Postural Strategies in Skilled Riders

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Title. Subtitle

Abstract

For optimal horse-rider communication, high-levels of technical riding-skills are needed which requires both self-coordination of the rider and coordination with the body of the horse. The scientific documentation of the optimal postural position and the technical skills for a rider is limited. It is generally agreed that good riders should be highly symmetric and must continue to develop symmetry in themselves and their horses for optimal performance in riding. On the other hand, asymmetry in riders is recognized as a negative trait. To improve the technical skills needed to develop high-level performance, the kinematics of the core segments of the rider's body must be understood and objectively characterized. The aim of this thesis was to target the intersegmental postural strategies of the foot, pelvis, trunk and head in skilled riders under three conditions: riding, walking and rocking a balance chair. 3D high-speed motion capture and inertial measurement unit techniques were used. The individual studies acquired and analysed data from 7 to 20 high-skilled riders. Sagittal-plane riders kinematics were compared between passive and active riding situations; three different intersegmental strategies were found in active riding. Most of the riders applied increased pressure on the withers area during active riding and with increased collection of the horse. Furthermore, associations were found between intersegmental postural strategies while riding, sitting on a balance chair, and walking. During walking the foot with the higher degree of eversion/pronation was associated with greater contralateral pelvic drop in early stance. Skilled riders showed a higher degree of trunk movement compared to pelvic movement while rocking a balance chair. The results suggested high degrees of movement asymmetry in these skilled riders, when comparing the individual segmental strategies on left versus right directions both when seated but unmounted and during riding. It is well accepted in the equestrian community that skilled riders should communicate with the horse through pelvic movements. The ability to characterize the intersegmental postural strategies of the rider´s seat may enhance the possibilities to train body awareness and improve equestrian performance in the future. The long-term goal should be to produce healthier individuals and better performance and the results from this thesis may promote this development.

Keywords: rider, posture, asymmetry, dressage, balance, equestrianism

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Dedication

To horses and riders worldwide, to help improving their performance and health.

”Alla har en dröm, vissa har en vision, några har mål, den som lyckas har en plan”

Nina Fox Stark

Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Engell, M.T., Clayton, H.M., Egenvall, A., Weishaupt, M.A., & Roepstorff, L. (2016). Postural changes and their effects in elite riders when actively influencing the horse versus sitting passive at trot. *Comparative Exercise Physiology*, 12 (1), pp. 27-33

II Engell, M.T., Hernlund, E., Egenvall, A., Bergh, A., Clayton. H.M., & Roepstorff, L. (2015). Does foot pronation in unmounted horseback riders affect pelvic movement during walking? *Comparative Exercise Physiology*, 11 (4), pp. 231-237

III Engell, M.T., Hernlund, E., Byström, A., Egenvall, A., Bergh, A., Clayton. H.M., & Roepstorff, L. Head, trunk and pelvic kinematics in the frontal plane in unmounted horseback riders rocking a balance chair from side to side. Submitted

IV Engell, M.T., Byström, A., Hernlund, E., Egenvall, A., Bergh, A., Clayton. H.M., & Roepstorff, L. Frontal intersegmental strategies in moderately-skilled level riders analysed in ridden and unmounted situations. Manuscript

Papers I-II are reproduced with the permission of the publishers.

The contribution of Maria Terese Engell to the papers included in this thesis was as follows:

I Not involved in the planning of the study and collection of data. Shared responsibility for data analysis, shared responsibility for summarizing the data, shared responsibility for writing and revising the article.

II Main responsibility for planning the study, shared responsibility for execution of data collection, took main part in data analysis, main responsibility for summarizing the results, main responsibility for writing and revising the article with input from co-authors.

III Main responsibility for planning the study, main responsibility for data analysis, main responsibility for summarizing the results, main responsibility for writing and revising the article with input from co-authors.

IV Main responsibility for planning the study, shared responsibility for data analysis, main responsibility for summarizing the results, main responsibility for writing and critically revising the article.

Abbreviations

2D	Two dimensional
3D	Three dimensional
AUC	Area under curve
BOS	Base of support
C6	Sixth cervical vertebra
C7	Seventh cervical vertebra
CI	Confidence interval
CNS	Central nervous system
COF	Centre of force
COM	Centre of mass
CPG	Central pattern generators
FPI	Foot posture index
HROM	Range of motion for head segment
Hz	Hertz
IMU	Inertial measurement unit
Kg	Kilogram
kPa	Kilopascal
L3	Third lumbar vertebra
LAB	Laboratory based coordinate system
LMN	Lower motor neurons
OR	Odds ratio
PCA	Principal component analysis
PCs	Principal components
PMAX	Pelvic maximum rotation
PMIN	Pelvic minimum rotation
PROM	Range of motion for pelvic segment
PT-phase	Phase shift between pelvis and trunk
ROM	Range of motion

SE	Standard error
T10	Tenth thoracic vertebra
TMAX	Trunk maximum rotation
TMIN	Trunk minimum rotation
TROM	Range of motion for trunk segment
UMN	Upper motor neurons

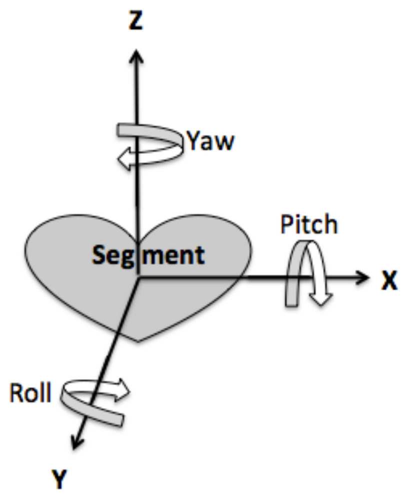


Figure I: Illustration of segmental rotations (pitch, roll, yaw) around the segmental axes (X,Y,Z).

1 Introduction

Equestrian sport, more often known as horseback riding, is one of the few sports that involves two separate individuals competing in unity, one horse and one human, both with their own mental and physical abilities. Apart from the mental skills that are common to most athletes in competition situations, the rider also needs to have a high level of technical riding skills to physically communicate with the horse. The communication is mainly based on tactile stimulation, with the rider reading signals from the horse and giving instructions to the horse through the riding aids; the seat, the legs and the hands. The technical skills necessary for high performance riders have not been defined in detail from a scientific aspect.

In the equestrian community, a general conceptual understanding is that the rider should guide the horse through pelvic movements and that riders that are more physically symmetrical are more able to perform well. Studies have shown that riders, even at advanced levels, display high degrees of movement asymmetries (Symes & Ellis 2009; Hobbs et al. 2014; Alexander et al. 2015). Therefore it is necessary to further investigate rider movements and their possible effect on the horse's biomechanics. Authors have also suggested that the rider's position during riding might cause pathological conditions in the equine back (von Peinen et al. 2010). At the same time research has demonstrated a high frequency of back pain in riders in general (Kraft et al. 2009). Back pain in the rider, the horse, or both is likely to be associated with sub-optimal performance. Therefore, both from the standpoint of welfare and competition, it is important to understand mechanisms and causes of movement asymmetries and how they can be prevented. Better understanding will help to define optimal riding posture for the different equestrian disciplines, and suggest how to train the specific technical skills necessary to ensure healthier individuals and better performance.

1.1 Background

1.1.1 Equestrian history

Equestrianism is popular worldwide, with millions of horses and riders participating in competitive horse sports and non-competitive leisure riding. Humans have always admired these beautiful animals. Although there is controversy over the exact date horses were domesticated and when they were first ridden, the best estimate is approximately 3500 BC. In the beginning, horses were used for warfare, whereas today they are mostly used for leisure and competitions in different disciplines based on the skills of riding, vaulting, and driving. The equestrian sports of dressage, jumping and eventing became part of the modern Olympics in 1912 and they are still Olympic disciplines today.

During the past four decades, there have been tremendous changes in the industry that revolves around equestrian sports. The focus on breeding talented athletes has produced horses with exceptional movement and athletic abilities that jump higher and run faster than previous generations of horses. With the increased interest in equestrian sport, it is of importance to spread knowledge on equine welfare and management (Walters et al. 2008; McLean & McGreevy 2010). A better understanding of the interactions within the horse–rider system is of critical importance, since many orthopaedic diseases are seen exclusively in ridden horses.

1.1.2 Horseback riding, what is it?

Riding involves a complex interface between horse and rider. By applying different signals or pressures to the horse through the rider's aids e.g. legs, hands/reins and seat, the rider instructs the horse to perform different movements (Micklem 2011). The equestrian discipline of dressage has a rich history with ancient roots in the writing of Xenophon (Xenophon 2006). Top-level dressage is an advanced form of riding performed at exhibitions and competitions, but also recognized as an "art" solely pursued for the sake of mastery.

The horse and rider are two independent systems that should move together in a coordinated manner. The two individuals are united by the saddle which improves the stability of the rider's seat and distributes the rider's weight more evenly over a larger area of the horse's back (Jeffcott et al. 1999; de Cocq et al. 2006; Clayton et al. 2013). The three components of the horse-saddle-rider system each have their own physical properties of inertia, elasticity and degrees of freedom of movement. During horseback riding the rider strives to move synchronously and rhythmically with the horse, like two wellchoreographed dancers. When horse and rider successfully coordinate their movements, it is intuitively perceived by equestrians and referred to as ‘‘harmony” (Witte et al. 2009), which is one of the main goals in riding.

Learning how to ride is, in essence, to develop the ability to follow the horse's movements (Lagarde et al. 2005), but also to act proactively and guide the horse into new movements while controlling its pace and tempo. At higher competition levels the demand to improve performance is immense, and it enforces the rider to continuously strive to improve his/her technical skills. In order to perform well in equine sport the rider needs to communicate with the horse with high precision. Optimal function of the riding aids is dependent on the rider having excellent postural control, balance and rhythm. Good postural control is a prerequisite for good balance and rhythmical qualities (Pollock et al. 2000).

1.1.3 The horse and its rider

Equine locomotion and neurobiology

Coordinated movement is dependent on a well-functioning nervous system. The upper motor neurons (UMN) are part of the motor system that is confined to the central nervous system (CNS). The UMN system is responsible for the initiation of voluntary movements, the maintenance of muscle tone for body support against gravity, and the adaption of posture. Nerve fibres connect the UMN with the lower motor neurons (LMN) over which they exert direct or indirect control (De Lahunta et al. 2008). The UMN system is divided into pyramidal and extrapyramidal tracts. In humans, compared to horses, the pyramidal system is more developed and enables fine-tuned motor activity and smooth fine movements. Consequently, horses are less able to perform fine motor skills. All voluntary movements depend on excitation of the LMN by the UMN. Skeletal muscle fibres are innervated by LMN classified as alpha motor neurons and gamma motor neurons. Alpha motor neurons innervate extrafusal muscle fibres which are directly engaged in muscle contraction, whereas gamma motor neurons innervate intrafusal muscle fibres or muscle spindles which are engaged in proprioception (De Lahunta et al. 2008).

When comparing horses to humans, it has been suggested that horses have greater dependency on central pattern generators (CPGs) in the spinal cord that can generate rhythmical movement patterns autonomously. The theory is that when a certain amount of sensory input is applied, these centres are activated and will create a rhythmical movement pattern (Duysens & Van de Crommert 1998; Grillner 2002) e.g. from walk to trot, trot to gallop. These CPGs remain unaltered during the animals lifetime, although they may become slightly adjusted (Duysens & Van de Crommert 1998; Dietz 2003). In horses it is well known that activation of trunk muscles differs between walking, trotting and galloping (Kienapfel et al. 2018). It is hypothesized that the trunk muscles are activated through CPGs, which produce the rhythmical activity of these muscles. This might be one of the reasons why scientists have recognized a more systematic gait pattern in horses compared to humans (Duysens & Van de Crommert 1998). CPGs are also hypothesised to be found in humans, but since humans have a more developed pyramidal system; it has been stated that "humans cannot reproduce the exact movement twice". For normal locomotion in humans, the UMN pathways are responsible for stimulation via the CPGs, but not through the CPGs alone (Duysens & Van de Crommert 1998; Dietz 2003). In horses, the roles of the UMN are minimal compared with those of humans (Cazalets et al. 1995).

The equine back

The equine spine provides an important structural and functional component of the locomotor apparatus. The rider is mounted on the thoracolumbar region of the equine spine and its functionality is considered to be important in riding. The thoracolumbar region links the four limbs together and is, therefore, central in the musculoskeletal system and also central for equine performance (Van Weeren 2006). During each stride cycle the horse's back movements involve gait-specific 3D translations (vertical, longitudinal, transverse) and rotations (yaw, roll, pitch, see abbreviations) (Faber et al. 2001). The range of motion for these rotations and translations varies with gait, with speed, and with horse (inter-individual qualities). The main function of the equine back is to transfer biomechanical forces between the thoracic and pelvic limbs (Van Weeren 2006; Van Weeren et al. 2010).

The mechanics of the horse's back have been described in terms of a bow-string concept, in which the bow is represented dorsally by the thoracolumbar vertebral column and the string is formed ventrally by soft tissues, mainly the *linea alba*, *m. rectus abdominis* and related trunk structures. This is the most accepted biomechanical model of the equine back (Van Weeren 2006; Van Weeren et al. 2010). The equine spine differs from the human spine in several aspects. The mass of abdominal contents tends to extend the intervertebral joints of the horse's horizontally-oriented spine and a rider´s weight adds to the downward force, creating a "hollow" back (Van Weeren 2006).

There are studies describing the effect of the rider in sitting and rising trot on the equine back. These studies showed that the rider movements induces an uneven biphasic load on the back, pelvis and limb kinematics (Roepstorff et al. 2009). Rising trot shows characteristics of both sitting and unloading conditions (de Cocq et al. 2009). Martin et al (2016; 2017) used inertial measurement units under the saddle to study the influence of the rider on the equine back. When the rider performed rising trot the range of motion (ROM) of the horse's back increased significantly in the standing phase compared to the sitting phase. The rider`s ROM (vertical displacement of COM) was lower during the standing phase compared to the sitting phase. During sitting phase the COM of the rider was closer to the COM of the horse (Martin et al. 2016, 2017).

The downward force on the thoracolumbar spine is counteracted by contraction of the ventral musculature with the epaxial musculature acting antagonistically. The psoas muscles, located ventral to the lumbosacral vertebrae and inserting on the pelvis and proximal femur, flex the lumbosacral region. Limb pendulations also affect flexion-extension of the back. In the forelimbs, protraction tends to extend the back, retraction results in flexion. The hind limbs follow the same in principle, but the effect is in the opposite direction (Stubbs et al. 2006; Van Weeren 2006; Van Weeren et al. 2010). The head also has a major influence on back movement: lowering of the head arches the thoracolumbar spine, whereas a raised head and neck position has the opposite effect.

In the horse, passive stability of the spine is high, due to the semi-rigid anatomy of most of the lumbar spine, but stabilizing muscles like *mm. multifidi* also play an important role in this species (Stubbs et al. 2006). The *multifidi* complex continues through the sacrum to the caudal vertebrae as the *m. sacrocaudalis dorsalis medialis* and *lateralis* muscles, with fascicles that mirror those of *mm. multifidi* (Stubbs et al. 2006).

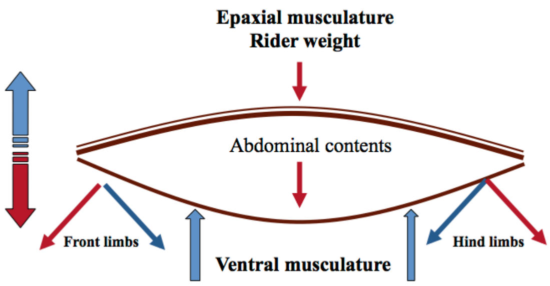


Figure 1: The mechanical function of the equine back according to the "Bow-String Concept".

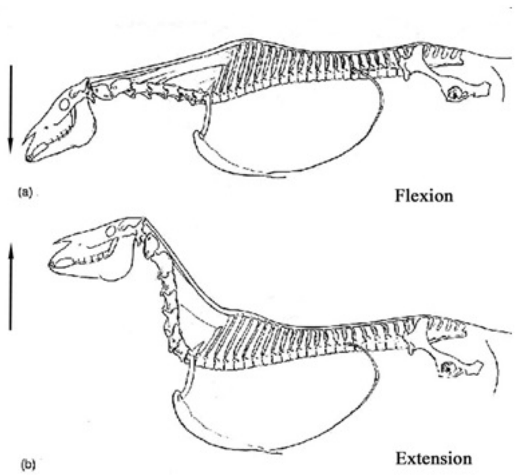


Figure 2: The flexion and extension of the equine back (Denoix & Denoix 2011).

The equine back is able to carry the rider over a wide range of speeds and distances. During a stride cycle the equine back creates perturbations that the rider`s body needs to handle and attenuate through its segmental system, pelvis-trunk-head, to maintain balance and rhythm. During trotting the diagonal limb support pattern stabilizes the horse in both the sagittal and frontal planes (Hobbs and Clayton, 2014) resulting in a small ranges of motion around the transverse and longitudinal body axes (Buchner et al. 2000).

Lateralities/asymmetries in horses

It is well known that horses have some degree of inherent laterality in their locomotion pattern. The term laterality refers to the preferred use of one side of the body over the other and has been recognized across a wide range of species (Rogers 1989). Typical examples of motor laterality in man include left/right side preferences with regard to use of the hands, legs, eyes, and ears. A typical example of equine motor laterality, recognised by the rider or trainer, is that the horse has an "easy side" and a more "difficult side" when trained. When lunging a horse it is often observed that horses are more willing to move to the left than to the right (Rogers 2009), and they remain on the peripheral circle line turning to the left, whereas they tend to cut across the circle when travelling to the right (Lucidi et al. 2013).

A central goal when training a horse is to minimize this natural laterality and create a horse that is more symmetrical, balanced and straight. Motor laterality in riding horses is a complex subject since both horse and rider can be asymmetrical making it difficult to distinguish whether the rider or the horse is the main cause for the asymmetrical outcome. The rider's influence on the laterality of the horse has been discussed in terms of unilateral handling (Farmer et al. 2010), rider position in the saddle (Nevison & Timmis 2013) and unevenness of rein tension (Kuhnke et al. 2010) or saddle (Von Peinen et al. 2009). Little is still known about how an asymmetrical rider influences the biomechanics of the horse, but it is documented that a rider with an asymmetrical position will transfer asymmetrical forces to the saddle and the horse's back (Peham et al. 2001; Licka et al. 2004; Byström et al. 2009).

Asymmetry in lameness

Orthopaedic diseases are the most common group of health problems in today´s sport horses and also the main reason for interruption of their career (Penell et al.2005). The main sign of orthopaedic disease is lameness, which is defined as "an alteration of the normal gait due to a functional or structural disorder in the locomotor system" (Buchner et al. 1995). Poorly-fitting saddles and poor riding are suggested to exaggerate asymmetries, and this may progress to subtle, but chronic, lameness before overt clinical signs of lameness become apparent (Greve & Dyson 2013).

A number of studies in equine biomechanics have been dedicated to enhancing the diagnosis, treatment and rehabilitation of equine lameness patients. Biomechanically, lameness is measured by quantification of left/right asymmetry in vertical displacement of head, withers and pelvis (Buchner et al. 1995; Buchner et al. 2000; Keegan et al. 2001). Until recently the visual clinical examination has been the prime tool to detect and quantify lameness. However, this subjective visual assessment of lameness has been shown to be inconsistent, with low to moderate agreement between observers (Keegan et al. 2010; Rhodin et al. 2017).

Biomechanical measuring technique

Kinematics is the study of movement. Kinematic analysis of locomotion analyses and compares sequential still images captured during motion of a human or animal. Kinetics is the study of external and internal forces acting on the body. Stationary force measuring platforms (i.e. force plates) are a popular technique for measuring ground reaction forces and for objective kinematic analysis of lameness in horses.

Biomechanical analysis of movements of the limb segments can be described in absolute terms within a reference coordinate system or relative to another body segment (e.g. a joint angle). Today, state-of-the-art 3D motion capture uses highly accurate automated systems in which cameras track reflective markers attached to the subject to identify specific anatomical locations. The cameras detect non-visible or infrared light reflected by the markers. These resulting data can be analysed in 3D or used for a 2D planar analysis. These systems are highly accurate and are therefore considered the "gold standard" for kinematic analysis. Because these systems are expensive and the equipment rather heavy and cumbersome, recent focus has been put on developing other solutions for motion capture. The most frequently used technology relies on inertial sensors attached to body segments. The sensors contain wireless, portable miniature accelerometers. More complex inertial measurement units (IMUs), incorporating gyroscopes and magnetometers, may provide a quick and user-friendly method of detecting asymmetries (Pfau et al. 2016). Such systems have become increasingly used for lameness detection by equine veterinarians and also in the scientific community to study equine locomotion.

1.1.4 The rider

The rider communicates with the horse by the riding aids; legs, hands/reins and seat. The purpose of this section is to give a short introduction to the complexity of the rider's seat. To understand the challenges of the rider's seat, it is necessary to explain the concept more in detail. The main goal for a rider is to develop a high level of automatic technical riding skills, which requires coordination of the rider's own body and the horse. To be able to perform this coordination riders must have control of their own seat. The basis for development of good seat strategies is control of rotations and translations of all body segments (head, trunk, pelvis, feet and hands) in space and time. To break down this concept to the next level; the awareness of posture and balance is critical for a good seat strategy. Postural control for riders implies organizing the body segments in a functional way to facilitate balance control and the capacity to handle perturbations provoked by the horse. A prerequisite to control posture and balance is to correctly interpret sensory input. For example, the brain might interpret an over-pronated foot or a laterally tilted pelvis as a normal and accepted postural alignment, while it in fact might be a critical hindrance for development of good technical riding skills. In such cases it is important to make the rider aware of this postural aberrations, teach the rider to sense the segmental positioning, and finally provide a strategy to correct it. The leg segments are part of a kinematic chain, and every link of the chain plays a role in achieving optimal performance. In the following sections each of these levels will be described in more detail.

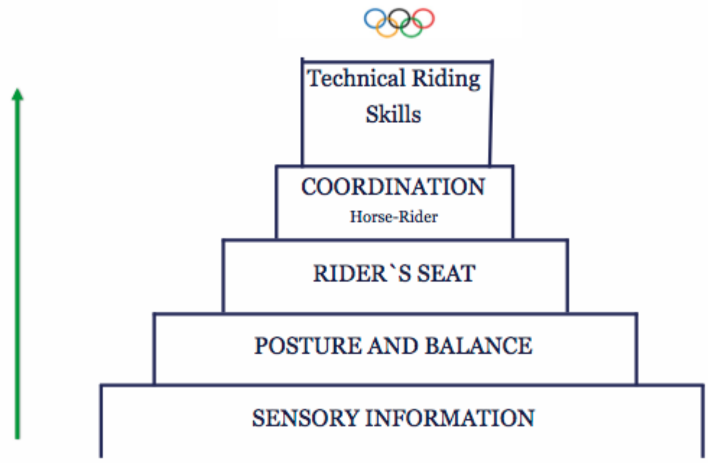


Figure 4: An illustration of the concept for development of technical riding skills as presented in this thesis.

Sensory information

Sensory information is mainly based on three different systems, visual and vestibular and proprioceptive/somatosensory systems. Vision plays an important role in balance and postural control, presenting positional information in relation to horizontal and vertical lines (Thomas et al. 2016). In general, postural sway (horizontal movement around the centre of gravity) increases in the absence of vision (Schmit et al. 2005). Sensory information helps the rider to maintain the posture and balance.

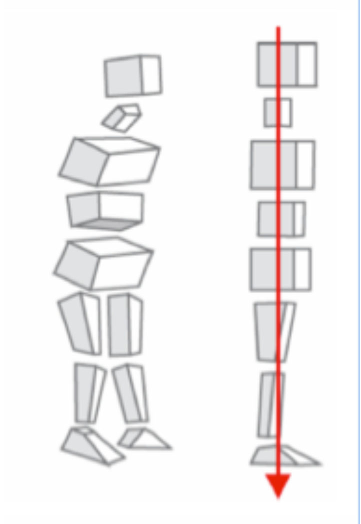
The vestibular system is the human's own IMU, which senses linear and angular accelerations (Olivier et al. 2017). The vestibular system is of major importance in, for instance, show-jumping when the velocities change to a large degree between deceleration before a jump and acceleration after the jump.

The proprioceptive system consists of a multitude of receptors that sense position and movement of all body segments, contact with the external environment, and gravity. These mechanoreceptors are stimulated by mechanical forces e.g. stretch, vibration and pressure. Recent research has noted a significant influence of skin sensory information with a close relationship between tactile information and posture (Beaudette et al. 2017). The muscle and tendon receptors also provide neural input for static-position sense (Mccloskey 1978).

It is currently thought that in the absence of visual information, muscle spindles are responsible for the sense of position and movement, tendon organs provide the sense of tension in a muscle, and the vestibular system is responsible for the sense of balance (Proske 2005; Winter et al. 2005). New research puts more focus on skin receptor information as an important factor for postural control (Beaudette et al. 2017). The sensory information influencing the brain creates a proprioceptive map (Bolognini & Maravita 2007), that might be highly specific or more generalized, but is always adaptive in relation to new variables (Bolognini & Maravita 2007).

Posture and Balance

Posture is defined by the positions of the core body segments (head, trunk, pelvis) and limb/arm segments relative to each other in relation to space. All body segments have their own weight and might provoke a change in the position of other segments to maintain balance (Fig. 4) (Shumway-Cook & Woollacott 1995; Winter 1995; Brodal 2004). Postural control has been defined as the ability to control the body in space and ensure its stability and orientation (Brodal 2004).



A B

Figure 4: Alignment of the body segments in standing posture. A= poor alignment, B= good alignment.

The word ‘posture’ is often related to a more static position. Posture and movement are usually perceived as two different characteristics of motor control. The interesting question is to what extent posture can be distinguished from movements and this has not yet been answered convincingly (Massion 1998). The most intuitive definition is based on the static nature of posture compared with the dynamic character of the movement (Winter 1995; Massion 1998). However an individual is most often in motion to some degree, even though the range of motion may be very small. Posture can also be described as the anatomical position of the body segments in relation to base of support (BOS) (Winter 1995; Massion 1998). Thus, the focus is on how the axial and proximal limb musculature serves to support the distal limb segments.

The word balance is a commonly used term, and often used in association with terms such as stability and postural control (Pollock et al. 2000). The term balance is also used frequently by riders and riding instructors. Despite the widespread use of the term, there is no universally accepted definition of human balance. In mechanics, it is somewhat similar to equilibrium and, as such, is defined as the state of an object when the resultant forces and moments acting upon it sum to zero (Newton's First Law) (Pollock et al. 2000). The ability of an object to balance in a static situation is related to the position of COM relative to the area of its base of support. If the line of gravity, which drops vertically from the COM falls within the BOS of an object, then the object is in static equilibrium and is described as being balanced. Stability depends on the location of the line of gravity within the BOS and how far the line of gravity can be displaced before it falls outside the BOS and the object becomes unbalanced (Winter, D. A. 1995; Pollock et al. 2000). The further the line of gravity can be displaced before losing balance, the greater is the stability. The relationship between stability, BOS, line of gravity and centre of gravity (COG) are all components of the concept of balance (Winter 1995; Pollock et al. 2000).

The main goal for the moving human is to remain in sufficient balance while executing motor tasks. Postural control strategies may be either 'reactive' (compensatory) or 'predictive' (anticipatory), or a combination of both (Massion 1998; Chiba et al. 2016). A predictive strategy involves a voluntary movement, or increase in muscle activity performed proactively, while a reactive strategy involves a movement or muscular response following an unpredicted disturbance. These responses may be 'fixed-support', where the COM is moved but BOS remains fixed, or 'change-in-support', were the BOS is changed to maintain balance. Swaying from the ankle or hip ('ankle strategy' or 'hip strategy') are commonly described fixed-support strategies (Runge et al. 1999), while stepping is a common example of change-in-support strategies (Pollock et al. 2000). This view of postural control implies that balance control can be considered to be a fundamental motor skill learned by the CNS. Thus, like any other motor skill, postural control strategies can become more efficient and effective with practice. Postural control can, therefore, be regarded as a complex motor skill integral to human posture and movement (Massion 1998; Runge et al. 1999; Chiba et al. 2016).

The rider´s back

The human spine has four distinct sagittal plane curvatures (cervical, thoracic, lumbar, lumbosacral) that facilitate absorption and transmission of perturbations and forces (Roussouly & Pinheiro-Franco 2011). For a standing human it has been shown radiographically that if a vertical line is drawn between Thoracic1 - Thoracic12 - Sacral1, mean values for the curvatures are: thoracic kyphosis: 45°; lumbar lordosis: 60°, and lumbosacral angle (sacral tilt): 30° (Harrison et al. 1999; Campbell-Kyureghyan et al. 2005). However, an exact standard sagittal measure for all humans does not exist. One of the spine's major biomechanical functions is to handle perturbations and transmit forces either from the lower to the upper body or in the opposite direction (Chiang & Potvin 1999). To accomplish this the spine needs to be stable. In the last decade, the focus has turned to understanding the function of deep spinal muscles, particularly *m. transversus abdominis* and *mm. multifidi*, instead of focusing on the global mobilizing muscles like *m. rectus abdominis*, *m. external/internal abdominal obliques*, and *m. longissimus dorsi* in relation to stabilizing the spine and preventing back pain (Tsao & Hodges 2008).

In sitting positions, several upright postures have been hypothesised as 'ideal', to limit low back pain (Claus et al. 2009), and there is some evidence that some positions are more ideal for sitting posture in relation to reduction of back pain than others (Claus et al. 2018). With an optimal curvature, the spine is assumed to use the least muscular force, both in the deep stabilizing musculature and the superficial mobilizing musculature, to maintain posture and handle the perturbations. Those positions that showed increased activation of the global mobilizing muscles (*m. external abdominal oblique, m. rectus abdominis* and *m. latissimus dorsi)* had higher frequency of pain (Nairn et al. 2013; Schinkel-Ivy et al. 2013). By using the global skeletal muscles instead of the deep stabilizing muscles (e.g *mm. multifidi*) to maintain the normal spinal curvature, there is potential consequence of abnormal spinal loading and provocation of back pain (Claus et al. 2018).

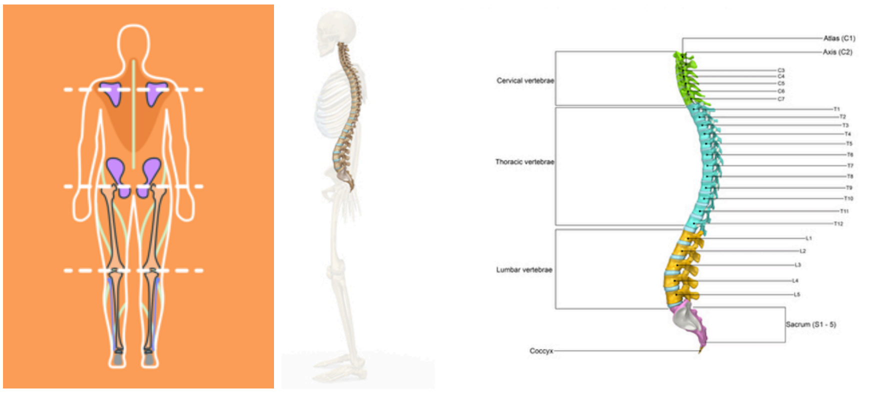


Figure 5: Frontal full body alignment (GaitLine) and sagittal curvature of the spine (iStockphoto).

Rider's foot posture

The human foot plays a fundamental role in standing and walking by connecting the body with the ground, and the symmetry of the pelvis and upper body is highly dependent on foot position (Pinto et al. 2008; Duval et al. 2010; Svoboda et al. 2014). Foot posture is known to influence pelvic alignment both in the sagittal and frontal planes (Khamis & Yizhar 2007; Pinto et al. 2008; Resende et al. 2015; Resende et al. 2016) and, consequently, affects spinal posture (Levine & Whittle 1996; Legaye et al. 1998; Gurney 2002).

A common and important foot posture, during standing and walking is foot pronation (walking on the inside of the foot), generally evaluated as calcaneal eversion, which measures rotation around the longitudinal axis (heel to toe) of the foot (Fig. 6). Foot pronation may consist of eversion in the frontal plane and external rotation in the transverse plane. Further, eversion is the movement that occurs when the sole of the foot rotates away from the median plane. Transverse and sagittal plane deformations of the metatarsus under load have been subject to limited analysis (Leardini et al. 2007). The Foot Posture Index (FPI) is a generally accepted scoring system for defining the degree of foot pronation (Horwood & Chockalingam 2017). The FPI consists of a series of criterion-based observations that is combined to provide a quantification of postural variation in three major regions of the foot (rearfoot, midfoot, forefoot) in the three cardinal body planes. The FPI shows that a normal foot pattern also displays some small degree of pronation. The FPI classifies the feet into 'normal' (0 to +5 on FPI), 'pronated' (+6 to +9), 'highly pronated' (+10), 'supinated' (−1 to −4) and 'highly supinated' (−5 to −12) with the higher the scoring the more pronation markers recorded (Keenan et al. 2007).

When higher degrees of foot pronation are present, eversion of the calcaneus and adduction of the talus lead to internal rotation of the lower limb with a functional reduction in length of the lower limb (Gurney 2002). When the person is viewed in the standing position in the frontal plane, this produces a pelvic drop on the same side of the pronated foot (ipsilateral pelvic drop), which, in turn, may cause a certain degree of functional scoliosis (Gurney 2002; Pinto et al. 2008). Several studies performed in the standing position show that when a unilateral increase in calcaneal eversion is induced by the use of medially tilted wedges, there is an ipsilateral pelvic drop due to shortening of the lower limb on the wedged side (Pinto et al. 2008; Souza et al. 2014; Resende et al. 2015). During the normal gait cycle the pelvis moves laterally and downward (drops) toward the contralateral side during the period from heel strike to mid stance. Excessive foot pronation has been associated with low back pain, possibly because it may lead to lateral tilt of the sacral base and consequently to lumbar scoliosis (Gurney 2002; Aebi 2005; Pinto et al. 2008).

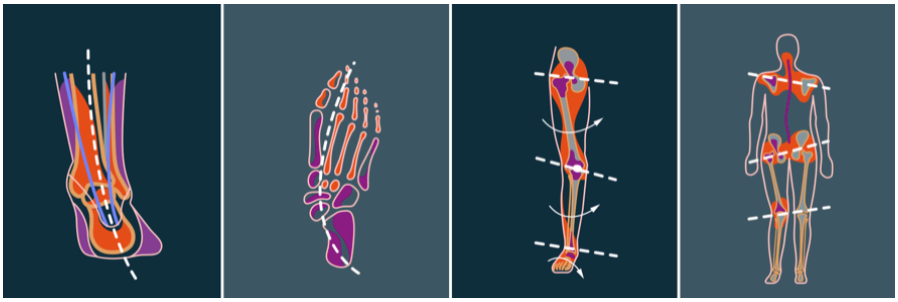


Figure 6: From left: first fig.: shows calcaneal hyper pronation (frontal view seen from behind). Second fig.: the walking pattern in stance phase (from heel strike to toe off) with hyper pronation (transversal view). Third fig.: shows consequences of the proximal limb joints and segments (frontal view). Fourth fig.: an example of the consequences, which might occur in axial body segments (GaitLine).

Motor control

Motor control is the systematic regulation of movements by the nervous system. This includes postural control as well as muscular action to create intentional movements. When performing a complex movement it is the neuromotor control system in the CNS that is in charge, controlling the muscle recruitment and timing, depending on sensory information from receptors in skin, muscles, tendons, joints as well as visual and vestibular systems (Hodges 2011). The CNS provides a stabilising system for maintaining joints in their appropriate position throughout locomotion and perturbations (Hodges et al. 2008). The response of the nervous system to stimuli may either be voluntary or involuntary. A hallmark for voluntary control is that the individual can stop the movement at will (Ghosh et al. 2014), whereas in an involuntary response the reflex action is not under conscious control (Ghosh et al. 2014), but instead is a reflex action mediated at spinal cord level.

Feedback control takes into account the information received from the sensory systems and modifies the movement outcomes accordingly. This produces movements with high accuracy and with the possibility for correction, but is necessarily slower than the feedforward loop (Seidler et al. 2004). In contrast, since feedforward movements do not need feedback information they can occur very rapidly (Seidler et al. 2004). Optimal movement control includes both feedforward and feedback mechanisms.

During the acquisition of new motor skills, movement control changes from feedback to feedforward during the learning process. This means that a novice rider will become faster and more accurate as the rider becomes more competent. A hallmark of advanced riders is that they are less reliant on feedback control (Seidler et al. 2004).

During painful conditions, neuromotor control is altered (Hodges et al. 2013). For example, in the presence of low back pain, the strategies used by the CNS to control the trunk muscles changes resulting in less efficient muscle recruitment strategies (Hodges, 2001). This has been an area of scientific interest over the last decade, especially in relation to management of back pain and rehabilitation in both human and equine medicine. The *mm. multifidi* change in relation to altered recruitment patterns that result in atrophy as evidenced by reduced cross sectional area and infiltration with adipose tissue (Hides et al., 1996; Stubbs et al., 2010). What is notable is that there is not an automatic reversal of dysfunction with resolution of pain. It requires highly specific rehabilitation exercises to restore the muscle's function and size.

"The human brain does not think MUSCLES, but PATTERNS"

The neuromotor system has exceptional abilities to perform skilful movements. For example, when the horse and rider are jumping a large obstacle, the take off, aerial phase and landing are completed within a period of one second. There are several issues that make this a difficult computational problem for the human (as well as the equine) brain to solve. In more general terms these computational problems revolve around:

- Uncertainty; This reflects incomplete knowledge either with regard to the state of the world or the task itself or the rewards that might be received. An example would be the uncertainty for the rider; whether the horse will maintain the same position and velocity during take-off, in the air and during landing.

- Redundancy; The rider must determine which of the over 200 joints and 600 muscles of the body he will use in order to move his body segments while maintaining his own balance and without interfering with the horse. These physical properties make the motor system ‘redundant’ because there are multiple coordination patterns through which the same task could be achieved, leading to an abundance of possible solutions.
- Sensory feedback; Information describing the fence`s location, visual appearance, and his motor outputs are corrupted by noise originating from the tack (e.g. saddle slippage), the audience (e.g. cheering), the environment (e.g. rain), the footing (e.g. slippery) etc. These may lead to variability in both perception and action.
- Delays; Both the processing of sensory feedback and the motor response are subject to delays. For example, visual perception of the fence location takes about 100 ms so the rider is constantly operating in the past. Delays are present in all stages of the sensorimotor system, from receiving afferent sensory information to executing efferent motor responses (Franklin & Wolpert 2011).
- Non-stationary; The system’s physical properties change over time requiring continual adaptation. For example, during a competition the rider must correct for muscle weakness as fatigue develops.

Rider’s seat

A rider’s posture is often suggested to be optimal if a vertical line can be drawn between the rider’s shoulder-hip-heel and a straight line between the elbow-forearm, reins and horse’s mouth. These rules of thumb are used by many riding instructors and generally thought to be essential characteristics for a correct dressage seat (German National Equestrian Federation 1997).

During the last decade studies have investigated the coordinative connection between horse and rider, mainly in trot. At the trot, the rider’s pelvis accommodates both pitching (craniocaudal) rotations and vertical displacements of the horse while the trunk compensates for longitudinal translational motions (see appendix) (Terada et al., 2006). Therefore, the velocity vector of the horse’s trunk affects the rider’s segmental positions and movements. Byström et al. 2009 showed that the rider’s pelvis had a biphasic pattern in sitting trot and that this pelvic pitching motion is highly repeatable. From early stance to midstance the rider’s pelvis cranially rotated in pitch and away from the supporting hind limb in roll and yaw. The upper body caudally rotated in pitch related to pelvis and yaw rotated towards the supporting hind limb. From midstance to the next diagonal pitch (anterior-posterior) rotations were reversed (Byström et al. 2009).

Many studies have focused on differences in the rider's position depending on their riding skill levels. Peham et al. (2001) demonstrated that an experienced, professional rider was able to ride a horse more consistently compared to a recreational rider, and with a smaller phase shift between the horse and rider (Peham et al. 2001; Peham et al. 2004). In 1993, Schils et al. studied differences in rider positions between various skill levels across riding disciplines and gaits. They found that advanced riders adopted a more vertical position in all gaits with the thigh and lower leg positioned under their body and the upper arm carried ahead of the trunk. The authors suggested that rider skill level would affect the horse's gait and that it is important to consider the rider when performing biomechanical studies on the ridden horse (Schils et al. 1993). Olivier et al. showed that highly skilled professional riders maintained a higher degree of postural stability and were less dependent on visual input compared to novice riders (Olivier et al. 2017). Further, Peham et al. (2004) reported that movement stability in a horse trotting on a treadmill improved under a professional rider. These results were supported by Lagarde et al. (2005) and Schöllhorn et al. (2006) who showed that, compared to novice riders, expert riders were better able to coordinate their own movement pattern with that of the horse and elicit more consistent, stable movement patterns in the horse (Lagarde et al. 2005). Münz et al. (2014) analysed the interaction of the rider's pelvis with the horse making comparisons between 10 professional and 10 novice riders in walk, trot and canter. Rider skill level influenced the rider posture. Also passive dynamics changed between gaits with the largest anterior-posterior pelvic rotation being found in canter, followed by trot and walk (Münz et al. 2014).

Since riders essentially communicate with the horse using the seat, the hands/reins and the legs, and constantly deal with impulses from the back of the horse, they depend on alignment and coordination of the axial body segments. The rider's seat is central in the performance for the equestrian athlete because it is a determinant of the rider's ability to give precise and symmetrical signals to the horse by changes in pelvic kinematics and weight distribution. An effective seat is described to be upright, balanced, elastic, solid, and interactive (Blokhuis et al. 2008). The degree of symmetry in both horse and rider is highly relevant for the level in the sport (Symes & Ellis 2009; Hobbs et al. 2014). In many equestrian disciplines, such as dressage and show-jumping, the aim is for the horse to be as dynamic, balanced and flexible when being ridden to the left as it is when being ridden to the right (Blockhuis et al. 2008, Münz et al. 2014). In the equestrian community it is generally thought that a symmetrical rider has a better possibility to influence the horse in an optimal way (Hobbs et al. 2014).

In general humans exhibit mild functional asymmetries/lateralities (Nevison & Timmis 2013). Functional asymmetry, in contrast to structural asymmetry (eg. leg length difference), can be improved by training for more symmetrical movements. In other sports reduction of asymmetry is thought to enhance performance and reduce health risks such as back problems (Nevison & Timmis 2013). Several recent studies have focused on the symmetry of riders both ridden and unmounted. Hobbs et al. 2014 performed a study on 127 riders at different skill levels evaluating static and dynamic symmetry of the trunk segment. They found that the riders were highly asymmetrical. Intriguingly, asymmetry in height of the acromion process during standing increased with competition level. They also noted that the prevalence of back pain in the riders tended to increase with increasing competition level (Hobbs et al. 2014). Symes et al. (2009) found a relationship between asymmetry of the rider's shoulder rotation (left rotation) during riding and leg length discrepancy (right leg shorter) during standing, but did not take foot posture or head and pelvic segmental alignment into consideration (Symes & Ellis 2009). Another study, including 10 dressage riders, showed asymmetric trunk and pelvic postures during sitting trot (Alexander et al. 2015). Gandy et al. 2014 studied hip rotation in 12 riders during riding. Asymmetry between left and right hip in external rotation, was revealed in all of the riders (Gandy et al. 2014).

It has been stated that for lateral movements (see appendix), the rider should always shift weight in the direction of movement of the horse. For the travers, in which the hind quarter is brought to the inside and the horse bends to the inside, the weight shift should go towards the inside of the horse. Shoulder-in is a more complicated topic. The riding literature states that it is the only exception to the rule, i.e. here more weight should be put on the inside where the opposite would be expected based on the general rule (Hess, et al. 2014). A study performed by de Cocq et al. in 2010 could not display this type of weight shift in shoulder in, even in experienced riders. They could show that there was a slight tendency towards the opposite side instead. In travers the theory of placing weight towards the inside of the horse, was confirmed.

Health risks for riders

Horseback riding is one of the most dangerous sports, with injuries being due to acute traumatic incidents, often related to falls or horse-kicks (Quinn & Bird 1996; Kraft et al. 2009). Apart from these acute incidents, riders frequently complain of orthopaedic pain. Low back, hip joint, and hamstring muscle pain are the most common symptoms among competitive riders (Quinn

& Bird 1996; Kraft et al. 2009). When comparing riders to the general population, it has been shown that 73% of riders have back pain (Kamaz et al. 2007). The causes of low back pain remain unknown but there are likely to be multiple factors affecting this high rate of back pain among riders. One may relate to overuse syndrome of the lumbar spine (Quinn & Bird 1996; Kraft et al. 2009). Sitting in general has been discussed in the literature as a potential cause of low back pain because the pelvis is often rotated posteriorly allowing the lumbar lordosis to flatten. This posture increases strain on the posterior passive elements of the spine e.g. paraspinal muscles and ligaments. It is generally accepted that prolonged sitting, for example during driving is likely to aggravate low back conditions or instigate the development of a new condition (De Carvalho et al. 2010). Thus, poor posture in combination with the effects of perturbations has been identified as sources of increased risk of low back injuries. Top-level dressage riders often ride often as many as 6-8 horses per day over a period of several hours and are constantly affected by perturbations. It is argued that to maintain a healthier low back, it is important to maintain a degree of lordosis, since this will have a protective effect on the spinal structure (De Carvalho et al. 2010). This has been suggested (Quinn & Bird 1996) but is yet not evaluated in the context of riding.

On the other hand, multiple studies have presented positive effects of therapeutic riding (Matsuura et al. 2008; Håkanson et al. 2009; Kim et al. 2014), even in patients with back pain (Yoo et al. 2014) or head/neck pain (Kim et al. 2015). The horse's movements stimulates the patient's proprioceptive system and challenges active control of the patient's posture, balance and righting reactions (Winchester et al. 2002; Kim et al. 2015).

1.1.5 Development of rider skills

To develop high level of postural control, balance and stability, which is necessary in almost all dynamic sports (ballet, alpine skiing, judo, paddling etc.), athletes need to train with high precision, at varying speed, and in different environments to drill the specific movement patterns necessary for the given sport. Proper balance control when learning motor skills is mainly based on muscular synergies that minimise the displacements of the COM while maintaining upright stance, proper orientation, adapted locomotion and adequate techniques imparted to the sport practised. Choice of the neuromotor strategy most appropriate for the given tasks is developed through years of training and understanding the given sport (Perrin et al. 2002). Classical ballet dancers work at varying speeds within stable environments, either in front of a mirror or on stage, with unwavering visual spatial references. While ballet dancers mainly train balance in relation to well-known and anticipated situations, judoists train to handle unknown balance challenges and, therefore, focus more on proprioceptive rather than visual feedback for balance. Judoists are constantly subjected to unexpected movements imposed by their opponent in order to make them fall on soft ground. In some aspects judoists are therefore comparable to riders. This similarity suggests that it is important for the rider to first develop balance and stability independent of the horse, in order to develop the appropriate level of proprioceptive/sensorimotor adaptabilities and postural control. In almost all sports these different factors are clearly defined and athletes are trained to handle these challenges in a competition situation. These factors that are crucial for equestrian sports have not yet been defined.

Balance is extremely trainable, but to develop balance at higher levels of performance, the human body needs frequent repetition with high precision (Pollock et al. 2000). Ballet dancers exhibit high levels of expertise in movement control and balance, and several studies have indicated better balance control in dancers than in control participants (Schmit et al. 2005; Bläsing et al. 2012). This is because a ballet dancer defines strict limits for how much they can accept in the degree of the loss of balance.

Little is described in relation to how the rider might learn to improve posture, balance and coordination un-mounted. In the last few years it has become more generally accepted in the equestrian world that it is not only the horse that needs to be physically strong and flexible but also the rider has to become physically fit for the requirements of the sport. Hampson et al. 2015 showed decreased asymmetry in left-right pressure profiles on the horse's back after performing a 8-week specific exercise programme for riders (Hampson & Randle 2015). There is otherwise little scientific literature in this area at the present time, but in the near future this will probably become an important field of study. Some riding instructors e.g. Suzanne von Dietze (Dietze 2015), Sally Swift (Swift 2002), Mary Wanless (Wanless 2002) and Wendy Murdoch (Murdoch 2010) have promoted different exercise regimes unmounted, but their regimes have not been scientifically evaluated.

1.1.6 Challenges within the equestrian world

During the last four decades there has been tremendous changes in the equestrian sport industry. The focus on breeding 'better' athletes has produced horses capable of exceptional performance. However, this development has produced increased demand on the riders to match their horse's ability. This is also recognised by the equestrians. For example, in an interview with Dressage Today (2015) (https://dressagetoday.com/rider-wellness/adelinde-cornelissen-fit-riding-16503) the world-class dressage rider Adelinde Cornelissen says that she is very passionate about her own fitness program. She says, “that fitness is an important aspect of dressage riding because nowadays the horses are all of high quality, and the riders need to physically improve since talent is not where you’re going to make the difference in competition anymore. If you want to win, you need to have the full package. You need to be mentally and physically at the top. That’s where all the little percentages can be gained in competition.”

There are also increasing welfare concerns surrounding the ethics of the sport, including discussions about training methods (McGreevy et al. 2009) e.g. the rollkur training method in dressage horses (König von Borstel & McGreevy 2014) and use of different riding equipment’s like spurs, whips and curb bits (Uldahl & Clayton 2018). However, if the riders develop better control of their own body, the need for tougher signals like kicking harder with the legs, increased rein tension, hitting with the whip etc., might not be necessary. Better understanding of how the aids work, e.g. how the rider’s own body puts pressure onto the horses back, may result in lighter aids and better welfare. The result of poor posture is often poor balance and again poor coordination.

The horse is dependent on the physical signals from the rider, so the rider needs to know how to apply the signals not only through the legs and hand, but how the weight applied by the rider’s pelvis is transmitted through the saddle and onto the horse’s back. If the physical signals from the rider are asymmetrical when they are meant to be symmetrical, the signals can be very confusing for the horse. This may affect training by influencing the rider’s ability to deliver clear and consistent signals to the horse. This could potentially give rise to conflict behaviour in terms of welfare because of stronger aids/signals will be applied when the horse fails to respond to a light aid (Symes & Ellis 2009). Long-term repeated application of asymmetrical forces over a series of training events could be detrimental to both the horse and rider, likely contributing to injury and pathology to the back and limbs of both horse (Stubbs et al. 2006) and rider (Quinn & Bird 1996; Kraft et al. 2009).

During ridden exercise, the rider’s weight applies substantial forces to the horse’s back (von Peinen et al. 2010). Back problems are poorly understood in horses (de Cocq et al. 2004). There is currently increasing interest in equine back pain, both in clinical awareness and scientific research, since it has been recognized that there is an association between back pain and poor performance.

To be able to understand how to improve and train the important technical skills that riders need, we must increase our understanding of how to objectively characterize the rider’s seat. Therefore, this thesis focuses on the rider's posture, especially intersegmental strategies, with a future perspective to develop strategies to improve technical riding skills.

2 Aims of the thesis

2.1 General aim

The general aim of this thesis was to develop objective methods to study the rider's posture in skilled riders relative to segmental and intersegmental strategies in order to improve equestrian performance.

2.2 Specific aims

- Compare intersegmental postural strategies for the pelvis, trunk and head in sagittal view in elite dressage riders when using the seat actively to influence the horse versus passively following the horse's movements (paper I).
- Evaluate the rider's foot eversion in relation to pelvic locomotion in walk (paper II).
- Evaluate the rider's frontal intersegmental strategies for pelvis, trunk and head when rocking a balance chair from side to side (paper III).
- Compare the rider's intersegmental postural strategies for pelvis, trunk and head between walking and sitting in frontal view (paper III).
- Evaluate the rider's intersegmental strategies in frontal view for pelvis, trunk and head while riding, and compare performance between the left and right direction (paper IV).
- Compare the rider's intersegmental strategies for pelvis, trunk and head, in frontal view, between riding and sitting (paper IV).

3 Hypotheses

The following hypotheses were developed:

- Pitch angulations of the pelvis, trunk and head segments change when the rider is actively influencing the horse versus sitting passively to follow the horse's movements (paper I).
- There is an association between the foot with higher degree of pronation and increased pelvic drop on the contralateral side during walking (paper II).
- Riders have larger pelvic movements compared to head and trunk movements when rocking the balance chair from side to side (paper III).
- Rider's intersegmental strategies of pelvis, trunk and head segments are commonly asymmetrical (paper III).
- Asymmetries of pelvis, trunk and head segments detected in individual riders while seated, are related to left-right differences in foot eversion during walking (paper III).
- Riders display individual asymmetrical postural strategies while riding (paper IV).
- Moderately skilled riders display systematic mirroring symmetry between right and left directions while riding (paper IV).
- There is an association between the types of asymmetries shown while sitting on the balance chair to those while riding (paper IV).

4 Material and methods

In this section a general description of the material and methods are presented. A more detailed presentation is found in each of the papers.

4.1 Study designs (paper I-IV)

Paper I: Advanced riders rode in two different riding postures. The postures included one passive riding posture with long reins (free head and neck position of the horse) when the rider was passively following the horse's movement and an active riding posture with the horse ridden in collected trot (flexed poll position). Kinematic data were recorded on a high-speed treadmill with an integrated force measuring system. Saddle pressure was measured in synchronisation with the kinematic system.

Paper II-IV: Associations between postural asymmetries during walking, sitting and riding were studied in a common set-up. Riders were recorded while walking, sitting on a custom designed balance chair and riding a short dressage program. Kinematic, IMU and video data were recorded. Data for papers II and III were recorded when subjects walked barefoot across a 15 m distance on a linoleum floor. Data for paper III were collected when riders rocked a custom-made balance chair from side to side. The riders were then seated on this balance chair, constructed with a stable base, and an adjustable height element with a seat on top. The seat could be tilted and rotated in all directions, forward/backward and sideways around a tilt element positioned about midway between the seat and the floor, to simulate the rotation of the trunk of the horse. The chair incorporated a spring element, which gave progressive resistance towards the endpoints on each side. This was intended to provide a little help to the rider to return to a neutral position, similar to the situation when the horse is changing weight between the hind limbs.

The riders were instructed to rock the chair by placing more weight alternately on their left and right seat bones, with a frequency of 40 beats per minute guided by an audible metronome. Four trials were recorded per rider.

The ridden dressage program (IV) consisted of exercises in walk, trot and canter. The following exercises in trot were used for further evaluation: riding straight on left and right hands, left and right 15 m circles, and left and right leg yield across the half-diagonal. In all cases subjects were allowed a warm-up phase before data collection started. Two video cameras from two different angles recorded the riders in the riding arena.

Some data were missing due technical issues. In Papers II and III kinematic markers were missing sporadically or not correctly detected by the cameras. In Paper IV there were problems with missing data because IMU-sensor logging failed. In Table 2 the number of riders contributing data to each paper is displayed.

Paper	N/strides	Situation	View	Statistical method
I	7/224	Riding	Sagittal	Wilcoxon matched pair test
II	24	Walking	Frontal	Mixed model analysis, Fischer Exact, Logistic regression
III	20	Sitting	Frontal	Principal component analysis, Linear regression
IV	10/1888	Riding	Frontal	Mixed model analysis

Table 2: Summary of number (N) of test persons and number of strides, different situations, different views and statistical methods in the given papers (I-IV).

4.2 Study populations (paper I-IV)

Paper I: Seven riders were included; three male and four female with an average body weight of 78±17 kg. They were all competing at intermediate level or above. The horses were warmblood dressage horses (14±4.3 years and height 1.70±0.07 m). Each horse was ridden by its usual rider, with their own standard riding equipment consisting of a dressage saddle and a snaffle bridle, which were checked to fit correctly by one of the researchers.

Paper II-IV: 29 moderately skilled female riders were enrolled in the study. They were aged between 21-25 years, with a mean weight of 68 kg (range: 61-75 kg). An experienced person trained in human biomechanics classified their foot posture by visual inspection. Subjects with obvious foot abnormalities other than foot eversion were excluded. The angle between the bisection of calcaneus and the floor was evaluated with the subject standing; foot eversion was identified as hind foot valgus with eversion of the subtalar joint. Two riders were excluded because of other foot aberrations other than pronation (supination and high plantar arch), and three riders were not able to attend during the whole process of walking-sitting-riding sequences. That left 24 riders for the walking situation. Because of failure of marker detection; 20 riders could be analysed in the seated unmounted situation.

The horses used in the ridden study (paper IV) were two Swedish warmblood school horses, ten and twelve years of age, from the National Equestrian Centre, Strömsholm, Sweden. The horses were sound based on clinical examination by an equine practitioner, before the measurements were made. Out of the 20 riders only 10 riders in total (because of various technical issues with the IMU-sensors) could be analysed in the ridden situation. 9 riders rode one horse and 1 rider rode the other horse.

4.3 Measuring techniques (paper I-IV)

Paper I: Reflective markers attached to the rider's helmet (back, front, left, right); trunk (C6, left/right acromion processes); pelvis/hip (lumbosacral joint, left/right greater trochanters); and over the horse's L3 were tracked by 12 infrared optical cameras (ProReflex; Qualisys AB, Gothenburg, Sweden). After warming up a stance file was recorded with the rider sitting in a self-chosen neutral spine and pelvis position. Kinematic data were collected for 15 s in each riding posture at 140/ 240 Hz. The vertical ground reaction force was measured synchronously with the kinematic data. Saddle pressure was measured with Pliance-X System (Novel GmbH, Munich, Germany) using sampling rates at 70 or 60 Hz synchronised with the kinematic system. Prior to data collection the 256 sensors were equilibrated and calibrated for pressures ≤64 kPa. The mat was placed symmetrically on the horse's back, aligned with the dorsal midline and positioned to accommodate the entire saddle panels. The 3D marker positions were reconstructed using a direct linear transformation algorithm. The raw X-, Y- and Z-coordinates and raw pressure data were exported into MATLAB (The MathWorks Inc., Natick, USA) for further analysis. The rider's head, trunk, and pelvis were subjected to rigid body analysis using the neutral position in the static files to define rigid body zero state. Segmental rotations were defined for the given coordinate system, and rotations around the Y (transverse) axis were defined as pitch. The longitudinal position of the centre of force (COF) was measured from the posterior edge of the saddle mat and its craniocaudal ROM was calculated. The loaded area was represented as the mean number of loaded cells per stride.

Papers II-IV: Spherical markers, 8 mm diameter, were fixed to the rider's skin according to a full marker body-set model. Once attached, all markers remained on the skin during both standing calibration trials and dynamic trials. The markers were positioned bilaterally on the following anatomical points:

the acromial edge, the spinous processes of C7 and Th10, the anterior and posterior superior iliac spines, the greater trochanter, the lateral and medial malleoli, the heads of the first, second and fifth metatarsi, and the distal aspect of the Achilles tendon insertion on the calcaneus. Clusters of markers distributed in a non-collinear manner were attached bilaterally to the participant's mid shanks and mid thighs, and on the back front and top of the helmet. This was done for walking trials (papers II-III) and sitting trials (papers III, IV).

For the ridden data collection (paper IV) the riders were measured by inertial measurement units (IMUs, X-io Technologies Limited, UK) recording at 256 Hz attached using adhesive tape and/or elastic girth to the head (top of the helmet), trunk (between the shoulder blades) and pelvis (over the sacrum). The horse was equipped with an IMU-sensor on S1.

Kinematic data (papers II, III) were collected in 3D (250 Hz) using eight motion capture cameras (Qualisys Oqus, AB Gothenburg, Sweden). Baseline marker positions were recorded in a static calibration trial with each participant in a neutral standing position on a marked area on the floor. The feet were placed 10 cm apart, toes pointing forward. Shoulders and hips were aligned along the walking direction. In the seated stance; for the unmounted seated situation (paper III) and ridden situation (paper IV), the riders were placed in a custom-designed stance chair (Fig. 8) enabling control of a standardized base line orientation of pelvis, thorax and head. Each subject's acromial edges and iliac crests were aligned horizontally so that they were symmetrical in the frontal plane. In the sagittal plane, the head, trunk and pelvis were aligned vertically, in a neutral spine position. The IMU`s were synchronized by use of a sync signal before and after the kinematic measurements.

4.4 Data processing (II-IV)

Paper I: All data were split into strides based on left forelimb contacts. All strides were thereafter normalised to 101 points (0-100%). For each standardised stride, discrete values were determined for the following variables: minimum, maximum and range of motion for pitch rotation of the rider's pelvis, trunk and head segments; difference in time of occurrence between PMAX and TMAX (PT-phase shift) expressed as % stride cycle; mean number of loaded saddle mat cells per stride; longitudinal ROM of the COF on the saddle mat, and ROM for vertical excursion of the horse's L3.

Paper II: Data processing and model building were performed in Visual 3D^{TM} (C-Motion Inc., Germantown, MD, USA). Marker data were gap-filled and signals were filtered with a low-pass Butterworth filter at 15 Hz. The foot was modelled as a single segment. Local coordinate systems were used for both foot and pelvic segments. Foot orientation was measured relative to the floor to evaluate eversion. Segment rotations were calculated using a Cardan sequence of rotations with six degrees of freedom (Z-X-Y), to describe segment motion in the global coordinate system. Heel contact was identified for each foot and for each stride. Joint and segment angles were expressed relative to angles obtained in the standing calibration position and time normalised to 100% of stride. One stride from each of the four trials was used for further kinematic analysis. The following kinematic variables for the foot were determined: ROM was calculated as the difference between the maximal and minimal angles of roll and yaw of the foot during stance. Foot eversion was calculated for each stance by summing ROM for roll and yaw. The maximum pelvic drop (visualised in the frontal plane) was registered for the ipsilateral and contralateral sides, relative to the side of the more everted foot, during each foot stance. The differences between right and left stance phases for each of the four kinematic variables were calculated for each stride.

Paper III: Data processing and model building were performed in Visual 3D^{TM} (C-Motion Inc., Germantown, MD, USA), and filtered with a 15 Hz, low-pass Butterworth filter. Segment rotations were calculated using a Cardan sequence of rotations with six degrees of freedom (X-Y-Z). In the seated data, the segment angles were expressed relative to the reference position (reference-chair. Fig. 8), in the global coordinate system. Head, trunk and pelvic translation was measured along the transverse axis of the laboratory-based coordinate system (LAB), which was aligned with the balance chair. Three to seven complete movement cycles per subject were used for the analysis. Roll rotation of the head, trunk and pelvis were exported to MATLAB for further processing. The symmetry of rotation to the right and left sides was evaluated as the difference between positive and negative areas under the curve (AUC) over the available number of full left/right motion cycles.

Figure 8: Stance chair (left) used to create stance files (marker tracking) and calibrate the IMU sensors. Balance chair (right), which was rocked from side to side.

Paper IV: IMU raw data were exported to MATLAB. Roll, pitch and yaw angles, and vertical acceleration were extracted from each sensor. A stance chair was used to calibrate orientation and position of sensors relative to body segments. The riders were placed in a seated position (see fig. 8) with both feet on the ground, with horizontal alignment of shoulders and pelvis. In the sagittal view the head, trunk and pelvis were placed within the borders of normal spine curvature; the ear, shoulder and hip were in vertical alignment (Fig. 8). In the data analysis the vertical accelerations were double-integrated and high-pass filtered to yield vertical translations. The ridden data were segmented into specific exercises based on observation of the video footage and the corresponding clock times together with measurements of the horse's pelvis heading (rotation around the vertical axis, Z), to determine direction of travel. The data for each exercise were then split into strides based on the vertical translation and roll rotation of the horse's pelvis. Rider angles were expressed in the global coordinate system and were adjusted for the rider's position in the stance chair, such that the angles were expressed relative to stance. Stride mean roll for head, trunk and pelvis was determined for each stride, and averaged over available strides for each rider and exercise (left/right).

4.5 Statistical methods (paper I-IV)

The statistical analyses were performed using the statistical software SAS (SAS Institute Inc., Cary, NC, USA). The significance level was set to <0.05.

Paper I: Standardised mean data for the passive and active rider postures were compared using the Wilcoxon matched-pair test.

Paper II: A mixed model was constructed with the difference in pelvic drop as the dependent variable. The independent fixed-effect variable was the difference in pronation between left foot and right foot. Subject was modelled as a random effect. A generalised estimating equation logistic regression model, with rider as the repeated effect, was developed using the dichotomised variable for pelvic drop (positive/negative). The included fixed effect variables were similar dichotomisations of foot external rotation (yaw) and eversion (roll) differences. Two-way interactions between differences for external rotation (yaw) and eversion (roll) were tested in the logistic regression model. Variables with $p<0.05$ were retained. Finally, Fishers exact test, accompanied by odds ratios and 95% confidence intervals (95% CIs), was used to test the association between the foot with the higher degree of pronation (right/left) and maximal pelvic drop during the same stance phase, all done on mean values for each person.

Paper III: To identify intersegmental strategies, a principal component analysis (PCA) was performed. Asymmetry variables were normalised to have a zero mean and unit variance. The principal components (PCs) were sorted by the percentage of variance explained by each. A linear regression was constructed with the difference in foot eversion between left foot and right foot as the dependent variable, which was found to be normally distributed by Shapiro-Wilks test. The independent fixed-effect variables, evaluated one at a time, were the translations and roll symmetry variables (head, trunk and pelvis) as well as the sum of the pelvic and thoracic roll symmetry values. Independent variables were plotted versus the dependent variable to evaluate departure from linearity. In this analysis, only riders with an eversion value of at least 1.5 degrees were used. The cut-off was set to 1.5 degree because it was judged that smaller asymmetries would not be accurately detected. The p-value limit was set to <0.05. The trunk and pelvic roll data were summed to include both riders that compensated for COM displacement more with the pelvis or more with the trunk, to eliminate the variation of individual segmental strategies. The main aim was to seek a correlation between torso roll asymmetry and the foot with the higher degree of pronation.

Paper IV: Stride mean was averaged over the available strides for each horse and rider combination for each exercise. An asymmetry measure was created for each body segment by summation of the values recorded when performing each exercise in the left and right directions. In a first category of mixed models, to elucidate systematic differences between left and right counterparts for each exercise, ridden stride mean segment roll variables were modelled as outcomes and exercise as a fixed effect. Random effects were rider and horse. Pair-wise comparisons were done between data for the same exercise in the left and right directions around the arena when moving in straight lines, in left and right circles, and in left and right leg-yield. In the second mixed model category the ridden asymmetries were modelled against chair asymmetries with exercise included as a fixed effect. The random effect was rider. The variables tested against each other were: ridden head vs chair head, ridden trunk vs chair trunk, and ridden pelvis vs chair pelvis. In the second model category only models with significant asymmetry variables were kept. To evaluate normal distributions of model residuals, these were plotted according to standard methods (SAS). Similarly, linearity for independent variables vs dependent variables was evaluated through plotting.

5 Main results

5.1 Paper I

Analysing the seven riders in trot, in the passive riding posture the pitching (anterior-posterior, see abbreviations) rotations of the pelvis, trunk and head segments followed a sinusoidal pattern with two oscillations per stride. The timing of pelvic oscillations in the passive posture were consistent across riders with the pelvis rotating posteriorly from late stance of one diagonal through suspension and reaching maximal posterior pitch early in the next diagonal stance. The pelvis then rotated anteriorly through mid-stance reaching maximal anterior pitch in late stance. Trunk oscillations followed the pelvic pattern but were delayed by 13% (5-22%) of the stride cycle. Head pitching movements were out-of-phase with the pelvis. Range of motion was largest for the pelvis and least for the trunk.

Comparing mean values between the passive and active riding postures revealed significant differences for at least one variable per segment. Overall, the active rider posture involved significantly greater posterior pelvic pitching rotation (-5.6 degrees for PMIN; -4.1 degrees for PMAX), so the entire cycle of pelvic rotation pitched more posteriorly, and PROM (pelvis) increased by 1.4 degrees. When evaluated individually, six of seven riders showed significantly increased posterior pelvic pitching in the active riding posture. The trunk also displayed a significantly greater posterior pitching rotation in the active riding posture by -3.4 degrees in TMIN (trunk) and -2.8 degrees in TMAX but TROM did not change. Posterior trunk pitch increased in five of seven riders. Neither HMIN (head) nor HMAX differed between rider postures but HROM increased significantly by 1.6 degrees when riding actively.

Saddle mat variables indicated that in the active riding posture the pelvis translated significantly further anteriorly by 25.4 mm in the most anterior position and 17.2 mm in the most posterior position, indicating a more anterior position onto the horses shoulder, throughout the stride. The anterior-posterior ROM of the COF on the saddle mat increased significantly in the active riding posture though only by 0.6 mm while the mean loaded area decreased by 29.2%, producing a focused cranial pressure onto the shoulders. Vertical displacement of the horse's L3 decreased significantly while riding the horse at the collected trot (active riding posture).

5.2 Paper II

The 24 moderately-skilled riders were analysed walking barefoot in the frontal view. Thirteen riders had greater right foot pronation, and 11 of those displayed a greater contralateral pelvic drop (0.2-2.9 degrees difference in mean pelvic drop and 0.07-17.5 degrees difference in foot pronation) during early right foot stance. The two deviant riders had 0.9-3.0 degrees difference in mean pelvic drop and 1.8-4.5 degrees difference in mean foot pronation. Five riders had greater left foot pronation, and four of those displayed a greater contralateral pelvic drop (1.3-4.1 degrees difference in mean pelvic drop and 1.4-13.8 degrees difference in foot pronation) during early left foot stance. The one deviant rider had 2.9 degrees difference in pelvic drop and 0.0 degrees difference in foot pronation. Accordingly 3 subjects deviated from the rest of the group by displaying a lower degree of contralateral pelvic drop when the foot with the higher degree of pronation was in stance. The odds ratio (OR) was 22 (95% CI; 1.5-314), indicating a greater risk that the pelvis dropped further to the contralateral side when the more pronated foot was in early stance, compared to the opposite foot stance. From the mean value analysis, riders with more pronation on one foot relative to the other foot displayed a significant difference in pelvic drop in early stance (p=0.02). The mixed model showed that pronation was linearly related to the outcome (i.e. to contralateral pelvic drop). With each unit of increase in pronation, pelvic drop became 0.11 degrees more pronounced. The logistic regression model showed that eversion (roll) and external rotation (yaw) were associated with ORs of 2.6 (95% CI; 1.1-6.4) and 3.1 (95% CI; 1.1-9.2) respectively, i.e. both increased the risk for increased contralateral pelvic drop during early stance.

5.3 Paper III

Frontal view kinematics of the head, trunk and pelvis in 20 moderately skilled riders were analysed in a seated position on a balance chair and rocking it from side-to-side. Most of the riders showed individual intersegmental strategies for rotation and translation in the frontal plane when moving the chair from side to side. Some riders could be grouped together based on having the same pattern of asymmetries but, in general, there was considerable variation between riders. In spite of individual characteristics, the data revealed tendencies to common intersegmental strategies among the riders: when one or two segments were rotated or translated significantly more to one side, another body segment automatically compensated for the COM displacement by rotating or translating to the opposite side. The trunk segment had the most pronounced tendency for roll rotation. The pelvis showed only a small degree of roll rotation but had more translation. The head was the segment with the most pronounced tendency for translation (in relation to the pelvis). When applying PCA to the data, four PCs accounted for 98% of the explained variance. The first three principal components alone explained the majority of different strategies between riders (89%). For the first component, the major effects were the trunk and head translations, which are in the same direction and, to compensate for the COM translation, the pelvis roll rotated to the opposite side. For the second component the pelvis, trunk and head roll rotations had the major effect, with the head and pelvis rotating to the same side and the trunk to the opposite side. The third component also had roll rotation of head, trunk and pelvis as the major effect, but in this component, the pelvis and trunk rotated to the same side and the head towards the opposite side. When comparing segmental coordination while sitting with foot eversion during walking, the cut off for the eversion (excluding subjects with absolute eversion values <1.5 degrees because such low asymmetry values were considered to have less biological significance and less accurate detection within the study measurement setup) excluded one rider (number 3). Only the regression of the sum of pelvic and trunk roll during sitting, versus the degree of eversion during walking was significant (p=0.0232). The intercept was -2.71 (SE 1.47) and the slope was 0.95 (SE 0.37), in degree units. The data suggest an association between eversion on one foot and a higher degree of rotation in either the pelvis or trunk, or a combination of the two, to the opposite side of the more everted foot.

5.4 Paper IV

The data were evaluated in the ridden situation in frontal view and the results were compared with the seated situation on the balance chair. Significant associations for the rider´s intersegmental strategies were found between the ridden and the unmounted seated situation on a balance chair. The positional asymmetries were positively associated with each other for both the head and pelvic segments (pelvis: p=0.01, head: p=0.02, trunk: not significant).

This means that if the rider sat predominantly to the right on the chair, the rider would also sit predominantly to the right while riding.

The riders were evaluated on straight lines of both left and right directions, circles to the left and right and leg yield to the left and right. There were statistical differences between the left and right directions. The significances were as follows; between straight conditions for pelvis roll and trunk roll when traveling straight ($p=0.01/p<0.0001$), between left and right circles for trunk roll ($p<0.0001$) and between left and right leg-yield for head roll ($p<0.0001$) and trunk roll ($p=0.0002$). Whenever exercise was significant, the pelvis and the trunk were more rotated to the left on the left direction and more rotated to the right to the right direction. For the head the opposite was found.

The findings indicate that the riders were asymmetrical. Most of the riders demonstrated substantial asymmetry in stride mean roll e.g. the pelvis did not mirror itself when comparing data for the right and left directions. Some riders did not change their segmental positions when traveling in the right versus left directions; instead they positioned themselves to the same side throughout (e.g. the rider no 9 in Fig. 2, paper IV). When comparing between left and right directions, the riders showed some degree of mirroring, but the majority of the riders changed their trunk angle more than the pelvic angle (Fig. 2, paper IV).

6 Discussion

The scientific documentation of the optimal postural position and the technical skills for a rider is scarce. It is generally agreed that good riders should be highly symmetric and must continue to develop symmetry in themselves and their horses for optimal performance at riding (Symes & Ellis 2009; Hobbs et al. 2014). In this thesis basic postural strategies have been evaluated biomechanically and intersegmental coordination (between head, trunk and pelvis) has been demonstrated. By studying the rider's postural control through objective quantification and categorization of segmental kinematics between head, trunk and pelvis during riding, postural characteristics of the rider's seat was defined. In the sagittal plane three distinct segmental strategies were identified for changing between passive and active riding seats. Associations between postural strategies while riding, sitting on a balance chair, and walking were also described. In accordance with other studies, the results suggest that there is high degree of asymmetry in skilled riders (Gandy et al. 2014; Hobbs et al. 2014; Alexander et al. 2015). The ability to characterise the rider's seat with respect to direction and magnitude of movement facilitates the development of methods to train body control and, together with existing knowledge, can be used in the future to improve equestrian performance. The long-term aim for riders should be to improve both their health and their competitive performances. The results from this thesis will make a useful contribution to these goals.

6.1 The passive and the active seat

When coping with the horse´s motion and perturbations during the stride cycle, the rider rotated the pelvis posteriorly from late stance of one diagonal through suspension reaching maximal posterior pitch early in the next diagonal stance. The pelvis then rotated anteriorly through mid-stance reaching maximal anterior pitch in late stance (paper I). The terms the passive seat and active seats were introduced. The passive seat was defined as the rider following the movements of the horse without trying to influence the horse's performance. This is in contrast to the active seat in which the rider actively communicates with the horse and proactively guides the horse to move in a certain manner that is perceived as being more desirable.

When riders adopt an active seat, they typically shorten the reins, collect the horse and start to actively influence the horse's movements. The results of this study showed that, in the active seat, six of seven riders rode with an increased posterior rotation of the pelvis and trunk (paper I).

Rotating the rider's pelvis and trunk posteriorly is likely to decrease the lumbar lordosis. The resulting flattening of the lumbar curvature can be associated with increased activation of the global mobilizing muscles, compared to a more lordotic curvature that requires the use of the deep stabilizing muscles rather than the global mobilizers (Barrey et al. 2011). In the active seat, it is hypothesised that the upper segments (head, trunk) must be more stable to allow the pelvis to move more freely. Only when the upper segments are stabilized is it possible for the rider to be in full control of pelvic movements and to control how the rider's seat exerts pressure on the saddle and the horse's back. On the contrary, if the trunk has a high degree of roll (lateral) and pitch (anterior-posterior) rotation as well as anterior-posterior and lateral translations, pelvic motion may be restricted due to a need to compensate for the upper segments movements.

The phase shift (in this thesis) is a parameter explaining the delay between pelvis and trunk movements. This parameter (Bystrom et al. 2009; Byström et al. 2010; Byström et al. 2015) may reflect dynamic aberrations from the normal sagittal curvature. In the passive seat, pelvic motion was delayed, on average, by 13% compared with trunk motion. In the active seat there was a further increased phase shift between pelvis and trunk in five of seven riders. In the active seat the pelvis and trunk rotated posteriorly and the pelvis translated anteriorly (paper I).

Further, if a poor posture is maintained over an extended period of time, back problems and poor performance may occur as sequelae (Norris 1998; Claus et al. 2009; Barrey et al. 2011; Roussouly & Pinheiro-Franco 2011). There are conflicting reports regarding the effects of riding on back pain in humans. On the one hand it has been reported that riders have some of the highest frequencies of back pain compared to other sports (Pilato et al. 2007). Further, riders have been shown to have a higher prevalence of back pain compared to non-riders (Quinn & Bird 1996). On the other hand, therapeutic horseback riding is known to have a beneficial effect for people with a variety of physical disorders (Matsuura et al. 2008), and stimulates the patient to use a more normal range of spinal curvature and stability (Martins 2015). In one study (Yoo et al. 2014) horseback riding was shown to decrease back pain in human patients. A major difference between competition riding and therapeutic riding may be that in therapeutic riding the patient is passively following the horse, whereas the competition rider is riding more actively and simultaneously changing the core segments coordination.

6.2 Rider's seat during collection

As described, in the active situation six of seven riders rotated the pelvis posteriorly (paper I). This was not unexpected because when collecting a horse riders are instructed to rotate the pelvis posteriorly and push the seat bones into the saddle (Branderup 2014). A reason for the posterior rotation of the pelvis might be to stimulate the horse to place more weight on its hindquarters and lift the forehand/shoulders and neck. Even if the descriptions of how to do this varies, as well as being scant, this is generally accepted in the equestrian community as a means for increasing the level of collection in the horse (Hess et al. 2014) During the posterior pelvic rotation six of seven riders simultaneously rotated the trunk posteriorly. In paper I the rider's pelvis translated anteriorly towards the horses shoulders and displayed a significant increased pressure under the cranial part of the saddle-mat (paper I). Maintaining balance when rotating the trunk and pelvis posteriorly is likely to hinder simultaneous posterior pelvic translation. As a result of the anterior location of the centre of force (COF) beneath the cranial part of the saddle, it is necessary to be vigilant in checking for signs of pressure-induced injuries around the withers and shoulders in horses that perform in collection for long periods (von Peinen et al. 2010).

Three of the seven riders in the experiment in paper I were also subjected to rein tension measurements (Eisersiö et al. 2013). In the active seat the mean rein tension through the stride cycle was about 10-15 N, compared to 0-3 N in the passive seat. Since the majority of the riders were leaning backwards, one solution for keeping their balance and not falling off the horse might be to lean on the reins for support. This would imply that, even in high-level dressage riders, rein tension is somewhat dependent on the rider's posture. An independent relationship between the rider's hand and the core body segment (pelvis and trunk) could theoretically be suggested as the most fine-tuned solution for the hand-rein-horse mouth interplay. Regardless of whether the riders were really leaning on the reins, it is likely that their rein management would become even more independent if the rider had a better postural awareness, then the rider would not depend on his balance by stabilising the posture through the reins. The variation of the magnitude and pattern of rein tension varies considerably with both riders and horses (Eisersiö et al. 2013; Clayton et al. 2017).

Further, the posterior rotation of the rider's trunk and pelvis would most likely cause the rider to become more rigid and less dynamic, which again could lead to increased tension in the musculature of the horse's spine. This is not optimal, especially during collection where the goal is to keep the horse supple, dynamic and rhythmic with more weight on its hindquarters and lifting the withers (German National Equestrian Federation 1997). Maybe there is another way of positioning the riders, which might be more optimal?

6.3 Rider's asymmetries during riding

In the equestrian community, asymmetry in general is recognized as a negative trait and one of the main goals is to train the horse to become more and more symmetrical (Hess et al. 2014). Straightness in the horse is one of the fundamental goals in the scale of training a horse for higher performance (Hess et al. 2014), and it is well recognised that, in order to develop proper symmetry in the horse; the rider himself should exhibit a high degree of symmetry. Any horse will show movement asymmetries on a circle (Lucidi et al. 2013; Rhodin et al. 2016), but in principle the non-lame horse will mirror itself between left and right circles (Starke et al. 2012; Pfau et al. 2016; Rhodin et al. 2016).

Also when studying rider symmetry it is important to compare right and left directions. Some studies have documented asymmetry in rider position while riding (Symes & Ellis 2009; Alexander et al. 2015). Symes et al. 2009 also studied riders trotting on straight lines and found a high degree of asymmetry. Albeit intriguing, these riders only rode in the left direction and were thus not compared between right and left. The moderately skilled riders in paper IV showed high degrees of asymmetry when compared between right and left directions, both on straight lines, circles and leg yields. Many riders demonstrated individual intersegmental strategies of the core body segments irrespective of the direction of travel. Some riders were highly asymmetrical even though they had some degree of left-right mirroring. But when comparing the strategy between right and left directions at group level, they presented a more symmetrical picture and were able to present a more mirroring between the directions. To compare the findings in paper IV with the study from Symes et al. 2009 is therefore a bit difficult.

An equestrian question relates to whether riders should position themselves symmetrically when riding straight or if they should perform a weight shift towards the inside-rein? There is no science-based answer to this question, but at least we should expect the riders to be able to mirror themselves symmetrically at individual level.

6.4 Rider's frontal kinematics while walking

The vast majority of humans are right-handed and most people also prefer to use the right eye, right leg and right ear. This type of sidedness is based in the cerebral hemispheres. Asymmetries can also be evident in peripheral parts of the body, as an example foot pronation which may cause leg length discrepancy (Gurney 2002; Pinto et al. 2008; Resende et al. 2015). Papers II and III are based on data from unmounted testing of moderately-skilled riders when walking and sitting on a balance chair. The riders in these studies had different degrees of foot pronation and data from 18 riders revealed a significant association between the degree of foot pronation, here named eversion (roll and yaw rotation) and the amount of contralateral pelvic drop during walking. The majority of riders showed more contralateral pelvic drop when the foot with the higher degree of eversion was in early stance, compared to when the other foot was in early stance. These results suggest that foot aberrations affect pelvic motion (demonstrated as pelvic movement changing together with foot eversion during walking), which can indicate a possible effect on pelvic control during riding.

Some riding instructors suggest that the rider's foot is not critically relevant, especially in dressage, since this is a sitting sport. However, the human foot plays a fundamental role in standing and walking by connecting the body with the ground, and symmetry of the pelvis and upper body is highly dependent on foot position (Pinto et al. 2008; Duval et al. 2010; Svoboda et al. 2014). Studies show a high frequency of hyper-pronation, both unilaterally and bilaterally in the European human population (Aenumulapalli 2017; Horwood & Chockalingam 2017). Studies on unilateral foot hyper-pronation display an ipsilateral functional leg length shortening and a ipsilateral tilted pelvis in static standing position (Pinto et al. 2008; Duval, Lam & Sanderson 2010), but the effect on pelvic tilt during sitting has not been addressed. Therefore, it was deemed relevant to evaluate whether the locomotor patterns established during walking could affect pelvic movements even if the feet were not in use during sitting, and further during riding. Symes et al. 2009 evaluated leg length discrepancy relative to shoulder rotation and all of the 17 riders in the study showed a shorter functional right leg. Hyper-pronation is known to be related to ipsilateral leg length shortening (Pinto et al. 2008; Duval et al. 2010). The result from Symes et al. 2009 is in somewhat contrast to our studies. The riders tested showed variation between right and left foot eversion, not only right foot, implying that the functional shorter leg varied (paper II). The reasons for this are unknown.

6.5 Rider's intersegmental strategies during seated situation on a balance chair

When comparing the sitting data with the walking data, an association was found. The side of the body that had a higher degree of foot eversion displayed greater trunk and pelvic roll (lateral rotation) to the opposite side when sitting and rocking the chair. Technically eversion on one foot and a higher degree of rotation to the opposite side in either the pelvis or trunk, or a combination of the two segments was compared (the sum of pelvic and trunk roll was contrasted to the left/right difference in eversion). The reason for this finding might be that over time walking with the same postural asymmetry (e.g. contralateral pelvic drop due to a highly pronated foot) eventually leads to a change in the organization of movement representations in the primary motor cortex (Jensen et al. 2005; Lakhani et al. 2016).

The data from paper III are from the same group of riders as in paper II, albeit now they were seated on a balance chair. When moving the chair the riders used an active seat to initiate the movements. They were instructed to conduct the movement by alternately placing more weight on their left or right seat bones, just as they would do during many ridden exercises, such as on circles, in canter transitions, piaffe and during the lateral movements.

In order to tilt the balance chair from side to side when seated in an upright position, the rider had to create a lateral movement of one or more body segments to exert a turning force. Because the subjects were experienced riders, it was expected that they would accomplish this weight shift primarily by displacing their pelvis, since this is generally suggested in the equestrian community (Hess et al. 2014). An example of an exercise where riders are thought to use their left and right sides of the pelvis differently is shoulder-in (Hess et al. 2014). In shoulder-in the horse is expected to move the forehand to the inside of the direction of movement. According to most riding instructions, the rider will use a series of aids coordinating the hands, legs and seat, and initiate the movement by moving the pelvis and as a result put weight on the inside, in shoulder-in (Hess et al. 2014).

While moving the chair from side to side the riders showed high degrees of asymmetries in segmental (head, trunk and pelvis) rotations and translations (paper III). The riders performed the movements primarily by using the trunk, either by rotating or translating or a combination of the two, and not by initiating the movement from the pelvis. A reason for this unexpected pattern could be that the balance chair presents a situation that does not totally replicate the typical movement performed on horseback, which especially during the passive seat is driven by the horse and followed by the rider. On the other hand, the chair is constructed so that, as the rider feels the progressive resistance in one direction, the force applied in that direction is reduced and transferred towards the opposite side, which mimics how the weight is transferred on the horse during mid-stance of each hind limb. The discovered strategy of rolling the trunk and head laterally might be the simplest and most intuitive way of rocking the chair, since it takes advantage of the long lever arms of these segments. However, the chosen movement strategy is suggested to be sub-optimal when riding. Even if the trunk strategy was unexpected, it was anticipated that the riders would be able to perform the movement symmetrically in the left and right directions. Despite the proposed importance of symmetry expressed by many riding instructors, our results show that the riders showed asymmetrical movement. A new question arises; how can the riders train the horses to become symmetrical if the riders themselves are substantially asymmetrical in their movement strategies? Some riders could be grouped on the basis of having the same pattern of asymmetries, but in general there was a considerable variation between riders. Although the chair is not a horse, it could initiate individual movement strategies similar to those when riding. More studies are needed to evaluate whether the chair is a good instrument for training rider-specific technical skills.

These results (paper III) suggest an association between walking and sitting postures. Together with the movement asymmetry found in most riders this suggests that the rider's seat might be improved if the rider's symmetry, and likely body awareness, is developed through un-mounted training.

6.6 Similarities between sitting on a balance chair and riding

Riding theory often focuses on pelvic interaction with the horse (German National Equestrian Federation 1997; Münz et al. 2014). Paper IV, however, showed that when comparing between left and right circles, the riders were leaning inwards by rolling the upper trunk. The data illustrated a more static pelvis and a more moveable trunk in most riders in this exercise. Similarly, when moving the balance chair from side to side, the riders displayed either a larger range of trunk roll (lateral) rotation or translation, but only a very low degree of pelvic roll rotation and translation (paper III).

When comparing the intersegmental strategies between unmounted and ridden situations, the data displayed a significant correlation, which suggests that it is not the horse that causes the rider to move asymmetric. It has been demonstrated that the horse may be the cause for rider asymmetry in the case of lameness, in particularly hind-limb lameness and saddle-slip (Greve & Dyson 2013). One way to determine whether it is the rider or the horse that is asymmetric is to measure or study the same rider on different horses, and different riders on the same horse. In paper IV all riders, except one, were measured on the same horse but still showed individual patterns of movement asymmetries. This and the correlation with the results from the balance chair strongly suggest that these asymmetries were inherent to the riders.

The ridden data gathered for paper IV was also used for subjective scoring by three highly qualified riding instructors (Elkjær et al. 2013), where the individual rider's efficiency of the seat (postural alignment and use of aids) and the effects on the horse were evaluated. The seat data for each rider were contrasted against whether the rider had more (n=10) or less (n=10) foot pronation as determined by a trained human biomechanist. Movies of each rider in all three gaits were scored blindly relative to how effective and harmonious the riding was perceived to be. Riders with the least foot pronation had the highest scores and vice versa. The instructors also scored the segmental asymmetry of the riders by evaluating the individual movies. Qualitatively there was poor agreement between trainers regarding which segments were rotated or translated in the possible directions. It is interesting that the three instructors demonstrated high agreement on level of scoring for each rider but they did not agree on what the specific segmental corrections that were needed to help the individual riders to become more symmetrical. The results suggest an association between degree of foot pronation and the rider's seat efficiency during riding and there is a correlation between subjective and objective analysis. These findings indicate that the objective parameters chosen are correct for presenting the riders seat, while qualified trainers are not necessarily able to analyse the underlying segmental motions. The results suggests that education of riding instructors may prove useful for enhancing pedagogy and communication

6.7 Development of technical riding skills

The overall results of these studies suggest that it is not only the horse that causes the asymmetry in movements of the horse-rider combination. By applying this objective kinematic method, intersegmental strategies in the riders could be identified during walking, sitting and riding. In other sports, asymmetry has received considerable scientific attention (Schmit et al. 2005; Šimenko 2016; Hildebrandt et al. 2017), but given the nature of riding it is perhaps surprising that rider symmetry has not been studied more extensively (Symes & Ellis 2009; Gandy et al. 2014; Hobbs et al. 2014; Alexander et al. 2015). The reasons may include the fact that biomechanical techniques must be used, which require expensive equipment and time-consuming analysis.

Even if the riders showed a repetitive pattern in their intersegmental strategies while sitting on a balance chair, it cannot be assumed that they would chose the same strategy while riding, neither on a population or individual level. Therefore, the ridden data were compared to the seated situation. In paper IV the riding sequences in trot on straight lines, circles and leg-yields (left/right) were chosen for analysis. These data revealed a significant relationship between the rider's postural strategies when sitting on balance chair and when riding. Overall, the results from the present studies show that an association between the individual rider's postural strategies when walking and sitting, sitting and riding. This suggests that unmounted training might affect rider's asymmetries and intersegmental strategies and this, in turn, is likely to benefit the health and performance of both rider and horse.

When riding a horse, the human brain must cope with multiple tasks; handling the rider's balance and posture, coordinating the rider's use of aids, sensing the horse, guiding the horse into new movements, stabilizing the horses gait, and controlling changes in velocity to mention a few. Since the horse is a biological system, which might change the forces acting on the rider at any time, the rider always has to be prepared for unpredictable changes in movements. This makes it a complex task for the rider to develop his/her balance, stability or posture during riding. It might be easier to break down specific exercises into smaller and more precise pieces that can be addressed individually then reassembled into the entire skill. This approach has been used by athletes in other sports for several decades (Perrin et al. 2002; Schmit et al. 2005; Yarrow et al. 2009; Bläsing et al. 2012). This concept is also known as deliberate training or practice. The theory of deliberate practice, articulated by Ericsson, Krampe and Tesch-Romer (1993), is predicated on the concept that it is not simply training of any type, but the engagement in specific forms of practice, that is necessary for the attainment of expertise. Training activities that fall within the definition of deliberate practice to develop the required skills are characterized the fact that they may not be the most enjoyable activities to perform, they require effort and concentration, and they do not lead to immediate competitive rewards (Baker et al. 2017). Research generally supports the application of the theory of deliberate practice to sport and has shown a positive relationship between hours of high quality training and ultimate achievement (Baker et al. 2017). Instead of riding many horses per day and training with the same asymmetries, it might be more beneficial to train specific technical skills and then ride with the improved symmetry, balance and qualities that are necessary to improve performance. It might be assumed that a more advanced rider would have a greater need to refine their skill training and to define what type of movement strategy is optimal for superior sports performance.

In general, human beings are more reliant on the CNS for locomotor control compared to horses. As described in the introduction, humans are pyramidal and horses are extrapyramidal (Martins 2015). Horses have the ability to repeat their stride cycle with low variability as long as speed remains constant (Peham et al. 1998; Andersson et al. 2012). The central pattern generators (CPGs) develop these rhythmical patterns (Andersson et al. 2012), and the horse can be compared to an oscillator with a rhythmical pattern that repeats itself with minimum damping (Peham et al. 1998). This is not the same for humans, even if CPGs are present to some degree (Martins 2015). The main goal in sport is to repeat the perfect performance many times. To make the horse repeat the optimal performance, the rider's main focus is to develop straightness, symmetry, balance and technical movements in their horses and guide the horse to repeat these technical skills in each exercise. But as shown in our studies and other studies described earlier, riders even at elite level are highly asymmetrical. Likely they have little focus on training themselves to become symmetrical, balanced and able to repeat the optimal movements from a technical perspective. If the riders focussed first on improving their own posture, balance, symmetry and rhythmical skills, it might be expected that they would find it easier to train the horses and improve their skills.

Especially in sport, most movements have goals, ultimately to win. To be able to perform at top level, competitors in other sports drill the specific technical skills which they know are the most optimal in order to eliminate extraneous variation. The technical skills necessary depend on many variables presented in figure 9. Dressage riders are in need of different technical skills compared, for example, to show-jumpers; one is dancing on the ground, the other is flying through the air. Further the skills necessary depend on the mechanical and dynamic qualities of the specific horse (e.g. top-level dressage horses compared to Shetland ponies). The challenges relative to intersegmental strategies and rhythmical qualities will further vary with gaits. A study performed by Münz et al. 2014 showed that the rider's passive dynamics changed with gait. The largest pelvic movement in the anterior-posteriorly direction was found in canter, followed by trot and walk (Münz et al. 2014). Different exercises require different technical skills that the rider must specify and specifically train for. The riders may train and fine-tune all of these different exercises unmounted, so they learn how to coordinate their own body in each of them. Last, but not least, the strategies need to be perfect in relation to space, stride length, rhythm (tempo, beat) and degree of collection.

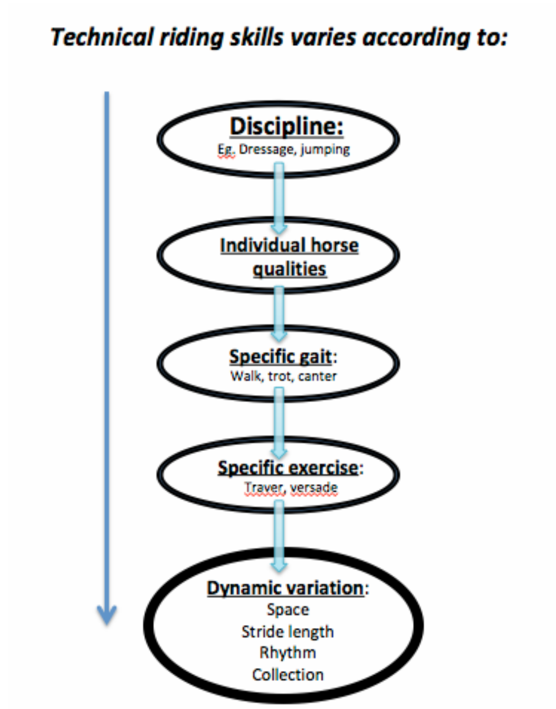


Figure 9: Presents the different variables the rider must consider in order to define the technical skills needed in each exercise and situation.

Based on the fact that the chair data and rider data showed significant associations between the intersegmental strategies between head, trunk and pelvis in the frontal view, it is suggested that riders could benefit from unmounted training with specific focus on technical riding skills, since asymmetry is recognised as a negative trait with regards to equestrian performance (Symes & Ellis 2009; Hobbs et al. 2014). Even though back pain in horses is unlikely to be a new entity, recognition of back pain in horses has increased substantially in recent decades with the availability of improved imaging systems (Wennerstrand et al. 2004; Roethlisberger et al. 2006; Stubbs et al. 2006). Back pain is frequently treated in veterinary clinics (Roethlisberger Holm et al. 2006) as well as by practitioners of alternative therapies (Gómez Álvarez et al. 2008). Many horses are presented at the clinic with mild asymmetries that may be due to subclinical lameness or may reflect motor laterality. Little is published on how an asymmetrical rider changes the biomechanics of the horse, but it is documented that a rider with an asymmetrical position will transfer asymmetrical forces to the saddle and the horse's back (Peham et al. 2001; Licka et al. 2004; Byström et al. 2009).

It is further important to distinguish between laterality and lameness in the horse, because handling and treatment differ between the two situations. Laterality requires an exercise program directed towards addressing that specific asymmetry with the goal of training the horse to become more symmetrical rather than allowing the laterality to continue and, perhaps, develop into lameness. Since lameness is usually associated with pain, lame horses need medical treatment. If the rider is the main cause or a primary contributor to asymmetry of the horse, then it is reasonable to target the rider instead of the horse?

In the future it would be highly interesting to evaluate riders trained to become more symmetrical by unmounted deliberate training on different balancing instruments. The training must be individually tailored, taking account of the rider's individual asymmetries, the horse and the different exercises. The findings would indicate whether unmounted training helps the riders to become more symmetrical and to develop better pelvic dynamics during riding. Would this improve rider's health, horse health; lighter aids and less risk of misunderstanding and suboptimal performance in the future? This might be one of the main areas for future exploration with regard to improving performance in equestrian sports, since the riders seems to have the possibility for improvement.

6.8 Benefits and limitations

A major limitation was the low number of subjects in the studies, particularly in papers I and IV. A low number of participants have two potential effects; there may be insufficient statistical power to detect effects that are present in the target population and the results from the study population may not be extrapolated to the target population because the populations from which data were collected differ in some important respects. Concerning study I, data were from a previous study in which a large number of variables were registered simultaneously with several types of equipment and the number of participants was limited because of practical concerns with the time required to collect data from each subject. Sample size calculations were considered (not shown) before the collecting data for papers II-IV and the goal was to have more than 20 participants in these studies to take into account of the anticipated variation between the human subjects. Unfortunately missing data occurred in different riders in different situations. Multiple-significance testing corrections were not applied, as these have been critiqued (Perneger 1998). Concerning the similarity of the study population to the target population, this was evaluated as a relevant population since the riders were riding multiple hours every day, i.e. less than professional riders, but more than novice or recreational riders. These riders (paper II-IV) had all taken part in the same equestrian education, which may have reduced the between rider variation to some extent.

More than 50% of the general population are considered to have unstable feet due to pronation, so this is unlikely to have made the study population particularly biased compared to the general skilled rider population. It was good for comparison of the results in study IV that most riders rode the same horse, but it could of course affect possibilities for extrapolation to riders riding other horses.

A relevant question is the skill level of the riders and horses that are used in rider-horse interaction studies and this will have effect for the findings. The results from the current studies are likely valid for slightly higher and slightly lower skill levels.

Limitations in study I include that the passive seat was not evaluated in relation to an optimal stance file. Therefore only the dynamic variables e.g. ROM for a variable and change in segment angles between the two seats, could be evaluated. The marker placement was suboptimal for the definition of the upper trunk segment. In study II-IV both these problem was taken into account, both by the change in marker position and placing the riders in the stance chair for producing an optimal stance file. In paper I it was chosen not to study the rider frontal position because of the limitations of the stance files, since the passive seat could not be evaluated as the optimal sitting position in relation to spinal curvatures and frontal alignments. Therefore only the dynamic variables e.g. range of motion for a variable and change in segment angles between the two seats, could be evaluated.

In further studies (paper III-IV) a designed stance chair was used that made the stance position as symmetric as possible. This enabled the analysis of rider position and zero crossing, not only dynamic variables. The discrepancy of results in the current study compared to some other studies may be due to a more-strict placement of the rider in the current study. A stance chair securing frontal and sagittal alignment has not previously been used to my knowledge.

In paper II including a wedge in the stance file could have improved the categorisation of pronation level. This is recommended for future studies. In paper III the task of rocking the chair might have been too difficult for the riders. Either the chair may have had a simpler construction or the riders could have been allowed to train on the chair for a longer period before testing. In papers II-IV only data from the frontal view have been presented, but sagittal and transverse views could have added to the picture. In paper IV it would have been beneficial to also compare translations for the given segments, not only rotations, this was not possible with the IMU-technique used.

Kinematic marker analysis will always be subjected displacement of the skin or clothing relative to the underlying bones and attached IMU-sensors have the same problem, but bone-mounted markers were not an option. The most optimal in relation to marker placement would have been to define much smaller segments to be able to calculate the forces acting on the spinal segments or others smaller structures.

In future studies it would be interesting to measure rider asymmetries simultaneously with horse asymmetries in a larger population.

7 Conclusions

7.1 Main conclusions

- ❖ A method for describing a rider's postural strategies has been developed. Rider's intersegmental strategies can be measured objectively and analysed both ridden and unmounted.
- ❖ The substantial asymmetry shown in riders implies a possibility to improve equestrian performance by training body awareness, balance and symmetry in riders.
- ❖ Ridden and unmounted postural intersegmental strategies in skilled riders were associated. Unmounted testing and training may improve rider's body awareness and equestrian performance.
- ❖ When rocking a balance chair from side to side and when comparing between left and right circles during riding, the riders rotated the trunk more compared to the pelvis. This will likely inhibit fine control of pelvic movements needed for precise communication with the horse. Improved body-awareness in riders and detailed descriptions of the technical riding skills relevant for higher performance are crucial.

7.2 Summary of findings and detailed conclusions

- ❖ When comparing the active seat with the passive seat, posterior rotation of the trunk and pelvis in the active seat were associated with increased anterior translation of the pelvis toward the horse's shoulder and withers (paper I).
- ❖ When the rider's pelvis was translated anteriorly in the active seat the rider's centre of force (COF) moved cranially onto the shoulder region. Focused cranial pressure under the saddle during collection may cause pressure injuries onto the horse`s back (paper I).

- ❖ Riders with a higher degree of eversion on one foot relative to the other displayed an association with asymmetry in pelvic drop during walking. When the foot with greater eversion was in early stance, the pelvis displayed an increased contralateral drop compared to early stance in the opposite foot. Foot pronation has an effect on pelvic movements, and thereby may influence the control of rider's seat (paper II).
- ❖ Most of the riders displayed an asymmetrical intersegmental strategy (head, trunk, pelvis) in frontal plane (lateral) rotations and translations while moving the balance chair from side to side (paper III).
- ❖ An association was found between the directions of foot eversion during walking and frontal plane rotation of the pelvic and trunk segments during sitting: The side of the body that had a higher degree of foot eversion displayed greater trunk and pelvic roll to the opposite side when sitting and rocking the chair. As foot eversion might have an effect on the rider's seat, a more symmetrical seat may be promoted by improving/decreasing foot eversion in riders (paper III).
- ❖ Movements of the pelvis during riding were not mirrored when comparing data for the left and right directions; instead most of the riders positioned the pelvis to the same side throughout. Poor symmetry in the rider may decrease the possibility for improving symmetry in the horse (paper IV).
- ❖ The majority of riders changed their trunk angle more than the pelvic angle when comparing left and right circles (paper IV).
- ❖ An association was found between the individual intersegmental strategies during walking and sitting (paper II) and between sitting and riding (paper IV). This might affect the rider's seat while riding, and indicates that unmounted training might improve the rider's seat.

7.3 Implications

- ❖ With poor ability for postural mirroring while riding, the ability for the rider to develop straightness in the horse may be compromised and cause misunderstandings in the rider-horse communication.
- ❖ The results indicate that by improving the rider's body awareness and symmetry it is reasonable to expect positive effects on sport performance, and on health and welfare of the rider and horse.
- ❖ Parallel to what is done in other sports, it might be useful to train specific technical skills in the unmounted situation, so that the rider can focus on increasing symmetry and body awareness.

8 Future research

- Unmounted training regimens for riders deserve evaluation. There is a need for development of training methods with good ability to train the desired skills, which are likely of critical importance. The evaluation of the tested methods should include whether they lead to improvement of horse locomotion, riding quality and performance.
- Further studies should be made on intersegmental strategies in riders. This should be done on a large rider population, on different skill levels, on different horses, during overground riding, in order to evaluate effects on horse locomotion. This should be performed with more-optimal instruments able to measure both rotations and translations of rider and horse segments, including optimal stance file methodology.
- Develop standard measuring equipment to help veterinarians and instructors to objectively determine a rider's seating technique and load patterns onto a horse. This may improve equestrian teaching by increasing knowledge on how to describe and understand the rider's seat and its effect in a more objective manner.
- To be able to evaluate the long-term effects of different techniques we need longitudinal studies, incorporating state-of-the-art measuring techniques and including continuous registration of horse health and rider health, and equestrian performance.

9 Populärvetenskaplig sammanfattning

Då man skall utbilda en häst är rakriktning ett viktigt steg i utbildningsskalan där målet bland annat är att få hästen lika smidig och stark i båda sidor. Detta kallas också liksidighet. Hästen föds med och utvecklar ofta asymmetrier i sitt rörelsemönster, men genom utbildning och träning kan hästen bli mer liksidig. Inom ridsporten anses det allmänt att ju mer symmetrisk ryttaren är desto bättre kan denna påverka hästen. En asymmetrisk ryttare kan däremot skapa en asymmetrisk tryckbelastning på hästens rygg vilket förhindrar eller försvårar en liksidig kommunikation. Risken finns att en mer asymmetrisk ryttare, som inte är helt medveten om sin asymmetri, använder ”fel” och för stora hjälper och därmed med inte uppnår sina mål. Asymmetrin kan dessutom vara hälsovådlig för både häst och ryttare. Ganska få vetenskapliga studier finns inom området, men några studier visar att ryttare på hög nivå kan vara tydligt asymmetriska i sina rörelser.

Det första steget med denna avhandling var att finna bra objektiva metoder för att karakterisera ryttarens sits, position och balans. För att göra detta analyserades hur ryttaren koordinerar rörelserna i och mellan sitt huvud, bröst, bäcken, fot (intersegmentala strategier) och hur ryttaren agerar i samklang med hästen. Det andra steget var att använda dessa metoder för att studera ryttaren både under ridning och under avsuttna balansövningar. Syftet var att jämföra de intersegmentala strategierna som ryttaren använde under avsuttna övningar, gående och sittande, därefter på hästryggen.

De metoder som användes i studierna var tryck- och rörelsemätning med hög precision. Vid rörelseanalysen, oavsett om det gällde häst eller ryttare, analyseras individen sett från sidan (sagittalt) respektive bakifrån (frontalt).

I den första studien studerades Grand Prix ekipage i trav på ett rullband. Ryttarna jämfördes med sig själva när de red med en passiv respektive (travade på lång tygel) en aktiv sits (red hästen i samlad form).

Ryttarens position studerades genom att huvudets, bröstets och bäckenets rotationer och linjära rörelser (translationer) mättes. Både de enskilda segmentens rörelser (segmentala strategier) respektive hur de rörde sig i förhållande till varandra beskrevs (intersegmentala strategier). När ryttaren samlade hästen visade det sig att sex av de sju ryttare roterade både bröstet och bäckenet bakåt. Detta medförde att bäckenet flyttades framåt mot manken och trycket blev förhöjt i detta område.

I den andra delen i avhandlingsarbetet gjordes fördjupade studier av segmentala strategier i frontalplanet (ryttare och häst sedda bakifrån). Detta gjordes genom en serie studier både med och utan häst av ryttare på medelhög nivå. Målet var att analysera om det fanns ett samband mellan hur segmentala strategier användes i de olika situationerna. I sista delen av studien var det intressant att ta reda på om ryttarens rörelsemönster påverkades mest av de egna segmentala strategierna eller möjligen av hästens rörelse.

För att inkluderas i studien skulle testryttarna pronera (gå på insidan av foten) mer på en fot än den andra. Detta urval gjordes eftersom pronation är mycket vanligt hos unga vuxna i dagens europeiska samhälle. Det finns också ett antal studier som visar ett samband mellan pronation och hur en människa roterar sitt bäcken. Det var därför intressant att studera om ”hur man går” (pronerar i detta fall) påverkar hur man går respektive sitter både på en balansstol och på hästryggen.

Resultaten visade ett tydligt samband mellan gående, sittande och ridande med avseende på ryttarens segmentala strategier och dessutom kunde en tydlig oliksidighet mellan vänster och höger sidas rörelser ses hos en majoritet av ryttarna. Eftersom det är ett mål att vara liksidig som ryttare kan det antas att ryttarna inte hade förmåga till att kontrollera eller full medvetenhet om hur huvud, bröst och bäcken rörde sig i förhållande till varandra vid gående, sittande och ridning och detta oavsett vilket varv eller vilken riktning (vänster eller höger) de befann sig i. Detta talar för att avsutten träning där ryttaren kan ha fullt fokus på sin egen kropp skulle kunna göra dig till en bättre ryttare och att man så småningom också kan definiera vilka avsuttna övningar man skall göra som ryttare.

Det är väl accepterat inom ridning att ryttaren i första hand skall kommunicera med hästen via sätet, dvs med hjälp av rotationer, translationer och tryckändringar genom bäckenet. Ryttaren måste helt enkelt ha kontroll på sina sittben.

I studierna både på en balansstol, och i en jämförelse mellan ryttarnas position på vänster och höger volt under ridning, använde de större rörelser i bröstsegmentet och betydligt mindre i bäckenet. För att en ryttare skall kunna utföra exakta rörelser med sätet, utan att mista balansen, behöver huvud och bröst centreras samt överdrivna rörelser undvikas. Resultaten visar igen exempel på områden där specifik träning av ryttarens kroppskontroll och balans sannolikt kan göra ryttaren till en bättre ryttare.

Att prestera på topp inom idrott är ingen lätt uppgift. När ett ekipage skall prestera på toppnivå måste två biologiska individer röra sig i samklang och koordinera sig optimalt. Som idrottsutövare har man som mål att många gånger repetera 'den rörelsen man gjorde som uppnådde ett så gott resultat så möjligt'. Rörelser är ett resultat av ett komplicerat samspel mellan sinnesintryck, motorisk kontroll och kroppens mekaniska och fysiologiska egenskaper. Att ha förmåga för att skapa perfekta rörelsemönster handlar om att kunna eliminera och kontrollera faktorer som förstör det perfekta inövade rörelsemönstret. Genom hjärnans kognitiva och sensoriska banor tar hjärnan in en extrem mängd information om situationen och rummet som ryttaren befinner sig i. Hjärnan behandlar informationen och sänder därefter ut signaler till musklerna (motoriska signaler) så att musklerna kan utföra de uppgifter som är mest lämpliga. Många av dessa motoriska signaler sker omedvetet och andra har ett större inslag av medvetna, kognitiva processer. I en given situation, för att hjärnan skall sända ut en signal som är så optimal som möjligt är det en stor fördel om förutsättningarna för en funktionellt bra rörelse redan är väl preparerade i utövarens egen kropp. Det mest optimala skulle vara om utövaren har repeterat de bästa lösningarna så många gånger att hjärnan automatiskt väljer dessa lösningar varje gång den givna situationen uppstår.

Begrepp som balans, liksidighet, sittben och symmetri är begrepp som används mycket inom ridundervisning, men som förmodligen kunde ges en tydligare innebörd om ryttaren hade större förståelse för och skicklighet i att kontrollera sin egen kropp. Det finns ett behov av att skapa en större objektiv och vetenskaplig insikt och förståelse för vilka idrottsliga egenskaper en ryttare bör ha. Det finns också ett behov at att utveckla träningsmetoder för ryttare som kan leda till utveckling av goda funktionella kroppsstrategier som i sin tur är bas för goda ryttarprestationer. Genom att ta fram mera precisa och tydliga definitioner av ryttarens grundläggande position och rörelsemönster kommer det att bli enklare att karaktärisera vad som är goda ridtekniska färdigheter. På detta sätt kan sporten utvecklas i en positiv riktning både vad gäller ökad prestation och för ökad hälsa hos häst och ryttare.

Populærvitenskapelig sammendrag - Norsk

Et av de viktigste målene ved å skolere en hest er å utvikle hesten til å bli like smidig og sterk på begge sider av sin kropp. Dette begrepet er et eget punkt på treningsskalaen og benevnes som ”retthet”. Hesten er naturlig asymmetrisk, men ved skolering og trening kan hesten utvikles til å bli mer liksidig eller rett. Det er et vel akseptert begrep innen ridesporten og innen vitenskapen at jo mer symmetrisk rytteren er, desto bedre kan rytteren påvirke sin hest. Derimot kan en asymmetrisk rytter skape et asymmetrisk trykkbelastnings-mønster på hestens rygg som forhindrer en liksidig kommunikasjon. Det er en risiko for at en asymmetrisk rytter, som ikke innehar bevissthet om egen kropp og sine asymmetrier, bruker ”feil” og/eller for kraftige hjelpere for å skape et ønsket resultat- et resultat som muligens ikke har forutsetningene for oppnåelse. Dette kan igjen kan være helseskadelig både for hest og rytter. Det er enda lite vitenskapelig litteratur innen emnet, men enkelte studier viser at ryttere på høyt nivå er betydelig asymmetriske.

Metoden som har blitt anvendt i disse studiene er basert på trykk sensorer og Motion-Capture systemer (bevegelses målinger) med høy presisjon. Rytterne ble analysert i to plan, fra siden (sagitalt) og bakfra (frontalt) Det overgripende målet med denne avhandlingen var å finne en god objektiv analysemetode og deretter analysere rytterens intersegmentale relasjoner (altså hvordan rytteren koordinerer bevegelsene mellom hode, bryst, bekken og fot) og rytterkroppens samhandlingen med hesten.

Det første studiet ble gjennomført på Grand Prix dressur hester og ryttere, i trav på tredemølle. Rytterne ble sammenlignet med seg selv i to forskjellige situasjoner, passivt i trav på lang tøyle og aktivt i trav i samlet form. Rytterens posisjon ble analysert ved å se på hodet, brystet og bekkenets rotasjoner og forflytninger (translasjoner). Både de individuelle segmentenes bevegelser (segmentale strategier) og deres relasjon til hverandre (intersegmentale strategier) ble analysert. Når rytteren skulle samle sin hest viste det seg at 6 av 7 ryttere roterte både brystet og bekkenet bakover. Dette medførte en fremover forflytning av bekkenet mot manken til hesten og et kraftig forøket trykk i dette området.

I den andre delen av avhandlingsarbeidet var målet å se på segmentale strategier i frontal plan. Dette ble det gjennomført igjennom en serie av studier både med og uten hest, av ryttere på middels nivå. Målet var å analysere hvorvidt det finnes en sammenheng mellom hva rytteren gjør uten hest i forskjellige situasjoner og når rytteren rir. Under riding var det interessant å vurdere hvorvidt den segmental strategien rytteren valgte ble igangsatt/initiert av rytteren på grunnlag av hestens bevegelser eller om strategien var en tendens som lå i rytterens egen kropp.

Inklusjonskriteriet for studiet, var at rytterne viste til en forøket grad av pronasjon (å gå på innsiden av foten) på en fot. Grunnlaget for inklusjonskriteriet var at over-pronasjon er høyt frekventert blant unge-voksne individer i dagens europeiske samfunn. Det finnes også studier som viser sammenheng mellom fot pronasjon og bevegelser i bekkenet. Det var derfor interessant å studere hvordan rytterne går respektivt sitter på en balansestol og deretter ved ridning.

Resultatene viste en tydelig sammenheng mellom gående, sittende og ridende med henhold til segmentale strategier. Samtidig viste dataene en tydelig grad av asymmetri, mellom venstre og høyre side, hos majoriteten av rytterne. Siden det er mest hensiktsmessig å ha en symmetrisk sits kan dette bety at de rytterne som ble testet manglet bevissthet om hvordan hodet, bryst og bekken (og fot) beveget seg i forhold til hverandre ved gange, sittende og ridende situasjon. Dette taler for at trening uten hest, der rytteren kan ha fullt fokus på egen kropp i relasjon til posisjon, balanse og symmetri kan utvikle ride tekniske ferdigheter som ansees som viktige for prestasjon innen sporten.

Det er en vel akseptert strategi innen ridning at rytteren skal kommunisere hovedsakelig med sitt sete, det vil si ved hjelp av rotasjoner, forskyvninger og trykk endinger igjennom bekkenet. Ryttere skal ha god kontroll på bruken av sine sitteben. I studiene på balansestolen og ved ridning, når rytterne red på volte og ble sammenlignet mellom høyre og venstre hånd, viste majoriteten en større grad av bevegelse i brystsegmentet i forhold til bekken. For at en rytter skal kunne utføre definerte bevegelser med sete, uten å miste balansen, er rytteren nødt for å sentrere hodet og brystet. Resultatene fra testene på balansestol og ridning viste tydelig at rytterne gjorde tvert imot. De viste nemlig store bevegelse i hodet og bryst, og mindre bevegelser i bekken.

Å prestere godt innen idrett er ingen enkel oppgave. Skal ekvipasjen nå internasjonale gode prestasjoner, må to biologiske individer samhandle og koordineres optimalt. Som idrettsutøver har man som mål å repetere de perfekte bevegelsene som gav de gode resultatene. Målet er ikke å vinne en-enkel gang, men å gjenta den nær opptil perfekte prestasjonen så mange ganger som mulig i løpet av karrieren. Bevegelser er et resultat av et komplisert samspill mellom sanseinformasjon, motorisk kontroll og kroppens mekaniske og fysiologiske egenskaper. Det å ha evnen til å skape de perfekte bevegelsene handler om å minimalisere faktorer som forstyrrer den perfekte bevegelsesløsningen. Hjernen får inn en ekstrem mengde informasjon om situasjonen og rommet rytteren befinner seg i, gjennom kognitive og sensoriske baner. Hjernen behandler informasjonen og sender deretter ut kommandoer til musklene (motoriske kommandoer) slik at musklene kan utføre aksjoner som er hensiktsmessige. Mange av disse motoriske aksjonene skjer helt ubevist, mens andre har større innslag av bevisste, kognitive prosesser. For at hjernen skal sende ut en aksjon som er så optimal som mulig i relasjon til den situasjonen man er i, er det en stor fordel om forutsetningen for en funksjonelt god handling allerede er godt preparert i rytterens egen kropp. Det optimale ville være om rytteren har repetert den gode løsningen så mange ganger at hjernen automatisk velger de optimale bevegelsesløsningene hver gang de gitte situasjoner oppstår.

Begreper som balanse, liksidighet, sitte-ben og symmetri er begreper som brukes mye innen rideundervisning i innland og utland, men som antageligvis ville gitt større praktisk forståelse om rytteren hadde større bevissthet om egen kropp. Det er etter all sannsynlighet et behov til stede for å skape større innsikt og forståelse på et vitenskapelig nivå for hvilke spesifikke kroppstekniske ferdigheter en rytter bør ha. I tillegg er det behov for å definere gode treningsøvelser for å stimulere rytterne, slik at de utvikler funksjonelle, automatiserte, kroppslige strategier som en base for gode rytter-prestasjoner. Gjennom å utarbeide en mer presis og tydelig definisjon av rytterens grunntekniske posisjon og bevegelsesmønster, vil det kunne bli enklere å definere hva som er gode ride-tekniske ferdigheter. På denne måten kan ride-sporten utvikles i en positiv retning både i form av økt prestasjon for ekvipasjen og en bedring av hestens og rytterens helse.

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10 Appendix

10.1 Normal gait pattern in horses

A gait can be defined as a typical coordination of the limbs in a rhythmical and automatic manner that produces repetitive movements. Depending on the different footfalls that can be heard when the horse is moving in the different gaits; walk, trot and canter/gallop, the gait is classified according to beat; two, three or four beat. The gaits are often classified as symmetrical or asymmetrical (Back & Clayton 2001):

- Symmetrical gaits: walk, trot, running walk, rack, toelt, fox trot, paso, stepping race
    - Left/right fore- and hind limb footfalls are evenly spaced in time.
- Asymmetrical gaits: canter, transverse and rotary gallop, half bound.
    - Footfalls occur as couplets.

Another way of defining the gaits is through phase lag or advance placement between the footfalls (Hildebrand 1965). The stride cycle is then separated into stance phases and swing phases.

- Walk: a 4-beat gait with large overlap between the stance phases of the limbs and no suspension period.
- Trot: a 2-beat, symmetrical and diagonal gait. The trot can be subdivided into collected, working, medium and extended trots with differences in speed and stride length. Passage and piaffe are also considered variants of trot.
- Pace: a 2-beat lateral symmetrical gait.
- Canter: a 3-beat gait, slower speed with suspension. The stance phases of the diagonal limb pair are synchronized.

Gallop: a 4-beat gait in higher speed. The stance phases of the diagonal limb pair are dissociated.

10.2 Coordinate system

How the coordinates are aligned might vary. In these studies the X is medio-lateral, Y is posterior-anterior, Z is upward-downward.

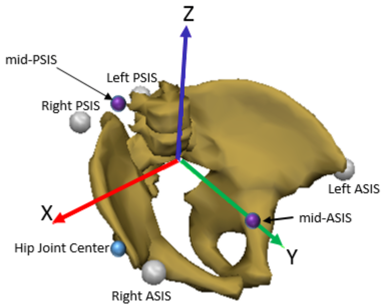

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Figure 3: standard model in Visual-3D (https://www.c-motion.com/v3dwiki/index.php/V3D)

When analysing riders both unmounted and ridden, translational and rotational movements of the body segments of interest are evaluated. Translational movements are movements in relation to the line of the coordinate. Rotational movement is rotations around the coordinates, either positive or negative. This is named differently in different communities, but in general ROLL is around (in this thesis) Y axis, PITCH is around (in this thesis) X axis and YAW is around (in this thesis) Z axis. The main scientifically accepted definition of a movement strategy of an individual is to divide the body into separate segments and describe how the segments translate and rotates in the local and/or global coordinate systems

> *"Every body or object continues in a state of rest, or of uniform motion in a straight line, unless acted upon by an external force. The force is what causes the body to accelerate or decelerate*" *– Newton's first law*

> *"The second law states that the acceleration of an object is dependent upon two variables - the net force acting upon the object and the mass of the object. The acceleration of an object depends directly upon the net force acting upon the object, and inversely upon the mass of the object. As the force acting upon an object is increased, the acceleration of the object is increased. As the mass of an object is increased, the acceleration of the object is decreased."- Newton's second law*

10.3 Basics of rider's seat

Symmetry versus asymmetry

A *symmetrical* dialogue pattern means that there is equal pressure between the right and left buttocks, equal weight in the left and the right stirrup and equal tension in the left and the right rein. This is for example used when the horse performs a halt (Swift 2002). An increased pressure on the right buttock compared to the left can exemplify a non-symmetrical dialogue pattern. Examples of this can be seen when the horse is doing half-pass, shoulder in, renvers and pirouettes (Swift 2002). The rider needs capability of changing between different patterns of dialogue in a functional way in order to stimulate and resolve the set of motions the horse and rider want to perform.

Different types of seats

The rider typically varies seat position depending on gait, discipline and exercises performed. The "two point seat" refers to the contact of the legs in the stirrups with no contact between the seat and the saddle. This is used when the rider is e.g. approaching a jump. As the rider prepares to fly over the jump, he will move forward and into the two-point position. In trot the rider may also use the two-point seat in what is called the rising trot. The rider sits only during one stance (left or right) in a motion cycle and it is the stance of the hind limb that determines the left or right rising trot (Peham et al. 2010). Sitting trot is more used in dressage, where the rider remains in continuous contact with the saddle, during the whole motion cycle. The goal of the sitting trot is to follow the horse's movements and to stay stable in a central position (Peham et al. 2010). The two-point seat creates a more constant load on the horses back compared to a more varying load in the other two positions when the rider is doing rising trot or sitting trot.