LIMITATIONS

- Factors influencing muscle activity were not controlled, that is the exact room temperature, warm up phase in preparation and exact announcement when the whole experiment will start for the individual subject.
- Surface electrodes have limited use in recording activity from deeper muscles.
- Time of measurement could be longer with more repetitions.
- Number of subjects was too small for statistical generalization.
- Measurements were not video recorded to synchronize them with signal recordings as it is commonly done in kinesiological EMG recordings.

- We were aware that discussion due to limited results could end up cherry-picking (to pick or accept the best people or things in a group), and ending with logical fallacies with the wrong explanation. For that reason we mention more possible explanations and theories.
- The pelvic angle, which influences the position of the spine and consequently the surrounding tissues, was not considered and monitored so conclusions were made based on assumption that it is always in slight anteversion.

9.6 RESEARCH SAMPLE AND SUBJECTS

Subjects for the experiment were chosen from the students of Faculty of Physical Education and Sport, Charles University in Prague. All participants agreed voluntarily and read and signed an informed consent document in English language approved by the Ethics Board Committee of the Faculty of Physical Education and Sport, Charles University in Prague. Subjects were healthy, without any history of balance dysfunctions or current pathologies. A single test group consisted of 6 subjects, of whom 3 were female and 3 male, between the age of 25 and 30.

9.7 DEVICE DESCRIPTION

COP was measured using RS Scan International Footscan force plate (500Hz sampling rate). Data from the force plate was collected using company's computer programme Footscan Balance 7. The floor and structure underneath the force plate were rigid and straight in order to minimize any vibrations or force deviations in case of possible inclination.

EMG activity was recorded using Noraxon EMG devices (Noraxon, Arizona, U.S.A.). We used Noraxon TeleMyo 2400 transmitter for telemetric data transmission technique, with the sampling frequency of 1500 Hz. EMG signal processing was done using computer programme Noraxon MyoResearch MR-XP 1.08.27 Master Edition.

Electrodes we used were disposable, self-adhesive Ag/AgCl snap electrodes for surface EMG applications only, designed for both research and clinical use with hypo-allergenic gel and adhesive. Dimension of the figure 8-shaped adhesive is 4cm x 2.2cm, while diameter of the two circular adhesives is 1cm and inter-electrode distance is 1.75cm.

Paired observation t-test calculations were performed for paired values after posturography measurements using GraphPad Software QuickCalcs. It is the internet provided free-to-use statistical calculator (GraphPad Software, Inc., 2016).

9.8 MEASUREMENT PROCEDURE

The EMG measurement took place simultaneously with posturography in March 2016, in the course of one day between 9.00 o'clock in the morning and 15.00 in the afternoon. Subjects were individually invited into an evenly lit room, heated to normal room temperature.

Measurement preparation involved cleaning the skin with cotton pads soaked in ethanol before planting the electrodes. 6 electrodes were placed on muscle bellies parallel with fibres, one third of a distance from proximal do distal, unilaterally (right side of the subject). Reference (ground) electrode was placed on the ulnar styloid process, right side.

Muscles measured were m. tibialis anterior, m. gastrocnemius – medial head, m. rectus femoris, paraspinals lumbar part, paraspinals thoracic part, and paraspinals cervical part (as shown on the photographs below). Locations were chosen based on Noraxon manuals (Kasman & Wolf, 2002) (Konrad, 2006). MVIC (maximum voluntary isometric contraction) was measured during 3 repetitions for each muscle using manual muscle testing techniques according to Daniels & Worthingham's or Kendall (Hislop, Avers, & Brown, 2014) (Kendall, McCreary, Provance, Rodgers, & Romani, 2005). Subjects were allowed to take at least 10 second rest between each contraction testing. After the MVIC were set, subjects stepped on a force platform and proceeded with measurements following the instructions given by author of this thesis as the main researcher.

Data was obtained during two measurements, each lasted 90 seconds and was taken individually. Subject was instructed to stand normally and relaxed on the force plate barefoot, maintain his or her body weight on both legs (no weight shifting to one leg), with stable surface and surroundings, eyes open and looking straight forward. Foot position was not predetermined, only that the left and right foot were positioned on the left and right side of the force plate, respectively. Second measurement was taken about a minute after first. During that time, subject remained standing on the force plate and was instructed how to breathe. After a subject started breathing as instructed, command was given for the computer programme to start measuring.

Breathing was instructed to be strictly abdominal, that is, with minimal chest movement and visible belly repositioning (inward during expiration and outward during inspiration). Expiration and inspiration was done in the ratio of 3:2 (seconds).

During the whole procedure there were no reported problems from the subjects (e.g. dizziness, vertigo, sickness, blurry vision, ear ringing, muscle weakness, spastic contraction…). Sessions lasted on the average about 20 minutes.

Figure 4: showing the placement of all six electrodes, including one reference (ground) electrode and position of the subject during measurement.

9.9 EMG SIGNAL PROCESSING

In our experiment, we first made a test for each muscle to provoke maximal contraction before proceeding to the actual measurements. Acquired EMG signal in its primal form is called raw signal and requires additional processing, therefore each signal that came from its own electrode went through the following steps:

First we applied full-wave rectification. This processing method multiplies all amplitude values in a signal with +1, making all negative values positive. The reason for this operation is to achieve positive amplitude curves that allow the user to calculate parameters like mean amplitude, area under the curve, etc.

Secondly, signal was smoothed based on the mean algorithm in 500ms window. Typically, for amplitude based calculations and analysis, the raw EMG is smoothed by digital filters, root mean square or moving average algorithms. The result is, non-reproducible EMG spikes are eliminated and the mean trend of the EMG enervation is used. Benefit is the easier reading of EMG patterns.

In third and last step, each of the six signals was normalized. This involved setting each one from the corresponding MVIC testing as the peak value (in 1000ms window) and establish 100% muscle contraction reference. This gives us the necessary maximal voluntary contraction (MVC) parameter or also known as maximal voluntary isometric contraction (MVIC). MVC is used to compare each muscles' contraction to its maximal contraction ability and present the results in percentage instead of microvolts (μV), because presenting muscle activity in microvolts is relative and doesn't tell us anything about the struggle muscle had to endure during activity.

After all six signals from six different channels for individual subject were rectified, smoothed and normalized to their peak value, they could be compared to both measurements for proper presentation. This time when processing the raw signal obtained during measurements, rectification and smoothing were repeated using the same settings only normalization step was changed to comparison to the MVC values we had set earlier.

10.1 EMG

Analysis of results will first focus on comparison between the two measurements for each subject, later we'll compare and try to find plausible connections and effects of the abdominal breathing on muscle activities between individuals. Results are graphically presented in the tables and charts below.

	1		2		3		4		5		6	
GM	10.8	3.51	7.79	4.41	14.2	12.3	4.76	5.11	6.51	7.29	4.81	3.01
TA	5.8	3.56	1.58	5.51	4.3	2.26	4.23	1.81	2.55	2.16	2.39	7.71
RF	2.85	1.54	2.43	1.94	1.15	0.773	5	0.848	4.96	3.63	5.35	1.9
ES L	7.19	4.82	3.7	3.11	1.69	2.56	21	11.8	1.77	1.77	1.79	1.16
ES Th	6.35	2.63	2.92	3.44	2.29	2.23	3.22	3.38	8.82	5.87	4.68	4.03
ES C	8.98	1.72	4.92	6.38	7.53	2.27	34.8	50.1	5.31	4.65	5.39	5.54

Table 2: on the very top are numbers from 1 to 6 presenting each of the six subjects with the results from first and second measurement (grey and white column) in percent (%) of MVC for individual muscle. GM: m. gastrocnemius medial part, TA: m. tibialis anterior, RF: m. rectus femoris, ES L: mm. erector spinae lumbar part, ES Th: mm. erector spinae thoracic part, ES C: mm. erector spinae cervical part.

Six subjects combined with six electrodes (each measuring one muscle activity) gives us 36 blocks of information (each presented as a single cell in the table below). These blocks are meant as representations of before and after, where each block is a combination of two parts interdependent and equal in their meaning – comparing quiet standing with applied abdominal breathing that was done after.

Number of all blocks = 36 (100%)

To describe the results incrementally, we'll start by saying that generally the muscle activity was lower during breathing than during quiet standing. Quick comparison between the two measurements shows a decrease in muscle activity in 26 cases (72%), and an increase in 10 cases (28%). We see a decrease as a positive relation confirming our hypothesis and is coloured in green. This type of representation gives us a simple to understand comparison between the two measurements as a first glimpse into the obtained results.

Number of blocks presenting a decrease in muscle activity (green) = 26 (72%)

Number of blocks presenting an increase in muscle activity (red) = 10 (28%)

	1	2	3	4	5	6	Total	Total
GM	7.39	3.69	1.9	0.35	0.78	1.8	*1.13*	***14.78***
TA	2.24	3.93	2.04	2.42	0.39	5.32	***9.25***	*7.09*
RF	1.31	0.49	0.38	4.12	1.33	3.45	*0*	***11.08***
ES L	2.37	0.59	0.87	9.2	0	0.63	*0.87*	***12.79***
ES Th	3.72	0.52	0.06	0.16	2.95	0.65	*0.68*	***7.38***
ES C	7.26	1.46	5.26	15.3	0.66	0.15	***16.91***	*13.18*
Total	*0*	***5.91***	*0.87*	***15.81***	*0.78*	*5.47*	*28.84*	
Total	***24.29***	*4.77*	***9.637***	*15.745*	***5.33***	***6.53***		*66.3*

Table 3: representation of differences (% MVC) for individual muscles comparing first and second measurement among all 6 subjects.

	mean	median	mean	median
GM	***3.69***	*2.79*	*0.56*	*0.56*
TA	*1.77*	***2.14***	*4.62*	*4.62*
RF	***1.85***	*1.32*	*0*	*0*
ES L	***2.56***	*0.63*	*0.87*	*0.87*
ES Th	***1.84***	*1.8*	*0.34*	*0.34*
ES C	*3.9*	***5.26***	***5.64***	*1.46*

Table 4: mean and median values of the decreases (green) and increases (red) for each muscle.

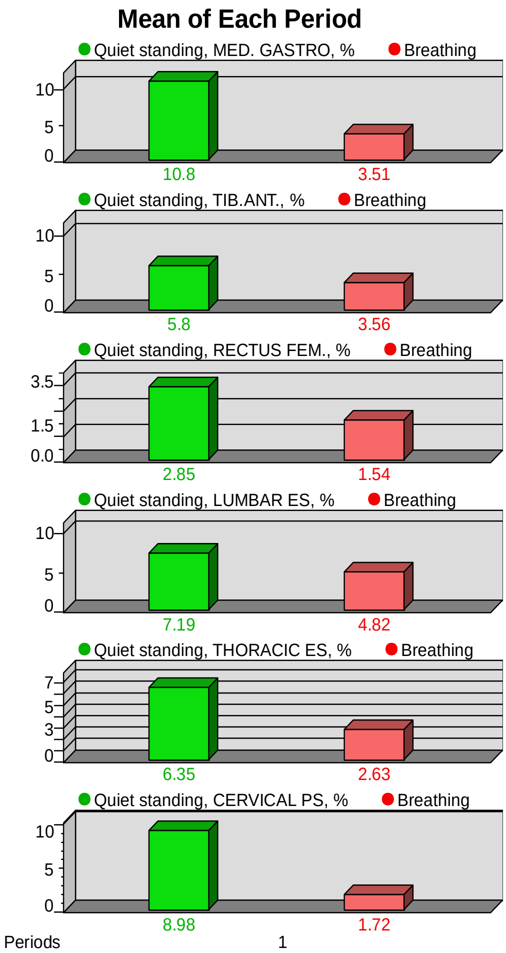

Figure 5: mean of each period, example of Subject 1.

On the left is a graphic representation of mean values for the first subject, as an example of showing EMG results in bar graph. This subject had shown most exceptional results during our measurements. It is the only case with a lower activity in all the muscles during abdominal breathing, totally for 4% of all included muscles (=24.29% of 600%). This gives this subject a biggest ratio between decrease and increase, in favour of the former. Lowest decrease was in the rectus femoris muscle, while highest was in m. gastrocnemius. Gastrocnemius together with thoracic and cervical part of erector spinae are the muscles with highest decrease among all subjects. Tibialis anterior doesn't fall far behind the fourth subject with its decrease value too. Lumbar muscles would also show a high decrease among subjects if it were not again for the fourth subject who shown the highest value.

The second subject showed decrease in muscle activity in half of the muscles: m. gastrocnemius, m. rectus femoris and mm. erector spinae lumbar part. Lowest decrease was in the m. rectus femoris followed by lumbar part of the erector spinae. This subject shown least amount of decrease in muscle activity. When comparing overall decrease with the amount of increase the values are very similar.

Third subject showed mostly a decrease with only one increase seen in lumbar part of erector spinae muscles for less than 1%. The decrease in thoracic part is almost 0%, while it is highest in the cervical part. This subject has the second biggest ratio between decrease and increase, in favour of the former.

Subject number four has by itself almost the same percentage when comparing decrease and increase in muscle activities, similar to the second and sixth subject, only that instead of an activity increase in m. tibialis anterior we can see it in m. gastrocnemius, where it was less than 1%. Also the increase in thoracic part of erector spinae is almost 0%, while it has the biggest deviation among subjects in decrease of muscle activity in the lumbar part and in m. rectus femoris. On the other hand it has by far exceptionally strong increase among all subjects in the cervical part, much greater compared to the other two who also showed increase.

Fifth subject only showed increase in m. gastrocnemius, for less than 1%. Activity in lumbar part of erector spinae was noted as 0% because it was negligible. This subject showed very little decrease in percentage, while being second behind the first subject in terms of least increased muscle activity.

Sixth subject has by itself about the same percentage when comparing decrease and increase in muscle activities, similar to the second and fourth subject. Increase is seen only in m. tibialis anterior where it's the biggest among all subjects, and cervical part of mm. erector spinae where it's the smallest (almost 0%).

10.2 SIGNAL OBSERVATION

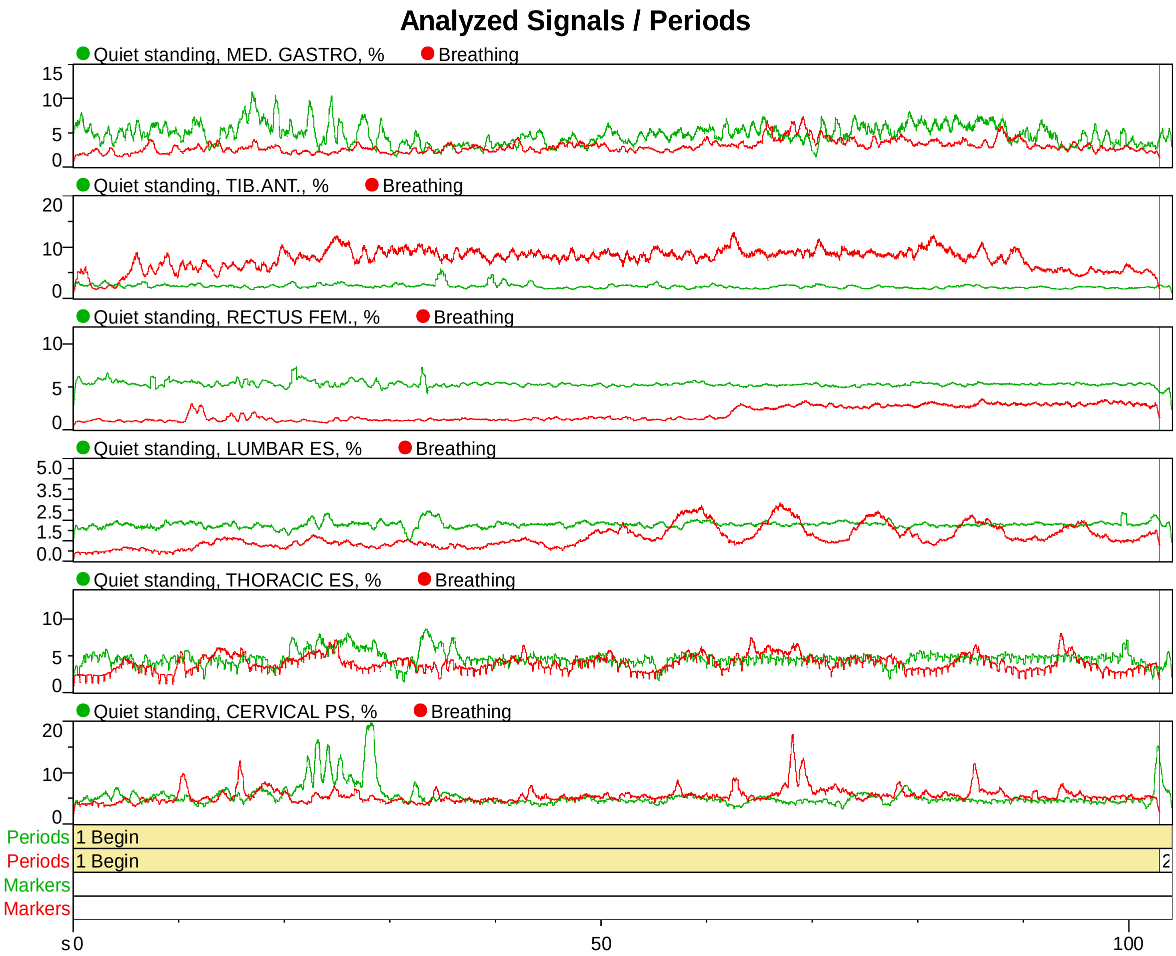

Figure 6: showing the analysed signals (smoothed with mean algorithm in a 500ms window) in the whole period of measurement (90 seconds). This is an example of Subject 6. Note that channels are vertically scaled making signals more visible.

First subject showed muscle activity through time as a steady wave in rectus femoris and gastrocnemius during first measurement, cervical erector spinae in both measurements and thoracic and lumbar part during second measurement. Especially interesting here is the case of lumbar muscles as they show during both measurements rhythmical bursts of activity, although much less during breathing. Thoracic part during breathing shows a unique pattern with more clearly rhythmical wave form, from start to the end, compared to the first measurement. Activity in m. tibialis anterior was most dynamic, but less during breathing. Correlation of this muscle can be made with m. gastrocnemius; if we compare both signals during second measurement, we can see that at the start the activity in tibialis was high and then low – an opposite to what was happening in m. gastrocnemius. After 45 seconds the activity of tibialis drops and gastrocnemius rises, until the time of around 80 seconds and at the end when it drops again with the opposing gastrocnemius rising up.

Second subject shown even movement for all the muscles without any obvious bursts of activity, except for m. tibialis and m. gastrocnemius. After 40 seconds during second measurement, activity of m. tibialis anterior increased dramatically up to 15%. Start of this change does not coincide with the activity of its antagonist or any other muscle. Gastrocnemius shows high fluctuations that are lesser, more even and with longer amplitudes during breathing. Rectus femoris together with lumbar, thoracic and cervical muscles shows a very clear and even signal during both measurements. In this muscles, a steady rhythm of wave patterns can be recognised.

Subject number three also had a steady muscle activity in all the muscles except for m. gastrocnemius where fluctuations can be observed throughout both measurements. During first ten seconds there is a rise in activity until it reaches its constant window of fluctuations between 10 and 25%. All the other muscles have an even pattern during both measurements, with increase in activity only in the lumbar muscles. This muscles together with the thoracic part show a distinct rhythm of wave pattern through both measurements.

Fourth subject shown most activity in the cervical part with the highest difference between increase and decrease among all subjects. The activity didn’t show any major change, very similar to m. tibialis anterior which becomes more in line during second measurement. Same can be said for the other muscles, except for m. rectus femoris and lumbar part during first measurement. While these two muscles were active around their same value, they are not as even as the others. Gastrocnemius has shown a shift to more dynamic activity during second measurement with increase to constant bursts after 40 seconds. Breathing affected the lumbar and thoracic part to change to more rhythmical pattern, with activity decrease of 9.2% in lumbar part and very low increase in thoracic part.

Fifth subject shown very low amount of changes in either increase or decrease. Second measurement brought more even and less dynamic signal to the activity of all muscles except for m. gastrocnemius where change in breathing caused more activity with more bursts. It could be that while activity in calf increased, it took over the stabilizing role and therefore decreased the work of other muscles. Thoracic muscles again showed more rhythm with clear wave-like pattern during second measurement. Lumbar part had 0% difference in activity, but during breathing, signal was more even.

Sixth subject has the most diverse and dynamic signal activity among all subjects in all of its muscles. While mean values show mostly a decrease, there was a big increase in the m tibialis anterior soon after second measurement started. Activity in m. rectus femoris, m. gastrocnemius and lumbar part was smaller, but it for all three there is a change in pattern after a minute into the second measurement. Lumbar part has distinct wave-like pattern that stands out, same as the thoracic muscles, which again show clear rhythm without major deviations.

10.3 POSTUROGRAPHY

Results from the measurements were first fitted into a table below as raw data. Basic comparison was made after to see the differences and through descriptive statistics we obtained the mean, median, standard deviation (SD) and standard error of the mean (SEM).

	1st measurement			**2nd measurement**			**DIFFERENCE**		
SUBJECT	**X**	**Y**	**TTW**	**X**	**Y**	**TTW**	**dX**	**dY**	**dTTW**
1	7	12	308	17	62	779	*10*	*50*	*471*
2	5	4	275	9	12	295	*4*	*8*	*20*
3	7	8	339	5	9	321	*-2*	*1*	*-18*
4	12	20	334	30	20	604	*18*	*0*	*270*
5	5	11	247	6	11	263	*1*	*0*	*16*
6	8	11	301	5	7	226	*-3*	*-4*	*-75*
MEAN	7.33	11	300.67	12	20.17	414.67	*4.67*	*9.17*	*114*
MEDIAN	7	11	304.5	7.5	11.5	308	***2.5***	***0.5***	***18***
SD	2.58	5.29	35.14	9.92	20.97	223.73	8.04	20.38	211.36
SEM	1.05	2.16	14.34	4.05	8.56	91.34	3.28	8.32	86.29
N	6								

Table 5: results for maximal X and Y amplitudes (in millimetres) and TTW (Total Travel Way) from both measurements for all 6 subjects.

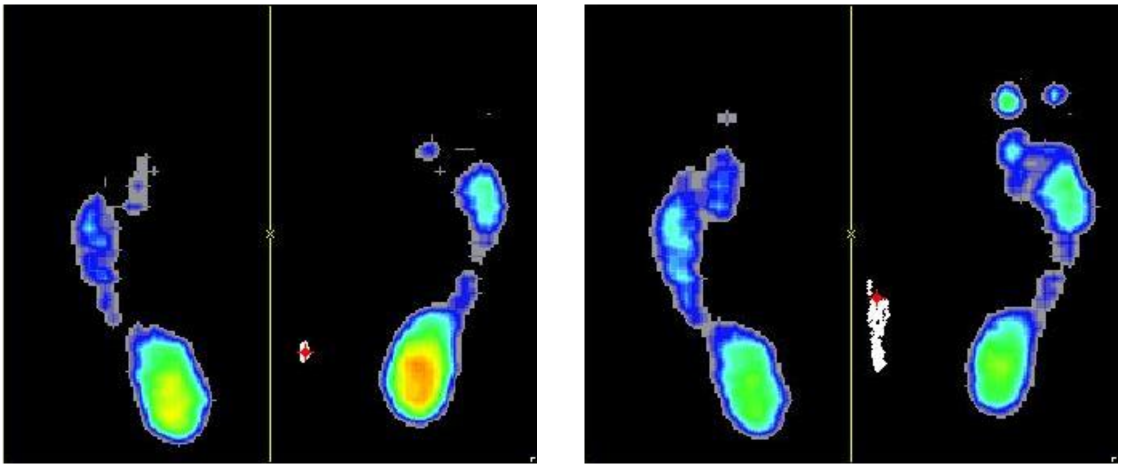

Figure 7: comparison between first and second measurement. This is an example of Subject 1.

First thing we can notice about all three variables (X, Y and TTW) is that mostly they all changed with only two exceptions between measurements (two Y variables). X variables are in 4 cases positive, while in 2 cases are negative. Y variables are positive in 3 cases, negative once and unchanged twice. TTW is longer in 4 cases and shorter in 2. None of the subject fell as all of their COP points remained inside of their BOS.

The first subject stands out as it showed much higher COP deviations in both X and Y axes and TTW. All variables show greatest deviations among all subjects, except for the X which only lacks about 7% behind the subject who showed the highest difference for this variable. First subject can be taken as an exception with its large differences between the measurements. The presence of strong deviation among results is visible in the difference between the mean and the median in all three columns under the difference section of the table. Second subject showed increase in all motion ranges, mostly for the Y variable. Third subject showed barely any difference for each variable, with a shorter length in TTW. Fourth subject's movement increased more than 100% in the X axis and almost as much in total travel way. This subject also greatly contributed to the difference between the mean and median seen in the difference section of the table. Fifth subject presented with increase in both X axis and TTW but without any significant differences. Sixth subject was the only one whose change of all variables went into negative.

Considering mean and median values of differences between measurements, the deviation is obvious as the first and fourth subject evidently stand out. In such case, taking the median value is a better option as it brings us closer to the mean value of the majority (remaining four subjects). The mean is the one used with symmetrically distributed data; otherwise, the median is used. The differences, as the calculations later show, are not statistically significant.

Observing different sample means is not enough to persuade you to conclude that the populations have different means. It is possible that the populations have the same mean (i.e., *that the breathing we were measuring has no effect*) and that the difference you observed between sample means occurred only by chance. There is no way you can ever be sure if the difference you observed reflects a true difference or if it simply occurred in the course of random sampling. All you can do is calculate probabilities (GraphPad Software, Inc., 2016). When we are looking at the differences between scores for two groups, we have to judge the difference between their means relative to the spread or variability of their scores. The t-test does just this. The t-test assesses whether the means of two groups are *statistically* different from each other. This analysis is appropriate whenever you want to compare the means of two groups (Trochim, 2006). T tests, and related nonparametric tests compare two sets of measurements (data expressed using an interval or ratio scale). Paired test is chosen when the columns of data are matched. That means that values on the same row (or column, as presented) are related to each other. For example, when measuring a variable in each subject before and after an intervention (GraphPad Software, Inc., 2016).

Paired observation t-test calculations were performed for paired values using GraphPad Software QuickCalcs. It is the internet provided free-to-use statistical calculator (GraphPad Software, Inc., 2016). P was set at 0.05.

Paired t test results for X variable:

- P value and statistical significance:

The two-tailed P value equals 0.2144

By conventional criteria, this difference is considered to be not statistically significant.

- Confidence interval:

The mean of first X results minus second X results equals -4.67

95% confidence interval of this difference: From -13.11 to 3.77

- Intermediate values used in calculations:

t = 1.4215

df = 5

Standard error of difference = 3.283

Paired t test results for Y variable:

- P value and statistical significance:

The two-tailed P value equals 0.3208

By conventional criteria, this difference is considered to be not statistically significant.

- Confidence interval:

The mean of first Y results minus second Y results equals -9.17

95% confidence interval of this difference: From -30.55 to 12.22

- Intermediate values used in calculations:

t = 1.1017

df = 5

Standard error of difference = 8.320

Paired t-test results for TTW:

- P value and statistical significance:

The two-tailed P value equals 0.2437

By conventional criteria, this difference is considered to be not statistically significant.

- Confidence interval:

The mean of Group One minus Group Two equals -114.00

95% confidence interval of this difference: From -335.81 to 107.81

- Intermediate values used in calculations:

t = 1.3212

df = 5

Standard error of difference = 86.288

11 DISCUSSION

11.1 EMG

Hypothesis 1: Abdominal breathing can during quiet standing reduce work of muscles, mostly of the paraspinals, which are commonly overused to maintain body upright.

Hypothesis 2: Activity in paraspinal muscles during quiet standing when breathing abdominally becomes more rhythmical, with more and steady oscillations

In the subjects 2, 4, 5 and 6 we can see a probable correlation of antagonistic muscles in the calf. As either activity on one side decreased, it caused an increase in activation in the opposite side. Subjects 2 and 3 show almost mirror image with its mean values (%) for the calf muscles, presenting complete antagonistic effect. Activity in the rectus femoris muscle is the only one that decreased in all subjects. Activity of all the paravertebral muscles mostly decreased, for total of almost 6%. Regarding number of decreases in activity, lumbar part of erector spinae is the second in line after RF. Probable relation of ES L muscles with the activity of the RF could be seen in the fact, that both muscles influence the pelvic rotation and can be assessed as over activated and shortened in people with the lower cross syndrome. This possible connection can also arise from the fact that the only increase in muscle activity of ES L is seen in the Subject 3 who at the same time had the lowest decrease in the activity of RF.

The decrease in activity of ES L in five of the subjects could indicate on some general influence of the lumbar part on maintaining the posture in relation with the abdominal breathing. Common case in postural deviations among people is hyperlordosis in lumbar part, so an increase in intra-abdominal pressure could reduce the lordosis and consequently the need for lumbar muscles to hold lumbar spine in extension. Functional compensatory correlation can be made in case of Subject 3, who had the biggest increase in cervical part with biggest decrease in lumbar part, as well as some increase in the thoracic muscles. If the breathing caused relaxation and slouching, it could had increased the activity in cervical and thoracic muscles which are located in the area that is usually painful in people who sit slouched for longer periods of time.

Also, let’s not forget we base our conclusion on the very fact that pelvis is always in slight anteversion (*written under Limitations*). Explanation could therefore also lie in the fact that during pelvic anteversion, pelvic muscles do not react adequately to the rise of intra-abdominal pressure caused by activity of diaphragm, resulting in increased activity of the antagonistic paravertebral muscles (Kolar, 2013). Our results clearly indicate that this is not entirely true as abdominal breathing did not cause any significant increase in the lumbar part of erector spinae muscles. But, because we do not know the exact inclination of each subjects' pelvis, it is also possible that pelvic anteversion was not present, resulting in confirmation of the explanation. In the previous paragraph we talked about slouching; shaping whole spine to anterior concavity causes the pelvis to rotate backward, as it can also be in cases when back thigh muscles are shortened.

Another strong influence comes from the role of m. transversus abdominis. The transversus abdominis wraps around the abdomen like a corset and its contraction compresses the abdomen and tightens the lumbar fascia. Although the muscle extends as far up as the diaphragm, it is the contraction of the lower fibres – between pubic bone and navel – that is crucial for lower back stability (Bond, 2006). First subject, as it can be seen from the photos showing electrode placement, has a strong physique. His abdominal strength could contribute to the work of abdominal breathing, resulting in a decrease of paravertebral muscle activity. And yet, even in this case, lumbar muscles were still relentless in decreasing their activity presenting the least decrease among all muscles for this subject. But, we can see the highest decrease among subjects in the thoracic muscles. The effect of intra-abdominal pressure is usually compared to an inflated balloon acting on a torque arm that is as much as three times greater than that of the erector spinae (Norris, 2008). Such mechanism could therefore reduce the activity of paraspinal muscles, especially the thoracic part, where diaphragm separates the stabilised abdomen from thoracic cage resting upon it.

When the transversus abdominis activates the lumbar fascia, the multifidi are stimulated to control the lumbar segments. This means that although the transverse abdominis is a broad expanse of muscle, its action on the lumbar spine is very specific (Bond, 2006). In order to confirm this statement, possible explanation could be due to strict abdominal breathing, which should activate the abdominal musculature in the expiration phase, the multifidi muscles consequently become active. This muscles lie very deep inserting on the spine, and their activation could reduce the demand on the superficial muscles. With our superficial electrodes we were obviously limited to the recording of superficial muscles without the insight into activity of deep muscles, but we know that only situations requiring greater muscle demands lead to the contraction of the superficial muscles. Therefore we can presume that abdominal breathing did influence the demand on the back extensors by reducing the demand placed upon them.

Bond, 2006, mentions in addition to its role in breathing, the diaphragm also has another feature by which it impacts posture; muscular fibres called the crura that can operate independently of the dome. Contraction of both the crura and the scalenes pulls the spine forward. To resist this tendency, we must engage our back muscles when we inhale. This means that the natural motion of breathing should include a very slight backward stretch of the spine with inhalation. When we exhale, the spine should relax to its neutral erectness (Bond, 2006). Problem with this explanation is the mentioned term *back muscles* is too broad including a lot of muscles. Also, during standing, the spine is supposedly the stable (fixed) element with mm. scalene instead in a reversed muscle action pulling the ribs. Levangie & Norkin, 2001, confirm this when they mention how during inspiration, if unopposed by the scalenes and the parasternals, the negative pleural pressure and the resultant decreased intrapulmonary pressure are strong enough to cause the upper chest to collapse inward during inspiration (Levangie & Norkin, 2001). The opposing statements could be verified through experimental testing, if maybe under third option, mm. scalene work separately and both movements are possible. Unfortunately we hadn't recorded the activity from scalene muscles and crural diaphragm, as well as spinal angles, and we can't tell when the inhalation phase was as we hadn't video recorded the activity *(written under Limitations)*, so we can only base our discussion on the presented theory alone. We can be certain about the fact that inhalation and exhalation are the only two phases of breathing, continuously repeating. Therefore, to connect, we can assume the back muscle activity, if present in such form, would in this instance be seen in the EMG signal chart (example below) as repeating pattern (a rhythm) of increase and decrease, for inhalation and exhalation respectively. Precise extend of effect from aforementioned crura fibres (also known as crural diaphragm) on the spine is unknown, only that the mechanical respiratory load is different for costal and crural diaphragm, with costal part being the more important force generator (Sanchez, Medrano, Debesse, Riquet, & Derenne, 1985). Some authors actually don't consider the crural part of diaphragm a respiratory muscle but a gastrointestinal sphincter preventing gastric reflux (Pickering & Jones, 2002) (Collis, Kelly, & Wiley, 1954), while others claim the costal diaphragm is certainly a respiratory muscle, but the crural diaphragm has two functions, respiratory and gastrointestinal (Mittal & Goyal, 2006). The diaphragm receives its motor innervation via the phrenic nerve, with separate branches innervating the crural and costal regions (Gordon & Richmond, 1990). The proprioception function transduced by the muscle spindles located in the crural diaphragm is likely to be important in the reflex contraction of the diaphragmatic sphincter secondary to stretch exerted on it during increases in intraabdominal pressure (Mittal & Goyal, 2006). There are also moments when the diaphragm doesn't contract. In order for a food bolus to pass easily into the stomach, the crural diaphragm briefly ceases to contract with the rest of the diaphragm during inspiration. Interesting feature of selective inhibition of the crural diaphragm is that it only seems to be selective at low, physiological volumes (Pickering & Jones, 2002). A lot of information on the anatomical differentiation of nerve supply and sensory-motoric behaviour comes from the experiments done on animals. In the dog, large volumes inhibit the activity of both the crural and the costal diaphragm. It was found that the peak inspiratory electromyogram of the costal diaphragm decreased with increasing distension volumes, but not as sharply as the crural diaphragm did (Pickering & Jones, 2002). In the cat, paralysis of the diaphragmatic sphincter by curare results in the loss of inspiratory pressure oscillations or phasic contraction at the lower esophageal sphincter (Boyle, et al., 1985). The validity of this kind of information for humans is questionable as its conclusions are based on animal studies, for which we already mentioned in the *Paradigm shift* chapter, that they can later lead to wrong conclusions. For example, in awake humans, esophageal distention–induced inhibition is not as complete as the one seen in anesthetized animals (Mittal R. K., 1989). Furthermore, in the literature is enough evidence to prove the amount of activation coming from human diaphragm is different in different positions (sitting, standing, lying), as well as in animals (Price, Schartz, & Watson, 2014) (Van Lunteren, Haxhiu, Cherniack, & Goldman, 1985). The position and diaphragm angle in humans is unique compared to other living beings, more exactly mammals, who developed it (Kitaoka & Chihara, 2010). Based on anatomical connection it could be concluded that crural part in humans can have an effect on the spine with its pull on the lumbar vertebrae, but we do not know to what extent and if it has any significant net value on activity of other muscles. During our measurement however, there was no physiological activity going on (no food boluses passing down) and the activity of the thoracic and lumbar muscles decreased instead of increased. What can be noticed is that activity in mostly thoracic and lumbar part did start to show regular wave-like patterns of rise and fall in activity, but we do not know if the increase actually coincides with inspiration phase.

Another thing to consider is that function of spinal extensors is balanced by a flexion synergy that comprises the deep neck flexors and the synergy between the diaphragm, abdominal muscles and the pelvic floor muscles (Kolar, 2013). During our experiment we didn't measure activity of the aforementioned muscles, so we can't make a conclusion based on this statement. Only connection could be made, that if deep neck flexors contract, extensors relax. Notable decrease in muscle activity was only seen in two subjects, while one's activity actually increased quite significantly.

One of our hypotheses also talks about rhythm in the muscle activity. Let's first try to define rhythm. Rhythm, in music, is the placement of sounds in time, a pattern of regular or irregular pulses. It is a sequence in time, repeated, movement or procedure with uniform or patterned recurrence of a beat, accent, or the like. In its most general sense rhythm (Greek *rhythmos*, derived from *rhein*, "to flow") is an ordered alternation of contrasting elements. The notion of rhythm also occurs in other arts (*e.g.,* poetry, painting, sculpture, and architecture) as well as in nature (*e.g.,* biological rhythms). It is a regular, repeated pattern of sounds or movements, events, changes, activities, etc. Plato's observation that rhythm is "an order of movement" provides a convenient analytical starting point (Crossley, 2016) (Dictionary.com, 2016) (Merriam-Webster, 2016).

By its nature, raw EMG spikes are of random shape, which means one raw recording burst cannot be precisely reproduced in exact shape. This is due to the fact that the actual set of recruited motor units constantly changes within the matrix/diameter of available motor units: If occasionally two or more motor units fire at the same time and they are located near the electrodes, they produce a strong superposition spike. By applying a smoothing algorithm non-reproducible contents of the signal is eliminated or at least minimized. Even in highly standardized movement patterns or repetition cycles, such as normal gait or isokinetics knee extension/flexion, a significant signal difference is visible in the smoothed rectified EMG between repetitions. The principal reason is likely the coordinative variability which is typical for human locomotion. Not being robots, it is difficult for normal subjects to really reproduce a movement a second time: all biomechanical data/curves reveal variance. In addition to the asynchronous nature of the signal, the main reason is the neural interplay/coordination between muscle agonist, antagonists and synergists, which can be considered as continuous motor control/balancing processes between all involved components (Konrad, 2006).

With sustained muscle contraction, the higher frequency components of the signal decrease, but the low frequency components gradually increase. This change results in a shift in the power spectrum towards lower frequencies. It has been found that higher frequency components of the EMG spectrum decrease with fatigue (Motion Lab Systems, Inc., 2009). Reason for this is because the conduction velocity of the motor actions potentials on the muscle membrane decreases over time (Konrad, 2006).

Repetition of a pattern in signal can be observed in most of the muscles we have measured, especially those which didn't present any significant changes in muscle activity. For them we can say they were evenly active throughout the both measurements.

Ideal technical or mathematical sinusoidal wave form is not seen in nature, but can be only created using machines and devices or presented in theory. Even heart beats do not completely match in a healthy person after so many repetitions through the years. Although instances of clear wave-like signal form were rare in our measurements, we can still stay that also all the signals recognised as even didn't distinctly fluctuate when reaching a certain point, therefore presenting a repeated pattern during measurement. Based on this, we can say that all signals seen as rhythmical remain rhythmical, and all the even signals can be also considered as rhythmical in a way of more practical and less strict philosophical evaluation.

> **Hypothesis 1** can be **confirmed** as the activity in the muscles mostly decreased (72%), as well as it did in paraspinal muscles. Subject 4 is considered as an exception and if it were not for it, the decrease in activity of the mm. erector spinae cervical part would significantly exceed increase.

> **Hypothesis 2** can be **rejected**. Change of signal patterns to rhythmical, with more distinct steady oscillations was observed only in thoracic muscles, most of the lumbar muscles, and not in the cervical muscles of the erector spinae group.

11.2 POSTUROGRAPHY

Study of results limited the analysis of these plots to summary of linear parameters, ignoring the dynamic characteristics of stabilogram, i.e., the magnitude and direction of displacements between adjacent points, the temporal ordering of a series of COP coordinates, etc. (Collins & De Luca, 1993). While most has been described in the results section, here we will talk about general aspects of COP movement. The comparison with muscle activity is also not emphasized as this was not the purpose of this study.

> Hypothesis 3: COP movement during quiet standing when breathing abdominally increases more in the Y axis than in the X axis.

The movement in general increased for all variables and was positive for both mean and median values for all the parameters (X, Y, and TTW). Comparison between mean and median values shows high difference for all the variables, therefore it is recommended in this cases to take the median as it, firstly, brings us closer to the majority, and secondly, data are not symmetrically distributed. Taking the median instead of the mean value shows the highest increase was in X axis, that is in medio-lateral direction. Even if the first subject is excluded as an exception, changes in the X axis remain higher compared to the Y axis.

When we are trying to find possible correlations between TTW and muscle activity we need to be aware of the term "correlation" (mutual dependency). A correlation between two variables does not imply causation. For example, in case of another experiment where someone would be first moving and then just lay on the ground, the TTW would most probably decrease to zero together with muscle activity. In another example where someone would do isometric contraction of muscles while laying down, no TTW increase would most probably be expected; there is absolutely no general causal relationship (positively, negatively or not correlated at all) for the comparison between muscle activity and TTW. We believe it all depends on the position and situation. In our case, where the posture itself of the subject didn't change, we could still presume what effect did the abdominal breathing indirectly had on the movement of COP.

One potential correlation we had to consider was that if there was a change in Y axis, changes should be observed in the muscles regulating body sway in this direction (antero-posterior). The ankle plays a central role in postural correction. Small changes to the COG are corrected through the ankle to reposition the COG over the BOS. The correction occurs distally to proximally while the head and hips move synchronously. This response is also known as an *inverted pendulum.* Because the LOG is anterior to the ankle joint, gravity is continuously pulling the tibia anteriorly. This would result in enough dorsiflexion to unbalance the body were it not for constant opposing resistance provided by muscle action from the soleus. The LOG passes in front of the knee joint axis (but behind the patella), forcing the femur anteriorly and creating an extension torque resisted by the posterior knee structures (Norris, 2008) (Page, Frank, & Lardner, 2010) (Levangie & Norkin, 2001) (Nashner & McCollum, 1985). We didn't measure muscle activity in the m. soleus as well as in posterior knee muscles, for the exception of medial head of m. gastrocnemius. Results from one research suggest that in the ankle part of postural control, the whole triceps surae group is involved in the plantar flexor activity, but m. gastrocnemius may have an especially important role for the phasic control of balance (Borg, Finell, Hakala, & Herrala, 2007). In another research, using bilateral electromyographic signals recording from the tibialis anterior and medial gastrocnemius muscles, they compared metrics of sway amplitude with activity increase in the relaxed standing condition, and they found significant sway increase at muscle activation levels of 30% and 40% MVC with increased frequency measures. In contrast, passive ankle stiffness significantly decreased sway, decreased COG velocity, and increased mean COP frequency (Warnica, Weaver, Prentice, & Laing, 2014). In a research by Masani et al., 2011, the correlation and the time shift between motor command from right m. soleus and body sway were estimated by means of cross-correlation analysis. They found that sway size was correlated with the identified time shift: that is, a smaller sway size was associated with a longer preceding time. The obtained results suggest that a control strategy generating a larger preceding time can stabilize the body more effectively. This result was found in both the young and elderly, suggesting that the particular control aspect associated with the time shift is a common feature in both age groups (Masani, Vette, Abe, Nakazawa, & Popovic, 2011).

We were dealing with linear parameters so possible direct relation could be made with first 3 subjects, where muscle activity in m. gastrocnemius decreased and so did proportionally increased the movement in Y axis. Subjects 3, 4, 5 and 6 who shown least amount of changes in the Y axis also had the smallest decrease (even increase) for the m. gastrocnemius which regulate movement in this directions during quiet standing. Sixth subject had the highest decrease in TTW with highest increase in the m. tibialis anterior. In this case the subject 6 stands alone as the others whose TTW also decreased didn't experience activity increase in the same muscle; second subject who also had high increase for m. tibialis anterior didn't show similar movement in Y axis. In subjects 4 and 5, there was an increase in muscular activity of GA without any changes in movement in Y axis. Possible connection of COP movement and total muscle activity can be found for the first and fourth subject who both had the highest difference for both results, where high decrease in muscle activity can be correlated with the higher increase in TTW. This two subjects also had the highest decrease in the lumbar part of erector spinae. Inversely, subjects 2, 3, 5 and 6 who didn't have so much difference in TTW as the subjects 1 and 2 had, shown the smallest difference (even increase) in muscle activity for the lumbar part of erector spinae. Such correlations remain questionable, and answering them was not our purpose.

> Although the paired t-test between the values considers the differences statistically insignificant, **hypothesis 3** is under our experimental conditions **rejected** as the bigger increase in motion was noted in the X axis and not in the Y axis (median value). Considering generalization of abdominal breathing during quiet standing on bigger population, the question remains unanswered and hypothesis **unconfirmed**.

12 CONCLUSION

Our research focused on the intentional increase in activation of the diaphragm through abdominal breathing to quantify the effects it has on other muscles.

The reduction of activity was noticed in the majority of muscles we recorded showing the influence abdominal breathing has during quiet standing. The difference between decrease and increase in the paraspinal muscles is barely worth notice, but we had to take into account the effect individual recording can have on the final outcome. The shape of the signal was expected to change and oscillate more together with an increase in the sway pattern. Although one might coincide with the other, we could say the difference between measurements in antero-posterior and medial-lateral direction could actually be in favour of the Y axis if we took the mean value instead of median. Reasons we abided to reach the accepted decisions are described in the methodology and results section.

We have been limited in the number of subjects we could test as is the common problem when conducting the research. With our results we were unable to apply generalization or external validity and we didn't take advantage of every possibility technology at the time had to offer. Nonetheless, possible explanations were made with help of the theory we came across and formed the basis from where we derived. To provide real world practical results and improve the outcomes, we certainly suggest to increase the number of tested subjects and measurements.

13 LIST OF ABBREVIATIONS

In alphabetical order

AP	antero-posterior
BOS	base of support
CNS	central nervous system
COG	centre of gravity
COM	centre of mass
COP	centre of pressure
EMG	electromyography
ES C	mm. erector spinae cervical part
ES L	mm. erector spinae lumbar part
ES Th	mm. erector spinae thoracic part
GM	m. gastrocnemius medial part
IAP	intra-abdominal pressure
m.	musculus
ML	medio-lateral
mm	millimeter
mm.	musculi
ms	millisecond
MVC	maximal voluntary contraction
MVIC	maximal voluntary isometric contraction
Nm	Newton meter
RF	m. rectus femoris
TA	m. tibialis anterior
μV	microvolt

14 LIST OF TABLES

15 LIST OF FIGURES

16 REFERENCES

Quotation of sources was done in the APA 6th edition style using Microsoft Office Word 2013 built-in tool Citations & Bibliography.

Adel, T., & Stashuk, D. (2013). *Electrodiagnosis in New Frontiers of Clinical Research.* (H. Turker, Ed.) InTech. doi:10.5772/56033

Asai, Y., Tasaka, Y., Nomura, K., Nomura, T., Casadio, M., & Morasso, P. (2009). Postural Control in Quiet Standing: Robust Compensation of Delay-Induced Instability Using Intermittent Activation of Feedback Control. *PLoS ONE, 4*(7), 1-14. doi:10.1371/journal.pone.0006169

Bartelink, D. L. (1957, November). The Role Of Abdominal Pressure In Relieving The Pressure On The Lumbar Intervertebral Discs. *Journal of bone and joint surgery, 39B*(4), 718-725.

Basmajian, J. (1978). *Muscles alive* (4th ed.). Baltimore: Williams & Wilkins. doi:10.1002/mus.880020415

Bennington, J. (2013, November 29). *Sensing your own body is more complicated than you realize*. Retrieved November 21, 2015, from io9.com: http://io9.com/sensing-your-own-body-is-more-complicated-than-you-real-1473461740

Bergmark, A. (1989). Stability of the lumbar spine. *Acta Orthopaedica Scandinavica, 60*(230), 1-54. doi:10.3109/17453678909154177

Bertoti, D. B. (1988, October). Effect of Therapeutic Horseback Riding on Posture in Children with Cerebral Palsy. *Physical Therapy, 68*(10), 1505-1512.

Bond, M. (2006). *The new rules of posture: how to sit, stand, and move in the modern world.* Rochester, Vermont: Healing Arts Press.

Borg, F. G., Finell, M., Hakala, I., & Herrala, M. (2007, October). Analyzing gastrocnemius EMG-activity and sway data from quiet and perturbed standing. *Journal of Electromyography and Kinesiology, 17*(5), 622-634. doi:10.1016/j.jelekin.2006.06.004

Boyle, J. T., Altschuler, S. M., Nixon, T. E., Tuchman, D. N., Pack, A. I., & Cohen, S. (1985). Role of the diaphragm in the genesis of lower esophageal sphincter pressure in the cat. *Gastroenterology, 88*(3), 723-730.

Bullock-Saxton, J. (1993). Postural Alignment in Standing: A repeatability study. *Australian Journal of Physiotherapy, 39*(1), 25-29.

Butler, D. S., & Moseley, L. G. (2013). *Explain Pain* (2nd ed.). Adelaide, Australia: Noigroup Publications.

Cambridge Dictionaries Online. (2015). *Meaning of "posture" in the English Dictionary*. (Cambridge University Press) Retrieved December 7, 2015, from Cambridge Dictionaries Online: http://dictionary.cambridge.org/dictionary/english/posture

Casadio, M., Morasso, P. G., & Sanguineti, V. (2005). Direct measurement of ankle stiffness during quiet standing: implications for control modelling and clinical application. *Gait & Posture*, 410-424.

Coelho, P. (2008). *The Witch Of Portobello.* New York, U.S.A.: Harper Perennial.

Collins, J. J., & De Luca, C. J. (1993). Open-loop and closed-loop control of posture: A random-walk analysis of center-of-pressure trajectories. *Experimental Brain Research, 95*, 308-318.

Collis, J. L., Kelly, T. D., & Wiley, A. M. (1954). Anatomy of the crura of the diaphragm and the surgery of the haitus hernia. *Thorax, 9*(3), 175-189. doi:10.1136/thx.9.3.175

Colloca, C. J., & Hinrichs, R. N. (2005, October). The Biomechanical and Clinical Significance of the Lumbar Erector Spinae Flexion-Relaxation Phenomenon: A Review of Literature. *Journal of Manipulative and Physiological Therapeutics, 28*(8), 623-631. doi:10.1152/jn.00719.2001

Conti, P. B., Sakano, E., Ribeiro, M. A., Schivinski, C. I., & Ribeiro, J. D. (2011). Assessment of the body posture of mouth-breathing children and adolescents. *Jornal de Pediatria, 87*(4), 357-363. doi:0021-7557/11/87-04/357

Creath, R., Kiemel, T., Horak, F., Peterka, R., & Jeka, J. (2005). A unified view of quiet and perturbed stance: simultaneous co-existing excitable modes. *Neuroscience Letters*(377), 75-80. doi:10.1016/j.neulet.2004.11.071

Crossley, P. H. (2016). *Rhythm*. Retrieved March 10, 2016, from Encyclopaedia Britannica: http://www.britannica.com/art/rhythm-music

Danis, C. G., Krebs, D. E., Gill-Body, K. M., & Sahrmann, S. (1998, May). Relationship Between Standing Posture and Stability. *Physical Therapy, 78*(5), 502-517. doi:78:502-517

Dejoie, J., & Truelove, E. (2001, February). *The Starchild*. Retrieved November 4, 2015, from StarChild Question of the Month for February 2001: http://starchild.gsfc.nasa.gov/docs/StarChild/questions/question30.html

Di Giulio, I., Maganaris, C. N., Baltzopoulos, V., & Loram, I. D. (2009). The proprioceptive and agonist roles of gastrocnemius, soleus and tibialis anterior muscles in maintaining human upright posture. *Journal of Physiology, 587*(10), 2399-2416.

Dictionary.com. (2016). *Rhythm*. Retrieved March 10, 2016, from Dictionary.com: http://www.dictionary.com/browse/rhythm

Enoka, R. M. (1994). *Neuromechanical Basis of Kinesiology* (2nd ed.). Human Kinetics.

Enoka, R. M. (2015). *Neuromechanics of Human Movement* (5th ed.). Champaign, Illinois, U.S.A.: Human Kinetics.

Gilman, M. (2014). *Body and Voice Somatic Re-education.* San Diego, California, U.S.A.: Plural Publishing, Inc.

Gilman, S. L. (2014, March). "Stand Up Straight": Notes Toward a History of Posture. *Journal of Medican Humanities, 35*(1), 57-83. doi:10.1007/s10912-013-9266-0

Gordon, D. C., & Richmond, F. J. (1990). Topography in the phrenic motoneuron nucleus demonstrated by retrograde multiple-labelling techniques. *Journal of Comparative Neurology, 292*(3), 424-434. doi:10.1002/cne.902920308

GraphPad Software, Inc. (2016). *GraphPad Statistics Guide*. Retrieved February 27, 2016, from GraphPad Software: http://www.graphpad.com/guides/prism/6/statistics/index.htm?stat_checklist_pairedt.htm

GraphPad Software, Inc. (2016). *QuickCalcs*. Retrieved February 29, 2016, from GraphPad Software: http://www.graphpad.com/quickcalcs/

Gray, E. R. (1969, October). The role of leg muscles in variations of the arches in normal and flat feet. *Physical Therapy, 49*(10), 1084-1088.

Green, L. W., Ottoson, J. M., Garcia, C., & Hiatt, R. A. (2009). Diffusion Theory and Knowledge Dissemination, Utilization, and Integration in Public Health. *Annual Review of Public Health, 30*, 151-174. doi:10.1146/annurev.publhealth.031308.100049

Gross, J. M., Fetto, J., & Rosen, E. (2009). *Musculoskeletal Examination.* Chichester: Wiley-Blackwell.

Hamill, J., & Knutzen, K. M. (2008). *Biomechanical Basis of Human Movement* (3rd ed.). Philadelphia, Pennsylvania, U.S.A.: Lippincott Williams & Wilkins.

Han, J. T., Lee, M. H., & Lee, K. H. (2013). Effects of Local Muscle Vibration on the Displacement of Center of Pressure during Quiet Standing. *Journal of Physical Therapy Science, 25*(12), 1643-1645.

Harbourne, R. T., & Stergiou, N. (2009). Movement Variability and the Use of Nonlinear Tools: Principles to Guide Physical Therapist Practice. *Journal of The American Physical Therapy Association, 89*(3), 267-282. doi:10.2522/ptj.20080130

Haywood, K. M., Roberton, M. A., & Getchell, N. (2012). *Advanced analysis of motor development.* Champaign, Illinois, U.S.A.: Human Kinetics.

Heroux, M., Luu, B., Dakin, C. J., Inglis, J. T., & Blouin, J. S. (2014). Absence of lateral gastrocnemius activity and differential motor unit behavior in soleus and medial gastrocnemius during standing balance. *Journal of applied physiology, 116*(2), 140-148. doi:10.1152/japplphysiol.00906.2013

Herschorn, S. (2004). Female Pelvic Floor Anatomy: The Pelvic Floor, Supporting Structures, and Pelvic Organs. *Reviews in Urology, 6*(5), 2-10.

Hirata, R., Jorgensen, T., Rosager, S., Nielsen, L., Bliddal, H., Henriksen, M., & Nielsen, T. (2013). Altered Visual and Feet Proprioceptive Feedbacks during Quiet Standing Increase Postural Sway in Patients with Severe Knee Osteoarthritis. *PLOS ONE*, e71253. doi:10.1371/journal.pone.0071253

Hislop, H. J., Avers, D., & Brown, M. (2014). *Daniels and Worthingham's Muscle Testing* (9th ed.). St. Louis, Missouri, U.S.A.: Elsevier Saunders.

Hodges, P. W., Butler, J. E., McKenzie, D. K., & Gandevia, S. C. (1997). Contraction of the human diaphragm during rapid postural adjustments. *Journal of Physiology*, *505*(2), 539-548.

Janda, V. (1983). On the Concept of Postural Muscles and Posture in Man. *The Australian Journal of Physiotherapy*, *29*(3), 83-84.

John Hopkins University. (1995). *Diaphragm*. Retrieved November 26, 2015, from John Hopkins School of Medicine's Interactive Respiratory Physiology: http://oac.med.jhmi.edu/res_phys/Encyclopedia/Diaphragm/Diaphragm.HTML

John Hopkins University. (1995). *Pleural Pressure*. Retrieved November 26, 2015, from John Hopkins School of Medicine's Interactive Respiratory Physiology: http://oac.med.jhmi.edu/res_phys/Encyclopedia/PleuralPressure/PleuralPressure.HTML

Johnson, J. (2011). *Postural Assessment.* Champaign, Illinois, U.S.A.: Human Kinetics.

Karlsson, A., & Frykberg, G. (2000). Correlations between force plate measures for assessment of balance. *Clinical Biomechanics, 15*(5), 365-369. doi:10.1016/S0268-0033(99)00096-0

Kasman, G., & Wolf, S. (2002). *Surface EMG Made Easy: A Beginner's Guide for Rehabilitation Clinicians.* Scottsdale, Arizona, U.S.A.: Noraxon USA, Inc.

Kendall, F. P., McCreary, E. K., Provance, P. G., Rodgers, M. M., & Romani, W. A. (2005). *Muscles Testing and Function with Posture and Pain* (5th ed.). Baltimore, Maryland, U.S.A.: Lippincott Williams & Wilkins.

Kim, K.-s., Byun, M.-k., Lee, W.-h., Cynn, H.-s., Kwon, O.-y., & Yi, C.-h. (2012). Effects of breathing maneuver and sitting posture on muscle activity in inspiratory accessory muscles in patients with chronic obstructive pulmonary disease. *Multidisciplinary Respiratory Medicine, 7*(9), 1-6. doi:10.1186/2049-6958-7-9

Kitaoka, H., & Chihara, K. (2010). The diaphragm: a hidden but essential organ for the mammal and the human. *Advances in experimental medicine and biology, 669*, 167-171. doi:10.1007/978-1-4419-5692-7_33

Knudson, D. (2003). *Fundamentals of Biomechanics.* New York: Kluwer Academic/ Plenum Publishers.

Kolar, P. (2013). *Clinical Rehabilitation.* Prague: Alena Kobesova.

Konrad, P. (2006). *The ABC of EMG: A Practical Introduction to Kinesiological Electromyography.* Scottsdale, Arizona, U.S.A.: Noraxon U.S.A., Inc.

Kowalski, R. J., Ferrara, L. A., & Benzel, E. C. (2005, March). Biomechanics of the Spine. *Neurosurgery Quarterly, 15*(1), 42-59. doi:10.1097/01.wnq.0000152406.39871.8e

Kubisz, L., Werner, H., Bosek, M., & Weiss, W. (2011). Posture Stability Evaluation Using Static Posturography in Patients after Cruciate Ligament Reconstruction. *ACTA PHYSICA POLONICA A, 119*(6A), 957-960.

Kuhn, T. S. (1970). *The Structure of Scientific Revolutions* (2nd ed.). Chicago: The University of Chicago Press.

Kyvelidou, A., Harbourne, R. T., Shostrom, V. K., & Stergiou, N. (2011). Reliability of Center of Pressure Measures for Assessing the Development of Sitting Postural Control in Infants With or at Risk of Cerebral Palsy. *Archives of Physical Medicine and Rehabilitation, 91*(10), 1593-1601. doi:10.1016/j.apmr.2010.06.027

Lafond, D., Corriveau, H., Hébert, R., & Prince, F. (2004). Intrasession reliability of center of pressure measures of postural steadiness in healthy elderly people. *Archives of Physical Medicine and Rehabilitation, 85*(6), 896-901. doi:10.1016/j.apmr.2003.08.089

Le Clair, K., & Riach, C. (1996). Postural stability measures: what to measure and for how long. *Clinical Biomechanics, 11*(3), 176-178. doi:10.1016/0268-0033(95)00027-5

Levangie, P. K., & Norkin, C. C. (2001). *Joint Structure and Function: A Comprehensive Analysis* (3rd ed.). Philadelphia, Pennsylvania, U.S.A.: F. A. Davis Company.

Levangie, P. K., & Norkin, C. C. (2011). *Joint Structure and Function: A Comprehensive Analysis* (5th ed.). Philadelphia, Pennsylvania, U.S.A.: F. A. Davis Company.

Li, Y., McClure, P. W., & Pratt, N. (1996). The Effect of Hamstring Muscle Stretching on Standing Posture and on Lumbar and Hip Motions During Forward Bending. *Physical Therapy, 76*(8), 836-845.

Locke, D. (1967). *Perception and Our Knowledge of the External World.* London, England, Great Britain: George Allen & Unwin Ltd.

Loram, I. D., Maganaris, C. N., & Lakie, M. (2004). Paradoxical muscle movement in human standing. *Journal of Physiology, 556*(3), 683-689. doi:10.1113/jphysiol.2004.062398

Maatar, D., Fournier, R., Lachiri, Z., & Nait-Ali, A. (2011). Discrete wavelet and modified PCA decompositions for postural stability analysis in biometric applications. *Journal of Biomedical Science and Engineering, 4*(8), 543-551. doi:doi:10.4236/jbise.2011.48070

Magee, D. J. (2014). *Orthopedic Physical Assessment* (6th ed.). St. Louis, Missouri: Elsevier Inc.

Magnus, R. (1926, September 11). Cameron Prize Lectures on some results of studies in the physiology of posture. *The Lancet*, 531-536. Retrieved November 26, 2015, from An Alexander technique notebook: http://alexander.area24.net/RudolfMagnus-PhysiologyOfPosture.htm

Masani, K., Vette, A. H., Abe, M. O., Nakazawa, K., & Popovic, M. R. (2011). Smaller sway size during quiet standing is associated with longer preceding time of motor command to body sway. *Gait and Posture, 33*, 14-17. doi:10.1016/j.gaitpost.2010.08.012

McGinnis, P. M. (2004). *Biomechanics of Sport and Exercise.* Human Kinetics.

Merriam-Webster. (2016). *Rhythm*. Retrieved March 10, 2016, from Merriam-Webster: http://www.merriam-webster.com/dictionary/rhythm

Mittal, R. K. (1989). Sphincteric action of the diaphragm during a relaxed lower esophageal sphincter in humans. *The American journal of physiology, 256*(1), 139-144.

Mittal, R. K., & Goyal, R. K. (2006). Sphincter mechanisms at the lower end of the esophagus. *GI Motility online*. doi:10.1038/gimo14

Morasso, P. G., & Sanguineti, V. (2002, October). Ankle Muscle Stiffness Alone Cannot Stabilize Balance During Quiet Standing. *Journal of Neurophysiology, 88*, 2157-2162. doi:10.1152/jn.00719.2001

Morris, J. M., Benner, G., & Lucas, D. B. (1962, October). An electromyographic study of the intrinsic muscles of the back in man. *Journal of Anatomy, 96*(4), 509-520.

Motion Lab Systems, Inc. (2009). *EMG Analysis: A software user guide for EMG Graphing and EMG Analysis.* Baton Rouge, Louisiana, U.S.A.: Motion Lab Systems, Inc.

Mukherjee, S. (2011, August 26). *SumanSpeaks: Science and Technology: Fluid mechanics*. Retrieved February 10, 2016, from SumanSpeaks: Science and Technology: http://sumanspeaksscienceandtechnology.blogspot.cz/

Nashner, L. M., & McCollum, G. (1985). The organization of human postural movements: a formal basis and experimental synthesis. *The Behavioral and Brain Sciences*, 135-172.

Newton, A. (1997). Breathing In The Gravity Field. *Rolf Lines*.

Norris, C. M. (2008). *Back Stability* (2nd ed.). Champaign, Illinois, United States of America: Human Kinetics.

Oba, N., Sasagawa, S., Yamamoto, A., & Nakazawa, K. (2015). Difference in Postural Control during Quiet Standing between Young Children and Adults: Assessment with Center of Mass Acceleration. *PLoS ONE, 10*(10). doi:10.1371/journal.pone.0140235

O'Sullivan, K., McCarthy, R., White, A., O'Sullivan, L., & Dankaerts, W. (2012). Can we reduce the effort of maintaining a neutral sitting posture? A pilot study. *Manual Therapy*(17), 566-571.

O'Sullivan, P. B., Grahamslaw, K. M., Kendell, M., Lapenskie, S. C., Möller, N. E., & Richards, K. V. (2002). The Effect of Different Standing and Sitting Postures on Trunk Muscle Activity in a Pain-Free Population. *Spine, 27*(11), 1238-1244. doi:10.1097/00007632-200206010-00019

Page, P., Frank, C. C., & Lardner, R. (2010). *Assessment and Treatment of Muscle Imbalance: The Janda Approach.* Champaign, Illinois, U.S.A.: Human Kinetics.

Peterka, R. J. (2000). Postural control model interpretation of stabilogram diffusion analysis. *Biological Cybernetics, 82*(4), 335-343. doi:10.1007/s004220050587

Pickering, M., & Jones, J. F. (2002). The diaphragm: two physiological muscles in one. *Journal of Anatomy, 201*(4), 305-312. doi:10.1046/j.1469-7580.2002.00095.x

Preachuk, D. (2012, May 30). *Proper Posture Circa 1947*. Retrieved January 25, 2016, from Pain Free Posture MN: http://www.painfreeposturemn.com/proper-posture-circa-1947

Price, K., Schartz, P., & Watson, A. (2014). The Effect of standing and sitting postures on breathing in brass players. *SpringerOpen Journal, 3*(210). doi:10.1186/2193-1801-3-210

Proske, U., & Gandevia, S. C. (2012, October 1). The Proprioceptive Senses: Their Roles in Signaling Body Shape, Body Position and Movement, and Muscle Force. *Physiological Reviews, 92*(4), 1651-1697. doi:10.1152/physrev.00048.2011

Pynt, J., & Higgs, J. (2010). *A History of Seating, 3000 BC to 2000 AD: Function versus Aesthetics.* Amherst, New York, U.S.A.: Cambria Press.

Quammen, D. (2012, December). *National Geographic*. Retrieved November 3, 2015, from Giant Sequoias: http://ngm.nationalgeographic.com/2012/12/sequoias/quammen-text

Robertson, G. D., Caldwell, G. E., Hamill, J., Kamen, G., & Whittlesey, S. N. (2004). *Research Methods in Biomechanics.* Champaign, Illinois, U.S.A.: Human Kinetics.

Rodgers, M. M., & Cavanagh, P. R. (1984, December). Glossary of Biomechanical Terms, Concepts and Units. *Physical Therapy, 64*(12), 1886-1902.

Sakaguchi, M., Taguchi, K., Miyashita, Y., & Katsuno, S. (1994). Changes with aging in head and center of foot pressure sway in children. *International Journal of Pediatric Otorhinolaryngology, 29*(2), 101-109. doi:10.1016/0165-5876(94)90089-2

Sanchez, J., Medrano, G., Debesse, B., Riquet, M., & Derenne, J. P. (1985). Muscle fibre types in costal and crural diaphragm in normal men and in patients with moderate chronic respiratory disease. *Bulletin Européen Physiopathologie Respiratoire, 21*(4), 351-356.

Sasaki, K., Senda, M., Katayama, Y., Ota, H., & Matsuyama, Y. (2013). Characteristics of Postural Sway during Quiet Standing Before and After the Occurrence of Neurogenic Intermittent Claudication in Female Patients with Degenerative Lumbar Spinal Canal Stenosis. *Journal of Physical Therapy Science, 25*(6), 675-678.

Saunders, C., Macnaughton, J., & Fuller, D. (2015). *The Recovery of Beauty: Arts, Culture, Medicine.* Basingstoke, Hampshire, United Kingdom: Palgrave Macmillan.

Schilling, R. J., Bollt, E. M., Fuk, G. D., Skufca, J. D., Al-Ajlouni, A. F., & Robinson, C. J. (2009). A quiet standing index for testing the postural sway of healthy and diabetic adults across a range of ages. *IEEE Transactions on Biomedical Engineering, 56*(2), 292-302. doi:10.1109/TBME.2008.2003270

Schubert, P., Kirchner, M., Schmidtbleicher, D., & Haas, C. T. (2012). About the structure of posturography: Sampling duration, parametrization, focus of attention (part I).

Journal of Biomedical Science and Engineering, 5(9), 496-507. doi:10.4236/jbise.2012.59062

Schwartz, M. S., & Andrasik, F. (Eds.). (2003). *Biofeedback: A Practitioner's Guide* (3rd ed.). New York: Guilford Press.

Sevšek, F. (2004). *Biomehanika.* Ljubljana, Slovenia: Visoka šola za zdravstvo UL.

Sherrington, C. S. (1906). *The Inegrative Action of the Nervous System.* New Haven, Connecticut, U.S.A.: Yale University Press.

Shirado, O., Ito, T., Kaneda, K., & Strax, T. E. (1995). Flexion-relaxation phenomenon in the back muscles. A comparative study between healthy subjects and patients with chronic low back pain. *American Journal of Physical Medicine & Rehabilitation, 74*(2). doi:10.1097/00002060-199503000-00010

Soames, R. W., & Atha, J. (1981, October). The role of the antigravity musculature during quiet standing in man. *European Journal of Applied Physiology and Occupational Physiology, 47*(2), 159-167. doi:10.1007/BF00421668

Soha, F. R., Szabó, I. A., & Budai, M. (2012). Dinamic and Static Centre of Pressure Measurement on the Forcplate. *Acta Physica Debrecina, 46*(143), 143-153.

Stemplewski, R., Maciaszek, J., Osiński, W., & Szeklicki, R. (2011). Test-Retest Reliability of Measurements of the Center of Pressure Displacement in Quiet Standing and During Maximal Voluntary Body Leaning Among Healthy Elderly Men. *Journal of Human Kinetics, 28*, 15-23. doi:10.2478/v10078-011-0018-9

Szalay, J. (2013, September 5). *Giant Sequoias and Redwoods: The Largest and Tallest Trees*. (Purch) Retrieved November 14, 2015, from Livescience: http://www.livescience.com/39461-sequoias-redwood-trees.html

Taghi, M. K., Jamshidi, N., Bahreinizad, H., Bani, M. S., & Omar, A. H. (2014). A new approach to measure stability during quiet standing. *Work, 49*(4), 663-668. doi:10.3233/WOR-131699

Tokuno, C. (2007). *Neural Control of Standing Posture.* Stockholm: Karolinska Institutet.

Toppenberg, R. M., & Bullock, M. I. (1986). The Interrelation of Spinal Curves, Pelvic Tilt and Muscle lengths in the Adolescent Female. *Australian Journal of Physiotherapy, 32*(1), 6-12.

Tortora, G. J., & Nielsen, M. T. (2012). *Principles of Human Anatomy* (12th ed.). New Jersey: John Wiley & Sons, Inc.

Transweb Global Inc. (2016). *Classification of Civil Engineering*. Retrieved February 10, 2016, from Transtutors.com: http://www.transtutors.com/homework-help/civil-engineering/fundamental-concepts/classification-of-engineering-mechanics.aspx

Trochim, W. M. (2006, 10 20). *The T-Test*. Retrieved 2 2016, 27, from Research Methods Knowledge Base: http://www.socialresearchmethods.net/kb/stat_t.php

Unite For Sight, Inc. (2015). *Module 6: The Importance of Research*. Retrieved February 29, 2016, from Unite for Sight: http://www.uniteforsight.org/research-methodology/module6

Van der Kooij, H., Campbell, A. D., & Carpenter, M. G. (2011). Sampling duration effects on centre of pressure descriptive measures. *Gait & Posture*(34), 19-24. doi:10.1016/j.gaitpost.2011.02.025

Van Lunteren, E., Haxhiu, M. A., Cherniack, N. S., & Goldman, M. D. (1985). Differential costal and crural diaphragm compensation for posture changes. *Journal of Applied Physiology, 58*(6), 1895-1900.

Vele, F. (1997). *Kineziologie pro klinickou praxi.* Prague: Grada Publishing.

Vieira, T., Loram, I., Muceli, S., Merletti, R., & Farina, D. (2012). Recruitment of motor units in the medial gastrocnemius muscle during human quiet standing: is recruitment intermittent? What triggers recruitment? *Journal of Neurophysiology, 107*, 666-676. doi:10.1152/jn.00659.2011

Warnica, M. J., Weaver, T. B., Prentice, S. B., & Laing, A. C. (2014). The influence of ankle muscle activation on postural sway during quiet stance. *Gait and Posture, 39*, 1115-1121. doi:10.1016/j.gaitpost.2014.01.019

White, A. A., & Panjabi, M. M. (1978). *Clinical biomechanics of the spine.* Philadelphia, Pennsylvania, U.S.A.: JB Lippincott Co.

Whiting, W. C., & Zernicke, R. F. (2008). *Biomechanic of Musculoskeletal Injury* (2nd ed.). Champaign, Illinois, U.S.A.: Human Kinetics.

Winter, D. A. (1995). Human balance and posture control during standing and walking. *Gait & Posture, 3*(4), 193-214.

Winter, D. A., Patla, A. E., Rietdyk, S., & Ishac, M. G. (2001, June). Ankle Muscle Stiffness in the Control of Balance During Quiet Standing. *Journal of Neurophysiology, 85*(6), 2630-2633.

Winter, D., Patla, A., Prince, F., Ishac, M., & Perczak, K. G. (1998). Stiffness Control of Balance in Quiet Standing. *The American Physiological Society*, 1211-1221.

Wood, D. (2015, November). *Understanding the Center of Mass & Center of Gravity*. Retrieved November 11, 2015, from Study.com: http://study.com/academy/lesson/understanding-the-center-of-mass-center-of-gravity.html

Yamamoto, T., Smith, C., Suzuki, Y., Kiyono, K., Tanahashi, T., Sakoda, S., . . . Nomura, T. (2015). Universal and individual characteristics of postural sway during quiet standing in healthy young adults. *Physiological Reports, 3*(3), 1-24. doi:10.14814/phy2.12329

Zatsiorsky, V. M., & Duarte, M. (1999). Instant Equilibrium Point and its MIgration in Standing Tasks: Rambling and Trembling Components of the Stabilogram. *Motor Control, 3*, 28-38.

Zatsiorsky, V. M., & Duarte, M. (2000). Rambling and Trembling in Quiet Standing. *Motor Control, 4*, 185-200.

17 APPENDICES

Appendix 1: Approved Application for the research project.

Appendix 2: Informed Consent given to every subject before the start of the research.

Appendix 1:

UNIVERZITA KARLOVA V PRAZE
FAKULTA TĚLESNÉ VÝCHOVY A SPORTU
José Martího 31, 162 52 Praha 6-Veleslavín

Application for Approval by UK FTVS Ethics Committee

of a research project, thesis, dissertation or seminar work involving human subjects

The title of a project: Differences in postural activity during quiet standing when breathing abdominally
Project form: master's thesis
Period of realization of the project: March 2016
Applicant: Sebastjan Gantar
Main researcher: Sebastjan Gantar
Co-researcher(s):
Supervisor (in case of student's work): doc. Paed Dr. Dagmar Pavlů, CSc.
Financial support: no financial support

Project description: My intention is to measure muscle activity and changes in centre of pressure during quiet standing and compare them with the second measurement when subjects will be instructed to breath strictly abdominally. Each of the two measurements will last for about 90 seconds. Subject chosen for this experiment will be healthy young people from the Faculty of Physical Education and Sport, CU. They will be required to stand on the force plate and have EMG electrodes stuck on their skin, so they will have to be in their underwear for approximately 20 minutes. This is the time required for the necessary preparation of the subjects and actual measurement. Standard procedure of preparation includes cleaning the skin with ethanol to ensure electrical conductivity from subcutaneous tissue (in this case muscles) to the electrodes. Each subject will be in the investigation room individually.

Ensuring safety within the research: For the purpose of research the EMG and posturography (force plate) will be used. Help will be provided by two assistants, operating with EMG and force plate computer, and my supervisor.

Ethical aspects of the research: Personal data will be anonymised.

It is a duty of **all participants of the research team** to protect life, health, dignity, integrity, the right to self-determination, privacy and protection of the personal data of all research subjects, and to undertake all possible precautions. Responsibility for the protection of all research subjects lies on the researcher(s) and not on the research subjects themselves, even if they gave their consent to participation in the research. All participants of the research team must take into consideration ethical, legal and regulative norms and standards of research involving human subjects applicable not only in the Czech Republic but also internationally.

I confirm that this project description corresponds to the plan of the project and in case of any change, especially of the methods used in the project, I will inform the UK FTVS Ethics Committee, which may require a re-submission of the application form.

In Prague, 24.3.2016 Applicant's signature: Sebastjan Gantar

Approval of UK FTVS Ethics Committee

The Committee: Chair: doc. PhDr. Irena Parry Martínková, Ph.D.
Members: prof. PhDr. Pavel Slepička, DrSc.
doc. MUDr. Jan Heller, CSc.
doc. Ing. Monika Šorfová, Ph.D.
Mgr. Pavel Hráský, Ph.D.
MUDr. Simona Majorová

The research project was approved by UK FTVS Ethics Committee under the registration number: 098/2016

Date of approval: 24. 3. 2016

UK FTVS Ethics Committee reviewed the submitted research project and **found no contradictions** with valid principles, regulations and international guidelines for carrying out research involving human subjects.

The applicant has met the necessary requirements for receiving approval of UK FTVS Ethics Committee.

Stamp of UK FTVS

UNIVERZITA KARLOVA v Praze
Fakulta tělesné výchovy a sportu
José Martího 31, 162 52, Praha 6
1

Signature of the Chair of UK FTVS Ethics Committee

Appendix 2:

INFORMED CONSENT

Dear Sir or Madam,

In line with The Universal Declaration of Human Rights, Protection of Personal Data Act No. 101/2000 Coll. as amended, Czech Republic, and other generally binding legal regulations *(such as especially the Helsinki declaration, adopted by the 18th WMA General Assembly, Helsinki, Finland, June 1964 and its later amendments (Fortaleza, Brazil, 2013); Act No. 372/2011 Coll., on Health Services (especially Section 28, paragraph 1) and the Convention on Human Rights and Biomedicine, Act No. 96/2001 Coll., if applicable),* I ask you for your consent to your participation in a research project within my master thesis with the title "Differences in postural activity during quiet standing when breathing abdominally" carried out at The Faculty of Physical Education and Sport, Charles University in Prague.

1. *Our intention is to measure muscle activity and changes in centre of pressure during quiet standing and compare them with the second measurement when you will be instructed to breathe strictly abdominally. Each of the two measurements will last for ninety (90) seconds.*

2. *Research will be done using muscle activity measuring devices (EMG) and stability measuring devices (posturographic force-plate).*

3. *Before the measurement will start, you will have to tell us your birth date, weight and foot size (shoe number). For the purpose of electrode placement on the skin you will have to be in your underwear. None of the electrode placement sites involve any intimate part of your body. Undressing can be done in the examination room or in the changing room we will provide. To ensure privacy, each individual will be in the examination room separately. Preparation demands the part of your skin where electrodes will be placed to be cleaned using standard medical rubbing alcohol (ethanol based liquid). After this, you will be asked to produce the strongest possible contraction for each of six (6) chosen muscles. For the purpose of measuring your centre of pressure, you will have to stand on a steady force-plate for 90 seconds. Muscle activity and stability measurement will be done simultaneously.*

4. *Whole procedure will take approximately 20 minutes. You will be called to the room after previous subject has exited, and you will be allowed to leave after or during measurement for your own reason. After the measurement will finish, your participation in the research will be no longer required.*
5. *For this research you should be healthy without any issues, diseases or pathologies regarding stability or neurological and muscular state. In case you will feel dizziness, vertigo, sickness, blurry vision, ear ringing, muscle weakness, spastic contraction or any other changes you should say or indicate immediately.*
6. *In case you will feel any problems or just a need to relax, there will be chairs to seat, table to lie down, water to drink, and windows to open for more fresh air if needed. Main researcher will be present in the examination room during the whole procedure.*
7. *There is no reward or any kind of benefit.*
8. *The data and all information we will obtain will remain in the private property, possession and use of the main researcher only. Personal data will be anonymised and stored in anonymised form.*
9. *In case photographs will be taken for the purpose of proof and showing the methods and procedures, you will be asked for permission and if this photos will be used in the thesis only, they will be edited so your face will not be seen in the photo.*
10. *If you will be interested in the results you should personally contact the main researcher or ask at the Faculty of Physical Education and Sports, Charles University in Prague, to view the thesis after it will be published.*
11. *I shall ensure to the maximum extent possible that the research data will not be misued.*

Name and surname of the applicant....Sebastjan Gantar.... Signature: ....

Name and surname of the main researcher and co-researcher(s) ....Sebastjan Gantar....

Name and surname of the person, who informs the participant ....Sebastjan Gantar....

Signature: ……………………..

I declare and with my below mentioned personal signature confirm that I voluntarily agree with my participation in the above mentioned project and that I have been given an opportunity to ask questions and consider all relevant information about the research project and my participation, and that I received clear and comprehensible answers to my questions. I was informed about my right to refuse participation within the research project or to withdraw my consent at any time without penalisation, by writing to the UK FTVS Ethics Committee, which will consequently inform the applicant.

Place and date...

Name and surname of participant..

Signature: ....