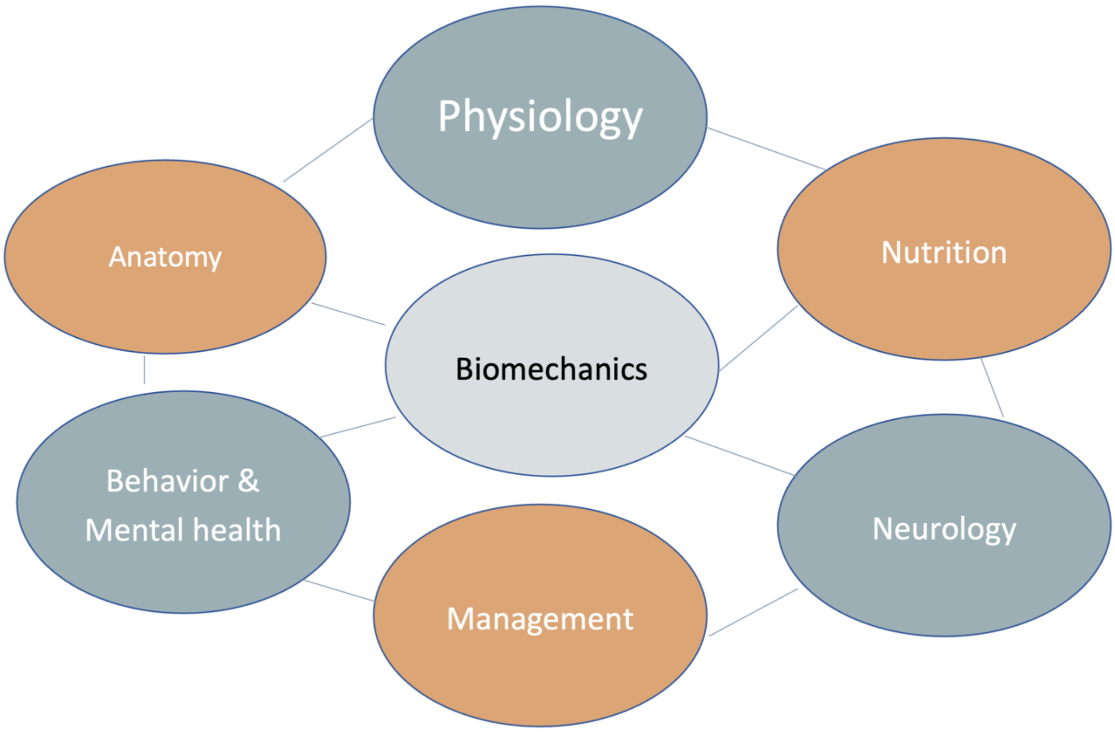
BIOMECHANICAL MODELS

Biomechanical models are aimed to explain how the body is designed for motion and how it accomplishes that motion. The production of movement requires close integration of various body systems, making it highly complex and multi-layered.

Biomechanical models are simplifications of a complex reality to help us understand. Although simplifications are the greatest achievement of



knowledge, simplifications without knowledge are the greatest cause of equine injuries (Cornille 2012). In other words, preaching concepts such as ''ride your horse over the back'' or ''engage the hind limbs'' are empty without proper mechanical understanding and often lead to incorrect practices. It is thus crucial to study the horse's biomechanics to reduce the risk of overload and injuries.

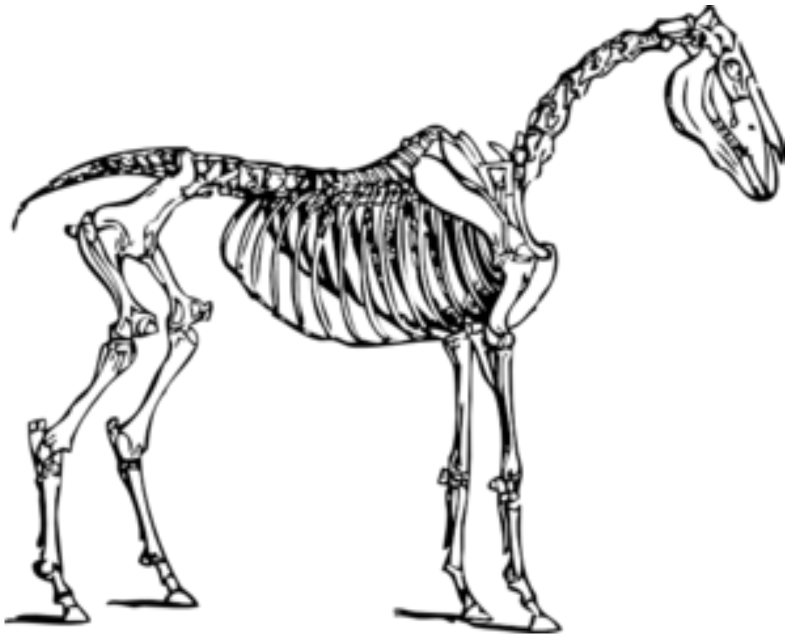
The one constant force that influences biomechanics is gravity. Pregnancy, excess weight, tack, and a rider increase the mass that gravity acts on. Hence, the horse's body needs to be equipped with refined mechanical systems that allow it to move while resisting gravity.

Equine biomechanics is often explained from a comparative human perspective. However, despite some similarities, humans and horses are very different in their anatomical design. Humans are two-legged and built in the vertical plane whereas horses are four-legged and built in the horizontal plane.

Due to their vertical build, humans have an advantage when it comes to defying gravity since two vertical forces in opposite directions can relatively easily annual each other out. Horses, however, draw the short end of the straw; being built horizontal, it is much harder to defy gravity. The horse is thus not a human and has to rely on different sophisticated mechanical systems to maintain balance against gravity. So, what do we know about equine biomechanics?

When looking at the horse's anatomy, we can observe differences in anatomical design of the front limbs and hind limbs. The hind limbs are angular, like that of a cat, and allow for bending. As such, their main task is to produce horizontal forces (forward movement). In certain situations, the hind limbs are also tasked to produce breaking forces to keep the bodyweight balanced between the fore- and the hindlimbs.

When looking at the design of the forelimbs, they are much more upright like a rigid strut. Hence, their main task is to produce a vertical incline against gravity. Balance control is thus essentially in the horse's forehand – not in the hind end.



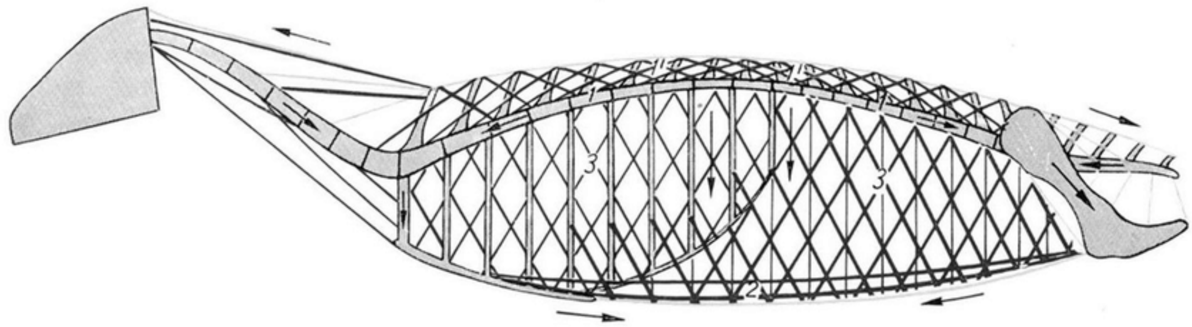
Picture showing the differences in anatomical design between the hind- and front limbs

From a neurological perspective, there are more nerves governing the forehand than the hind end, demonstrating that the front limbs tend to predominate over the action of the hind limbs. This is the result of the action of two neural oscillators referred to as central pattern generators. These central pattern generators maintain the purity of the gaits and cause the hindlegs to follow similar patterns of movement as the forelimbs. The front central pattern generator is thus the decision maker as it informs the hind end, which provides feedback. There is some feedback from hind end to front end but the main message regarding the gait itself is coming from the front central pattern generator (McLean, 2021).

In essence, equine biomechanics is about producing horizontal forces (forward movement) and converting these forces into a vertical incline against gravity to ensure balance control and maintaining spinal integrity.

The hind- and front limbs are connected through the pelvic articulations and thoracolumbar spine. The thoracolumbar spine is the main horizontal component in the horse's anatomical design and thus heavily burdened by gravity. Maintaining spinal stability and integrity is essential to ensure sound biomechanics against gravity.

To understand the interactions between the vertebral column and limbs, various efforts have been made to develop a crude biomechanical model. To date, there is only one widely accepted model available that continues to shape our thinking and training practices, namely the infamous string-and-bow theory.

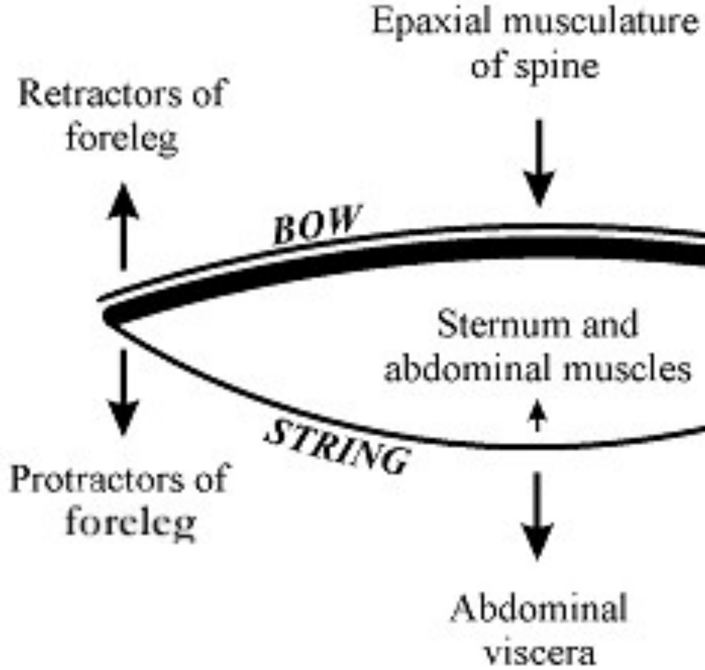


The idea of the trunk-skeleton connection as a bow and string construction was first proposed by Barthez in 1798, but his work was ignored until rediscovered by Dutch scientist Slijper in 1946, who described it as follows:

"The horse has a very flat shaped bow which is made up of the vertebral column, its epaxial muscles and ligaments. The whole structure is kept rigid and under tension from the string formed by the sternum, abdominal muscles, Linea alba and the muscles of the limbs." - E. J. Slijper, 1946

The bow and string are connected through the ribs, the oblique and transverse abdominal muscles.
For the string-and-bow theory to work, it relies on two additional influences:

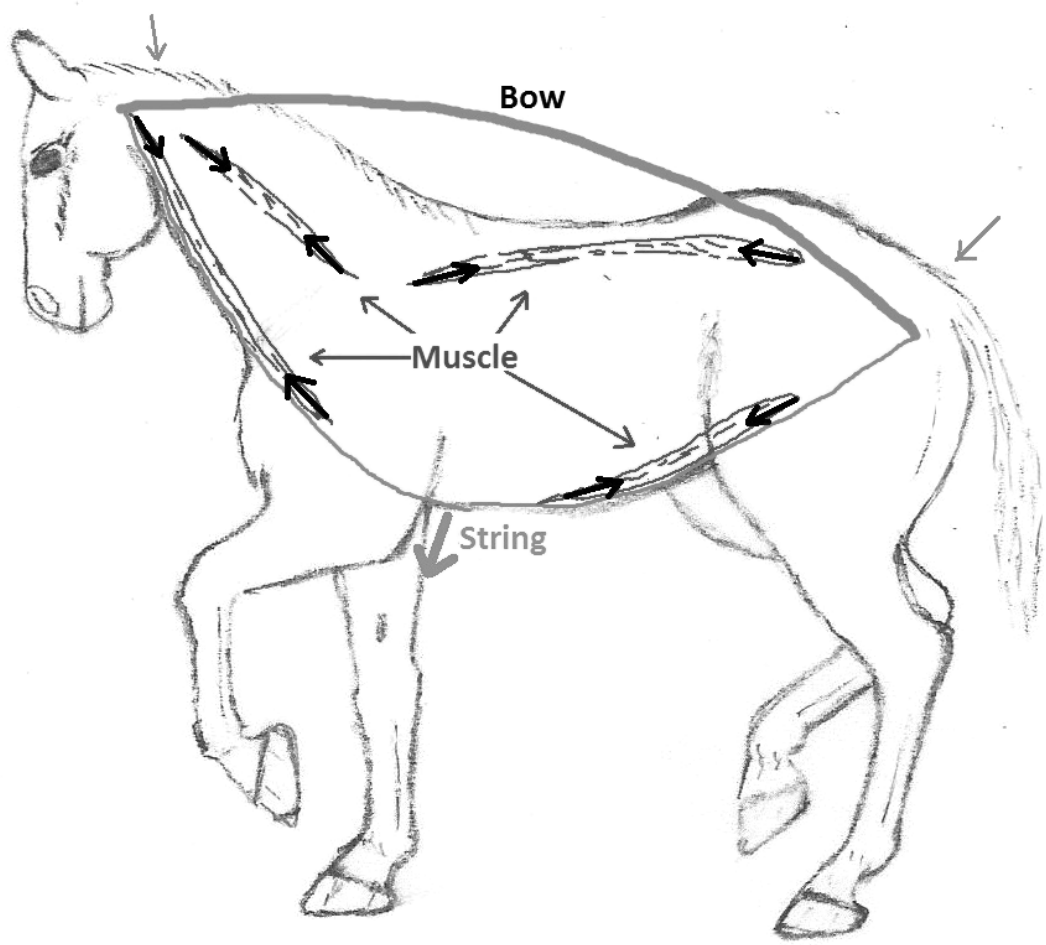
- The head and neck position
- The engagement of the hind limbs



Simply put, the string-and-bow theory teaches that by engaging the horse's hindlimbs and lowering and flexing the head and neck position, the horse's back flexes through activation of the abdominal muscles allowing the horse to balance against gravity and carry a rider with minimal wear and tear.

After its initial publication, Slijper's crude model became widely accepted. Today, the string-and-bow theory is of biblical proportions in equitation. It has been responsible for training dogma's such as long and low, low deep and round, rollkür, core stability for horses and hind limb engagement. Sounds familiar right?

The string-and-bow has become part of equitation tradition without room for critical thinkers. Questions on the validity already arose in the 1960s, by scientists such as Ricard Tucker, Leo Jeffcott and James Rooney, but were met with resistance by the equestrian elite. Research disproving the string and bow theory continued in the early 2000s, but its outcomes seem to have fallen on deaf ears. It appears that in the equestrian world, tradition is often favored over science and the myth of the string-and-bow continues.

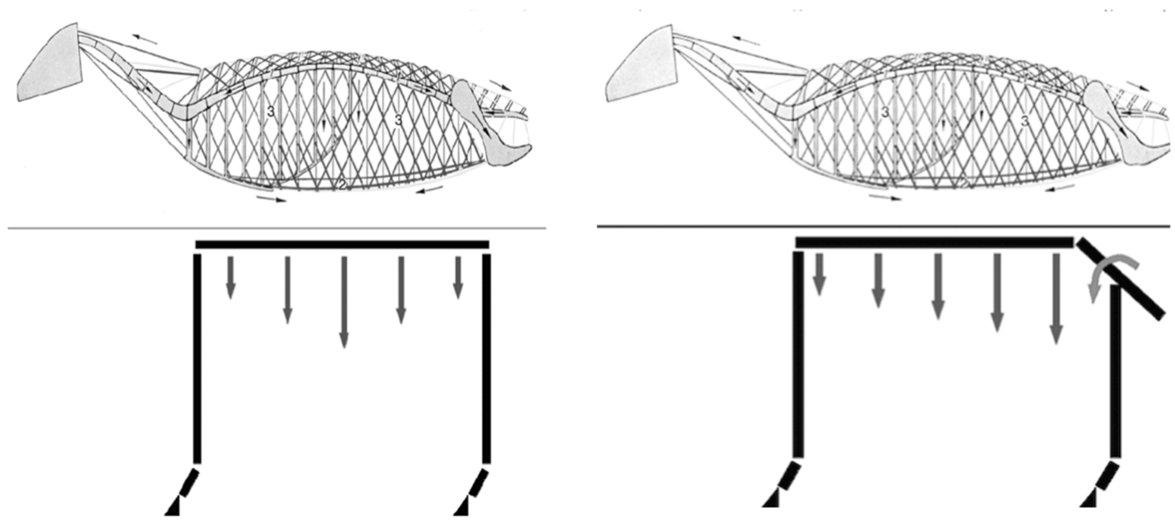


To give the model some credit, it was one of the first models that allowed for the fact that the back is in dynamic balance under constantly changing tension. A force on one part, alters the biomechanics of the other parts. However, modern day science has helped us to evolve our understanding of this complex topic. There are three main reasons why the string-and-bow theory in its current shape is flawed and should be revised:

1. The role of the lumbo-sacral joint
2. Redefining the ''core'' muscles
3. The negative effect of long and low

1. The bow and string theory does not help with analyzing the pelvis or the interaction between sacro-lumbar spine, pelvis, and hind limbs.

The string and bow theory surmises that peak forces of flexion and extension occur mid-back (the center of the bow). However, science has shown that peak forces of flexion – extension occur at the lumbo-sacral joint, which acts like a hinge and greatly contributes to the horse's athletic capacity due its loin-coiling ability.



Picture adapted from Van Weeren (2016) showing the string-and-bow theory (1) not accounting for pelvic articulations and (2) an adaptation accounting for flexion/extension of the lumbosacral joint.

The lumbo-sacral joint is part of the sacral-pelvic sling and in turn is greatly influenced by the hind limb's rotation around the hip joints. Biomechanics of the sacro-pelvic sling are thus crucial for whole body movement.

Since peak forces do not arise mid-back, the entire concept of a ''rounded'' or ''lifted'' back should reconsidered. Rather than the back arching like a bow, it is more a case of the sacrum lowering, the thoracic sling lifting while keeping the back as straight as possible against gravity.

2. Within the string-and-bow theory, the abdominal muscles of the horse are considered the ''core'' muscles responsible for flexing the thoracolumbar spine and this has led to an overflow of ''core stability'' training programs for horses. However, the abdominal muscles of the horse function differently to common belief and are not responsible for creating flexion in the spine.

One of the main tasks of the abdominal muscles in the horse is to assist the breathing process. As already explained in the anatomy manual, the breathing process of the horse is more active than that of humans and requires more engagement of the abdominal muscles to support the diaphragm. A strong abdominal line, especially that of the external oblique is rather a sign of breathing difficulties as opposed to the horse having a strong ''sixpack''.

On a mechanical level, the abdominal muscles have two functions. Firstly, they stabilize the visceral content in the higher gaits. Secondly, various ECG studies (Tokuriki, 1997; Von Scheven, 2010) found that the abdominal muscles are active during the extension phase and not the flexion phase of movement. This is completely contradictory to what the string-and-bow theory makes us believe.

We often think of the back as something that should move, but it should also limit movement to remain straight and resist gravity. As such, the abdominal muscles engage in an antagonistic relationship to the long back muscles, such as the Longissimus Dorsi to maintain tensegrity.

With gravity acting downwards, the Longissimus Dorsi and External Oblique act in a harmonious concert to keep the spine within its integrity. Instead of creating flexion, the External Oblique activates to limit (excessive) extension. The opposite is true for the Longissimus Dorsi that instead of creating extension, acts to limit flexion. This phenomenon can be clinically observed as well. When a horse presents with a strong muscle line of abdominal oblique under the rider, have a look to the posture of the lumbar spine: 99% of the times it is in extension. If the horse is trained in a contracted posture, the lower back is succumbing to gravity and the increased mass it is acting on.

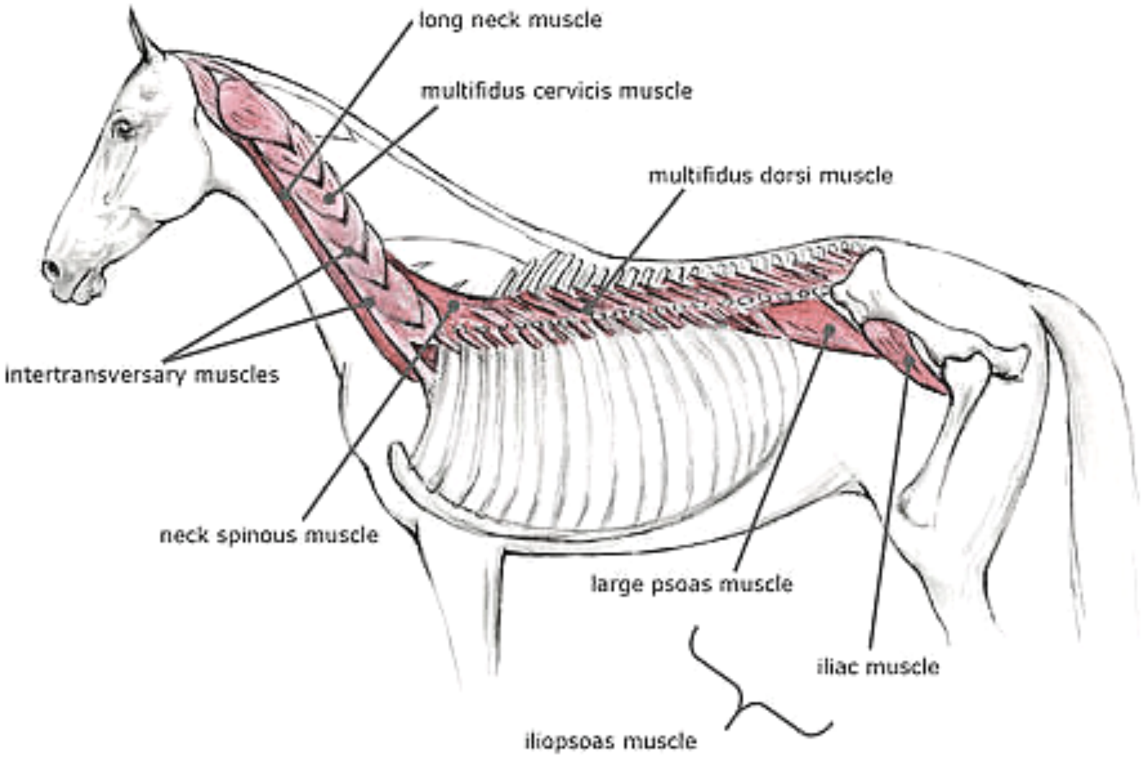
As a result, the external oblique will contract heavily, not to create flexion, but to limit the extension to keep the back stabilized and straight as much as possible against gravity and the rider.

Picture showing an extended lumbar spine in combination with a clear muscle lining of the External Oblique

The question is, if not the abdominal muscles, what muscles are mainly responsible of back tensegrity instead? The answer lies in the cybernetic stabilizers.

As explained in Module 1. Anatomy, the cybernetic stabilizers are highly innervated postural muscles closely connected to the vertebral column.

These are the deepest layers of muscles and thus are the true ''core muscles'' of the horse. These true core muscles of the horse include the Quadratus Lumborum, Multifidi, Intertransversarii, Longus Coli, Scalenus and Iliopsoas.



These previously overlooked postural core muscles are major players in spinal stability and there extremely important to ensure correct biomechanics as horses require a stable spinal platform from which to execute voluntary movement. Spinal stability is necessary to respond to destabilizing forces such as gravity and a rider and reduce the horse's chance of injury.

A recent study that aimed to explain the relationship between the Multifidus muscle and chronic lameness found that horses with a unilateral forelimb lameness showed bilateral atrophy of the Multifidus causing a lack of spinal stability in these horses (Sullivan et al. 2022).

The importance of the postural muscles become increasingly clear and should therefore gain more attention in biomechanical models.

This is not to say the abdominal muscles have no function at all, but that they merely complement biomechanics rather than creating it. Flawed understanding of the function of the abdominals lead to one-sighted approaches that completely bypass the true core muscles that ensure posture and sound locomotion.

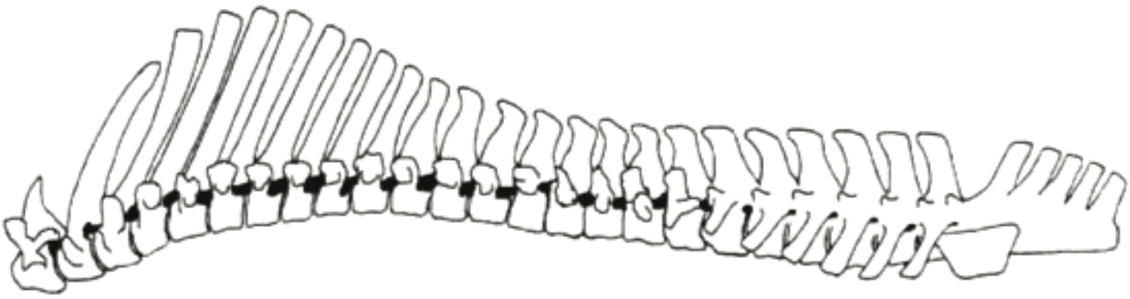
Core training for horses based on abdominal contraction (only) is thus flawed simply because it doesn't address the actual core muscles, the deep postural stabilizers surrounding the spine itself. Therefore, the string-and-bow theory needs to be revised as it has been responsible for many misinformed training practices not benefiting the horse.

3. Finally, for the string-and-bow theory to work, it relies on two additional influences, namely a lowered head and neck position and the engagement of the hind limbs. However, the two concepts are incompatible with one another since a long and low(er) head and neck position naturally disengages the hind limbs through extension in the lumbo-sacral joint.

The string-and-bow theory compares the spine to a homogenous bow. However, in reality, different design and orientation of vertebrae allow for different range of motion. This means that a single action (such as lowering the head and neck position) causes different reactions throughout segments of the thoracolumbar spine.

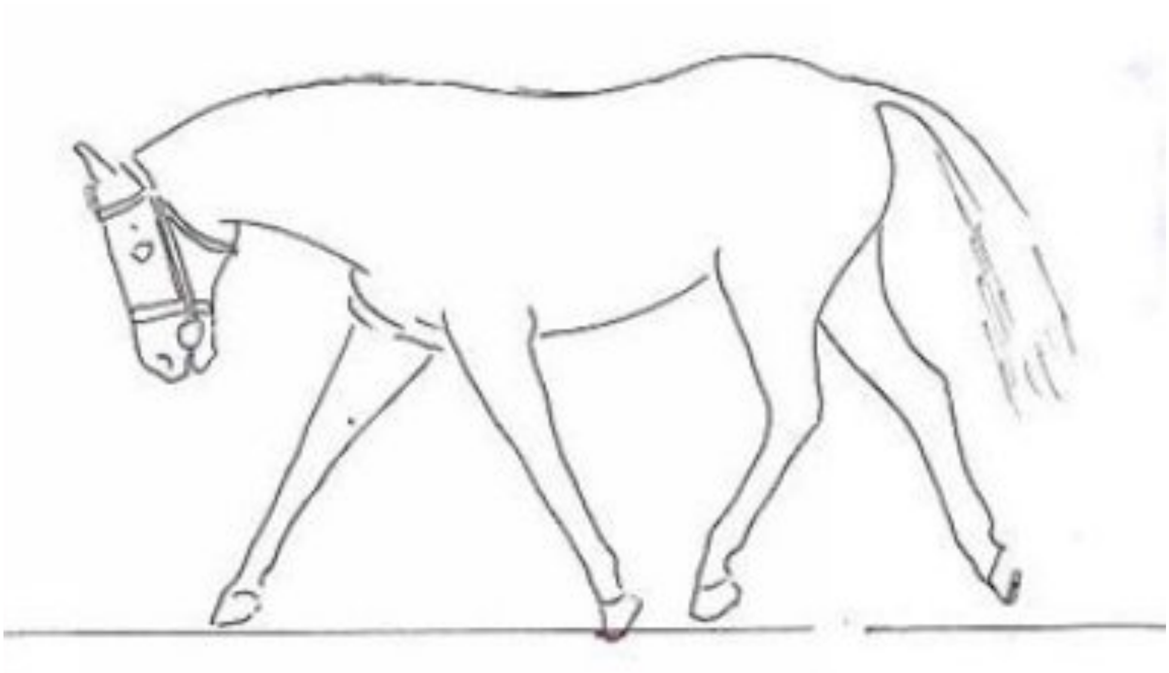
When looking at the orientation and design of the thoracolumbar vertebrae, there is somewhat of a curve. The dorsal spinous processes of the first thoracic vertebrae are long and orientate slightly backwards (caudal). Gradually continuing mid-back, the spinous processes become shorter and orientate more upright. Progressing through the lumbar spine, the dorsal spinous processes change angle again and orientate forwards (cranial). The thoracolumbar spine has thus an evident curve that changes from a caudal to a cranial orientation of the dorsal spinous processes.

These processes are influenced by muscle and ligament attachments – for example the Supraspinous ligament.



Picture showing the curvature in the spine. A single action of the head and neck forwards-downwards will result in flexion in the thoracic spine, but extension at the lumbar spine.

When the horse is asked towards a lower and/or rounder head and neck position, qualified as any position with the ears at least a hand lower than the withers and croup, the Supraspinous ligament pulls in the same direction as the head and neck. However, the effect won't be same over the entire length of the thoracolumbar spine. In the thoracic vertebrae, the pull direction will straighten the backwards orienting processes more upright through muscular and Supraspinous ligament actions creating flexion. However, in the lumbar spine, the exact same forward pull direction will tip the naturally forward orientating processes even more forward, resulting in extension. As a result, the sacro-pelvic angle flattens, and the pelvis wants to ''tip over''. In reaction to the extension of the lumbar spine and increased load on the forehand, the hind limbs will increase their extension (thrust) rather than their flexion (carrying) phase. As such, a long and low head and neck position and engagement of the hind limbs are two incompatible concepts.

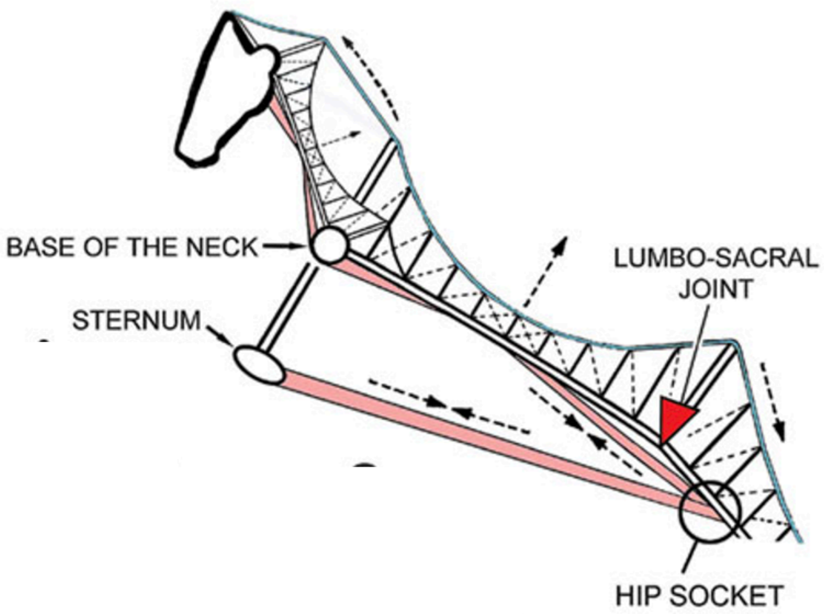


Picture adapted from Cornille (2012) showing the ''wheelbarrow'' effect of long and low and how it is incompatible with the concept of hind limb engagement.

All the above-mentioned reasons clearly debunk the string-and-bow theory and demands it to evolve using modern day science. Biomechanics is far more complex and sophisticated than what the string-and-bow theory accounts for and this can lead to flawed training practices. It is necessary to break down tradition to build up a more accurate biomechanical model that serves justice to the horse and include more sophisticated intricacies.

Going back to the drawing board using current scientific knowledge and experience, a more accurate biomechanical model can be realized including the close integration of the following mechanisms:

1. Rotation about the hip joint (sacro-pelvic sling)
2. Flexion – Extension of the lumbo-sacral joint (sacro-pelvic sling)
3. Postural vertebral integrity (core muscles)
4. Thoracic sling engagement
5. Abdominal support
6. Elastic strain energy of tendons



Picture displaying a more accurate biomechanical model. All the intricacies of this model will be explained extensively in Module 2. Advanced Biomechanics.

Simplified, this model states that biomechanics starts with force production from the hind limbs that is realized through rotation of the hip joint (1) and flexion – extension of the lumbar sacral joint (2). These forces are then transmitted through the back, which absorbs and redirects these forces through postural support from the core stabilizer muscles (3). Once the forces end up at the forehand, it must be converted into a vertical incline against gravity through engagement of the thoracic sling (4). The action of biomechanics is then concluded through abdominal support (5).

Finally, efficiency of movement (6) to reduce muscular effort is realized through elastic strain energy of tendons which ensure that motion is both balanced as well as light, allowing the horse to move with optimal efficiency, but minimal effort.

Due to the complexity of this model, Module 2. Advanced Biomechanics explains each of these mechanisms in depth, dealing with both mechanics as well as equine energetics.