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Horse's laterality: methods of determination, genetic aspects, interaction with human handedness and the influence on horse-rider communication, horse's muscle status, sport success and risk of injury

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Meinen Lehrmeistern und Wegbegleitern

Roxanne und Luna

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1. Introduction

In several highly evolved mammals, one side of the bilaterally largely symmetric body is stronger developed than the other, be it with regard to bone measurements, muscle development, vascularisation, or - most important – the neural system including the brain (Ludwig 1932, Coren & Porac 1977, McManus 2002, Hammond 2002, Bagesteiro & Sainburg 2002). All these asymmetries of the principally bilaterally symmetric locomotor apparatus and nervous system are usually subsumed under the term"laterality". Based on side-biased behaviour on different levels, various types of sensory and motor laterality can be distinguished. The existence of laterality has been observed in many species including humans and horses since longtime (de la Guérinière 1733, Steinbrecht 1901, Coren & Porac 1977). The majority of humans are proven to be right-handed, i.e. they are lateralized such that they prefer their right hand for reaching tasks or using tools (Volkmann *et al.* 1998, Dragovic *et al.* 2008). The opposite might be true for motor laterality in horses (McGreevy & Rogers 2005, McGreevy & Thomson 2006, Murphy & Arkins 2008). However, some authors disagree (Müseler 1933, Podhajski 1968, Klimke 1985, Loch 2000, Williams & Norris 2007), which might be explained by varying definitions of laterality. Factors influencing the degree and direction of horses' laterality, as well as the influence of laterality on the communication between horse and rider, have not been satisfactorily investigated yet. The results of previous studies, however, indicate that human handedness and horse's laterality might both influence rein tension which is an important measure of horse-rider communication.

2. Aim of the present study

The reins are one of the main means of communication between horses and riders and asymmetric rein tension might lead to negative impacts of the horse's balance, horse-rider communication and training. Therefore, this study aims at investigating the following questions:

1. Is there agreement between laterality tests used in horses?
2. Do laterality test results obtained on the ground relate to laterality during riding?
3. What is the most common direction of horse's motor laterality in the populations of warmbloods, ponies, American Quarter Horses and Thoroughbreds?
4. Is the lateral displacement of the hindquarters a valid indicator for horse's motor laterality and if so, what is the heritability in warmbloods and Thoroughbreds?
5. Does motor laterality and race track direction affect performance in racing Thoroughbreds?
6. Does a relationship between motor laterality and shortened or stiff muscles exist?
7. How do horse's laterality and human handedness affect rein tension in different riding styles and disciplines?
8. Which influence could the matching of horse –rider-laterality have on communication, training, risk of injury and sport results?
9. Which other factors might influence rein tension, symmetry and performance?

3. Literature

3.1 Laterality in ancient and modern human populations

Laterality, the preference of one body side over the other, occurs in humans (*Homo sapiens)* and horses (*Equus caballus*), as well as many other species (McManus 2002, McGreevy & Rogers 2005, Vallortigara 2006). Ever since the appearance of humans, handedness was present (Coren & Porac 1977, McManus 2002). Since handedness has been documented on the population level in great apes, too (Christel 1993, Christel et al. 1998, Hopkins et al. 2011), it is hypothesized that it might have been inherited from a common ancestor (Forrester et al. 2013, Tabiowo & Forrester 2013). The preference of one hand over the other leads to structural asymmetries not only of muscles, but also of bone structure (Lazenby *et al.* 2008). This is manifested in differences such as increased bone surface density, bone volume fraction and trabecular number according to the principle of articular constraint (Lazenby *et al.* 2008). In professional athletes whose preferred side is loaded heavier than that of the average population from early childhood on, this occurs to an even greater extend (Steele 2000). However, even school children tend to develop an increased length of the long bones of their dominant side (Steele 2000). Bone adapts to its general loading in order to form a functional structure (Lazenby *et al.* 2008). This knowledge was used in studies investigating handedness in ancient populations and hominids e.g. by measuring bone dimensions such as cerebral asymmetries (Holloway & de la Coste-Lareymondie 1982, Mcmanus 2002, Lazenby *et al.* 2008). Findings of asymmetric bone lengths and muscle attachment sites (Walker & Leakey 1993, Trinkaus *et al*. 1994) as well as evaluations of ancient tools and weapons suggested the existence of handedness and especially of left-handed subjects (Coren & Porac 1977, McManus 2002, Toth 1985) in ancient populations. Even among great apes, the overall directions of laterality seems to differ among the species (Christel 1993), with orang-utans being mostly left-handed whilst other species show right-handedness overall (Hopkins et al. 2011, Tabiowo & Forrester 2013). However, handedness in great apes has been influenced by situational factors, posture and grip morphology too (Christel 1993, Christel et al. 1998).

3.2 The development of handedness

There are many theories how handedness developed and why it persisted. The development of language is suspected to be an important trigger (Hugdahl & Westerhausen 2009), as well as an increasing complexity of activities through the use of tools (Uomini 2009). It is argued, that handedness developed from manual gestures during the process of language development (Corballis 2003). The majority of humans (up to 89%) are categorized as right-handed (Annett 1978, Volkmann *et al.* 1998, Dragovic *et al.* 2008). Especially females are most often right biased (Greenwood *et al.* 2007), whereas the majority of left-handed humans are male (McKeever 2004).

Left-handed parents are significantly more likely to have a left-handed child than right-handed parents are. In order to explain these tendencies, several genetic models have been suggested and modified over the last 30 years. The “Right Shift Theory” by Annett (1978, 1985, 2007) as well as the model by McManus (1985, McManus & Bryden 1992) mainly suggest handedness to be a single gene trait. It occurs very frequently in the population, but is not passed on by the Mendelian mechanism of inheritance (Van Agtmael *et al.* 2001). The basic idea is the existence of a dominant “right shift” gene (Annett 1978) or a “dextral” gene and a “chance” gene (McManus 1985). According to these models, right-handedness is caused in dominant homozygotes and heterozygotes (rs++, rs+-/ DD, DC). The direction of handedness in recessives (rs--/ CC) in contrast is completely left up to chance (Annett 1978, McManus 1985). However, especially the mechanisms of the maternal effect, i.e. that left-handed women produce more left-handed children than left-handed men do, remain unexplained (Van Agtmael *et al.* 2001). Furthermore inheritance of handedness was suggested to be discrete instead of continuously (Dragovic *et al.* 2008) or based on three genes in males and six genes in females that are additive (Mckeever 2004). Currently, it seems that both models by Annett and McManus were proven wrong by genome wide studies, which revealed that the genetics behind laterality might be more complex (Armour et al. 2014) and that a major laterality gene or mutation might not exist after all (Ocklenburg et al. 2017).

The development of lateralized behaviour appears to be influenced by more than just genetic factors (Jones & Martin 2008). Physical, environmental and in utero factors such as maternal hormones, anxiety, day length, temperature, disease pattern and nutrition have often been suggested as influential too (Jones & Martin 2008). In the individual, lateralized behaviour is already present during early infancy (Morange-Majoux *et al.* 2000) and manifests by the age of two (Nelson et al. 2013). The degree of handedness increases with age (Greenwood *et al.* 2007), but seems to have decreased again in the population of “older adults” (Przybyla et al. 2011). Since there is a bias in embryos to preferably suck their right thumb, laterality seems to develop in utero (Hepper *et al.* 1991) e.g. with the cytoskeleton during early stages of the embryogenesis (Vandenberg et al. 2013).

Also cultural influences have determined the direction of laterality in many populations. For a long time left-handedness has been regarded as wrong and un-natural (Peters 1997, McManus 2002). Up until the 1950’s, left-handed children in European countries such as France and Italy have been converted to writing with their right hand (Viggiano *et al.* 2001, McManus 2002, Coude *et al.* 2006).

Especially older subjects, who grew up in these countries are less likely to use their left hand for writing (Medland *et al.* 2004). Even within a country such as Great Britain or Italy, the number of left-handed inhabitants varies according to the different regions (Viggiano *et al.* 2001, Raymond & Pontier 2004). In England, the incidence of left-handedness is higher than in Scotland and Wales together (Leask & Beaton 2007). The incidence of left-handedness and ambidexterity in the overall population is approximately 11% (McKeever 2004). In some cultures such as Arabia, China and India, the number of left-handers is low due to cultural pressure (McManus 2002, Kushner 2013). In others such as the island of Tristan da Cunha, left-handedness is non-existent. The reason for this is suggested to be a combination of founder effects, bottleneck situations and random drift causing the responsible genes to disappear from the gene pool (McManus & Bryden 1993).

3.3 Structural asymmetries related to laterality

Laterality affects many different structures, functions and behaviours even in the modern populations. The majority of right-handers are also right-footed and right-eyed (Elias 1998). However, neither does every type of laterality seem to be related to handedness, nor does the strength of dominance relate to each other. The preferred chewing side e.g. does not correlate to handedness (McManus *et al*. 1999, Martinez-Gomis *et al*. 2009) and strong motor laterality does not enhance sensory laterality (Carey & Hutchinson 2013). Sensory and motor differences have been discovered in right and left-handed humans. In modern populations greatest asymmetries have been found in upper and lower limb bones, showing a stronger right- bias in upper limbs and females and the incidence of crossed symmetry between upper and lower limb dimensions (Auerbach & Ruff 2006). In contradiction, significant differences in bone length of modern populations have also been argued to occur without any relation to handedness. According to these assumptions, lateralized stresses experienced in modern societies are not sufficient anymore to lead to bone asymmetries (Danforth & Thompson 2008).

Hand movement seems to be controlled not only by the responsible hemisphere, but also by central pattern generators (CPGs) and other biomechanical factors responsible for motor control (Olex-Zarychta & Raczek 2008). The primary motor cortex is larger in the dominant hemisphere (Triggs *et al.* 1999, Hammond 2002) and finger movements are represented asymmetrically (Volkmann *et al.* 1998). Motor nerves in dominant limbs showed higher conduction velocities (Friedli *et al.* 1987, Sathiamoorthy & Sathiamoorthy 1990) and an increased amount of slow-twitch (type I) muscle fibres with reduced firing-rates (Fugl-Meyer *et al.*1982, Adam *et al.* 1998). In the dominant hand lower average firing rates, lower recruitment thresholds (Goble & Brown 2008) and greater firing rate /force delay occur. This leads to the conclusion that the lifetime preference of one limb results in muscle adaptations causing an increased effectiveness of motor units (Adam *et al.* 1998). Shoulder muscles of the dominant side, such as the *m. trapezius*, show less EMG muscle activity (Bagesteiro & Sainburg 2002) and less fatigue (Mathiassen *et al.* 1995, Farina & Merletti 2003).

In contrast to males, who moved their upper limbs asymmetric according to their hand dominance, females were faster and more symmetric (Adamo et al. 2012). Movement asymmetry depends on movement frequency and is more pronounced in right-handers. It seems to result from interlimb-coupling during movement with the non-dominant limb being in charge (Poel et al. 2007). For hand movement, greater torques was found in men, in supination as opposed to pronation and in the dominant hand (Rey et al. 2014). These findings further indicate an advantage when it comes to movement of dominant limbs. However, the type of movement has an important effect on muscle fatigue and EMG activity (Diedrichsen *et al.* 2007, Hansson *et al.* 2009). Wrist movement with low velocity usually allows much muscular rest. The exception is intensive mouse operations in front of a computer which usually allows only very little rest (Hansson *et al.* 2009). Additionally, the joints of dominant hands usually show a greater range of motion (Bonci *et al.* 1986). However, the range of movement in the shoulders, arms and wrists decreases with age while at the same time the risk and incidence of injuries and disabilities increases especially for persons confronted with high manual strain (Klum et al. 2012).

The advantage of the dominant hand is greater, the more difficult the type of movement is. It is e.g. larger for handwriting than for grip strength (Provins & Magliaro 1989). The greatest grip strength was found in the age group of 30-49 year-olds (Klum et al. 2012). Grip strength was discovered to increase with more repetitions and less resting time (Lim & Kong 2014). The greatest pulling strength was exhibited when the pulled object was located at the side and below the level of the shoulder (Lin et al. 2013). Women were discovered to show significantly greater grip strength in the right as opposed to the left hand, an asymmetry that might be opposite to men (Klum et al. 2012). No difference between dominant and non-dominant hand was detected when it comes to the control of fingertip force, though. It is suggested that laterality should not only be regarded from a kinetic, but also from a kinematic point of view (Buckingham et al. 2012).

3.4 Differences between left and right-handed humans

Both sides of the body are suggested to be represented and controlled by the opposite hemisphere of the brain. Different regions of the brain are supposed to be responsible for different tasks (McManus 2002). A more demanding task would require action of additional brain regions (Weissman & Compton 2003). This way of dividing tasks between the different hemispheres is thought to speed up processing. However, practicing a task means its performance becomes less difficult and the advantage decreases (Weissman & Compton 2003). In the right-handed population the non-dominant, left arm has been suggested to provide a frame for interactions with the dominant arm (Sainburg 2002). It is usually used for unskilled tasks such as picking up small objects and for stabilizing objects which are then manipulated by the dominant hand (Bryden *et al.* 1997, McManus 2002). Most of the time it is moved before the dominant arm starts to act (Sainburg 2002).

Both, left- and right-handers usually perform tasks better with their dominant hand. However, left-handed subjects are not just a mirror inverted version of a right-handed person (Goble & Brown 2008, Michałowski & Króliczak 2015). They seem much less lateralized in comparison to right-handed subjects (Goble & Brown 2008, Rousson et al. 2009). Left-handed subjects usually appear to be more skill-full and faster with their non-dominant hands and use them more often than right-handers do (Steenhuis & Bryden 1999, Rousson et al. 2009). Furthermore, left-handers often perform superiorly in bimanual tasks (Judge & Stirling 2003).

In contrast, in a recent study, non-dominant hands performed better than dominant hands in both, left- and right-handers in proprioceptive tasks. The effect of performing better unimanual than bimanual was greater in left-handers (Han et al. 2013). On the other hand, left-handers are considered to show superior proprioception in both arms (Schmidt et al. 2013). Left-handers perceived grip force more accurately and were able to perform more symmetrically, whereas right-handers showed asymmetric perception and grip force when their right hand was generally stronger than their left. With equal general strength or the left hand being stronger, asymmetry decreased (Adamo et al. 2012).

Handedness seems to be stronger in right-handers, since the areas responsible for motor function are connected more effectively compared to left-handers (Pool et al. 2015). It is suggested that the direction and degree of handedness strongly influences information processing on the levels of conception, perception and motor function and that mixed- or inconsistent-handers are more responsive and ready to update their decisions (Jasper et al. 2014). Also, the superior performance of many left-handers e.g. in cognitive tasks is hypothesized to be caused by bihemispheric activation and short inter-hemispheric transit times (Iwabuchi & Kirk 2009). Several studies have indicated that right- handed humans have their attention biased toward their right hand during bimanual coordination (Peters 1981, Buckingham and Carey 2009,). They seem to move their right hand faster and more readily than their left (Buckingham et al. 2011).

In the right-handed population, the dominant side usually shows more muscle mass (Steele 2000). The dominant hand achieves about 10% more grip force than the non-dominant hand does (Steele 2000), which is also confirmed for riders holding the reins (Hobbs et al. 2014). Annett (1998) has found that in tasks asking for rapid, precisely aimed movement, usually the dominant hand moves more skill-fully. Bilateral training of tasks such as dribbling a ball with both legs during soccer training, however, can potentially modify the performance of the non-dominant limb (Teixeira *et al.* 2003). The strength of handedness influences time perception with mixed-handers perceiving distant events to be more present than persons with strong handedness (Westfall et al. 2010).

Australian jockeys hold their whips rather in their dominant hand, than adapting the position of the whip to the direction of the race track (McGreevy & Oddie 2011). Only dominant hand backhand strikes were discovered to be more forceful than forehand strikes (McGreevy et al. 2013). In confrontational sports, such as fencing, boxing, cricket, baseball, ping-pong or tennis, a direct advantage of left-handed individuals over their right-handed opponents has often been argued (McManus 2002, Raymond & Pontier 2004, Economist 2004, Clotfelter 2008). In these sports, left-handed athletes are over-represented in comparison to their number in the overall population with about 15-33% depending on the discipline (Economist 1997, McManus 2002). As long as they are still in the minority, they are considered to be able to dominate their right-handed opponents since they hit from unexpected directions (Economist 1997, McManus 2002, Raymond & Pontier 2004, Clotfelter 2008). Increased peak force and hand speed was detected for dominant hand strikes (Neto et al. 2012), however, an advantage for left-handers could not be fully proven (Pollet et al. 2013). A different incidence of left-handedness has been found in martial (27%) and pacifistic (3%) tribes (Faurie & Raymond 2004).

In non-confrontational sports, such as swimming, the number of left-handed athletes resembles the proportion of the overall population (Economist 1997, McManus 2002, Raymond & Pontier 2004). Left-handed locomotive drivers e.g. have been suspected to be more prone to cause accidents, simply because their locomotives are designed for right-handed drivers (Bhushan & Khan 2006). Left-handed individuals are disadvantaged in sports such as polo, where the mallet has to be used with the right hand only (McManus 2002). In other areas, such as surgery or orchestras, left-handers seem to be non-existent. The reason for that seems to be either that they adapt to using their non-dominant hand or that they are not able to complete these tasks satisfactorily at all (McManus

2002). Both, left- and right-handed farriers tend to over-trim one half of the hoof, according to their hand preference (Ronchetti et al. 2011). Ambidexterity, the absence of handedness, is argued to be a disadvantage, too. Since subjects, who do not prefer a specific side as a matter of reflex, are argued to show a cognitive delay in time whilst choosing which limb to use for flight or defense, they might be at higher risk of death or injury (Uzoigwe 2013).

3.5 Laterality in horses

Different types of laterality have been investigated in equids using a variety of methods. Similar to humans, horses (*Equus caballus*) show lateralized behaviour on a sensory and motor level. A preference of the horse's right ear, when listening to neighbour calls was documented, while the call of strangers or group members did not show sensory lateral behaviour (Basile et al. 2009). Breed differences in emotionality such as increased sensitivity in Thoroughbreds are scientifically documented (Lloyd *et al.* 2008) and have often been described (Mader & Price 1980, Hausberger *et al.*1998, Houpt & Kusunose 2000, Larose *et al.* 2006). These differences include the horse's locomotion, nutrition, social behaviour and learning ability (McCann *et al.* 1988, Visser *et al.* 2003a, Lloyd *et al.* 2008), as well as eye preference during flight and investigative behaviour (Osterholz 2016). The use of the horse's left eye correlates with higher reactivity (Larose *et al.* 2006, Austin & Rogers 2007) and negative emotional reactions (de Boyer des Roches *et al.* 2008, Osterholz 2016). French Standardbred Trotters rated more emotional, investigated novel objects using their left eye, whereas less emotional horses mainly used their right eye. Austin & Rogers (2007) found a similar left-biased behaviour pattern for flight responses however the order of approach seemed influential. In contrast the right eye was related to novel objects and the left eye to objects associated with negative emotions in Arab mares (de Boyer des Roches *et al.* 2008), whereas for the investigation of objects associated with positive emotions either eye was used. Experience e.g. through daily routine in feral horses (Austin & Rogers 2012 & 2014) or specific training of domestic horses, might help to eliminate negative emotional reactions and decrease side bias for some reactions (Sankey et al. 2011). Riding horses are usually led, handled and mounted from the left side only (De la Guérinière 1733, Steinbrecht 1901, Klimke 1985). Amongst other practical reasons such as wearing armour on the left body side, this practice might therefore have improved horse handling by habituation to stimuli presented to the more reactive side. Still, handling horses from the right side might improve and speed up the habituation process (Austin & Rogers 2007), even though not all reactions were influenced with training (Farmer et al. 2010).

Emotionality has been investigated for a correlation to the position of hair whorls (trichoglyphs) in cattle (Olmos & Turner 2008) and horses (Swinker *et al.* 1994, Randle *et al.* 2003, Gorecka *et al*. 2007). In horses a correlation between hair whorl position and manageability or the approach of novel objects does exist (Swinker *et al.* 1994, Randle *et al.* 2003, Gorecka *et al*. 2007). In contrast, hair whorl position did not always deliver reliable results during assessment of flighty temperaments in cattle (Grandin *et al*. 1995, Olmos & Turner 2008). The direction of hair whorls is argued to be developed during early pre-natal embryonic phases from a similar mechanism as motor laterality (Klar 2003, Beaton & Mellor 2006). However, another theory suggests mechanical tension of the epidermis over the cranium simultaneously to the development of hair follicles to cause trichoglyphs (Samlaska *et al.* 1989). In both, horses and humans, the direction of scalp and facial hair whorls correlate with the direction of laterality. The clockwise direction is most commonly found in right-lateral subjects (Klar 2003, Murphy & Arkins 2008). In humans, left-handed and ambidextrous individuals show a random distribution of clockwise and counter-clockwise whorls (Klar 2003). In horses, left-lateral subjects showed counter-clockwise whorls most often (Murphy & Arkins 2008). A correlation of the direction of laterality during riding with the direction of facial hair whorls was documented (Elworthy 2004, Murphy & Arkins 2008, Shivley et al. 2016), but also rejected (Pywell 2005). However, a relation of facial hair whorls and side preference information either assessed during riding or obtained on the ground seems to be present overall (Elworthy 2004, Pywell 2005, Murphy & Arkins 2008, Shivley et al. 2016). No correlation was found for laterality and side of mane (Whishaw & Kolb 2017).

Information on motor laterality in horses has been obtained with a variety of different methods, too. While some studies focused on the preferred advanced forelimb during foraging either on pastures (McGreevy & Rogers 2005, McGreevy & Thomson 2006, Warren-Smith & McGreevy 2010, Austin & Rogers 2012) or with standardized preference tests (Van Heel *et al.* 2006, Van Dierendonck 2014), others regarded the preferred limb for the initiation of movement (Murphy *et al.* 2005) or truck loading (Siniscalchi et al. 2014), the preferred lead during flat racing (Williams & Norris 2007), as well as the preferred turning side to avoid obstacles (Murphy *et al.* 2005), the preferred side to roll on (Murphy *et al.* 2005) and the lateral displacement of the horse's hindquarters from the median plane while standing (Lerbs et al. 2014) or trotting on a circle (Lucidi et al. 2013). Even though ridden laterality as assessed by the riders (Elworthy 2004, Murphy & Arkins 2008, Shivley et al. 2016) or by experimenters based on judge's scores during competitions (Whishaw 2015, Whishaw & Kolb 2017) has been evaluated, other test methods have rarely been investigated for agreement with ridden laterality or among each other.

In most studies, the majority of horses that showed a side bias were left-lateralized (McGreevy & Rogers 2005, McGreevy & Thomson 2006, Murphy & Arkins 2008). Some authors, however, disagree that left-lateral horses are most common. Klimke (1985), Loch (2000) and Müseler (1983) describe the majority of horses as right-lateralized from their experience as riders. Williams & Norris (2007) identified a preference for the right lead during actual races and morning workout in 90% of their Thoroughbred sample population. Lucidi et al. (2013) found a side bias to the right mostly in older subjects suggesting horses to develop a right-side preference over time. Even though motor laterality has been seen in foals, too (Van Heel *et al.* 2006, Lucidi et al. 2013), the majority of young horses seem to be ambidextrous (McGreevy & Rogers 2005, Van Heel *et al.* 2006, Lucidi et al. 2013). Contradictive findings are available for a group of feral horses where limb preference in individual horses was exhibited rather by younger horses. This suggests a possible decrease of lateralized motor behaviour through experience. However, variations of side bias opposed to consistent bias have been reported as well (Warren-Smith & McGreevy 2010), possibly leading to varying results between trials for the same horse. The majority of horses are not intensively handled before the age of three years (Klimke 1985, McGreevy & Rogers 2005). Training, therefore, could be an explanation why the majority of young, untrained horses are ambidextrous and age has an effect on the degree of motor laterality (McGreevy & Rogers 2005). However, pelvic asymmetry was documented in horses as early as at birth without any improvement over time (Stroud et al. 2016). Structural asymmetry in young horses is not reinforced or diminished by the beginning of training (Nissen et al. 2016a). Furthermore, the mechanism behind training as an influence factor would be expected to affect domestic horses of all breeds and mostly ridden laterality, which is not the case.

Besides the method of observation, breed seems to be a decisive factor for laterality. In Thoroughbreds, Standardbred trotters and warmblood breeds lateralized behaviour was documented on a population base with a variety of test methods (McGreevy & Rogers 2005, McGreevy & Thomson 2006, Larose et al. 2006, Murphy & Arkins 2008). Quarter Horses in contrast seem to exhibit lateralized behaviour only with some methods (Siniscalchi et al. 2014). With other methods investigating motor laterality on the ground (McGreevy & Thomson 2006) or during riding (Whishaw 2015, Whishaw & Kolb 2017), side differences could be observed for some individuals, however laterality was absent in the population. Training, competition level or the phenotypic selection for performance might not be enough to explain these differences, especially since similar findings were made in a group of feral horses (Austin & Rogers 2012). Accounting for the fact that side bias of sensory or motor reactions were related between some, but not all methods, it seems that different levels of laterality might exist. Similar to human handedness, a combination of genetics and other environmental factors must play a role as well.

3.6 The effects of laterality on performance and health

In both, humans and horses motor laterality leads to asymmetries in muscles and muscle strength (Bagesteiro & Sainburg 2002, Farina & Merletti 2003, Pugh & Bolin 2004, Diedrichsen *et al.* 2007). Some disciplines such as dressage aim to balance the horse and increase symmetry (De la Guèrinière 1871, Steinbrecht 1901, Klimke 1985). Others, such as racing, are held responsible for enhancing asymmetry in horses (Dalin *et al.*1985, Knight *et al.* 2000). The horse's balance is very important for its performance in dressage (De la Guèrinière 1871, Steinbrecht 1901, Klimke 1985, Clayton 1990, Miesner *et al.* 2000) as well as show jumping (Powers & Harrison 2000). Still, even advanced dressage horses are often unbalanced (Klimke 1985, Murphy & Arkins 2008).

Unbalanced and asymmetric horses put more strain on one side of their body and are at higher risk of injury to those body parts (Stashak 1995, Tomlinson *et al.* 2003, Dyson *et al.* 2003, Pearce *et al.* 2005). The major reason for horses' sports careers in flat racing, dressage, show jumping or eventing to end are musculoskeletal injuries (Bailey et al. 1999, Wallin et al. 2000 & 2001, Perkins et al. 2005, O'Brien et al. 2005, Murray et al. 2010). The median career length is 2-3 years for racehorses in New Zealand (Tanner et al. 2011 & 2012) and 3-4 years for horses in disciplines such as dressage, show jumping and eventing in New Zealand, Germany and the Netherlands (Rogers and Firth 2005, Ducro et al. 2009, Friedrich et al. 2011). Egenvall et al. (2013) found that in a sample of 263 horses, 55%-22% of training days were lost to non-acute and acute orthopaedic injury, respectively. Risk of injury was increased strongly for horses with previous orthopaedic injuries, but also jump training increased the risk. Risk of injury also varied between different countries. Lameness often remains unnoticed by the riders. Up to 72.5% of horses that were perceived as sound actually showed gait abnormalities at trot in hand (Rhodin et al. 2015 & 2017). Variation in training, however, was identified as a protective factor for musculoskeletal injury in horses (Egenvall et al. 2013). In racehorses risk of injury was associated with age, the type of race, the firmness of the surface, the distance and speed of the race or during training, the weight carried, fatigue loading of the musculoskeletal structures and foot conformation (Pinchbeck et al. 2004, Oikawa & Kusunose 2005, Verheyen et al. 2006, Cogger et al. 2006, Henley et al. 2006, Parkin 2008, Thorpe et al. 2014), but also dam age and skeletal development seems to play a role (Verheyen et al. 2007). Even though the different types of musculoskeletal injuries seem to correlate, their heritability rates are small to moderate (Welsh et al. 2013). Some types of injury to the musculoskeletal system have been reported with an incidence of 69-82% in right limbs in racing Thoroughbreds (Ramzan & Palmer 2011). Also in Quarter Horse racing, different odds of sustaining several musculoskeletal injuries for each side and with regard to certain body measurements were discovered (Anderson et al. 1999). In Thoroughbreds and Standardbred trotters, several body measurements and biomechanical variables were also positively correlated to indicators of sport success, such as lifetime earnings and win percentages or an attribute of elite performers (Leleu et al. 2005, Smith et al. 2006). Symmetry, however, did not differ between elite and medium performers (Leleu et al. 2005).

In some situations however, asymmetry can also be of advantage (Williams & Norris 2007). In gaits such as canter and gallop, horses adopt an asymmetrical movement pattern as such (Deuel & Lawrence 1987, Drevemo *et al*. 1987). With high-speed videos Deuel & Lawrence (1987) investigated the gallop in four Quarter Horses and found slightly different movement patterns in the left and right lead. With changing to their preferred left lead, the horses kept a constant stride frequency. However, their stride length increased resulting in a longer suspension and shortened stance phase and increased overall speed. Williams & Norris (2007) assume that running in their preferred stride pattern might be a decisive advantage for racehorses. They take into account respiratory-locomotory coupling during canter with one breath per stride (Hoyt & Taylor 1981) and the asymmetry of horse's lung anatomy (Getty 1975). In-hand gait asymmetries such as differences in stride length do not seem to negatively influence the horse's race outcome (Sepulveda Caviedes & Pfau 2016).

Similar to humans asymmetric loading leads to differences in bone length and structure (Davies 1996, Davies *et al.* 1999). Pearce *et al.* (2005) studied cadavers of Thoroughbred racehorses and compared the bone structure of the left and right femurs. A number of muscle and ligament attachment sites were larger in the left limbs which they argue to be induced by the asymmetric stresses of permanent work on curved racetracks. During races in a clockwise direction, horses commonly lead with their inside (right) limb and put more strain on their outside (left) limb especially in turns (Biewener *et al.* 1983, Deuel & Lawrence 1987, Davies 1996, Barrey 2001). Therefore, it might not be surprising that in fatal accidents during races most often a left limb is injured (Peloso *et al.* 1996). Another study found elongated right third metacarpal bones in 76% of their Thoroughbred sample and suggested that these differences might be beneficial for racing on counter-clockwise tracks where the right (outside) limb has to cover a slightly longer distance (Watson *et al.* 2003). Conformational asymmetries and injuries of the hindquarters are one of the main triggers for poor performance in horses (Stashak 1995, Ross & Dyson 2003). Asymmetric muscle development of the thoracolumbar region e.g. seems to be associated with sacroilicac pain (Dyson & Murray 2003). Due to the repeated asymmetric stresses, asymmetries are more often found in racehorses than in competition horses of other disciplines such as dressage (Dalin *et al.*1985, Knight *et al.* 2000).

Especially conformational aspects such as uneven feet can cause asymmetric loading and lead to poor performance and lameness in the long run (Van Heel *et al.* 2006, Ducro et al. 2009a). Motor laterality and uneven feet are related and still present after the development into adult horses. Both variables were strongly related to sidedness in gait transitions (Van Heel et al. 2010). Although uneven feet can also be found in seemingly sound horses, the likelihood of injuries is positively correlated to conformation (Ross & Dyson 2003). The average prevalence of uneven feet was reported as 5.3% in one study with 78.500 horses (Ducro et al. 2009b). In up to 70% of horses with uneven feet the left hoof capsule is larger than the right (Kummer et al. 2006), thus leading to asymmetric braking force, ground reaction force and fetlock kinematics (Wiggers et al. 2015). Consequently, horses with uneven feet had shorter careers in dressage competitions and a high risk of injury in show jumping, especially at elite level (Ducro et al. 2009a). Moderate heritability estimates were revealed for hoof variables such as heel height (h^2=0.16) or hoof shape (h^2=0.27). Genetic correlation of uneven feet and performance in competitions such as dressage and show jumping was negative but low (Ducro et al. 2009b). In a group of semi-feral Catalan Pyrenean horses, however, feet were found to be highly symmetric (Parés i Casanova & Oosterlinck 2012). It seems that housing and rearing conditions and training rather than phenotypic selection might enhance asymmetry thus leading to conformational issues challenging the horse's balance and health.

3.7 The rider's influence on the horse

In order to move efficiently with little energy, horse's limbs move like pendula during swing phases and are compressed like springs during ground contact. While the walk is decisively determined by the oscilliations of the pendula formed by the limbs, trot frequency is influenced by the elastic energy of the active diagonal limbs acting as springs (Preuschoft 1993, Witte et al. 1995). During canter, horses move by storing energy in up to three "springs" at once and additionally exhibit ventral flexion of their thoracolumbar and lumbosacral region (Preuschoft 1993, Loitsch 1993, Witte et al. 1995). At walk and trot there is no difference between left and right limbs throughout one movement cycle (Falaturi 1998). At canter however, kinematics for the inside and outside hind limb differ, thus creating gait asymmetry (Hildebrandt 1985, Falaturi 1998).

The horse's rump rests on the extremities as support columns, thus tending to extend vertically (Preuschoft 1976, 1993, Preuschoft et al. 2008). The weight of the rider or just the saddle only, evokes further dorsal extension of the horse's spine in all gaits (de Cocq *et al.* 2004). This rider effect can only be reduced by "collecting the horse" thus increasing ventral flexion of the back when the horse steps with its hind limbs further underneath the rump and bends its head and neck ("on the bit") (Preuschoft et al. 1994a). The force acting on the horse's back is determined by acceleration and the rider's mass and differs between the different gaits being lower at walk (g-force: 1.2g) than at canter and trot (g-force approx. 2 g) (Preuschoft 2011). Horses increased their speed with increasing the duration of their swing phase and reducing the duration of their stance phase (Streitlein & Preuschoft 1987, Falaturi 1998). At trot the saddle displayed a rising movement twice per movement cycle (Streitlein & Preuschoft 1987). At canter and gallop, jockeys loaded the horse's back with up to twice their body weight (Geser-von Peinen et al. 2013).

During ridden work, asymmetry of gaits is often increased or created by the rider (de Cocq *et al.* 2009a, Roepstorff *et al.* 2009). In each gait and posture, the rider's centre of pressure is dislocated in a different movement pattern (Jeffcott *et al.* 1999), thus inducing a different range of forces on the horse's back (Peham *et al.* 2009, Martin et al. 2016). In canter, even though being categorized as an asymmetric gait according to the horse's irregular pattern of movement, horse-rider pairs exhibit the highest level of coordination compared to other gaits with symmetric pattern of movements. Rising trot as opposed to sitting trot seems to enhance horse-rider coordination (Wolframm et al. 2013) and provides more stability to the rider (Peham *et al.* 2009). The weight of the rider produces asymmetrical pressure and increases the duration of the stance phase of the front limbs to a greater extent than that of the hind limbs (Falaturi 1998). Rising trot as opposed to sitting trot causes asymmetric limb loading and kinematics comparable to hind limb lameness in the horse (Roepstorff *et al.* 2009, Robartes et al. 2013, Persson Sjödin et al. 2016). The gaits are less symmetric on a circle, due to a longer stance phase of the inside limbs compared to the outside limbs (Falaturi 1998, Chateau et al. 2013) and less symmetric dorsoventral movement in the thoracolumbar region (Robartes et al. 2013, Greve et al. 2017). The horses' limbs of the diagonal bearing the weight of the rider when sitting (sitting diagonal) were loaded more than those of the diagonal bearing the weight of the rider during rising (rising diagonal). However, in total, the load on the left fore/right hind sitting diagonal was larger than that of the opposite sitting diagonal (Roepstorff *et al.* 2009). The loaded hind limb displayed a longer protraction part of the stance phase and a greater extension of the pelvis with lower tuber coxae on the sitting diagonal (Roepstorff *et al.* 2009). The contralateral forelimb was retracted more and the horse's carried their heads lower (de Cocq *et al.* 2009a, Roepstorff *et al.* 2009).

The total force does not change between different rider positions in a standing horse, however, the force distribution increases towards the direction in which the rider is leaning (Preuschoft 2008, Preuschoft et al. 1994b, 2011, de Cocq et al. 2009a). Accounting for the rather small track width of the horse, this is suggested to enable the rider to communicate and influence the horse with weight signals (Preuschoft 2008, Preuschoft et al. 1994b, 2011). According to previous calculations (Preuschoft 2008, Preuschoft et al. 1994b, 2011), a well –fitting saddle tree successfully distributes the weight over a larger area, with lower mean pressures and localised pressure peaks in comparison to ill-fitting or treeless saddles with or without saddle panels and bareback riding (Peham et al. 2004, Meschan et al. 2007, Belock et al. 2012, Clayton et al. 2013 & 2014). However, pressure has been reported to be distributed unevenly in different types of saddles or saddle fit (Peham et al. 2004, Ramseier et al. 2013, Murray et al. 2017). Asymmetry between saddle panels was documented in up to 63% of saddles (Arruda et al. 2011) correlating with saddle slip, hind limb lameness or gait abnormalities and back asymmetries as well as back pain in horses and riders (Greve & Dyson 2014 & 2015, Murray et al. 2017).

3.8 The horse's balance

The 'natural crookedness' of the horse is an important part of nearly all riding theories (De la Guérinère 1733, Steinbrecht 1901, H.DV. 12 1937, Müseler 1933, Podhajski 1967, Klimke 1985, Auty 2003, Bürger & Zietschmann 2004, Hinnemann & van Baalen 2004, Loch 2000, Miesner *et al.* 2000, Holm 2008, Schmid 2014). In the riding literature, horses are most commonly described as having their hindquarters displaced to the right (De la Guérinère 1733, Steinbrecht 1901, Müseler 1933, Klimke 1985, Hinnemann & van Baalen 2004, Loch 2000, Miesner *et al.* 2000). The right is usually their 'hollow' more supple side. The right side is thus considered as their preferred side, whereas the left is described as rather stiff with tensed muscles (De la Guérinère 1733, Steinbrecht 1901, Müseler 1933, Klimke 1985). The 'hollow' side however, is often regarded as the actual problem. It is hypothesized that the muscles on this side are shortened, which restricts bending to the opposite side (Krüger 2009). These horses tend to lean on the left rein, which puts more strain on the left forelimb and avoid the right rein creating uneven contact (Müseler 1963, Klimke 1985, Bürger & Zietschmann 2004, Hinnemann & van Baalen 2004, Miesner *et al.* 2000,). Roepstorff *et al.* (2009) found that in trot horses put more weight on their right limb and less on their left regardless of the direction and the rider's seat. They argue that even though the definition of laterality and its distribution differs between sciences and riding theories, their results support the impression of the majority of horses being less supple on their left side (Roepstorff *et al.* 2009). On a circle, unbalanced horses tend to increase the diameter in one direction and decrease it in the opposite direction (Rachen-Schöneich 2007). The centrifugal and shear forces acting on the unbalanced horse on a circle are argued to put a huge amount of strain on structures such as the m. *longissimus dorsi*, joints and ligaments (Ross & Dyson 2003, Wyche 2004, Rachen-Schöneich 2007). In their investigation of the derailment in trot on a circle in foals and horses up to 2 years, Lucidi et al. (2013) found that if derailment could be detected, it was mainly to the right. They hypothesized that the right side might be the dominant one which is unable to step underneath the body adequately, thus creating the impression of being stiff, whereas the left side resembles the supporting side which seems “naturally flexed” with the limbs bearing the majority of weight during movement (Lucidi et al. 2013). In fact, in horses trotting on a circle, different forces and gait features were detected for the inside vs. the outside limbs which was more pronounced on a hard surface (Chateau et al. 2013).

Pelvic asymmetry was already detected in foals as early as at birth and in the first few weeks of their lives without any improvement over time (Stroud et al. 2016). Even though asymmetry in young horses does not seem to be reinforced or diminished by training (Nissen et al. 2016a), symmetry of gaits can be improved through osteopathic treatment with its effects lasting for at least 20 days in young horses. Older horses with consolidated asymmetry might require several treatments and re-education programmes to restore long-lasting symmetry (Burgaud & Biau 2016).

Balanced horses are equally flexible on both sides with their hind hooves landing on or beyond the tracks of their front hooves in both curved and straight lines (Müseler 1933, Klimke 1985, Loch 2000, Miesner *et al.* 2000, Bürger & Zietschmann 2004). Only this balanced way of movement enables true equilibrium, even paces, impulsion, collected work and prompt reactions to every displacement of the rider’s weight (Müseler 1933, Klimke 1985, Miesner *et al.* 2000). Laterality related problems such as uneven rein contact and a lack of balance in turns are often complained about by riders at all levels (Klimke 1985, Hinnemann & van Baalen 2004). In the riding literature it is regarded as the rider’s responsibility to adjust and balance the horse e.g. with lateral work and circles (Müseler 1933, Klimke 1985, Clayton et al. 2003, Hinnemann & van Baalen 2004, Loch 2000, Miesner et al. 2000). In young horses symmetry of trunk movement seems to improve after several weeks of training, even though it remains unclear if this effect originates from muscular adaptation or the riders’ influence (Nissen et al. 2016b). Even though motor bias was exhibited during grazing, horses did not show lateralized behaviour during canter on a circle either ridden or unridden, thus suggesting that ambidextrous training as such might be useless if the motor bias might be mainly influenced by the riders’ asymmetry (Wells & Blache 2008). Interference of the rider with negative effects to the horses gait patterns and balance have been recorded previously, e.g. in horses considered to be “reins lame”. Difficulties during lateral movements or the lateral displacement of the hindquarters as such also have been argued to be solely caused by the rider (Moore et al. 2010), however, this theory fails to explain the presence of lateralized movement in unridden horses (Lucidi et al. 2013).

3.9 The horse's muscles and „trigger points"

In humans, the influence of laterality on muscle strength and asymmetries has been intensively studied (Bagesteiro & Sainburg 2002, Farina & Merletti 2003, Pugh & Bolin 2004, Diedrichsen *et al.* 2007). The hypothesis of a hollow side with shortened muscles in horses presenting with a "natural crookedness" in the riding literature (de la Guérinère 1733, Steinbrecht 1901, Müseler 1933, Klimke 1985, Loch 2000, Miesner *et al.* 2000, Hinnemann & van Baalen 2004) has not been truly investigated yet. Furthermore, the muscular state has rarely been considered in studies on laterality in horses. Nevertheless, with their training programme, riders are able to influence and control the development of their young horses' muscular system and thus their health, and performance (Bürger & Zietschmann 2004). Inappropriate muscles of the back and hindquarters diminish the horses' ability to maintain their balance with a rider, thus inducing problems such as leaning on the reins or increasing speed (Kapitzke 2001).

The tremendous impact that structural imbalance of the body e.g. due to blocked joints can have on the health of the whole organism in humans, was first discovered by Andrew Taylor Still (Still 1902). The awareness has increased over the years and the principles of osteopathy, physiotherapy and massage have been transferred from humans to horses (Meagher 1985, Denoix & Pailloux 2000, Evrard 2004).

In the 1950's Jack Meagher developed the system of "sports massage", which applies a combination of compression, direct pressure and cross-fiber friction to hyperirritable areas ("trigger points") of the musculotendinous junction at the origin of the muscle (Meagher 1985). According to his theory, these are the areas where the most "stress" occurs in tensed muscles (Meagher 1985, Teslau 2006). With his application of this theory to horses he was able to establish a system of evaluation and treatment of "trigger points" (Meagher 1985, Teslau 2006). In horses 25 most common "trigger points" could be identified (Meagher 1985, Teslau 2006).

In addition to these 25 "trigger points", which can be precisely located bilaterally, trigger points could be discovered on any other muscle however, their location might not be possible as precisely (Teslau 2006). In fact, this system of „trigger points" has been enlarged by many experienced therapists for „trigger points" on the chest, forelimbs and hind limbs (Teslau 2006), the cleidobrachialis muscle (Macgregor & Graf von Schweinitz 2006) as well as on the masticatory muscles involved with chewing or horse-rider communication (Scott & Swenson 2009). The distribution of muscle fibre types varies between the different muscles, suggesting that some are important for postural stability, such as e.g. the deep epaxial muscles or the M. psoas minor, while others, such as the M. psoas major, M.

iliocostalis and M. longissimus dorsi, play a major locomotory role (Hyytiäinen et al. 2014). According to Meaghers' most common „trigger point“ locations, muscles with a major locomotory purpose are at higher risk to develop sensitive „trigger points“, as described in the following paragraph.

In both humans and animals, a “sensitive trigger point” or “myofascial trigger point” is precisely localised and develops a taut band, i.e. a bundle of contracted, hard muscle fibres with ischemia, hypoxia, cell damage and inflammatory mediators, along with local and referred pain and a local twitch response (Hong & Simons 1998, Gerwin 2008). Affected muscles are weak without being atrophied and show a restricted range of motion. The human patients' usual pattern of pain can be reproduced upon stimulation, however, this is considered to be impossible with animals (Macgregor & Graf von Schweinitz 2006). According to the horses' reaction to direct pressure applied to the „trigger point“, pain response has been scored with scales from 0-3 or 0-5 in previous studies. Trigger points with “0” reaction were declared inactive (Varcoe-Cocks et al. 2006, de Heus et al. 2010). Palpation results with this method are reproducible between physiotherapists and relate to results obtained using algometers to determine the mechanical nociceptive threshold (de Heus et al. 2010). Physiotherapists often use different subjective scales (e.g. pain, manual palpation of temperature etc.) to determine the muscular condition. Agreement between physiotherapists was best for the subjective determination of pain responses (de Heus et al. 2010). Even though sensitivity to touch on any body part varies considerably between horses, it does not seem to be related to their riding quality (Krauskopf & König von Borstel 2016). However, left-lateral horses exhibited less sensitivity to pressure on their back for unknown reasons (Krauskopf & König von Borstel 2016).

With the technique of „trigger point“ massage direct pressure is applied to the underlying tissue such as superficial fascia, connective tissue or the muscle tissue of a „trigger point“, over a few seconds up to a few minutes until the structure releases (Teslau 2006, Scott & Swenson 2009). Even though different reactions were recorded between several trials, diagnostic palpation does not reduce the pain response of „trigger points“ (de Heus et al. 2010). Sensitive „trigger points“ of the pectoral muscles are associated with girth aversion behaviour (Bowen et al 2017). Sensitive muscle „trigger points“ and pain have a negative impact on muscle strength and performance as well as motor control (Teslau 2006, Scott & Swenson 2009, Bowen et al. 2017).

In humans, neck pain is associated with latent „trigger points“ in the masticatory muscles and reduced jaw opening (De-la-Llave-Rincon et al. 2012). Treatment of „trigger points“ with different techniques results in reduced pain sensitivity and improved mobility and muscle strength (Mehdikhani & Okhovatian 2012, Cagnie et al. 2013). „Trigger points“ in human patients have been reported that lead to tremendous pain at the local area of the trigger point as well as referred pain at distant areas until normal locomotor function was impossible. If persistent, several months of intensive physiotherapy are required to eliminate pain and restore normal function (Muscolino 2013).

Treatment of the muscular system with massage has many beneficial effects on the horses' health, well-being and performance (Denoix &Pailloux 2000, Wilson 2002, Weeperpong et al. 2005, Teslau 2006, Scott & Swenson 2009). Compensatory tightness around joints or vulnerable structures can be reduced with massage techniques such as mechanical pressure, thus restoring the normal range of motion, improving flexibility and increasing stride length in walk up to 4% (Wilson 2002, Weeperpong et al. 2005, Scott & Swenson 2009, Hill & Crook 2010).

3.10 The rider's posture in European riding

Maintaining one's balance on a moving surface, such as a horse's back, is essential for performance and the rider's posture. Hippotherapy and horse simulators improve long-term balance, gross motor function, muscle symmetry and dynamic stability, especially of the head and trunk in patients and the elderly (McGibbon et al. 2009, Shurtleff et al. 2009, Giagazoglu et al. 2012, Kim & Lee 2015). The movement patterns when riding a horse are identical to those during walking for many characteristics (Uchiyama et al. 2011, Garner & Rigby 2015). However, balance of the rider is required to enable a correct seat as commonly described in the riding literature (De la Guérinière 1733, Steinbrecht 1901, H.Dv. 12 1937, Müseler 1933).

The rider's influence on the horse is determined by his/her mass and acceleration. During each gait with its own sequences of footfalls, different forces are acting on the rider (Preuschoft 1993, Falaturi 1998, Preuschoft et al. 1994b, 2011, Peham et al. 2009). Horizontal forces of approximately 0.8 – 1.2g e.g. due to the horse accelerating or slowing down, as well as vertical forces of 1 – 3g according to the horse's gait and speed have been estimated (Preuschoft 1993, Preuschoft et al. 1994b, 2011). The rider's weight is supported on the contact area of the seat bones, gluteal muscles, thighs and the foot in the stirrups. In order to communicate with the horse via weight signals, the rider needs to shift his/her weight without losing his/her balance (Preuschoft 1993). The rider's centre of mass is located slightly behind that of the horse. Even though the adaptation of the rider's centre of mass to that of the horse is regarded as essential (Müseler 1933, Miesner et al. 2000), it is more important for the rider's balance that the majority of the rider's weight is located over his/her support area (Preuschoft et al. 1994b). A lateral shift of the rider's weight has a great effect on the horse's centre of mass and thus serves as a rather effective means of communication (Preuschoft et al. 1994b).

Without active communication, the rider's centre of mass acts cranially. Only rider's in the demanded "dressage seat" are able to shift their weight slightly more caudally (Preuschoft et al. 1994b).

Conventional "European" riding is based on the riding theories of European riding masters (e.g. de la Guérinière 1733, Steinbrecht 1901) as well as riding instructions for military purposes (H.Dv. 12 1937). In conventional European riding the rider is requested to keep a constant contact to the bit which has to be independent of his/her position and the horse's movement (Müseler 1933, Miesner et al. 2000). To achieve this, his/her arms and trunk have to be moved separately. Throughout the stride cycle the rider's trunk and hip move into opposite directions (Terada et al. 2006) possibly supporting this demand. The rider has to create good coupling to his/her horse (Münz et al. 2014), thus being able to follow the horse's movements in a supple, steady way and ride with effortless or even invisible signals (Müseler 1933, Miesner et al. 2000, McGreevy et al. 2005). During rising trot riders tilt their upper body further forward than in walk (Lovett et al. 2005). Rising trot requires a balanced seat from the rider but also provides more stability than sitting trot (Peham et al. 2009). Rider position in canter is comparable to walk, but is likely to require more energy (Preuschoft 1993, Lovett et al. 2005). The main purpose of all muscle activity in riding appears to be co-ordination and postural stabilisation (Terada et al. 2004). The m. trapezius seems to stabilize the neck and scapula and prevents the scapula from being pulled forwards via rein tension, while the m. deltoideus provides stability. The alternating pattern of activity of the m. biceps brachii and m. triceps brachii suggests that they control the elbow and thus maintain a constant contact to the bit. The m. flexor carpi radialis seems to stabilize the rider's wrist. The m. rectus abdominis is likely to stabilize the rider's trunk and allow the pelvis to swing forwards. The m. teres major, m. serratus anterior and m. extensor carpi ulnaris might be contracted tonic thus controlling the position of the arms or wrist which might influence contact to the bit (Terada et. al. 2004).

Riders, who are well-coupled with their horse through their seat, only have to cope with the g-forces that are acting on the horse, whereas riders, who are less synchronized with their horse, are facing different vertical forces (Preuschoft et al. 1994b). The posture of advanced riders resembles the seat which is demanded by the majority of riding theories (Müseler 1933, H.Dv. 12 1937, Schils et al. 1993, Miesner et al. 2000). Skilled riders are able to keep their pelvis closer to the mid-position and further forward, thus reaching a higher coupling intensity to their horses (Münz et al. 2014) and co-ordinate their movements within all gaits (Terada 2000). They have developed better proprioception than novice riders, which enables them to adapt their postural coordination more quickly in order to keep their balance and communicate with their horses (Olivier et al. 2016). In contrast, novice riders lean forward with their upper bodies, thus carrying their arms closer to the imaginary vertical through their ear, shoulder, hip and ankle (Schils et al. 1993) and tilt their pelvis further to the right and more backwards (Münz et al. 2014). Even though novice riders were able to successfully synchronize with their horses movement within 10 – 30 minutes (Preuschoft et al. 2011), they show difficulties of co-ordination especially in sitting trot (Terada 2000). During the first 24 weeks of training novice riders frequently change their posture (Kang et al. 2010). However, especially for novice riders it seems to be essential to focus on learning to maintain their balance while communicating with and adapting to their horse first, rather than train a "correct" posture.

Riders trotting in a two-point seat are more stable than in rising or sitting trot (Peham et al., 2009). The uncoupled movement of horse and rider in two-point seats enable the horse to go faster (Pfau et al., 2009). The rider's weight influences the horse's movement pattern to a great extend (de Cocq et al. 2004, Preuschoft et al. 1995). The action of the rider's hands through their position and signals influences the position of the horse's poll and neck and limits their range of movement (Meyer 1996, 1999). In an optimum position, the horse is controlled through reins and weight without restricting its natural movement pattern (Meyer 1996, 1999). The horse's neck, rump and limbs are connected via muscle chains which makes them interdependent. In a "bow and string model" the rider's weight is carried by "the bow" (spine and m. longissimus dorsi) which is drawn by "the string" (sternum and abdominal muscles), thus counteracting dorsal extensions (Jeffcott & Dalin 1980, Budras & Röck 2000). Assuming instead that the horse's spine is borne by the limbs as support pillars, still the horse needs to be "collected", bringing its hind feet further underneath its rump and rounding its head and neck in order to counteract dorsal extension due to the rider's weight (Preuschoft et al. 1994a). Good riders are able to maintain synchronisation with the horse (Peham et al. 2001, Lagarde et al. 2005, Clayton et al. 2011, Münz et al. 2014) whilst keeping it in balance, on the bit and in a correct frame (Peham et al. 2004).

Correct training may improve the core strength and muscular support of the thoracolumbar spine of the horse (Licka et al. 2009). A well-adjusted, stable seat is the foundation for the rider to adapt his/her pelvis to the horse's gait specific motions and to communicate with their horse effectively (Peham et al. 2001, 2004, 2009, Symes & Ellis 2009). However, most riders tend to rotate their shoulder to the left and exhibit a greater range of movement in their right shoulder and different lengths of their legs (Symes & Ellis 2009). Crooked riders sit and move asymmetrically, which may result in a negative impact on educating and training horses, since their cues and signals are likely to be inconsistent. While the ability to ride in rhythm with the horse requires practice, training and sensitivity, it also depends on the riders' own symmetry and balance. Physical or postural asymmetry of the rider results in asymmetric distribution of force on the horses' back and might reduce horse's performance. The consequences range from local and overall changes in muscle tone to pain reactions and dysfunctions such as kissing spines (Meyer 1996, 1999, Zimmerman et al. 2011b). The most common poor postural characteristics in riders have previously been described subjectively as tipping forward, leaning backwards, hollowing of the back, rounding of the back, lateral flexion and rotation of the trunk and pelvis (Schils et al. 1993, Mason 2006, Symes & Ellis 2009, Alexander et al. 2015). Alterations in movement of the lumbopelvic region in riders are suspected to be very common in right-handed riders (Clayton 2013b, Alexander et al. 2015), however not every alteration might be just a “bad habit”. In healthy, young, often athletic male humans, the angle of the hip joint during riding is associated with curvature of the lumbar area, which contradicts the postulate of a “correct sitting posture” (Busching 1998). Riders forcing themselves into a position that does not come naturally to them, are more likely to tense up their muscles and thus lose suppleness and impact their ability to keep their balance and communicate with their horse effectively (Preuschoft et al. 1993, 2011). Variation of symmetry of saddle pressure is influenced by the horse’s movement and the rider’s posture with large differences between horse-rider pairs (Gunst et al. 2019). However, the position of the rider is also influenced by the saddle fit to the horse and to the rider (Peham et al. 2004, Mönkemöller et al. 2005). Deviations from the optimum positions, such as a “collapsed hip” or the need of different stirrup lengths to “feel straight”, might also be a result of an asymmetric saddle position or poor saddle fit (Guire et al. 2016). Symmetry might further be influenced by the familiarity to the equipment. On a symmetric mechanical horse, stirrup forces were more asymmetric in rider’s personal saddles as opposed to unfamiliar equipment (Biau & Debrils 2016).

Asymmetrical postures occur within dressage riders e.g. when performing sitting trot and influence horse’s asymmetries (Licka et al. 2004). Specific dressage movements such as shoulder-in and travers however, are designed to result in asymmetrical loading of the back, with differences in the maximum total saddle forces on the left and right sides (de Cocq et al. 2010b) in order to ultimately improve and straighten the horse’s “natural crookedness” (De la Guèrinère 1733, Steinbrecht 1901, Müseler 1933). Research agrees that the key to harmony and optimum performance is the riders’ ability to maintain a balanced postural alignment enabling him to adapt to the horses’ motions (Peham et al. 2001, 2004, 2009, Symes & Ellis 2009, Kang et al. 2010, Münz et al. 2014). Being able to maintain a balanced position is a matter of muscle strength rather than muscle mass (Bijlsma et al. 2013). Trunk rotation asymmetries are correlated to muscular imbalances (Al-Eisa et al. 2006). Asymmetric back muscle activation in the rider may potentially cause spinal instability and lead to back pain in horse and rider (Al-Eisa et al. 2006), which was reported with a prevalence of 25% in a large-scale study of British dressage horses (Murray et al. 2010). Structural asymmetry leads to increased loading of certain structures and body parts while others are loaded to a lesser extent than usual (Wallden 2011). Structures bearing greater loads are more prone to injuries due to compression or overuse. Unloaded structures might develop atrophy of the associated muscles and be at risk of traction injuries (Wallden 2011). The risk of developing osteoarthritis e.g. is much higher for the hip of the dominant body side (Cawley et al. 2015). Especially riders with postural asymmetries and pelvic rotation distribute their load unevenly (Symes & Ellis 2009) and thus might overload one side. In humans and animals, Wallden (2011) considers the non-dominant limbs to be preferred for standing since they are stronger and provide more stability, but lack power and accuracy for the actual task. He describes descending patterns of dysfunction that might be caused by laterality as such that the non-dominant shoulder is higher and therefore the anterior oblique sling from the non-dominant shoulder to the dominant hip might be weak too. This leads to pelvic tilt and closure at the dominant side of the sacro-iliac joint which might cause medial rotational instability through the dominant leg and weakness of the associated muscles as well as a deviation of movement pattern of the dominant foot. Taking laterality patterns and the associated structural asymmetries into account might help to align asymmetries, enhance balance and performance and reduce the risk of injury (Wallden 2011). If recognised, asymmetries can be addressed by osteopathy, taping and specific exercises, thus improving balance and range of movement (Nevison & Timmis 2013, Alexander et al. 2015, Biau & Bouloc 2016). Pelvic asymmetry has been reported in up to 93% of horse-rider pairs with the majority rotating in the same direction (Browne & Cunliffe 2014), therefore treatment of the horse or rider alone might not be successful long-term. Alterations from pelvic symmetry correlated with competition level and years of riding suggesting that dressage riding reduces rather than increases symmetry (Hobbs et al. 2014), although the horse's asymmetry might be another influencing factor. However, in humans, the shape of the spine relates to the angle of the hip joint, which determines whether the back shows a lordosis or kyphosis (Busching 1998). Trainers should take this into account when interpreting the riding literature and trying to adjust the position of a rider.

3.11 Rein signals in European riding

Riders utilize their hands for a range of tasks. They are used to control the horse's speed, impulsion, bend, position of head and neck and to support the horse's balance (Podhajski 1967, Meyer 1996, 1999, Auty 2003). In general, classical riding theories request the rider's hands to build a steady contact which is independent from the rider's seat and the horse's motion without remaining in a fixed position (De la Guèrinère 1733, Steinbrecht 1901, H.Dv. 12 1937, Müseler 1933, Podhajski 1967, Miesner *et al.* 2000, Auty 2003). On the other hand though, the rider's hands cannot be regarded as entirely independent from the seat, since rein aids are not to be given without seat or leg aids (Auty 2003, Miesner *et al.* 2000, Müseler 1933). Several ways to influence the horse via rein tension are described. Depending on the intended purpose, tension can be maintained passively on both reins or one of the two reins can be given or taken back (Müseler 1933, Miesner *et al.* 2000). To influence only one side of the horse e.g. to achieve lateral bend, one rein is taken back while the other is kept in position (Steinbrecht 1901, Müseler 1933). In order to ride bended lines, turns or achieve collection, riders often apply different rein tensions at once (Müseler 1933). On bended lines such as a circle, the two reins serve different purposes (Steinbrecht 1901, Müseler 1933, Podhajski 1967, Miesner *et al.* 2000, Auty 2003). The outside rein is used to control the impulsion from the inside hind limb as well as the horse's speed (Auty 2003). It supports the horse's balance (Auty 2003) and determines the position and size of the circle (Podhajski 1967). The inside rein controls the position of the horse's head and neck (Podhajski 1967). It indicates, accepts, controls and maintains the bend created by seat and leg aids (Podhajski 1967, Auty 2003). The inside hand is furthermore supposed to keep a light and flexible contact to the bit and encourage the relaxation of the horse's lower jaw (Auty 2003).

The reins are more actively used for turning and slowing down responses during education, but are supposed to become passive with a light connection to the mouth in the more advanced horse (Kapitzke 2001). Riders are not supposed to use the inner rein for turning and keep the outside rein in a fixed position at the same time, since this will diminish impulsion and turning responses and might result in the horse tilting its head (Kapitzke 2001). Instead riders are supposed to use their body weight through subtly turning their upper body and perform a gliding movement of both reins simultaneously to indicate turning, similar to bending and turning in Western riding (Kapitzke 2001).

3.12 The rider's posture and signals in Western riding

Western riding developed as a functional riding style mainly for ranch work and managing cattle (DQHA). The basic posture of the rider in Western riding is similar to that of the conventional European riding style. An independent, balanced and relaxed seat is important for communication with the horse (Holm 2008, Schmid 2014). In contrast to the conventional European riding style, Western riders position their pelvis slightly more rearward. For some manoeuvres no thigh contact is required. The shoulders can be positioned differently to underline certain cues e.g. outside shoulder and hip can be pushed forward however, they should be positioned level to each other. In Western riding there is no need for a 90° angle of the elbow joint (Holm 2008).

In Western riding, split reins are used most commonly. The reins are carried at a length which allows the horse to react immediately to any cue given however, constant contact is not required. Especially with younger horses, the reins are held bimanually with both reins running through each hand. On each side of the horse, the end of one rein should rest approximately at the level of the carpus. The hands are carried with a greater distance to each other and moved towards the horse's mouth simultaneously following the gait characteristics (Holm 2008, Schmid 2014, AQHA 2016). During one-handed rein handling, the hand carrying the reins might be higher than the elbow. One rein runs over the index finger, the other rein is held between index and middle finger, while the end of the reins rest on the same side of the horse's shoulders. The reins can be handled with one hand using a snaffle bit however with curb bits one-handed rein handling is mandatory. Cues are still given simultaneously and the reins should be held at equal length (Holm 2008, Schmid 2014, AQHA 2016).

Communication of horse and rider during Western riding is based on signals, mainly given by the weight of the rider which might be accompanied by leg and rein signals. Western riding aims to educate horses to follow the rider's signals immediately and keep working independently until they receive another signal. As soon as the horse shows the desired reaction, the rider stops giving the signal. If the horse does not react to a single signal, the intensity is increased or signals e.g. of the legs or reins are added. A rider should be able to ride a fully educated horse without any tack only with shifting his/her weight as a means of communication (Holm 2008, Schmid 2014). Change of speed and direction is mainly achieved through the position of the rider's upper body and pelvis. By leaning forwards or back, the rider indicates the horse to accelerate or to stop. By moving his/her pelvis the rider shifts more body weight to one side, thus inducing the horse to step underneath the shifted centre of gravity in order to restore balance (Holm 2008). With leg signals used without shifting his/her weight, the rider keeps the horse straight in its track. Through different positions of his/her legs, he controls the horse's shoulders, trunk and hindquarters. A leg signal combined with a shift of weight supports the change of direction (Holm 2008). Rein signals are given bimanually to support the weight and leg cues during speed control and backing up. In order to change direction or indicate bend, the outside rein is laid against the horse's neck, while the inside rein is moved away from its neck. Still, both hands are moved simultaneously from the wrist, elbow and shoulder. As soon as the horse reacts, the rein signal ceases. The hands are not supposed to pull or move backwards. The rider can carry the inside, but not the outside rein higher or more sideways, when controlling the front feet during bend. Voice commands are distinguished for change of gaits, speed control and stopping (Holm 2008, Schmid 2014).

Some specific manoeuvres are trained most commonly in Western riding. Many Western riders prefer to ask their horses for transitions from canter to halt or for sliding stops. Riders, who passively increase body tension and use a voice command, will receive a transition from canter to halt with the horse remaining in the same relaxed frame. In order to ask the horse to do a sliding stop with active engagement of the hindquarters and hind feet that slide a few metres while the front feet maintain forward movement, the rider has to use a voice command and move his/her upper body backwards, thus blocking the horse's forward movement with his/her body weight. With all gait transitions, the reins are only to be used if the horse does not react in the first place. With a shift of body weight and a rein signal for lateral bend, the rider can ask for a spin. In this manoeuvre the horse quickly performs several 360° turns on the haunches with minimal lateral bend. A rollback i.e. a single 180° turn on the haunches in canter is usually followed by cantering or galloping on a straight line. The rider can ask the horse to move backwards either by a change of posture or passively with leg, voice and bilateral rein signals (Holm 2008, Schmid 2014, AQHA 2016).

When it comes to performance, learning and possible discomfort, the skill level of the horse-rider combinations seems to be more important than the difference between Western and conventional European riding styles (König von Borstel et al. 2013).

3.13 The influence of bits and bridles on the horse

Commonly for riding, driving or leading a horse, reins or a lead rope are attached to a headcollar or a bridle (Preuschoft *et al.* 1999a, Miesner *et al.* 2000). With this equipment only tension but not pressure, torques or bending moments can be applied. Tension can be modified concerning its intensity, direction and duration (Preuschoft *et al.* 1999a). Both systems, bitted or bitless, function by applying pressure to sensible parts of the horse's head (Preuschoft *et al.* 1995, 1999a). Pressure is defined as force per area. Therefore, the thinner the straps and mouthpieces as a contact area between horse and handler, the more pressure is created on the horse's head when tension is applied to the reins or lead rope (Preuschoft *et al.* 1999a). When pressure is applied to a headcollar or bitless bridle, the skin between noseband and nasal bone (*Os nasale*) is compressed, thus activating sensory receptors in the skin and pain receptors in the periost (Preuschoft 1990c, Preuschoft *et al.* 1999a). In a bridle, the distance between upper and lower jaw is dictated by noseband and chin strap. When the mouth is opened, forces are transmitted to the nasal bone through the noseband (Preuschoft 1990c, Preuschoft *et al.* 1999a). In contrast, in a bridle without noseband, the distance of upper and lower jaw is dictated by the masticatory muscles, which transmit forces to the cranium (Preuschoft 1990c, Preuschoft *et al.* 1999a). For a broad cavesson noseband, the pressure on the lower jaw through the chin strap is higher than the pressure on the nasal bone. For a thin or flash noseband and flash strap, the forces are focussed on the nasal bone. Regardless of the type of noseband, however, the forces applied to the mouth through the bit are considered to remain the same (Preuschoft *et al.* 1999a). Since cavessons are assumed to increase bit pressure from the riders signals, the more they restrict chewing and jaw opening, no cavessons should be used whenever possible (Kapitzke 2001). In Western riding, cavessons are supposed to be used to correct horses that do not accept the bit readily. During most competitions, they are not allowed (Holm 2008, AQHA 2016; Overview of different types of bridles: Figure 52).

A bit usually consists of a mouthpiece and one ring attached to each side of it, where the reins are fixed to. Bits are positioned in the diastema of the oral cavity. Rein tension causes the bit to compress the gingivae and activates sensory and pain receptors similar to a bitless situation (Preuschoft 1990a, Preuschoft *et al.* 1999a). Furthermore bits affect any other structure they encounter e.g. the horse's tongue and teeth (Clayton 1985, Preuschoft *et al.* 1999a), resulting in possible damage of these areas (Bendrey 2007). There are several different types of bits (Overview: Figures 53 and 54). The most commonly used bit is the snaffle bit. Rein tension on both sides of an unjointed mouthpiece creates bilateral pressure on the lower jaw. Tension applied to one rein only leads to unilateral pressure on the lower jaw causing the opposite side of the bit to lift off (Clayton 1985, Preuschoft 1990a, Preuschoft *et al.* 1999a). A jointed snaffle bit consists of two cannons which are either jointed directly or contain a middle piece. These types of bits maintain their position in the oral cavity with unilateral rein tension as they are able to adapt to its shape (Clayton 1985, Preuschoft 1990a, Preuschoft *et al.* 1999a). The contact areas vary between the different types of snaffle bits (Engelke & Gasse 2002, Benoist & Cross 2018). Rein tension applied to jointed snaffle bits increases the pressure on the contact areas 1.3 – 3fold compared to rein tension applied to mullen mouth bits (Preuschoft 1990a, Preuschoft *et al.* 1999a, Preuschoft 2000). When the reins are tightened by the rider, all types of snaffle bits relocate caudally and rotate on their own axis, thus applying pressure to the tongue (Clayton 1985, Preuschoft 2000, Engelke & Gasse 2002, Benoist & Cross 2018).

Other bits such as the curb bit utilize lever action in order to increase the pressure to the contact areas applied by rein tension 2 - 4fold (Clayton 1985, Preuschoft 1990b, Preuschoft *et al.* 1999a & c). Curb bits are usually used with a curb chain positioned in the curb groove under the horse's chin. When tension is applied to the reins, the curb chain tightens and transfers pressure to the lower jaw and masticatory apparatus (Preuschoft *et al.* 1999a). With the use of curb bits with jointed mouth pieces (Figure 54), the pressure applied through the effect of the mouth piece and the levers add up

(Preuschoft 1999a &b, Preuschoft 2000). Fitting straps, such as the curb chain, rather tight to the horse's head is a means to increase precision since the horse detects even a small degree of movement and tension (Preuschoft *et al.* 1999). With bits utilizing the principle of levers for communication, more pressure was distributed to the poll, unless a curb chain was used, which diverted the pressure to the chin. In a double bridle, however, interference of the curb bit with the bridoon mouthpiece was discovered, suggesting the poll pressure being induced by the bridoon mouthpiece and their associated reins (Cross et al. 2017).

Consistent pressure of straps is considered to cause the horse to become blunt towards these signals (Preuschoft *et al.* 1999, Warren-Smith *et al.* 2007, McGreevy 2007). The same is suspected for bits (Warren-Smith *et al.* 2005). With negative reinforcement, horses are trained to avoid negative stimuli and evade pressure from the bit e.g. by slowing down (McLean 2003, Warren-Smith *et al.* 2007, McGreevy 2007). As the horse's mouth is a sensitive structure, bits have always been criticised for their ability to cause pain, damage and behavioural disorders (Friedberger 1970, Ödberg & Bouissou 1999, Cook 1999, Tell *et al.* 2008, Quick & Warren-Smith 2009). The misuse of bits has been proven to induce bone spurs in the lower jaw (Cook 2002, 2003) and is furthermore related to conflict behaviours such as bolting and rearing (Cook 1999, Ödberg & Bouissou 1999, McGreevy 2007). When riding is being linked to pain, it results in poor performance and a disturbed relationship to the rider (Harman 1999, Hausberger *et al.* 2008, Sullivan *et al.* 2008). Some opponents regard bits as a possible cause for disorders such as DDSP, facial neuralgia, stridor and pulmonary oedema (Cook 1999, Christie *et al.* 2006). It is even argued, that bits constrain the horse's ability to swallow and therefore, hamper respiration and locomotion (Cook 1999). However, Manfredi *et al.* (2005) proved video-endoscopically that horses are indeed able to swallow with a variety of different tack e.g. during canter. However, oral ulcers were detected in horses ridden with bits and bridles (Tell et al. 2008). The use of double bridles and nosebands, especially if fastened tightly, restricts vascular function leading to a decrease of temperature of the facial skin and increased eye temperature (McGreevy et al. 2012) as well as conflict behaviour (Kienapfel & Preuschoft 2010). Alterations in bridle design aiming to avoid pressure successfully reduced peak pressures and improved the gait characteristics of the forelimb (Murray et al. 2015).

Bits produce forces in caudal, ventral and dorsal directions, thus inducing a potential risk of injury to the lower jaw, the temporomandibular joint, the neck and cervical joints (Geyer & Weishaupt 2006). However, bitless bridles may induce injuries and nerve irritations to pressure to sensitive areas such as the nose or lower jaw as well (Geyer & Weishaupt 2006, Casey et al. 2013). When chewing or cued to back up, pressure under a crank noseband reached magnitudes associated with complications such as nerve damage in humans (Casey et al. 2013). In fact, radiographic evidence of damage to the nasal bone from tight nosebands do exist, indicating a higher risks for warmbloods than for other types of horse breeds (Crago et al. 2017). To ensure nosebands are not fastened to tightly, thus allowing the jaw to open wide enough in order to chew on the bit as demanded by the common riding literature, noseband tightness should be controlled at the nasal bone (Kienapfel & Preuschoft 2010, McGreevy et al. 2012). However, in a study, controlling noseband tightness, only 7% of riders had applied this rule correctly. In 44% of the horses the nosebands were fixed extremely tight (Doherty et al. 2016).

Many riders utilize headcollars or bitless bridles believing to apply less pressure this way (Cook 1999). However, compared to a bridle with a jointed snaffle bit, no significant difference of rein tension in a headcollar (Warren-Smith *et al.* 2007) or a hackamore (Bye et al. 2017, Kubiak et al. 2017) could be documented. With a bitless LG bridle utilizing short levers, Preuschoft and Kienapfel (reported by Herrmann 2011) found an increase in pressure at the nasal bone compared to the applied rein tension. In general, it is the aim to train horses to react to the lightest signals. Riders are urged to apply the lightest possible contact, which would be the weight of the reins only (Müseler 1933, McGreevy 2007, Warren-Smith *et al.* 2007). In practice, however, the opposite has often been documented (Ödberg & Bouissou 1999, Preuschoft *et al*.1999a, b & c, Clayton *et al.* 2003, 2005). Only Warren-Smith *et al.* (2007) recorded rein tension in walk and trot which was approximately 100 grams more than the weight of the reins only. In general, riders are unaware of the amount of tension they apply, which is in all cases more than they expected (Preuschoft *et al.* 1999, Clayton *et al.* 2003, Stahlecker 2007). In cases of horses that are described as unwilling to accept the bit, dental problems are sometimes considered to be a possible cause. However, dental treatment did not improve rideability scores or horse's performance in controlled trials (Moine et al. 2017).

3.14 Rein tension

In an experiment with 15 professional riders performing at international level in Western and European riding and participating with their own horses, Falaturi and Preuschoft measured rein tension of both reins during walk, trot, canter, rein-back and canter-halt-transitions (reported by Felsinger 2004). Although the riding theories provide official guidelines of how and when to use signals during different tasks (Miesner *et al.* 2000, Auty 2003), each rider applied rein signals in a different way throughout the protocol. During rein-back rein tension exceeded 245 N. Only one Western rider applied tension below 10 N permanently according to the different requirements of contact in the two disciplines (reported by Felsinger 2004). Riders employed lower ranges of tension when riding their young horses in contrast to their advanced competition horses. Also different patterns of tension were detected on the same horse in opposite directions.

Each gait produces a specific pattern of forces with two spikes per cycle in walk and trot and one spikes per stride in canter. These spikes can be explained in relation to the footfall sequences of the gait (Preuschoft *et al*. 1999a, Clayton *et al.* 2005). The reported amplitudes were greatest in trot. During ridden work some riders constantly remained below a rein tension of 20 N even during difficult dressage movements. The majority of riders, however, applied tension of 58 N on average with peaks of up to 147 N (Preuschoft et al. 1999a). In order to find out, whether these fluctuations of rein tension are due to the rider or to the horse, carriage horses were controlled in the same way. In an experiment with carriages rein tension was measured with curb bits in all gaits (Preuschoft et al. 1999b & c). Carriage drivers applied 49 N in everyday situations, about 98 - 177 N in dressage tasks and up to 245 N during transitions from trot or canter to halt. Standardbred trotters were controlled with at least 177N during training sessions. At fast paces tensions of up to 392 N were applied to the reins (Preuschoft et al. 1999b & c). The average rein tension was 29.4 N in walk, 58.8 N in trot and 98 N in canter (reported by Herde 2005). The pattern of spikes was displayed in all gaits in exactly the same way as in ridden horses. Obviously, movements of the horse´s head and neck are responsible for the spike patterns (Preuschoft 1999a, Preuschoft et al. 1999b & c). In walk e.g. horses nod their heads during the swing phase of their protracting front limb due to the contraction of the M. brachiocephalicus. Since the movement frequency is too large, this “nodding” is not visible at trot. However, it might be the reason for the often enormous increase in rein tension at trot compared to walk (Preuschoft 2008). Warren-Smith et al. (2005, 2007) found higher rein tensions during long-reining (5 N) compared to riding (3.9 N), regardless of the gait and head gear. The lowest range of tension was recorded when straight lines were ridden, whereas the highest range of tension was detected during halt transitions. In a horse pulling hard against the reins the maximum tension measured were 4 – 43 N in walk, 19 - 51N in trot and 21 - 104N in canter (Clayton et al. 2005).

In walk, rein tension spikes are found at hind limb stance (Egenvall et al. 2015a). In trot rein tension is highest at each suspension phase and lowest at stance. During rising trot only, differences in rein tension between the midstance phases can be documented (Egenvall et al. 2015a). At canter the range of movement of the horses’ head and trunk is largest (Clayton & Nauwelaerts 2016). During each canter stride a spike of tension occurs every time the diagonal inside fore/outside hind is in stance (Clayton *et al*. 2005). Maximal tension was found just before the beginning of stance. Tension release was more distinct on the outside rein. Minimum tension was reached close to the suspension phase (Egenvall et al. 2015b). In the equestrian literature, contact is defined rather inexplicit, leaving the amount of adequate tension up to the perception of the individual rider (Müseler 1933, Miesner et al. 2000). When blindfolded and asked to apply "adequate" tension, all riders applied much more tension than they expected (Stahlecker 2007). The recorded data also revealed a difference between the slightly sagging reins as claimed by the old masters and the tightened reins used by the cavalry (de la Guérinière 1733, Steinbrecht 1901). This tighter rein contact comes close to the type of connection which is demanded by the literature of conventional European riding disciplines and commonly used in practice (Miesner et al. 2000). Reins are visually identified as sagging if the slack span exceeds one cm, below this value the reins appear tight. Sagging reins with a slack span of two cm implicate about 5N of tension, whereas seemingly tightened reins with a slack span of 1 - 0.5 cm result in pressures of 10 - 20 N (Stahlecker 2007).

Higher rein tension peaks occured during sitting and lengthened canter. Lower minimal rein tension was revealed during collection (Egenvall et al. 2016a). However, the level of analysis proved to be essential for the interpretation of rein tension signals and statistical results (Egenvall et al. 2016b). Furthermore, considering the different movements of the head, neck and trunk according to gait and speed is regarded to be important for the interpretation of the cyclic rein tension patterns and the riders' compensatory movements (Clayton & Nauwelaerts 2016). When evaluating the variations in rein tension between gaits and exercises in professional riders, the different gaits and rider positions were the major influence factors for the magnitude of rein tension (Eisersiö et al. 2015). Riders mainly influenced the amount of minimum and mean rein tension, whereas the horses seemed to determine the range and maximum rein tension applied (Eisersiö et al. 2015). Horse-rider interactions are complex and include behavioural responses such as mouth opening, lip and mouth movement, ear flicking, head tilt and tail movement. Mouth movement is associated with the suspension phase at trot, possibly due to hand movement of the rider, and related to rein tension and the hand-mouth distance (Eisersiö et al. 2013). Mouth movements such as mouthing the bit, retracting the tongue and placing the tongue over the bit were associated with the application of rein tension (25N) and did not correlate to different types of bits (Manfredi et al. 2010).

Timing of the relief of rein tension as a reward, i.e. the correct use of negative reinforcement, seems to be of major importance. Relief of tension at the first sign of a correct response results in fewer attempts of the horse to push against the bit (Egenvall et al. 2012). Riders keeping their hands still or releasing pressure induced the horse to decelerate, which was associated with lower rein tension. Riders, who pulled back on the reins or released tension after the horse showed the correct response, were confronted with their horse pushing against the bit and showing less deceleration (Egenvall et al. 2012).

Considering both transitions with and without intermediate steps, Egenvall et al. found higher rein tension associated with transitions increasing speed and transitions to and from canter. The reported magnitude of tension ranged from 13 N for transitions increasing speed from walk to trot up to 41 N for decreasing speed from canter to walk (Egenvall et al. 2016c). The mean rein tension for walk-halt transitions applied to a model horse was significantly lower (4.6N left, 3N right) (Hawson et al. 2014) compared to walk-halt transitions with horse-rider interaction (15.9N) (Kuhnke et al. 2010). The mean rein tension reported in the different studies varies between the different gaits (walk: 1.3-29.4 N, trot: 3.4-58.8N, canter: 16.2-98N) (Preuschoft et al. 1999a, Clayton *et al.* 2003, 2005, 2011, Herde 2005, Warren-Smith *et al.* 2005, 2007, Kuhnke et al. 2010, Randle et al. 2011) and different locations and therewith associated training philosophies (König von Borstel & Glißmann 2014). It has to be taken into account that different types of equipments were used which were not always utilized on both reins due to the high weight (Clayton et al. 2003, Warren-Smith *et al.* 2007). On the other hand, however, the amount and pattern of rein tension varies with the individual horses (Warren-Smith & McGreevy 2005, Warren-Smith *et al.* 2007). Investigations how much rein tension horses would voluntarily apply to themselves e.g. to obtain food, revealed that the use of a bit or bitless bridle does not seem to be an influence factor. However, the type of horse might play a role. Ponies were willing to apply more rein tension to themselves (44N), than warmbloods or Thoroughbreds (29N) and rein tension remained on the same level over various trials (Kubiak et al. 2017). In a similar study, mean rein tension decreased over the consecutive days (5.7N on day 3 vs. 10.2N on day 1) and short reins with higher tension were accompanied by conflict behaviours. With single-jointed snaffle bits, naive horses initially applied up to 40N to themselves, but they seemed to avoid rather than to habituate to rein tension (Christensen et al. 2011). The application of rein tension induced the heart rate to increase. Rein tension was higher on the left rein, but decreased with subsequent treatments (Fenner et al. 2016). Rein tension varies between different head and neck positions of the horse during riding. The competition frame or Low-Deep-and-Round showed higher rein tension and cortisol levels than riding in a looser frame, thus indicating possible welfare issues (Christensen et al. 2014). On competition sites, up to 93% of the horses are ridden with their noselines behind the vertical, which was associated with frequent discomfort behaviour (Kienapfel 2011). Due to the long lever arms of the reins, riders are physically able to pull their horses' heads into a strongly flexed position. In order to decrease flexion, horses would need to exert forces of their neck muscles that are up to four times higher than the maximum passive forces required to maintaining a fully relaxed head and neck position (Kienapfel & Preuschoft 2016).

Factors influencing rein tension seem to be most of all training, breed and age (Warren-Smith *et al.* 2007). However, rein tension seemed to be determined more by the previous training programme rather than the age and time span the horse has been trained for (Warren-Smith *et al.* 2007). This finding contrasts the principle of habituation (McGreevy *et al.* 2007, Clayton *et al.* 2003, McLean 2003) and needs further research. For riders, the action type profile consisting of cognitive, emotional and motor preferences has been suggested to play a role (Leemans et al. 2016). The equipment has an impact on rein tension and the horses' locomotion as well. Rein tension differs between several types of reins and materials (Randle et al. 2011). With side reins, tensions are higher when the reins are short. Inelastic reins are associated with higher peaks whereas elastic reins lead to an increase of minimum tension (Clayton et al. 2011). Besides an increase in mean rein tension, riders influence the horses head position with martingales (Heleski et al. 2009). Training aids such as rubber bands or the chambon are used to modify the head and neck posture, thus influencing the activity of the fore- and hind limbs (Biau et al. 2002).

3.15 Rein tension and its relation to handedness in riders

The handedness of the rider is often suspected to induce or increase motor laterality of the horse (Wyche 2004, Stahlecker 2007, Krüger 2009). It is argued, that in right-handed riders, the left hand is weaker than the right hand causing differences in rein tension and rein signals (Wyche 2004). It is assumed that rein signals for bending given with the right hand are soft and flexible. In contrast, those of the weaker left hand are stiff, tensed and hindering which makes the horse move crookedly (Wyche 2004). Others, however, regard the right hand as the stronger hand applying more tension (Stahlecker 2007). The left hand which is mainly used for stabilizing tasks is considered to be more sensitive (Stahlecker 2007).

In riders, handedness is also suggested to increase the risk of injury. Especially the shoulder region and the muscles dealing with rein tension are more susceptible (Pugh & Bolin 2004, Ekberg et al. 2011). With high rein tension, the muscles stabilizing the scapula such as the m. *trapezius* (Pugh & Bolin 2004, Terada *et al.* 2004) as well as the rider's cervical and thoracic spine are more heavily loaded (Pugh & Bolin 2004). Unbalanced horses or riders pulling harder on the reins of one side evoke asymmetric rein tension and muscle imbalances in the long term (Pugh & Bolin 2004). In a worst case scenario, asymmetric rein tension causes asymmetric muscle strength. This results in recurrent micro-trauma and inflammation of the slackened side and further wastage (Pugh & Bolin 2004). The degenerated muscles induce muscle instability and the shoulder impingement syndrome (Pugh & Bolin 2004). This syndrome encompasses abrasion and compression of the rotator cuff and gleno-humeral joint structures (Ludewig & Cook 2000, Pugh & Bolin 2004). It includes alterations in muscle activity and the range of motion of the shoulder and can result in scapular protraction (Ludewig & Cook 2000, Pugh & Bolin 2004).

In fact, the rider's perception of rein tension is subjective (Weber 1978, Stahlecker 2007) and often varies between left and right hands (Weber 1978). Perception of hand-held objects such as reins depends on the structure of the rein and the applied grip force (Flanagan & Wing 1997). It can differ between static and dynamic objects (Flanagan 1996). Slippery or moving objects require a higher amount of grip force in order to stabilize them as static objects or those with a rather rough structure (Flanagan 1996, Flanagan & Wing 1997).

The results of previous studies and experiments provide hints for the influence of handedness in equestrian disciplines. In his experiment with blindfolded riders, Stahlecker (2007) recorded higher tensions in the right rein when an even contact to a wall was perceived. No difference could be found between left and right reins in a similar trial (Guire et al. 2016). However, most riders' perception of equally weighted seat bones was incorrect. The majority of riders had more weight on their left ischial tuberosity, thus creating an unintended weight signal for the horse (Guire et al. 2016). The magnitude of appropriate rein tensions is highly variable between different riders (Randle et al. 2011). An uneven and quite strong rein contact has been experienced as even and smooth by the rider (Clayton et al. 2013). Higher tension and a greater range of tension in the right rein in trot and canter as well as during long-reining have been recorded on a straight line compared to higher tension in the inside rein when riding turns (Warren-Smith et al. 2007, Eisersiö et al. 2015a). Furthermore, a higher amount of tension was necessary for turning to the right as compared to a left turn (Warren-Smith et al. 2007). Different tensions between the left and right rein and a pattern of increased mouth movements were revealed with left rein tension, while the right rein decreased mouth movements indicating that the riders' hands might be more synchronized with the horses' movement than the riders' seat, which would come close to the definition of an "independent seat" (Eisersiö et al. 2013). In that case however, an independent seat alone does not seem to guarantee good horse-rider interaction.

Even on a model horse rein tension was asymmetric for walk-halt transitions with more tension on the left rein. The results showed large variation between riders and were not related to rider morphometry or rein tension as such (Hawson et al. 2014). In other studies no asymmetry during transitions to halt (Clayton et al. 2017) or during bimanual and single-handed rein contact were documented (Randle & Loy 2017). However, a stronger right rein contact during trot and canter regardless of rider handedness was documented. When rider handedness was taken into account, higher tension was revealed in the rein of the non-dominant hand of left-handed riders. Even though asymmetry patterns were exhibited by left- and right-handers, they were not mirror images (Clayton et al. 2017).

In previous research, rein tension was measured in 11 right-handed riders. Each rode a left- and right-lateral horse in all gaits and both directions on a circle and made four walk-halt transitions. Rein tension was higher in the left rein of the left-lateral horse. In a counter-clockwise direction, more tension was applied to the inside rein. Rein tension varied most in the rein of the horses' non-dominant side. Results revealed a possible influence of both human handedness and horse's laterality on the symmetry of rein tension (Kuhnke et al. 2010).

These results indicate that a correlation between human and horse's laterality and asymmetric rein contact does exist. However, this hypothesis has not been entirely investigated with all combinations of horse-rider laterality and the mechanisms behind asymmetric rein tension remain unclear.

4. Laterality of horses and riders in equestrian sports and possible impacts on competition results and risk of injury

4.1 Aim

The aim of the study was to determine the distribution and main direction of horse's laterality in equestrian sports. Additionally, it investigated the possible influence of horse's and human laterality on competition results and the incidence of musculoskeletal injury for horses and riders. It is hypothesized that, comparable to the influence of handedness on competiton results and risk of injury in other sport disciplines, left-handed individuals might be more successful and dominant limbs might be more prone to injuries in both horses and riders.

4.2 Material & Methods

An online survey was designed containing 14 general questions about the participants (e.g. age, sex, discipline, years of riding experience). The horse-rider-combination was surveyed by a single question asking for the number of the participants' left- and right-lateral horses. Participants were asked 14 general questions about their horses (e.g. age, sex, breed, discipline) with the option to describe up to 4 left- and 4 right-lateral horses in more detail with 18 questions each (Appendix 13.1.1). The direction of laterality referred to the horse's preferred side for dressage tasks. The study design and questions were tested for clarity and comprehension by five test participants and adjusted accordingly. The survey was set up in German using the online platform soscisurvey.de. The link was published via the websites and social media platforms of several horse breeding and sports associations in Germany and Austria and was available for eight weeks.

Crosstabulations of two characteristics with 2-25 values were investigated for random distribution using chi-square tests, phi and Cramer's-V in SPSS.

4.3 Results

A total of 686 riders (13.7% left-handed (n=94), 79.2% right-handed (n=543), 5.7% ambidextrous (n=39), 1.5% not specified (n=10)) participated. In a single question investigating the combinations of horse-rider laterality, 1286 horses (55.4% left-lateral (n=713), 41.6% right-lateral (n=535), 3% without information (n=38)) were classified according to their preferred side for dressage tasks. Comparisons of laterality with other traits were based on the more detailed description of 1197 horses (57.1% right-lateral (n=684), 42.8% left-lateral (n=512), Table 1, Figure 1).

	Left-lateral horses	Right-lateral horses	No information given	Total number of horses
Overview with one single question	713	535	38	1286
Detailed description	512	684	0	1197

Table 1: The distribution of horse's laterality surveyed with different questions

The majority of riders was female (chi^2=469, df=1, p<0.0001; 90.4% (n=620), male: 9.6% (n=66)) and rode one or two horses on a regular basis, regardless of their handedness. Riders of all ages participated in the survey (0-18 years: 12.2% (n= 84), 19-30 years: 43.1% (n=296), 31-50 years: 37.3% (n= 256), 51 years and older: 7.3% (n= 50)). The participants lived in Germany, Austria and the Netherlands however, participation varied between the different regions (Bavaria: 1.2% (n= 8), Baden-Württemberg: 0.4% (n = 3), Hesse: 4.5% (n= 31), Lower Saxony: 2% (n= 14), North Rhine-Westphalia: 34.3% (n= 235), Rhineland-Palatinate: 0.6% (n= 4), Schleswig-Holstein: 6.3% (n= 43), Brandenburg: 0.1% (n = 1), Mecklenburg West-Pomerania: 3.4% (n= 23), Saxony: 4.2% (n=29), Saxony-Anhalt: 1.5% (n= 10), Thuringia: 21.4% (n= 147), Hamburg: 1.5% (n= 10), Berlin: 0.4% (n= 3), Netherlands: 0.1% (n= 1), Austria: 18.1% (n= 124). Riders preferred the disciplines dressage: 40.5% (n=278), show jumping: 21.1% (n=145), eventing: 8.3% (n=57), vaulting: 0.9% (n=6), hacking: 2.4% (n=17), gaited horses: 0.3% (n=2), Western riding: 6.4% (n=42) and leisure riding: 19.2% (n=132). The average years of riding experience was 19.9 years. The majority of riders was riding at German riding level A-L (E: 7.1% (n= 49), A: 28% (n= 192), L: 25.9% (n= 178), M: 17.5% (n= 120), S: 6.9% (n= 47), other systems or unable to categorise: 13.7% (n= 94)). Riders were active for several hours per week (1h: 1.7% (n= 12), 2-5h: 32.8% (n=225), 6-10h: 38.8% (n= 266), 11-15h: 14.3% (n= 98), 16-20h: 5.7% (n= 39), >20h: 5.1% (n= 35)), however 1.3% of riders were currently inactive (n=9). Riders who rode one (48.9%, n = 326) or more than one (51.1%, n = 341) particular horse and young (47.9%, n = 325) or experienced horses (49.7%, n = 336; 2.7% riding school horses, n= 18) were equally distributed. Most riders took part in competitions at a regular basis (57.9%, n= 387; 42.1% no competitions, n = 281) and were not active in additional sports (56.8%, n= 384; 43.2% additional sports, n= 292). The majority of participants had not sustained an injury to the shoulders, arms or hand in the past five years (67% (n= 457); 33% injured participants (n= 225)). Muskuloskeletal injuries did not have to be directly related to equitation.

The majority of horses was female ($chi^2=644$, $df=3$, $p<0.0001$; 53.4% (n=639); 46.6% male (n=558)). The mean age was 12.5 years. The horses were mainly active in the disciplines dressage: 40.4% (n=483), show jumping: 22.9% (n=274), eventing: 5.3% (n=64), leisure riding: 14.8% (n=177), hacking: 3.2% (n=38), Western riding: 3% (n=36), vaulting: 0.8% (n=10). No horses were used for endurance riding, but two horses were used for racing (0.2%) and one horse was used for gaited horse riding (0.1%). Horses of various international warmblood and pony breeds, as well as Arabs, Thoroughbreds, Western horse breeds (e.g. Quarter and Paint Horses), gaited breeds (e.g. Icelandic horses) and light draft horse breeds (e.g. Noriker) were represented in the sample. Horses were mainly ridden by one or two riders at the German riding levels E: 9.4% (n=104), A: 28.6% (n=316), L: 28.4% (n=314), M: 15.7% (n=174), S: 7.4% (n=82) and various other levels e.g. from Western riding: 5.7% (n=63) or could not be classified: 4.7% (n=52). While a large number of horses was not ridden in competitions (25.1% (n=359)), most horses had multiple placings (18.8% (n=268)) or multiple wins (11.2% (n=160); 1 win: 5.2% (n= 75), 1 placing: 6% (n= 86), unplaced: 8.5% (n=122)). While 58.5% of horses (n= 584) remained uninjured, 41.5% of horses (n=415) had sustained injuries within the past five years to either the left (39.5% (n=164)), the right (41.4% (n=172)) or both sides (19% (n=79)).

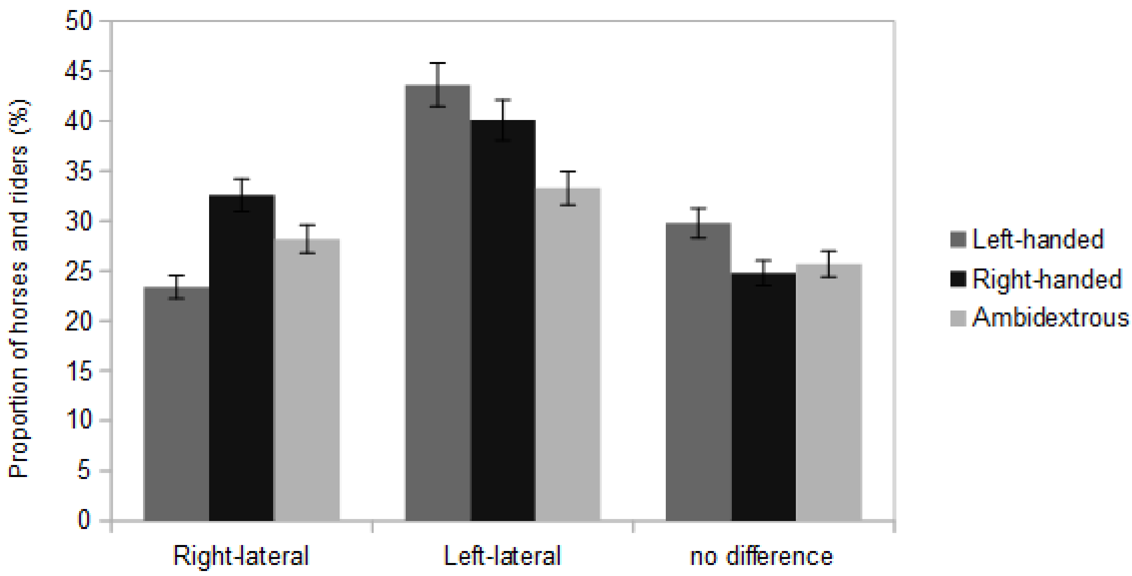


Figure 1: Distribution of rider's handedness by horse's laterality (%) in the surveyed sample of 686 riders and 1286 horses. Laterality was assessed based on the horse's preferred side for riding tasks ($p<0.0001$).

Regardless of the rider's handedness, left-lateral horses were more common in horse-rider pairs (Figure 1). However, left-handed riders rode left-lateral horses more often (43.6% left lateral vs. 23.4% right-lateral) than right-handed riders (40.2% left-lateral vs. 32.6% right-lateral). Horse-rider pairs were more equally distributed with ambidextrous riders (33.3% left-lateral vs. 28.2% right-lateral, <0.001, Figure1).

Dressage, show jumping and leisure riding were the most favoured disciplines amongst the participants (Figure 2). While right-handed riders mostly preferred dressage (41%) and show jumping (20%), left-handed riders showed a stronger preference towards show jumping (29%) than right-handers (p=0.02). Ambidextrous riders preferred leisure riding (23%), Western riding (10%) and alternative riding styles (3%) stronger than left-and right-handed riders (p=0.002). Age and sex did not relate to laterality in riders or horses (p>0.05). Additional sports and the participation at tournaments did not relate to handedness (p>0.05). However, riders of higher riding levels spent more hours per week riding (p<0.0001) and more frequently did not engage in additional sports (p<0.0001).

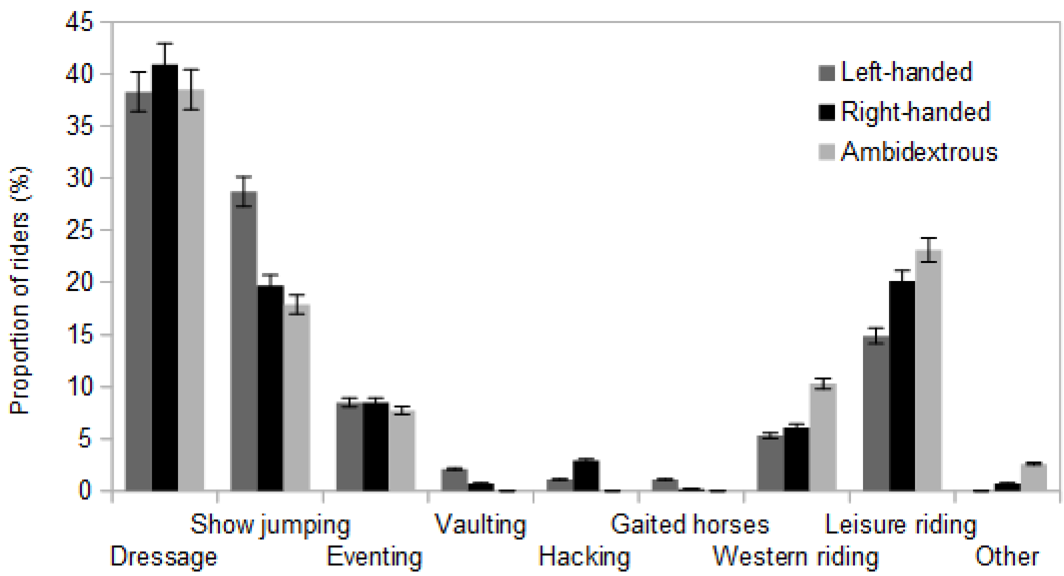


Figure 2: The distribution of rider handedness (p=0.02) within different equestrian disciplines (%) based on the surveyed sample of 686 riders.

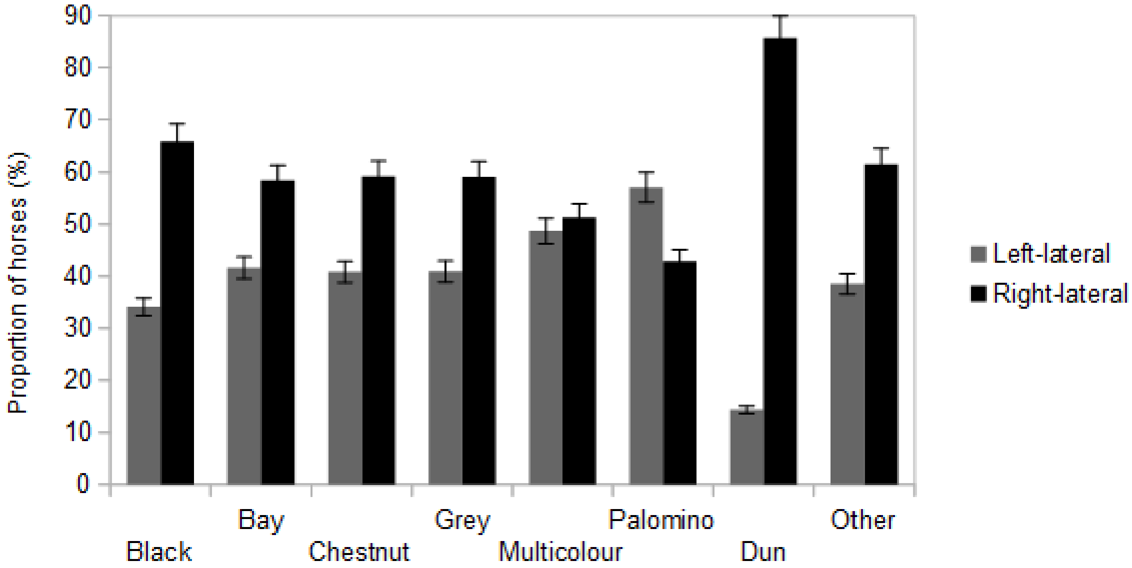


Figure 3: The distribution of coat colour (%) in relation to horse's laterality based on the preferred side for riding tasks in the surveyed sample of 1197 horses (multicolour= horses with more than one coat colour e.g. pintos, p<0.0001).

Within the sample of left –lateral horses (2%, n=8), the rare coat colour "palomino" was more often present than in the right-lateral sample (1%, n=6, Figure 3). The opposite was true for black (13% in right-lateral (n=91) vs. 9% (n=47) in left-lateral horses) and dun horses (3%, (n= 18) in right-lateral vs. 1% (n=3) in left-lateral horses). 57% of palominos were described as left-lateral, whereas and 66% of blacks and 86% of duns were categorized as right-lateral (p<0.001), Figure 3). Right-lateral horses carried their mane more often on their dominant, right side (54.7% vs. 41%, p<0.0001, Figure 4). No significant influence was found for horse's laterality and age, breed and the number and level of their riders (p>0.05).

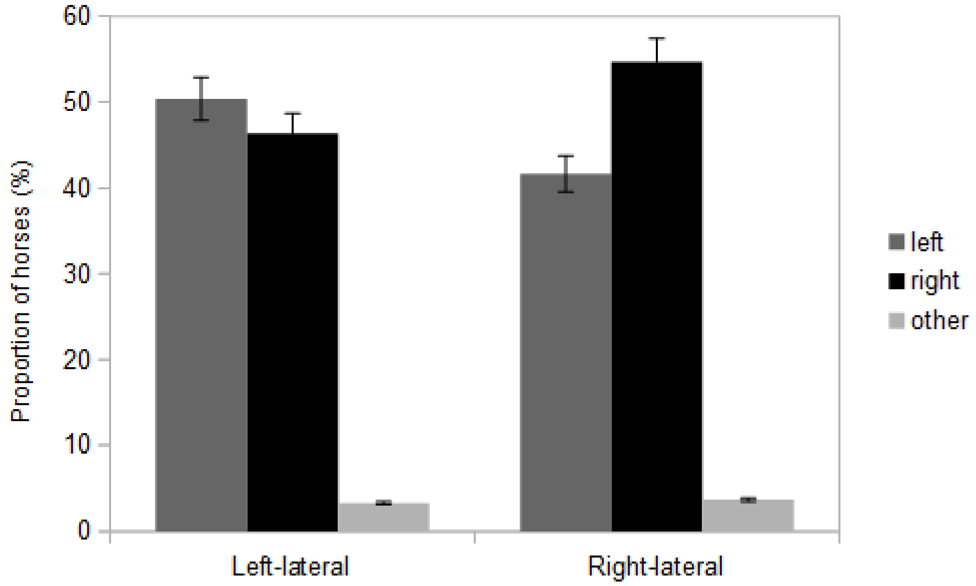


Figure 4: The direction of mane (%) in relation to horse's laterality based on the preferred side for riding tasks in the surveyed sample of 1197 horses (p<0.0001).

Regardless of their horse's laterality, the majority of the ambidextrous (33.3%) and left-handed riders (30.9%) of the present sample were active at high equestrian levels (German levels M-S; p<0.0001, Figure 5). In competitions, left-handed riders achieved multiple wins most often (21% vs. 12% right-handers and ambidextrous each), whereas right-handed riders most often achieved just one win (7% vs. 5% left-handers and ambidextrous each) or remained unplaced (12% vs. 5% left-handed and ambidextrous each, Figure 6). Ambidextrous riders most often achieved one (11% vs. 9% left-handers & 7% right-handers) or more placings (28% vs. 26% left-handers & 22% right-handers, p<0.001, Figure 6). The majority of horses that remained unplaced or received just one win were ridden for 1-7 hours per week, whereas most successful horses were trained for 4-12 hours per week (p<0.0001). At riding level M (p=0.018) and in the category of multiple wins (p=0.044), horse-rider combinations with matching directions of laterality (left-handed + left lateral, right-handed + right-lateral) were most common.

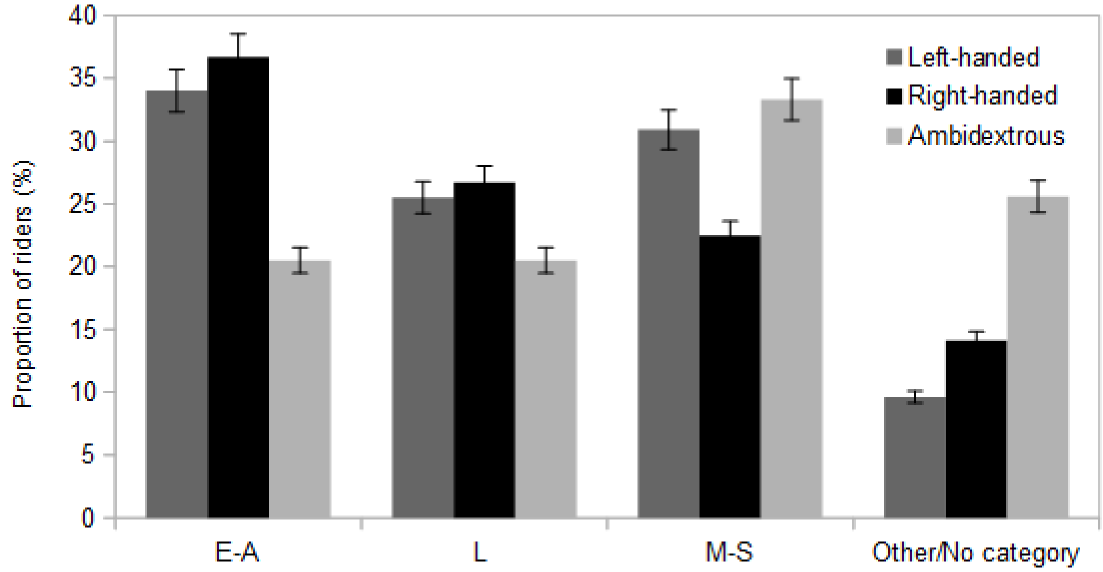


Figure 5: The frequency of German riding levels (%) in relation to rider handedness in the surveyed sample of 686 riders (p<0.0001).

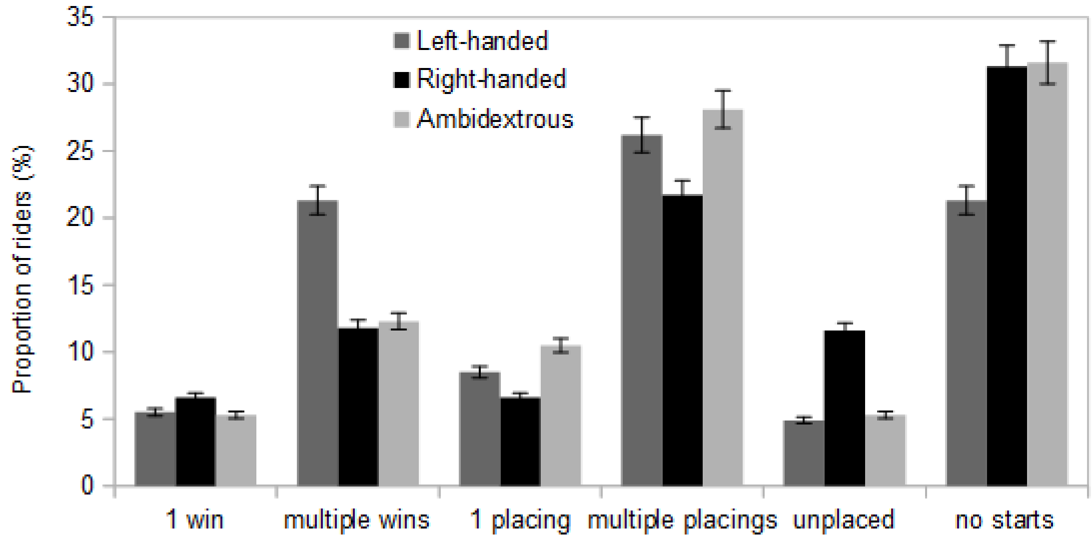


Figure 6: Sport success (%) in relation to rider handedness in the surveyed sample of 686 riders (p<0.0001).

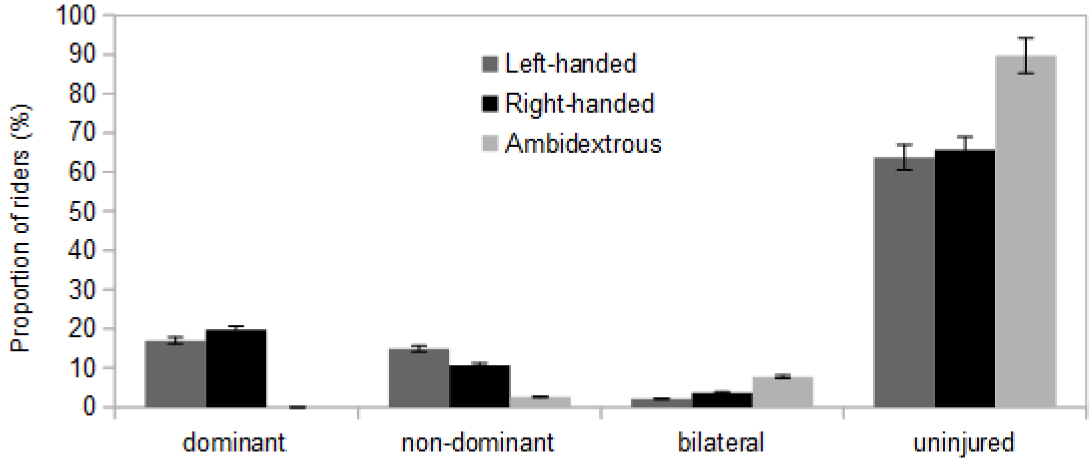


Figure 7: Incidence of musculoskeletal injuries in riders within the past five years (%) in relation to rider handedness in 686 riders of the surveyed sample. Reported injuries were not necessarily caused by horse riding (p<0.0001).

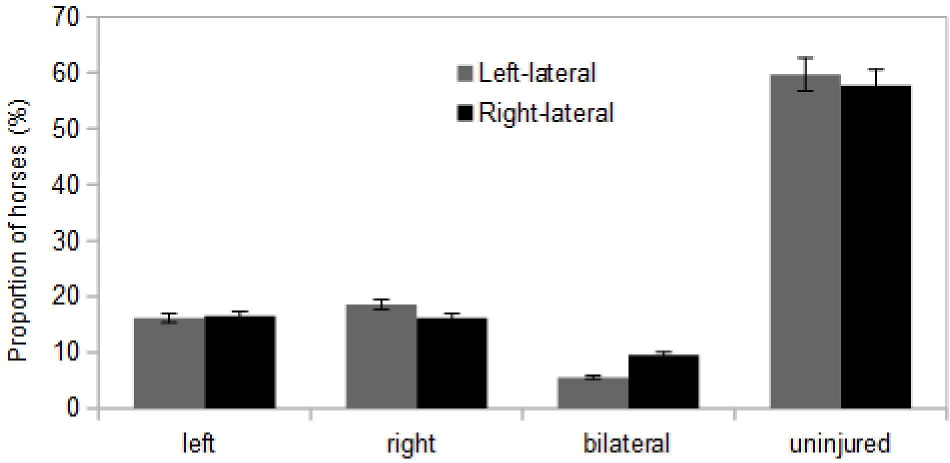


Figure 8: Incidence of musculoskeletal horse injuries within the past five years (%) in relation to horse's laterality in 1197 horses of the surveyed sample. Reported injuries were not necessarily caused by horse riding. Horse's laterality was assessed based on horse's preferred side for riding tasks (p=0.001).

Right-handed riders reported more injuries in their dominant hand (19.7% right hand vs. 10.7% left-hand, p<0.0001, Figure 7). Left-handed riders injured their non-dominant hands more often than right-handed riders (14.9% left-handed vs. 10.7% right-handed, p<0.0001, Figure 7). Ambidextrous riders remained uninjured more often (89.7%) than left-handed (63.8%) and right-handed riders (65.7%, p<0.0001, Figure 7). The number of injuries of the preferred and non-preferred side was similar for left- and right-lateral horses (16.2-18.6%). Left-lateral horses showed a tendency towards more frequent injuries of the non-preferred side (18.6% vs. 16.2% preferred side) and right-lateral horses towards bilateral injuries (9.6% vs. 5.6% in left-lateral horses, p=0.001, Figure 8).

No further relationships of laterality and injuries between riders and their horses or between injuries in riders and horses and in horse-rider combinations could be detected (>0.05). However, the different disciplines had a significant influence on the risk and side of injury (p<0.0001). In the disciplines hacking (63%), show jumping (58%), eventing (57%), and leisure riding (52%) the majority of horses remained uninjured as opposed to the disciplines dressage (48%), Western riding (44%) and vaulting (10%). In dressage riding (18%) and hacking (16%) injuries of the right limbs were more common, whereas injuries of the left limbs were more prevalent in eventing (15%), Western riding (22%) and vaulting (30%). In leisure riding (14%) and show jumping (13%) injuries occurred equally often to the left and right. Bilateral injuries were more prevalent in Western riding (13%) and vaulting (20%). The incidence of injuries and the risk of bilateral injuries increase with higher riding levels. Horses in the riding levels E, M and S are at higher risk of injuries to the left limb, whereas injuries to the right limb mainly occurred at levels A and L (p<0.0001).

Rider injuries were not directly related to horse riding, sport success or additional sports (p>0.05), however, the incidence increased with age (p<0.0001). Injuries of the left arms and shoulders were more prevalent throughout all riding levels (p<0.0001). The side of injury varied between the different disciplines (p<0.0001). Injuries to the left were more often seen in dressage (23%), show jumping (22%), eventing (27%), whereas the right arms and shoulders were more injury prone in riders of the disciplines vaulting (20%) and hacking (24%). Bilateral injuries were most often found in vaulters (10%). Leisure riders sustained injuries to either the left or the right side (16-18%).

4.4 Discussion

4.4.1 Survey sample

The survey participation among riders was satisfactory. The sample contained 19% left-handed and ambidextrous participants, which is a slightly greater proportion than that previously reported for entire populations such as Germany (McKeever 2004). This distribution of the different directions of laterality ensures a good validity of the results however, in order to proof the hypothesis of a greater number of left-handed and ambidextrous persons in equestrian sports, possibly due to advantages in performance, a larger sample might be necessary. Since the sample of riders seems to be representative for the population in Germany and most riders described a larger number of horses, the sample of horses is likely to be representative for the population of horses in European countries such as Germany and Austria too. The survey allowed riders to describe up to eight horses. However, not all riders were expected to own and describe a large number of horses. Therefore it was necessary to design a survey that allowed questions to remain unanswered. Due to the programme's design, participants could leave any question unanswered. This design was expected to increase the number of detailed horse descriptions, which was chosen to be of greater importance than the resulting number of participants leaving some questions unanswered.

Survey results were based on the subjective assessment of the participants and validity of answers could not be verified. However, the subjective assessment of horse's laterality by the horse's riders seems to be the most reliable and repeatable method to determine the direction of horse's laterality (Chapter 5, Murphy & Arkins 2008). Riders might have exaggerated with their riding level or sport successes however, if present, this is expected to be not biased for one or another group of participants, thus not impacting general conclusions drawn from this study. Injuries to the limbs were not defined any further for horses. On the one hand participants might have added some injuries that were induced by accidents (e.g. kicks) and would not have been defined as injuries to the locomotory system due to exercise or asymmetry. On the other hand however this open question encouraged the participants to give a good overview. For horses and riders a time span of five years was chosen, to ensure comparability between all age groups and improve reliability of the statements according to the side of injury.

4.4.2 The distribution of laterality in equestrian sports

Studies revealed different results of the main direction of motor laterality in horses according to different test designs and populations, as well as other influential factors such as training or housing (Loch 2000, McGreevy & Rogers 2005, McGreevy & Thomson 2006, Murphy & Arkins 2008, Williams & Norris 2007). In some studies the direction of motor laterality was related to certain body characteristics such as facial hair whorls (Murphy & Arkins 2008). For American Quarter Horses motor biased behaviour has been detected in individuals (Whishaw 2015). Some individuals preferred different sides for different tasks; however, motor laterality at a population basis could not be proven in all sample populations (McGreevy & Thomson 2006, Whishaw 2015). Similar observations have been made in several species of great apes (Christel 1993). The same seems to be true for this survey's sample population. Even though a preferred side was reported for almost every horse, the distribution changed from a majority of right-lateral horses in the single overview-question to a majority of left-lateral horses that were described in more detail. This was due to the study design, as some riders did not or could not describe all of their horses stated in the single overview-question. A difference between the percentage of left- and right-lateral individuals comparable to that reported in humans or other species (Coren & Porac 1977, McManus 2002, Hopkins et al. 2011, Tabiowo & Forrester 2013) does not seem to exist in horses.

Still, the preferred side of different individuals does seem to make a difference in equestrian sports. Left-lateral horses were most common in this survey's sample population in all riders for the detailed descriptions. However, riders seemed to prefer horses that matched their own direction of handedness. Left-handed riders preferred left-lateral horses stronger than the other riders, whereas ambidextrous riders showed almost no preference at all. The reason behind this preference in left-handed riders could be a possible advantage in horse-rider communication when it comes to rein tension. An impact of both, human and horse's laterality was documented for rein tension patterns in right-handed riders. Less asymmetry occurred in right-lateral horse-rider pairs, suggesting that matching directions of laterality might result in improved communication and training (Kuhnke et al. 2010). Similar to other sport disciplines (McManus 2002, Raymond & Pontier 2004, Economist 2004, Clotfelter 2008) left-handed and ambidextrous riders of this sample population were strongly represented at high riding levels and more successful in competitions than right-handed riders. At riding level M, the majority of horse-rider combinations had the same direction of laterality (left-handed/left-lateral & right-handed/right lateral). That was also the case for horse-rider pairs with multiple wins. This supports the hypothesis of an advantage for horse-rider-pairs with matching directions of laterality. Since a significant distribution according to this hypothesis could only be detected for level M and multiple wins though, left-handed riders are likely to be more successful for reasons related to their own direction of handedness. Left-handed individuals do not show mirror-inverted laterality patterns of right-handed individuals (Goble & Brown 2008, Michałowski & Króliczak 2015). Improved coordination on a motorneural and muscular basis, as well as differences in muscle strength and grip force have been reported for the left-handed human population, which seems to be less lateralized than right-handers (Rousson et al. 2009, Judge & Stirling 2003). These attributes are likely to affect rein tension and thus horse-rider communication, which will be investigated in another part of the thesis and might be an explanation for improved performance in left-handed or ambidextrous riders. The main goal in many equitation disciplines is to straighten the horse and train it to move in a balanced way. However, the importance of and focus on a balanced horse varies between the different disciplines and their requirements for successful performance (Steinbrecht 1901, Müseler 1933, Klimke 1985, Miesner *et al.* 2000). In addition to the asymmetric distribution of rider handedness when it comes to performance success and riding levels, the preference for certain disciplines seemed to relate to rider handedness. Left-handed riders preferred show-jumping more strongly than other riders, whereas right-handed riders favored dressage and ambidextrous riders showed a stronger preference for Western riding and alternative riding styles.

This suggests that riders might either favor certain disciplines that they are most successful in or avoid disciplines that require improved horse-rider symmetry. However, the mechanisms behind these asymmetric distributions remain unclear on the basis of a survey. In confrontational sports only, e.g. in boxing or tennis, left-handed humans are strongly represented and advantaged (McManus 2002), possibly because the direction of their strikes is unusual for their right-handed opponents. However, left-handed individuals are also more skill-full and faster with their non-dominant hands and use them more often than right-handers do (Steenhuis & Bryden 1999, Rousson et al. 2009). They often perform superiorly in bimanual tasks (Judge & Stirling 2003), which might provide an advantage when it comes to proprioception and communication with their horse.

4.4.3 The relation of laterality to other body characteristics

Unlike other studies (McGreevy & Rogers 2005, McGreevy & Thomson 2006, Williams & Norris 2007) laterality was not related to horse breed. However, horses of different colours were more likely to be either left- or right-lateral. The inheritance of laterality and the number and specific genes involved remain unclear in humans and are unknown in horses (Armour et al. 2014, Ocklenburg et al. 2017). Certain Body characteristics such as facial hair whorls however have been related to laterality in horses and other species before (Murphy & Arkins 2008). The same might be true for other characteristics such as coat colour. The number of blacks, palominos and duns in the sample population were rather small though, and the distribution of laterality in the whole sample did not clearly differ between left- and right-lateral individuals, so these results might not be reliable. The majority of horses had their mane on their dominant side. The mechanism behind that could be the horse's natural crookedness. The muscles on their preferred side are hypothesised to be shortened, thus creating the impression of the horse being naturally flexed towards its preferred side (Steinbrecht 1901, Müseler 1933, Klimke 1985, Miesner *et al.* 2000), which might facilitate the mane to fall to this side of the body. In a sample of American Quarter Horses however, side bias of mane did not correlate with actual laterality (Whishaw & Kolb 2017).

4.4.4 The relation of laterality to the incidence of injuries

Structural asymmetries and an increased risk of injury are associated with laterality in humans and horses (Stashak 1995, Dyson *et al.* 2003, Pugh & Bolin 2004, Pearce *et al.* 2005). Similar to other studies, right-handed riders reported more injuries in their dominant, right side (Cawley et al. 2015). Left-handed riders however were more prone to injure their non-dominant right side. It has been argued that non-dominant limbs play a stabilizing role and thus bear more load than the dominant limbs which are used for tasks requiring accuracy (Wallden 2011). This theory might, however, be more relevant for legs than for shoulders, arms and hands. Since the injuries reported in this study must not necessarily have been related to equitation, the reasons could be either accidents or excessive use of one body side during the normal course of life, which might explain the increased risk of injury and overuse for non-dominant limbs of left-handed persons which have to adapt to the mostly right-handed population and their tools. The reduced risk of injury in ambidextrous participants further supports this hypothesis. Another approach would be to differentiate between injuries due to compression (e.g. as a result of over-loading a non-dominant limb) or traction (Wallden 2011). However, the available information does not allow differentiating between different types of injuries.

The number of injuries of the preferred and non-preferred side was similar for left- and right-lateral horses. Studies focusing on structural asymmetries reported higher risks of injury as a result of laterality (Van Heel *et al.* 2006, Ducro et al. 2009a). However, other studies reported an increased number of injuries to one side without regard to horse's laterality (Anderson et al. 1999, Ramzan & Palmer 2011). Patterns of dysfunction (Wallden 2011) according to limb dominance and the associated loading patterns of the non-dominant limbs, which might provoke bilateral injuries or structural asymmetries due to compression of one side and traction as a result of muscular atrophy of the other side, have been documented in humans (Wallden 2011). Even though this cannot be examined on the basis of a survey, these mechanisms might explain why in horses the number of injuries to the dominant and non-dominant sides did not differ much. Incidence of injury as such varied between the different equestrian disciplines. While horses competing in some disciplines such as show jumping had the same incidence of injuries to their dominant or non-dominant side, in other disciplines such as dressage an injury to the right side was more prevalent. Similar findings have been reported for racing Thoroughbreds with up to 82% of injuries recorded in right limbs (Ramzan & Palmer 2011) or Quarter Horses (Anderson et al. 1999). In fact, jump training seems to increase risk of injury in horses, whereas variation in training might be a measure to reduce injuries (Egenvall et al. 2013). The incidence of injury varied between the different disciplines for riders too, however this sample might contain information that is not entirely related to riding. Even though no direct relationship between human handedness and injuries in horses could be proven in this sample, the laterality and symmetry of the rider still affects the horses balance to some extent (Symes & Ellis 2009, Münz et al. 2014). This might play a role on a different level, e.g. on the level of horse-rider symmetry in different disciplines, which –through different loading patterns- could explain the different risks of injury for left and right limbs and in total between disciplines.

4.4 Conclusion

4.5.1 The distribution of laterality in equestrian sports

Although left-handed and ambidextrous humans are less frequent in the population, the results indicate advantages of them with regard to riding level, competition results and risk of injury. Direction of laterality in the rider rather than the horse appears to be more important to equitation success and safety, even though horse-rider combinations with matching directions of laterality may be more successful.

4.5.2 The relation of laterality to other body characteristics

At the population level, horse's laterality does not seem to be strongly biased to one side. However, correlations between certain body characteristics and laterality seem to exist.

4.5.3 The relation of laterality to the incidence of injuries

Laterality patterns in horses seem to have a minor influence on their risk of injury compared to riders. Human handedness does not influence the risk of injury in horses.

4.5.4 Further research

Further research collecting direct data of horse-rider symmetry and communication e.g. via rein tension, as well as attestable information on competition results and injuries is needed to prove the hypothesis of an advantage for the left-handed and ambidextrous riders and horse-rider pairs with matching directions of laterality. This research question will be exmined in chapter seven.

5. A comparison of different methods to determine horse's motor laterality and its relation to rein tension

5.1 Aim

The study's aim was to compare agreement between results obtained by different methods to determine horse's laterality in German warmblood and pony breeds, as well as in Thoroughbreds. Furthermore, it aimed at investigating the relation of laterality results obtained on the ground to the riders' subjective assessment of the horse's preferred side during dressage tasks and turns and to investigate the results' relation to rein tension. Additionally, it intended to determine the lateral displacement of the hindquarters during Thoroughbred flat races from video analysis and compared the results to those in situ, when standing straight behind the horse in order to assess validity of the video analysis. Since results of a few methods have not agreed between and within some studies, it is hypothesized that results might agree between the majority of methods, while other methods are likely to either disagree or not allow conclusions on laterality during riding.

5.2 Material & Methods

5.2.1 Methods to determine the direction of horse's laterality

In the present study, horses were classified according to a variety of methods:

- The preferred advanced foreleg during grazing was recorded with scan sampling at intervals of 30 seconds and 60 seconds (counting every second recording) for 2 hours as previously described by McGreevy & Rogers 2005 (Figure 9).

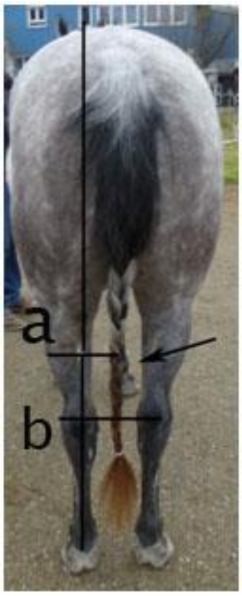
Figure 9: The preferred advanced (left) foreleg during grazing

- The preferred advanced foreleg when eating from a bucket off the ground was determined in 15 trials. Horses started the approach to the bucket from different distances individually in an alleyway as previously described by Van Heel et al. 2006 and optimised by Van Dierendonck 2014. When grazing or eating from a bucket, there had to be at least 28.5 cm space between the front feet for a valid trial in horses and 25.5 cm for a valid trial in ponies (Van Dierendonck 2014). Reference markers on the ground next to the food bucket ensured that the distances were estimated correctly. The laterality index (z-value) was based on the number of left vs. right advanced forelimbs in relation to the total number of valid trials (Van Heel *et al.* 2006, Van Dierendonck 2014). A Z-value of 1.96 was classified as significant and a Z-value of 1.0 was considered as a tendency towards a lateralized behaviour.

- The visual laterality (preferred eye for investigation) during confrontation with 3 novel objects (plastic bag, ball, toy) was determined as previously described by Larose et al. (2006) and de Boyer des Roches *et al. (*2008).

- As a new approach, the lateral displacement of the hindquarters in relation to the median plane was evaluated from behind for each horse while the horse was standing with square hind limbs. When viewed from behind, the hindquarters were regarded as a fixed point and the lateral deviation of the shoulders was determined depending on which front limb was visible between the hind limbs. To control observer position the hocks were used as a reference point. Consequently, as a second step, the deviation of the hindquarters was deduced when regarding the shoulders as a fixed point, i.e. for a deviation of the hindquarters to the right, the right front leg had to be visible between the hind limbs (Figure 10). This termination was chosen according to the theory of the “natural crookedness” in the common riding literature, which refers to a lateral displacement of the hindquarters.

- In order to determine the degree of the lateral displacement of the hindquarters, a photograph was taken showing the top of the horse's croup, back and shoulders from behind. Using anatomical landmarks to draw reference lines, the angle of deviation of the horse's spine from a perpendicular through the withers, was measured (Figure 11).



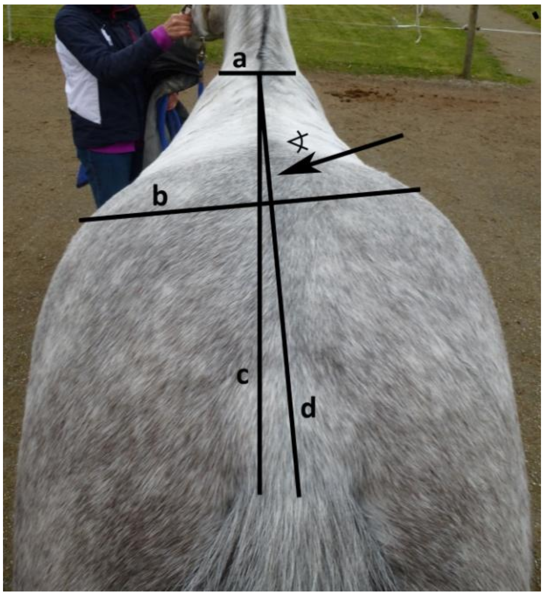


Figure 10 (left): Lateral displacement of the hindquarters to the right with the right forelimb visible between the hind limbs (arrow). Line b shows the position of the hind limbs (hocks). Line a indicates the position of the front limbs (fetlocks). The vertical reference line shows the position of the front fetlocks in relation to the hocks.

Figure 11 (right): Reference lines to determine the angle of deviation of the spine (line d) from the perpendicular through the withers (line c) in a horse with its hindquarters displaced to the right, using the shoulders (line a) and tuber coxae (line b) as anatomical landmarks.

- As a novel approach, the lateral displacement of the hindquarters from the median plane was determined during analysis of official videos of flat races taken from a raised position. The group of horses (2-12 horses at once) was visible frontally, laterally and from behind during the race. The direction of the lateral displacement of their hindquarters from the median plane (either left or right) was determined, when a horse was shown straight from behind before entering a bend or after passing the finish line. For each horse laterality was determined based on results of 2-6 races in one or both directions (i.e. some horses were observed in two races clockwise while others were observed e.g. in 4 races clockwise and 2 races counter-clockwise). Horses were considered to be ambidextrous, if they showed inconsistent laterality in one or both directions during at least two races. Consequently, horses were allowed one deviation only in order to be still considered as lateralized.

- The preferred lead during flat racing (as previously described by Williams & Norris 2007), was determined during video analysis. When the horses were galloping down straight towards the finish line in slow-motion, the lead and, if shown, a change of leads were recorded. Horses were categorized as preferring the left or right lead with regard to the direction of race or as ambidextrous, if recordings were inconsistent.

- The direction of facial hair whorls (trichoglyphs) (Figure 12) was recorded as previously described by Murphy & Arkins 2008.

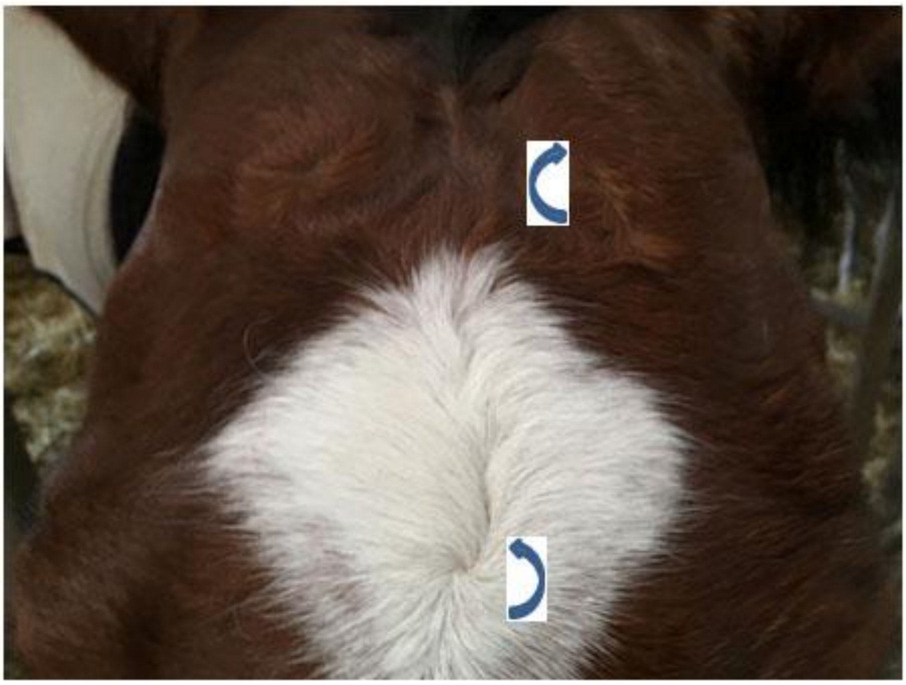


Figure 12: Clockwise (top right) and counter-clockwise (center) facial hair whorls

- Horse's laterality (preferred or suppler side for dressage tasks) was assessed by their riders as previously described by Murphy & Arkins (2008).

- Laterality patterns of mean rein tension in relation to the direction of movement (clockwise vs. counter-clockwise) were investigated as previously described by Kuhnke et al. 2010.

- The direction of mane (left, right, bilaterally) was recorded (Figures 13 and 14).

Figure 13 (left): A horse with its mane to the right

Figure 14 (right): A horse with a bilateral mane

- Additionally, age, sex and coat colour were recorded.

5.2.2 The different sample populations

The present study investigated the different test methods in five samples (A-E) of horses. For each sample a different set of test methods was applied (Table 2).

Sample A included three groups of warmblood typed horses (warmbloods, riding ponies and warmblood mixes, n= 67, age 0.25 – 23 years) observed at pasture in order to compare agreement between results of different methods and their relation to the riders' assessment as well as to rein tension. The majority of horses in this sample were young horses that had not yet been ridden. For some ridden horses, the riders were not available for questioning, so these horses were added to the category of unridden horses. For 21 ridden horses, laterality was assessed by their riders and 12 horses (age 7-23 years; 10 right-lateral, 2 left-lateral) with 10 right-handed riders were available for a test ride. Rein tension was collected during conventional European riding at walk, rising and sitting trot and canter in both directions on straight lines and circles. A rein tension device (Centaur, Netherlands) was fixed between the reins and the bit. The device was calibrated before each test ride. Rein tension was recorded with a frequency of 100 Hz, sent wirelessly to a computer and recorded with the Centaur software.

Sample B consisted of 3973 warmbloods (aged 0.5 – 20 years, 2379 male, 1594 female) and 368 riding ponies (aged 0.5 – 22 years, 231 male, 137 female) observed during breed shows or local and international competitions in situ or using video analysis in order to determine the lateral displacement of their hindquarters.

In **sample C**, 67 Thoroughbreds (36 male and 31 female) aged 2-12 years (mean age = 4.5 years) that competed in 8 different races in a clockwise direction on a grass turf, were observed in situ and during video analysis. Horses were led at walk by their grooms in the preparation area with and without a rider, up to the racetrack and back to the preparation area after finishing their race. All horses were categorized as either left-lateral or right-lateral according to the direction of the lateral deviation of their hindquarters from the median plane when walking away from the researcher at any of these occasions (i.e. up to 4 observations per horse). On the following day, official videos were available online of each race. The lateral displacement of the hindquarters was determined again based on the video analysis and results were compared for agreement.

In **sample D**, a total of 1822 Thoroughbreds (aged 2 – 15 years, 1003 male, 819 female) were identified and observed during video analysis of flat races in clockwise and counter-clockwise directions.

Sample E was a group of 61 Thoroughbreds (age 0.003–19 years) observed at pasture in order to compare agreement between results of different methods obtained on the ground and during flat racing as well as between results of the parents and their offspring. The group of horses consisted of one Thoroughbred stud and his offspring (n=42) over five consecutive years with the same 13 Thoroughbred brood mares, as well as 5 additional, unrelated Thoroughbreds. Additionally, 18 horses were either by another stallion or out of a different mare.

5.2.3 Statistical analysis

Data were tested for normal distribution using chi-square tests in SPSS. Crosstabulations of two variables (methods to determine laterality) with 2-30 values (e.g. left, right etc.) were investigated for random distribution using chi-square tests, phi and Cramer's-V. Additionally Pearson correlations were used to investigate relations between methods yielding numeric data.

Rein tension and agreement with other methods was analysed using a mixed model, considering gait (G), riding direction (D), task (T) and reins (Z) and their interactions as fixed effects, and rider (R), horse (H) and horse*rider as random effects. Additional variables were consecutively added to or exchanged in the term. The model was reduced again if a term was not significant. Consequently the terms were e.g.

“mean rein tension = R + H + H*R + G + D*T*Z + further variables + error"

5.3 Results

Significant lateral behaviour in at least one of the sample populations, respectively, was documented for the direction of mane, the preferred eye for investigation, the lateral displacement of the hindquarters, the preferred advanced foreleg during grazing, the preferred canter lead and the rider’s assessment of their horse’s laterality (Table 2). Results of several methods agreed significantly (Table 3). For all other methods conducted on the ground, no significant side bias or agreement with other methods could be documented ($p>0.05$). Age and sex did not correlate with the results ($p>0.05$). The facial hair whorls were randomly distributed ($p>0.05$). No relationship of the occurrence of lateralized behaviour or the direction of laterality between either, the stallion and his offspring, the brood mares and their offspring or both parents and their offspring was found ($p>0.05$).

Table 2: Overview of the applied laterality test methods and the different sample populations. (Mixed model analysis of mean rein tension accounting for horse*rider as random effects and gait, rein*direction*task, laterality*handedness as fixed effects.)

Method	**Variable**	**Sample**	**Results**	**Level of significance (chi²)**
Advanced foreleg during grazing	number of advanced forelegs	67 Warmbloods (Chapter 5, sample A)	Most horses without preference. Significance levels remained, decreased or increased but never changed direction.	$p<0.0001$
30sec. vs. 60 sec. Scan sampling	Z-value +/- 1.95 = significant	61 Thoroughbreds (Chapter 5, Sample E)	The majority of horses showed „no preference".	$p<0.0001$
Advanced foreleg during eating from a bucket (limb preference test)	number of advanced forelegs Z-value +/- 1.95 = significant	12 Warmbloods (Chapter 5, part of sample A)	none	$p>0.05$
Visual laterality (Novel object test)	preferred eye (left, right, none)	67 Warmbloods (Chapter 5, sample A)	none	$p>0.05$
Eye preference		61 Thoroughbreds (Chapter 5, sample E)	Left (one object only)	$p<0.0001$
Lateral displacement of the hindquarters in relation to the median plane while standing	displacement to the left or right	4408 Warmbloods & riding ponies (Chapter 5, samples A&B)	right	$p<0.0001$
		67 Thoroughbreds (Chapter 5, sample C)	Mostly right; ambidexterity observed	$p<0.0001$
		61 Thoroughbreds (Chapter 5, sample E)	none	$p>0.05$
Degree of the lateral displacement (Angle of deviation of the spine from the perpendicular through the withers)	degree of lateral displacement	12 Warmbloods (Chapter 5, part of sample A)	none	$p>0.05$
Direction of facial hair whorls (trichoglyphs)	clockwise, counter-clockwise, radial, mismatching double	67 Warmbloods (Chapter 5, sample A)	none	$p>0.05$
		61 Thoroughbreds (Chapter 5, sample		

	whorls	E)		
Rider's assessment (preferred side for dressage tasks)	Left-preference, right-preference	21 Warmbloods (Chapter 5, part of sample A)	The majority of horses were assessed as right-lateral.	p=0.021
Direction of mane	left, right, bilateral	67 Warmbloods (Chapter 5, sample A)	none	p>0.05
Direction of mane	left, right, bilateral	61 Thoroughbreds (Chapter 5, sample E)	right	p<0.0001
Preferred lead during flat racing	left, right in relation to the direction of track	1950 Thoroughbreds (Chapter 5, sample D)	Mostly outside lead	p<0.0001
Lateral displacement of the hindquarters from the median plane during flat racing (video analysis)	displacement to the left or right or inconsistent displacement	1950 Thoroughbreds (Chapter 5, sample D)	Mostly right; ambidexterity observed	p=0.002 – p<0.0001
		67 Thoroughbreds (Chapter 5, sample C)	Mostly right; ambidexterity observed	p<0.0001
Rein tension symmetry	rein tension (N) in relation to the laterality of horses and riders and the direction of track	12 horse-rider pairs (Chapter 5, part of sample A)	Higher mean tension was applied with the dominant (right) hand and to left-lateral horses. The magnitude and stability of mean rein tension varied in relation to the direction of riding and the horse's preferred side.	Rider: p=0.044* Horse: p=0.02* Stability: p<0.0001*

Table 3: Overview of the relation between the results of the applied laterality test methods in the different sample populations. (Mixed model analysis of mean rein tension accounting for horse*rider as random effects and gait, rein*direction*task, laterality*handedness as fixed effects; Methods to determine horse's laterality during riding are bolded.)

Method 1	**Method 2**	**Sample**	**Results**	**Level of significance (chi²)**	**Further research**
Advanced foreleg during grazing 60 sec. Scan sampling	Visual laterality	61 Thoroughbreds (Chapter 5, sample E)	Left eye preferred only in horses with left leg preference or no preference	Left leg: p=0.005 No preference: p=0.009	Relation to motor laterality with a larger sample of horses showing visual laterality
Advanced foreleg during grazing 60 sec. Scan sampling	**Rider's assessment**	21 Warmbloods (Chapter 5, part of sample A)	Most horses showed no preference. Some right-lateral horses tended to prefer either their left or right foreleg. Left-lateral horses showed a tendency to prefer the left foreleg only	p= 0.018	Relation of the advanced foreleg during grazing and eating from a bucket, the rider's assessment and rein tension with a larger sample of horses showing a distinct leg preference
Lateral displacement of the hindquarters in relation to the median plane while standing	**Rider's assessment**	21 Warmbloods (Chapter 5, part of sample A)	Results agreed for most horses. Only horses with their hindquarters displaced to the right were assessed as left-lateral.	P=0.003	Examine agreement of results in a larger sample of horses with distinct motor laterality and compare with rein tension symmetry in order to identify mechanisms of interaction
	Rein tension	12 Warmbloods (Chapter 5, part of sample A)	Rein tension tended to be higher in horses with a left-displacement	p=0.077	
	Lateral displacement of the hindquarters during video analysis	67 Thoroughbreds (Chapter 5, sample C)	79% agreement overall; 81.5% agreement for horses determined as right-lateral and 69.3% for left-lateral horses (Method1) in clockwise races	p=0.0001	
		4408 Warmbloods & riding ponies (Chapter 5, samples A&B)	No significant difference concerning the distribution of left-vs.right-lateral horses in both samples	p>0.05	
Preferred lead during	Lateral	1950 Thoroughbreds	The majority of horses were right-lateral or	all p<0.0001	

flat racing	displacement of the hindquarters from the median plane during flat racing (video analysis)	(Chapter 5, sample D)	ambidextrous based on results from races in both directions. The preferred lead and lateral displacement were identical, in left- and right-lateral horses (Preference of inside lead in one and outside lead in the other direction). Ambidextrous horses displaced their hindquarters according to the racing direction and preferred the outside lead in either direction.		
Rein tension symmetry	**Rider's assessment**	12 horse-rider pairs (Chapter 5, part of sample A)	Rein tension symmetry agreed mostly with the direction of laterality assessed by the riders	p=0.019	

5.3.1 The direction of the mane

Most horses in sample E carried their mane on the right side (25.6% left, 67.4% right, 7% both sides, $chi^2=23$, $p<0.0001$). Direction of mane did not relate to any other method ($p>0.05$) in sample E nor could a side bias be observed in any other sample.

5.3.2 Visual laterality (Preferred eye for investigation)

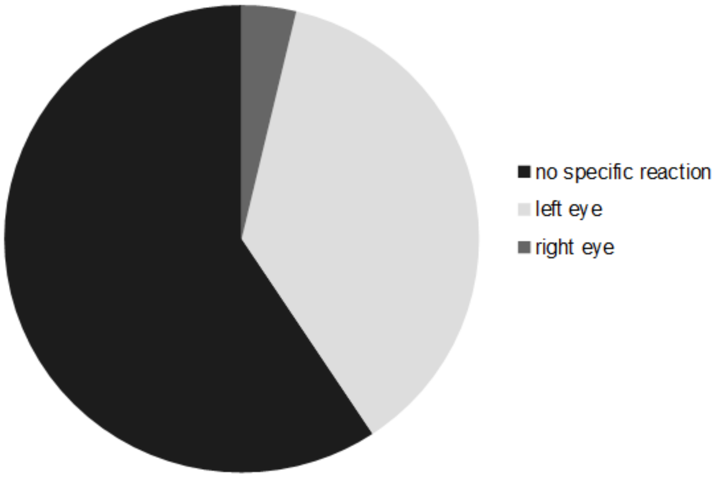


Figure 15: The direction of visual laterality during investigation of a novel object (ball) (proportion of horses in %, sample E, $p<0.0001$).

During frontal approach with novel objects (plastic bag, toy, ball), most horses of sample E did not use a specific eye to look at an object and thus showed no eye preference (53.7-59.3%, $chi^2=19$-20, all $p<0.0001$). However, for one specific object, a sensory bias to the left was found in 37-40.7% of the sample ($p<0.0001$, Figure 15). No eye preference could be documented in any other sample.

5.3.3 The lateral displacement of the hindquarters from the median plane

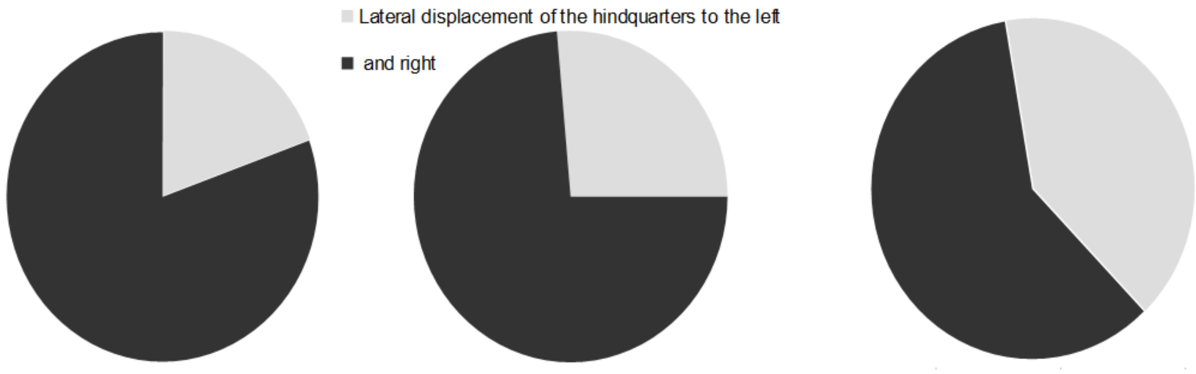


Figure 16: The lateral displacement of the hindquarters (proportion of horses in %) to either the left (grey) or the right (black) in German warmbloods (left; sample B, p<0.0001), German riding ponies (middle, sample B, p>0,0001) and Thoroughbreds (right, sample E, p>0.05). No significant difference was found between examinations on site and via live stream (p>0.05).

In sample E, a total of 40.5% of the 61 Thoroughbreds had their hindquarters displaced to the left and 59.5% showed a lateral displacement of their hindquarters to the right. However, laterality according to this method was equally distributed in this sample ($chi^2 = 2$; $p>0.05$) and not related to other methods ($p>0.05$). In sample B, horse's hindquarters were displaced to the left in 771 warmbloods (19.4%) and 97 ponies (26.4%). A lateral displacement of the hindquarters to the right was documented in 3202 warmbloods (80.6%; $chi^2 = 1486$, $p<0.0001$) and 271 ponies (73.6%) and was not equally distributed ($chi^2=81.5$, $p<0.0001$, Figure 16). Similar results were recorded for the smaller sample of warmbloods and ponies (sample A; right-lateral 73.13% vs. left-lateral 26.87%; $chi^2=14.3$, $p<0.0001$). Results of sample C are considered under section 5.3.4.

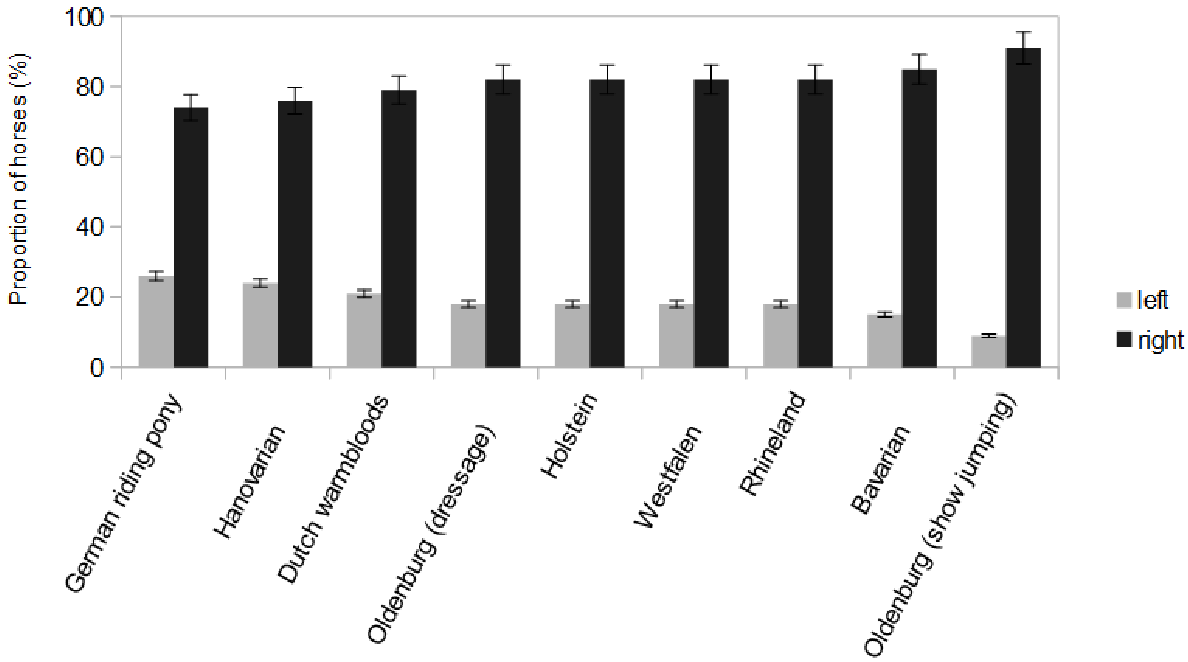


Figure 17: The distribution of lateral displacement of the hindquarters to the left or right (%) within different warmblood breeds (sample B, all p<0.05).

Sample B included a variety of different warmblood and pony breeds. Investigating breeds with at least 100 individuals in sample B, horses with their hindquarters displaced to the left represented 15 – 19% of the breed's population respectively (Figure 17). In all breeds, individuals with their hindquarters displaced to the right were more common (p = 0.006, Figure 17).

For the majority of coat colours, about 75-80% of the horses of sample B had their hindquarters displaced to the right (p<0.0001, Figure 18). A lateral displacement of the hindquarters to the left was most often seen in dun (58%) horses, however, numbers were low (n=25) and laterality was equally distributed (p >0.05, Figure 18).

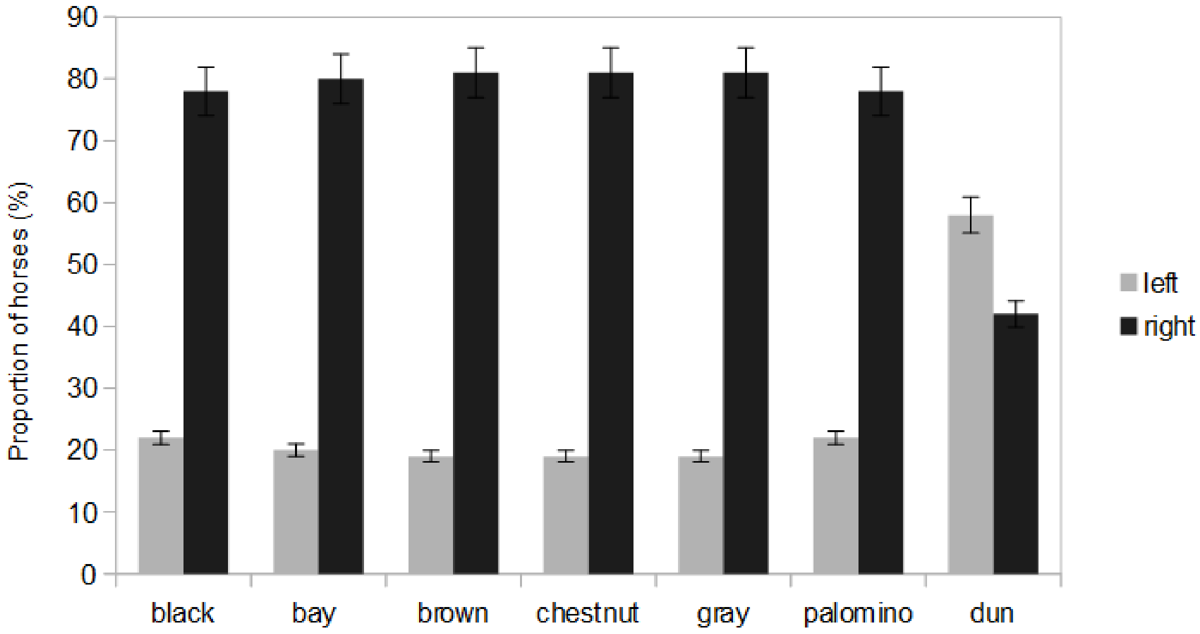


Figure 18: The lateral displacement of the hindquarters (%) within coat colours (sample B; dun: n=25, p>0.05, all other colours: p<0.0001).

5.3.4 The lateral displacement of the hindquarters in Thoroughbreds determined in situ compared to results obtained during video analysis

When evaluated from behind in situ (i.e. on the racetrack prior to the actual race), more (n=54) horses had their hindquarters displaced to the right than to the left (n=13, chi^2=25, p<0.0001; sample C). During video analysis of the same sample of horses racing on a clockwise track, 45 horses were categorized as right-lateral, 15 horses as left-lateral, while 7 horses showed lateral deviations of their hindquarters in both directions (chi^2=15, p=0.001). During their approach to the finish line, 46 horses galloped on the left lead, while 18 horses galloped on the right lead (chi^2=130, p<0.0001). A total of 11 horses changed their lead, however, the direction of lead change was equally distributed to the left and right (p>0.05).

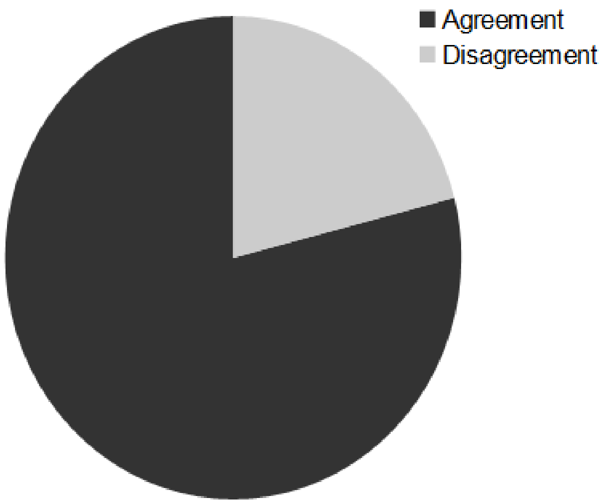


Figure 19: Proportion of agreement and disagreement between classification of laterality by assessment of lateral displacement of the hindquarters of Thoroughbreds at the racetrack in situ versus during video analysis of races (proportion of horses in %, Sample C, p=0.0001).

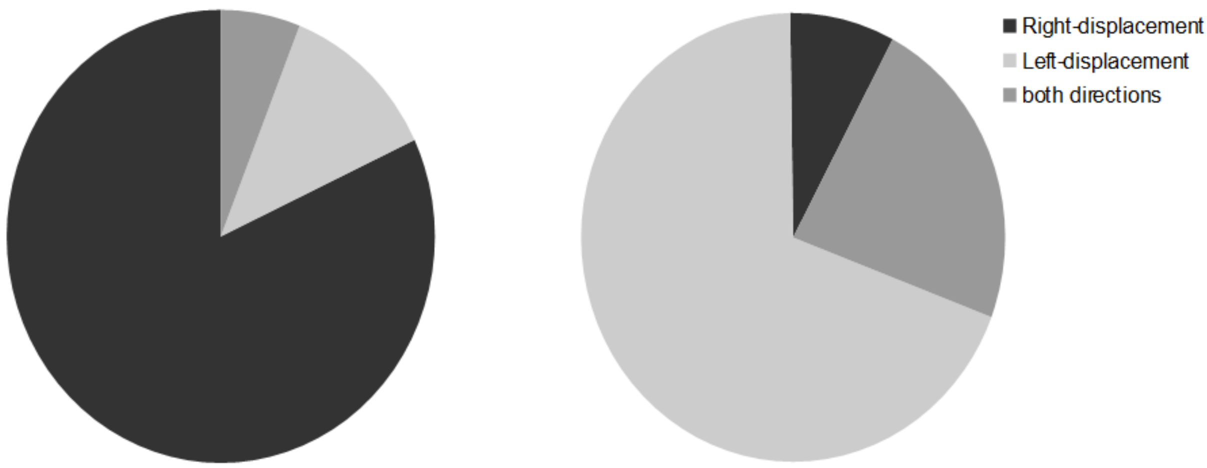


Figure 20: The lateral displacement of the hindquarters during video analysis for horses assessed as right-biased (left chart) and as left-biased (right chart) based on the lateral displacement of their hindquarters at the racetrack in situ (proportion of horses in %, sample C, p=0.0001).

There was no influence of the lateral displacement of the hindquarters assessed with either method on the lead or a lead change (p>0.05). In a total of 14 horses laterality did not agree between video analysis and the observation in situ or could not be clearly determined during video analysis. A total of 79% of horses showed the same direction of laterality in situ and during video analysis (p=0.0001, Figure 19). Of all horses determined as right-lateral in situ, 81.5% showed agreement of results obtained during video analysis. In all horses determined as left-lateral, only 69.3% showed agreement of results (p=0.001) (Figure 20).

5.3.5 The lateral displacement of the hindquarters assessed during video analysis compared to the preferred lead

The majority of horses (Sample D) was categorized as either right-lateral (n=778) or ambidextrous (n=661; left-lateral: n=383), based on the lateral displacement of their hindquarters during video analysis of multiple flat races (chi^2=518, p<0.0001).

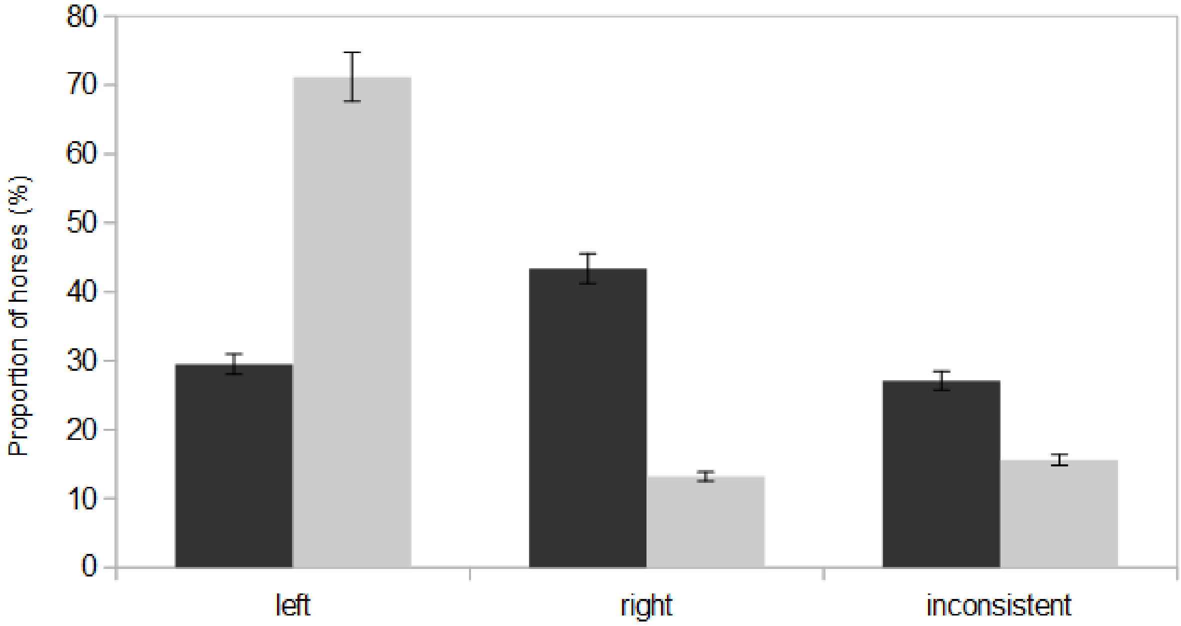


Figure 21: The lateral displacement of the hindquarters (black bars) and the preferred lead (grey bars) during clockwise races (Sample D, video analysis, all p<0.0001).

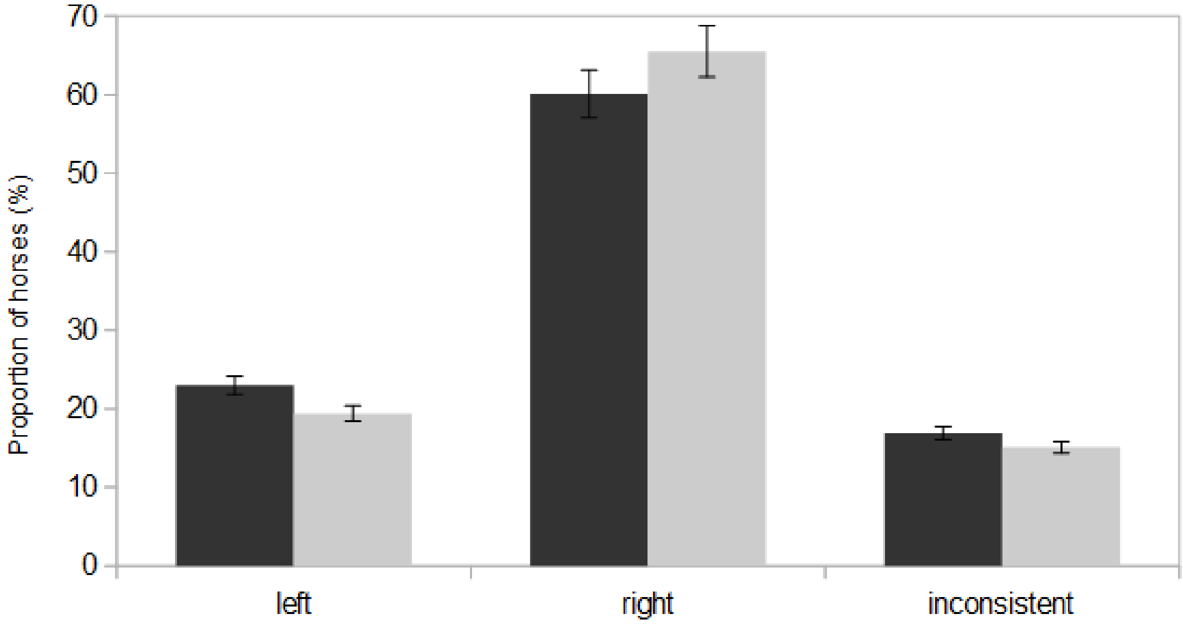


Figure 22: The lateral displacement of the hindquarters (black bars) and the preferred lead (grey bars) during counter-clockwise races (video analysis, all p<0.0001).

When racing in a clockwise direction, most horses had their hindquarters displaced to the right (43.4%), while the other horses showed either a left-displacement (29.5%) or inconsistency (27.1%, chi^2= 119, p<0.0001, Figure 21). The majority of horses preferred the left (outside) lead (71.2%) or showed inconsistency (15.6%) instead of performing in the right (inside) lead (13.2%, chi^2=2418, p<0.0001, Figure 21). In counter-clockwise races, the majority of horses had their hindquarters displaced to the right (60.1%). More horses showed a left-displacement (23%) than inconsistency (16.9%, chi^2=189, p<0.0001, Figure 22). Most horses preferred the right (outside) lead (65.5%), while the other horses mostly preferred the left (inside) lead (19.4%). A smaller proportion of horses showed inconsistency in this racing direction (15.1%, chi^2=1610, p<0.0001, Figure 22).

A total of 99% of horses that were determined as either right-lateral (Figure 23) or left-lateral (Figure 24) based on the lateral displacement of their hindquarters during multiple races in both directions actually had their hindquarters displaced to the left and right during all observed clockwise races, respectively (p<0.0001).

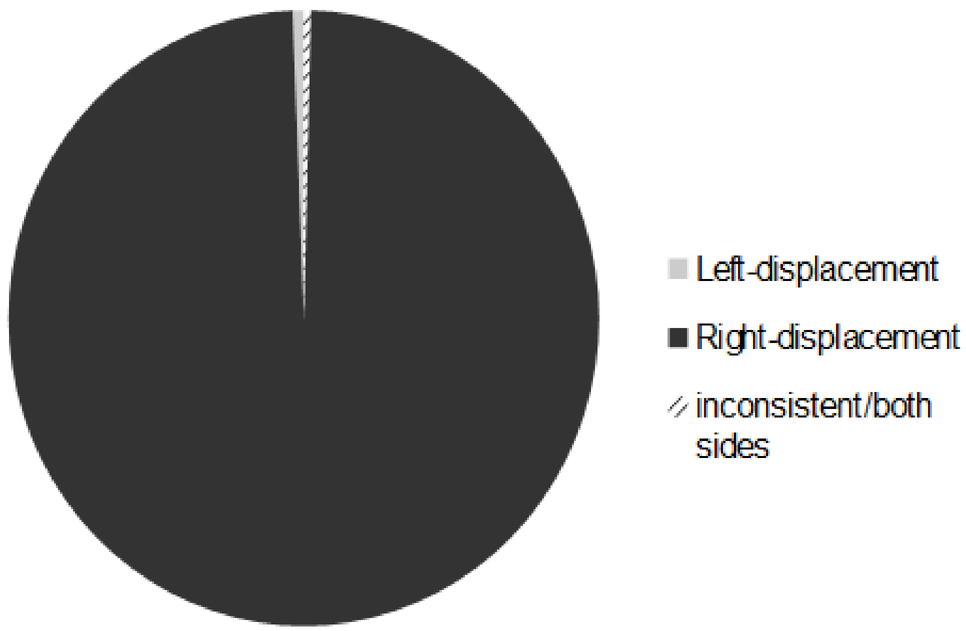


Figure 23: The lateral displacement of the hindquarters during clockwise races in horses determined as right-lateral based on the lateral displacement of their hindquarters overall during 2-6 races (Sample D, proportion of horses in %, p<0.0001).

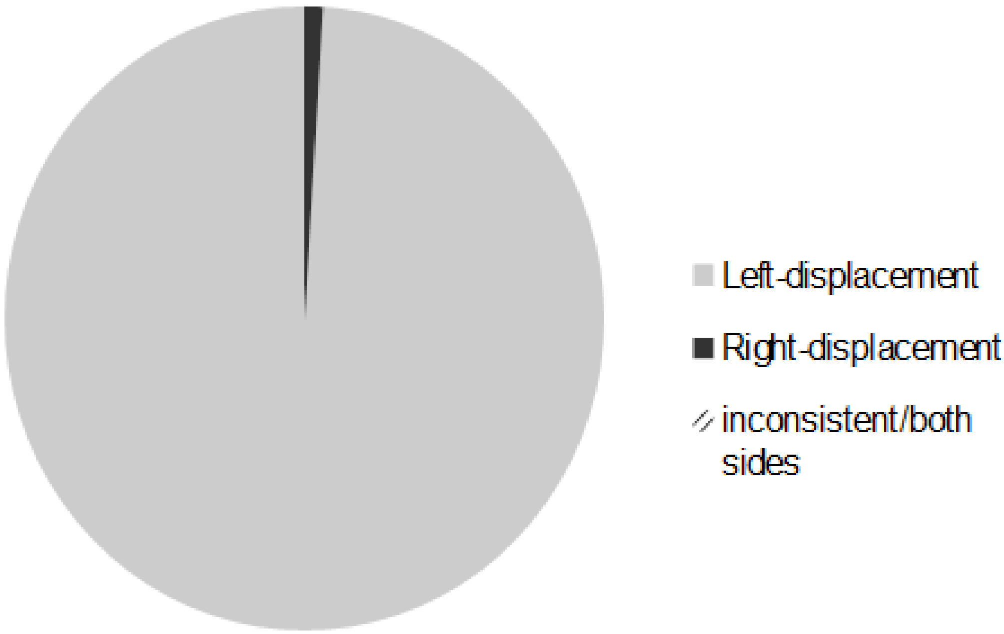


Figure 24: The lateral displacement of the hindquarters during clockwise races in horses determined as left-lateral based on the lateral displacement of their hindquarters overall during 2-6 races (Sample D, proportion of horses in %, $p<0.0001$).

In a counter-clockwise direction, 97% of right-lateral horses (Figure 25) and 96% of left-lateral horses (Figure 26) had their hindquarters displaced to the left or right during all races, respectively ($p<0.0001$). In both directions left-lateral horses that switched the position of their hindquarters in one race, had their hindquarters displaced to the right only (1-4%, Figures 24 & 26) and never showed inconsistency (i.e. switching direction multiple times during one race). In contrast, right-lateral horses were more likely to switch to the left (0.6-2%) than to show inconsistent lateral displacement (0.4-1%, Figures 23 & 25).

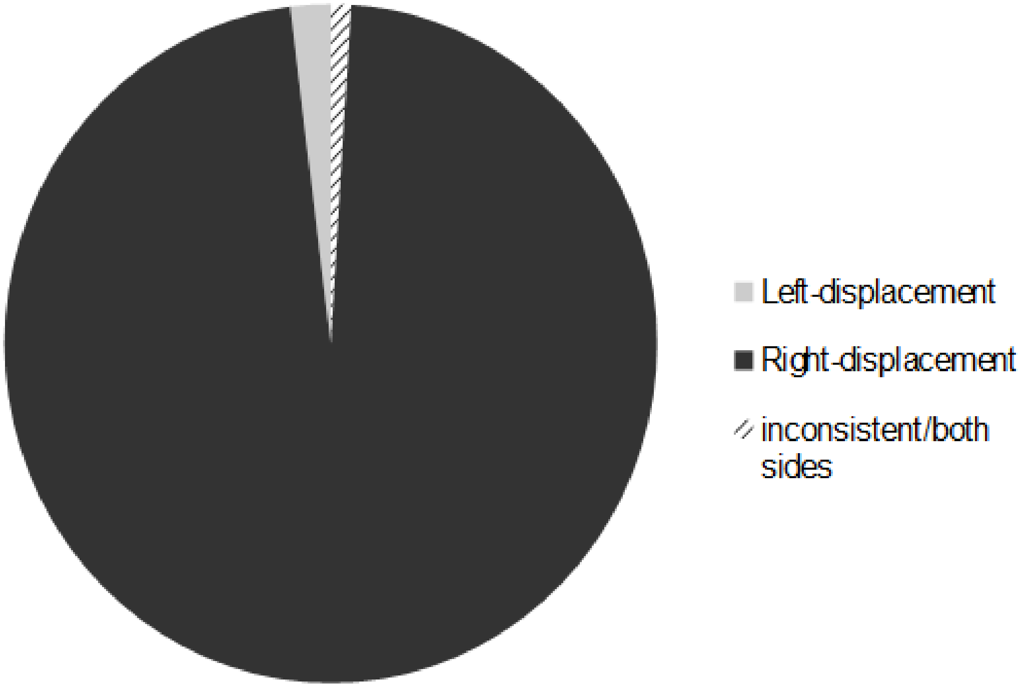


Figure 25: The lateral displacement of the hindquarters during counter-clockwise races in horses determined as right-lateral based on the lateral displacement of their hindquarters overall during 2-6 races (proportion of horses in %, p<0.0001).

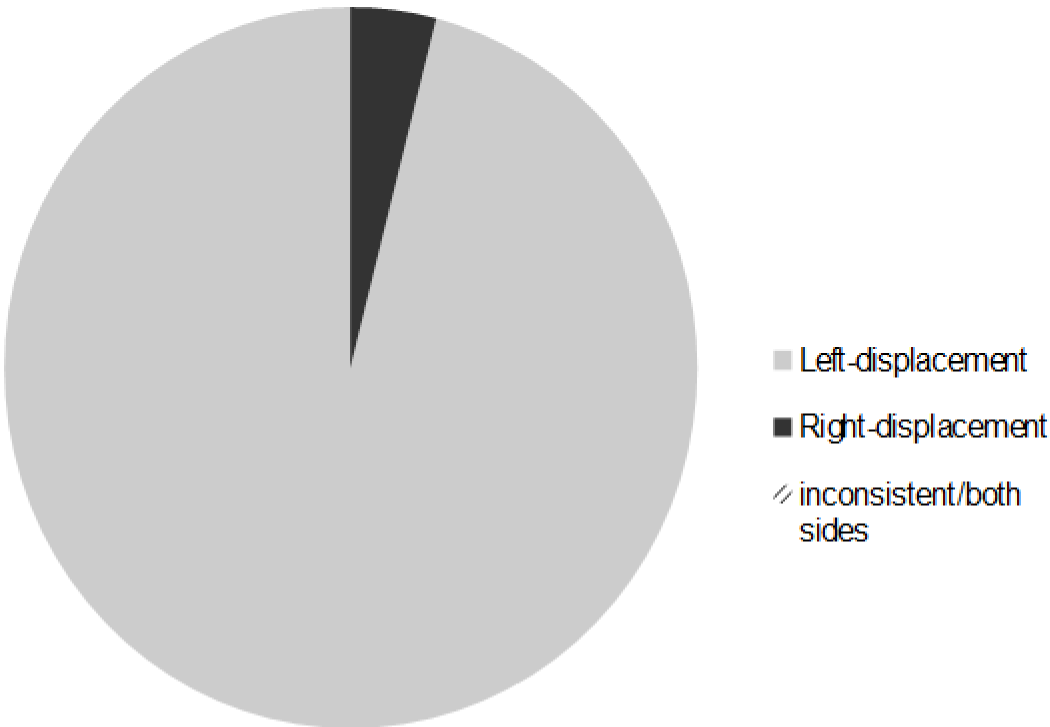


Figure 26: The lateral displacement of the hindquarters during counter-clockwise races in horses determined as left-lateral based on the lateral displacement of their hindquarters overall during 2-6 races (proportion of horses in %, p<0.0001).

Ambidextrous horses (inconsistent lateral displacement in one or both directions) mostly switched between a lateral displacement to the left and right (64%) or preferred either the left (22%) or the right (15%, p<0.0001) during clockwise races (Figure 27, left). During counter-clockwise races the majority of ambidextrous horses had their hindquarters displaced to the right (44%), showed inconsistent lateral displacement (38%) or a displacement to the left (18%, p<0.0001, Figure 27, right).

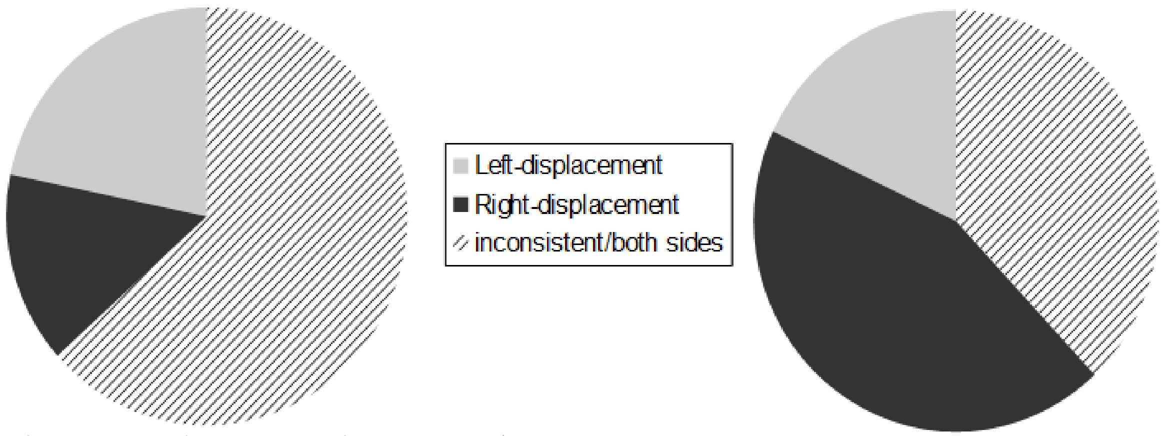


Figure 27: The lateral displacement of the hindquarters during clockwise (left) and counter-clockwise races (right) in horses determined as ambidextrous based on the lateral displacement of their hindquarters overall during 2-6 races (Sample D, proportion of horses in %, p<0.0001).

The direction of the horses laterality was weakly related to the preferred lead in a clockwise and a counter-clockwise direction (both r=0.2, p<0.0001). In a clockwise direction, the majority of horses preferred the outside (left) lead, regardless of their direction of laterality (left-lateral 84%, right-lateral 72%, ambidextrous 66%, p<0.0001, Figure 28). A less strong preference for the outside (right) lead was shown in a counter-clockwise direction (left-lateral 49%, right-lateral 75%, ambidextrous 62%, p<0.0001, Figure 29). The direction of lead changes during races in either direction was not significantly related to the horse's laterality (p>0.05).

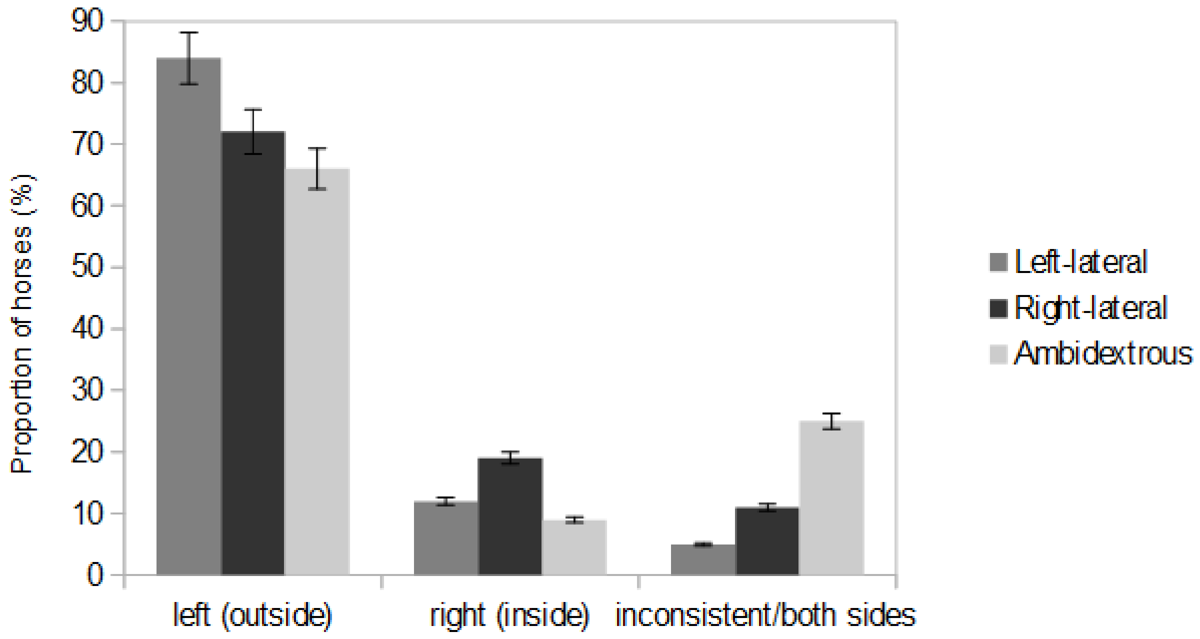


Figure 28: The preferred lead during clockwise races in relation to laterality based on the lateral displacement of their hindquarters overall during 2-6 races (Sample D, %, p<0.0001).

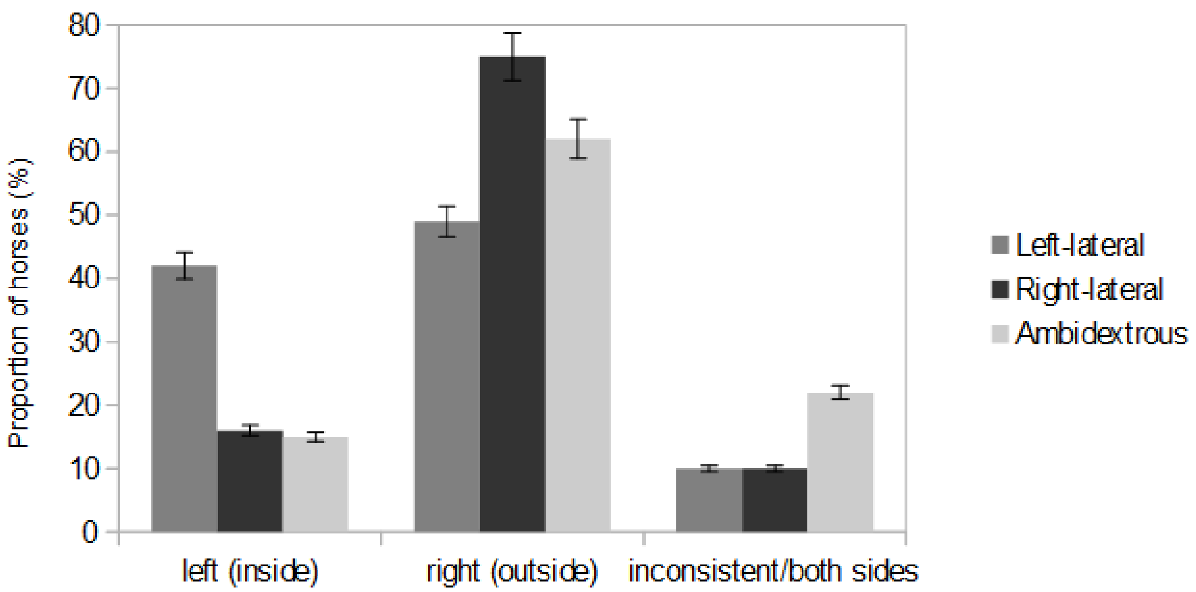


Figure 29: The preferred lead during counter-clockwise races in relation to laterality based on the lateral displacement of their hindquarters overall during 2-6 races (Sample D, %, p<0.0001).

In races on a clockwise track, the preferred lead was weakly related to the direction of the hindquarters (r=0.26, p<0.0001). Horses that had their hindquarters displaced to the left, preferred the left (outside) lead (34%), whereas horses that had their hindquarters displaced to the right preferred the right (inside) lead (62%). Horses with inconsistent hindquarters mostly showed no preference (62%) or preferred the left (outside) lead (29%, p<0.0001, Figure 30).

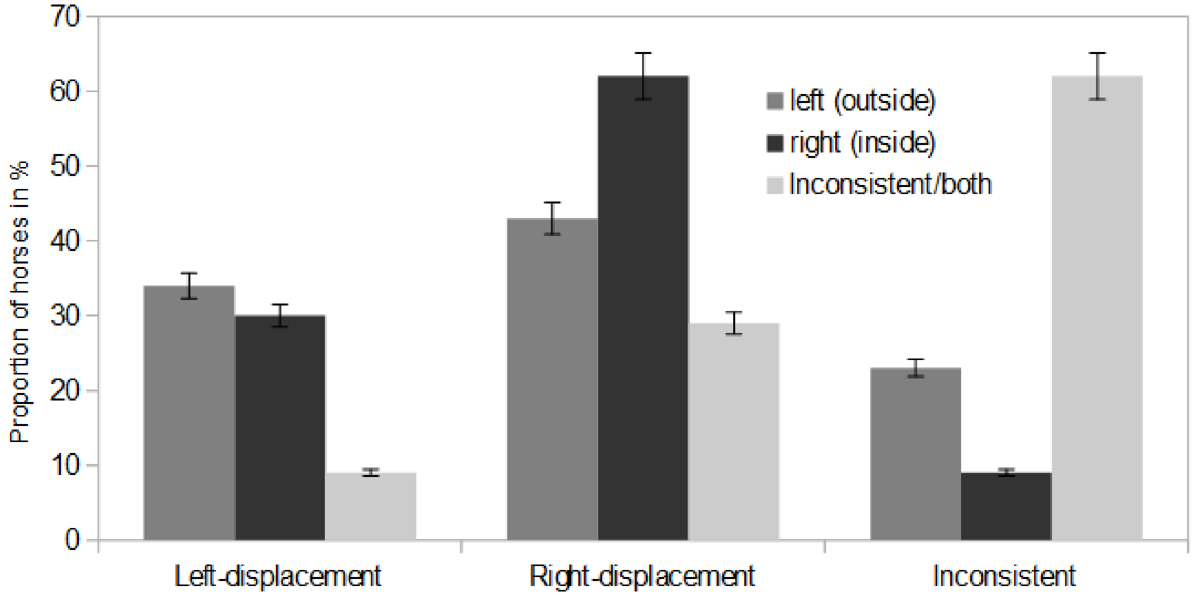


Figure 30: The preferred lead during clockwise races in relation to the lateral displacement of the hindquarters (Sample D, %, p<0.0001).

In races on a counter-clockwise track, the preferred lead was related to the direction of the hindquarters (r=0.37, p<0.0001). Horses that had their hindquarters displaced to the left preferred the left (inside) lead (55%), whereas horses with their hindquarters displaced to the right preferred the right (outside) lead (72%). Horses with inconsistent hindquarters showed no preference (49%) or preferred the right (outside) lead (34%, p<0.0001, Figure 31).

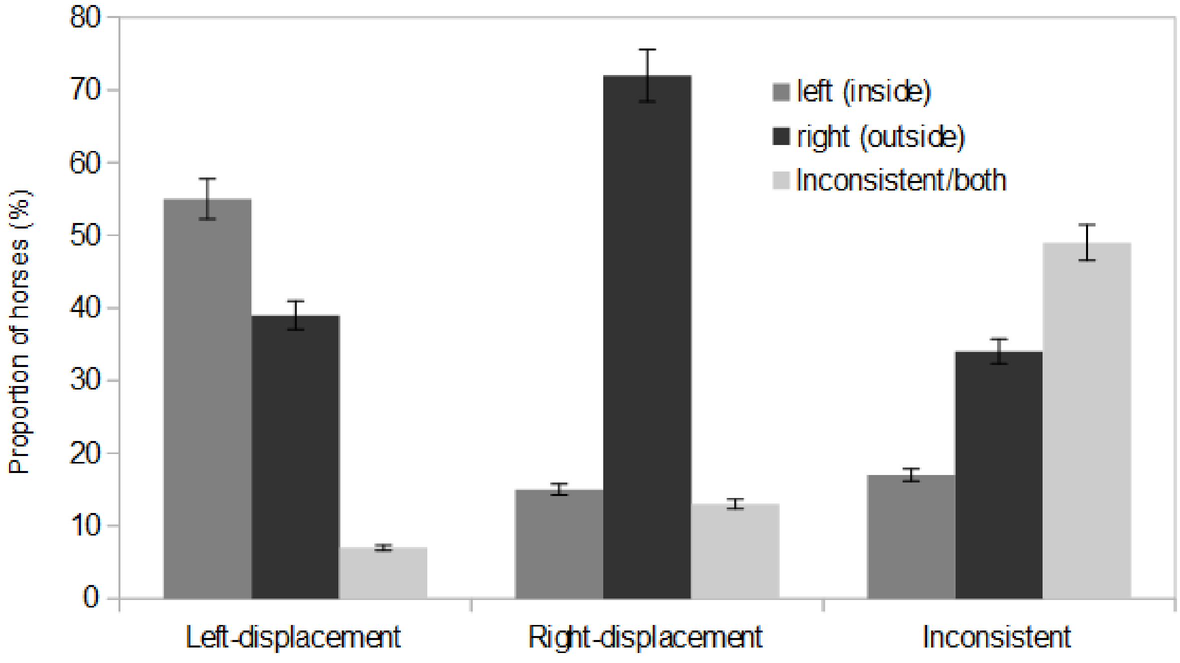


Figure 31: The preferred lead during counter-clockwise races in relation to the lateral displacement of the hindquarters (Sample D, %, p<0.0001).

5.3.6 The preferred forelimb during grazing in 30 second vs. 60 second scan sampling

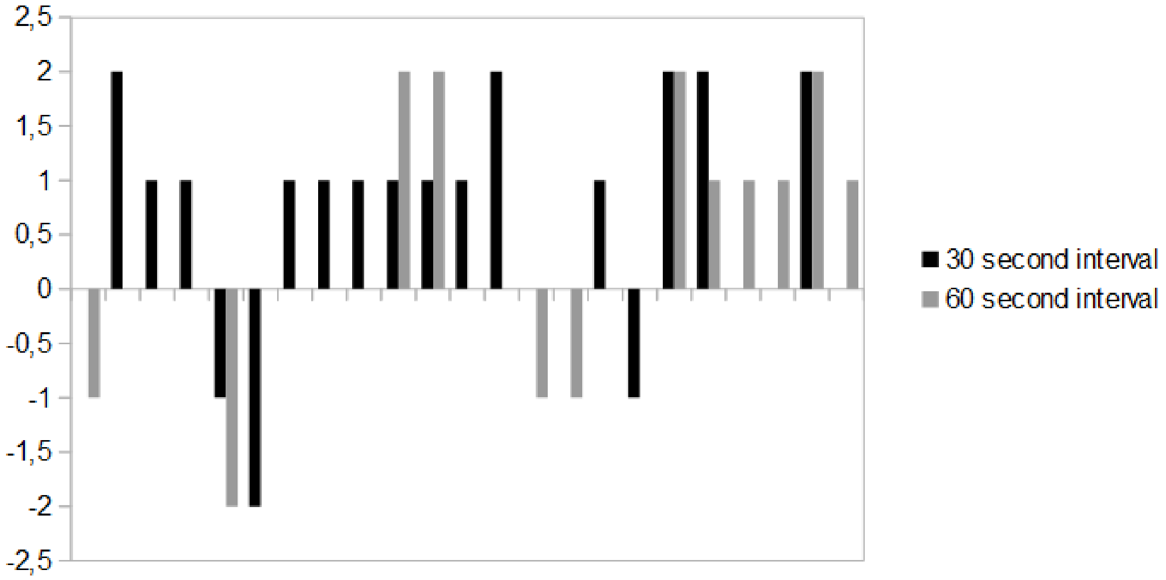


Figure 32: Leg preference of individual warmblood horses with 30 second (black) and 60 second intervals (grey, sample A, p<0.0001). Each pair of bars resembles one individual horse. Negative values resemble a preference of the left forelimb.

In a 30 second scan sampling of sample A, eleven warmblood horses (sample A) tended towards leg preference (z-value +/- 1-1.96). Significant (z-value >+/-1.96) leg preference was detected in 6 horses. Results changed considerably with the 60 second sampling: Only seven horses tended towards and five horses displayed significant leg preference. For the individual horses, the associated significance levels remained, increased or decreased between both samples but never changed direction (p<0.0001, Figure 32). Significant agreement with results from other laterality test methods could only be detected for the results of the 60 second sampling.

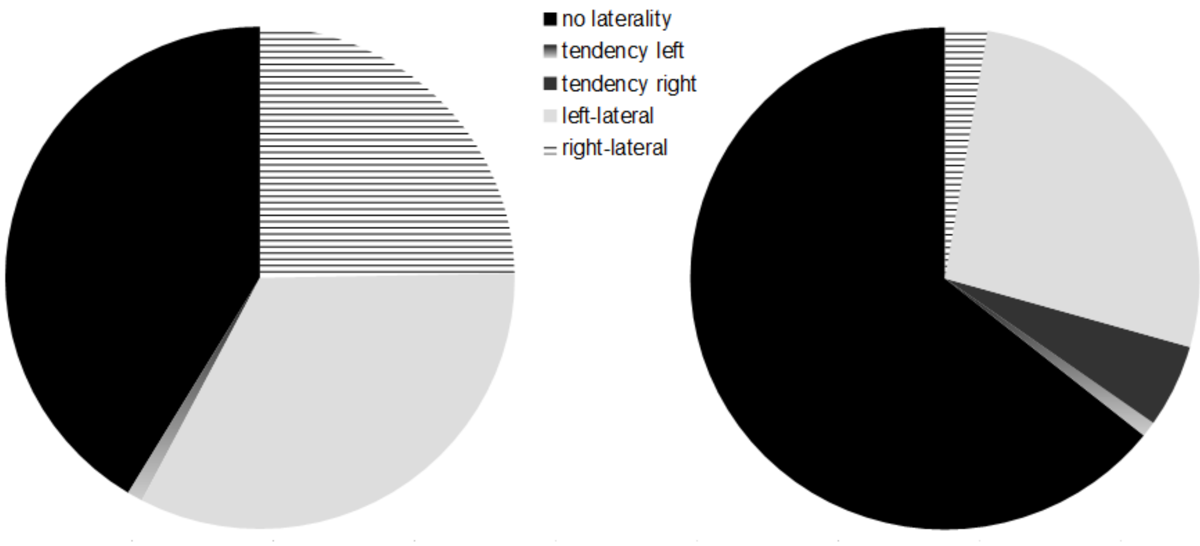


Figure 33: Leg preference (proportion of horses in %) during 30 second intervals in Thoroughbred stallions (left, p=0.017) and Thoroughbred mares (right, p>0.05) of sample E.

In a 30 second scan sampling only, 58% of the Thoroughbred stallions (n=24; Sample E) showed a preference of one forelimb (z-value >+/-1.96; 33.3% left, 25% right, p=0.017, Figure 33). Some tended to prefer their left forelimb, while a tendency towards a right-preference could not be documented in stallions. In contrast, even though a tendency towards or preference of either forelimb was documented in Thoroughbred mares, the majority of Thoroughbred mares (n=37) showed no significant preference (57%, p>0.05, Figure 33).

With both sampling intervals, the majority of horses showed no leg preference (30 second interval: 49.1%, chi²=28; 60 second interval: 42.6%, chi²=30; all p<0.0001). Most lateralized horses preferred their left foreleg (30 second interval: 34%; 60 second interval: 33.3%, p<0.0001). Direction and degree of laterality remained constant in most cases between both sampling intervals.

5.3.7 The preferred forelimb during grazing and the preferred eye

During frontal approach with objects (preferred eye for investigation of a plastic bag, toy and ball), most horses (sample E) did not prefer any eye (80-88% for the individual objects). Except for one horse, only left sensory bias was detected (n=9). Left-eye preference was observed only in horses with a left-leg (n=4, p=0.005) or no preference (n=6, p=0.009) during 60 second scan sampling.

5.3.8 The preferred forelimb during grazing and the rider's assessment of their horse's laterality

The majority of warmbloods (sample A, n=21) were assessed as right-lateral by their riders (n=11, p=0.021) and did not show a significant leg preference. Some, however, tended to prefer their left (n=2) or right leg (n=1, z-value +/- 1-1.96). Left-lateral horses tended to (n=1) or significantly preferred their left leg (n=1) or showed no preference (n=5; 60 second interval, p=0.018, Figure 34).

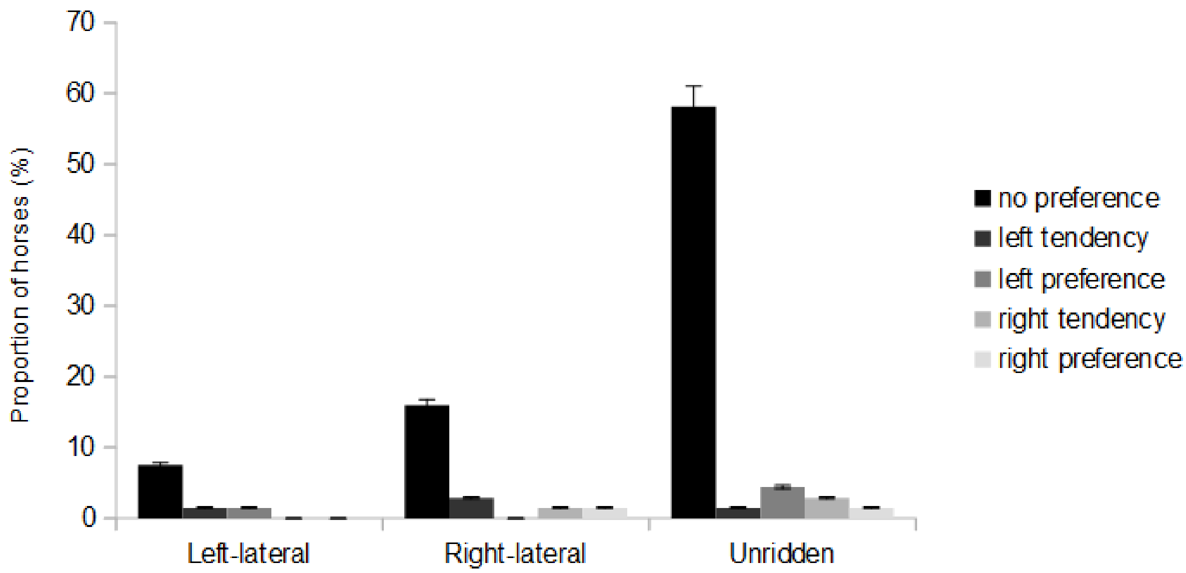


Figure 34: Horse's leg preference during grazing in relation to riders' assessment of their laterality (%, sample A, n=21, p=0.018)

5.3.9 The lateral displacement of the hindquarters and the rider's assessment of their horse's laterality

Most ridden horses (sample A, n=21) with their hindquarters displaced to the right (n=14) were classified as right-lateral by their riders. In some cases (n=2) however, horses with a right-displacement of their hindquarter were described as left-lateral. Riders classified all horses with their hindquarters displaced to the left (n=7) as left-lateral (p=0.003, Figure 35). Horses perceived as right-lateral by their riders had their hindquarters displaced to the right exclusively.

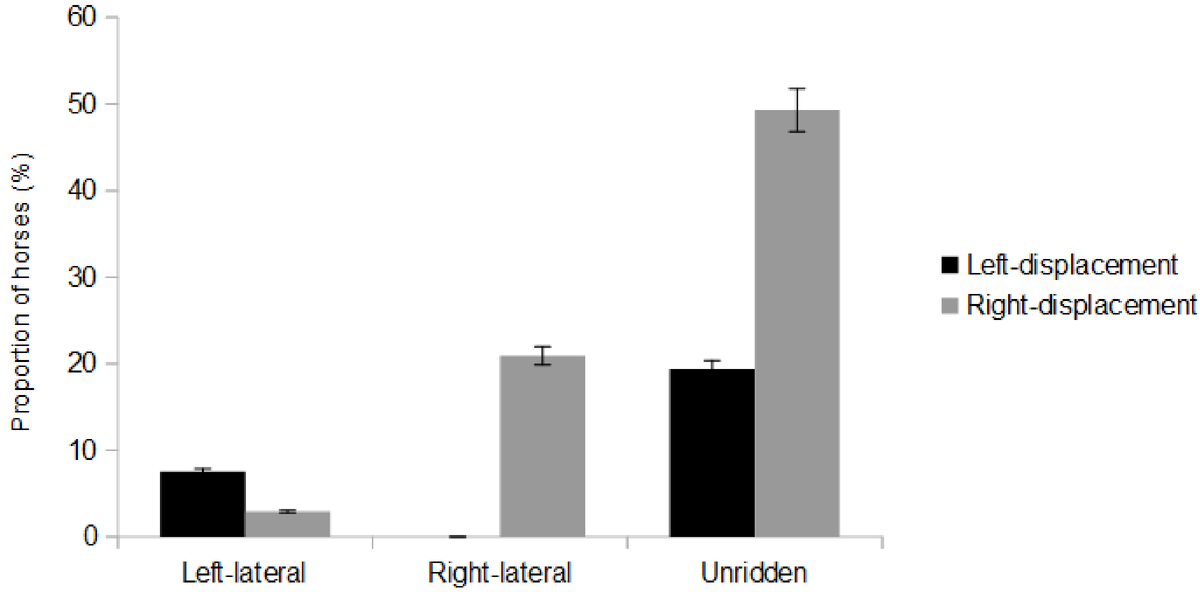


Figure 35: The direction of the lateral displacement of their hindquarters in horses assessed as either right- or left-lateral by their riders and horses with unknown laterality during riding (unridden) (%, sample A, n=21, p=0.003).

5.3.10 Rider's assessment of their horse's laterality compared to rein tension and the lateral displacement of the hindquarters

For the sample of 12 horses with rein tension analysis (sample A), no relation between rein tension and the results of the preferred forelimb during grazing (both intervals) or eating from a bucket, eye preference and the angle of lateral displacement of the hindquarters was found (all p>0.05). Asymmetric rein tension patterns were related to the rider's assessment of their horse's laterality (p=0.019). In this smaller sample of horses tested with rein tension, the rider's assessment and the horse's lateral displacement of the hindquarters were significantly related too (p=0.007, Figure 36).

The majority (75%) of horses were right-lateral with their hindquarters displaced to the right. All left-lateral horses (16.7%) had their hindquarters displaced to the left. Mixed results were obtained for 8.3% of horses, which had their hindquarters displaced to the right, but were assessed as left-lateral by their riders (Figure 36).

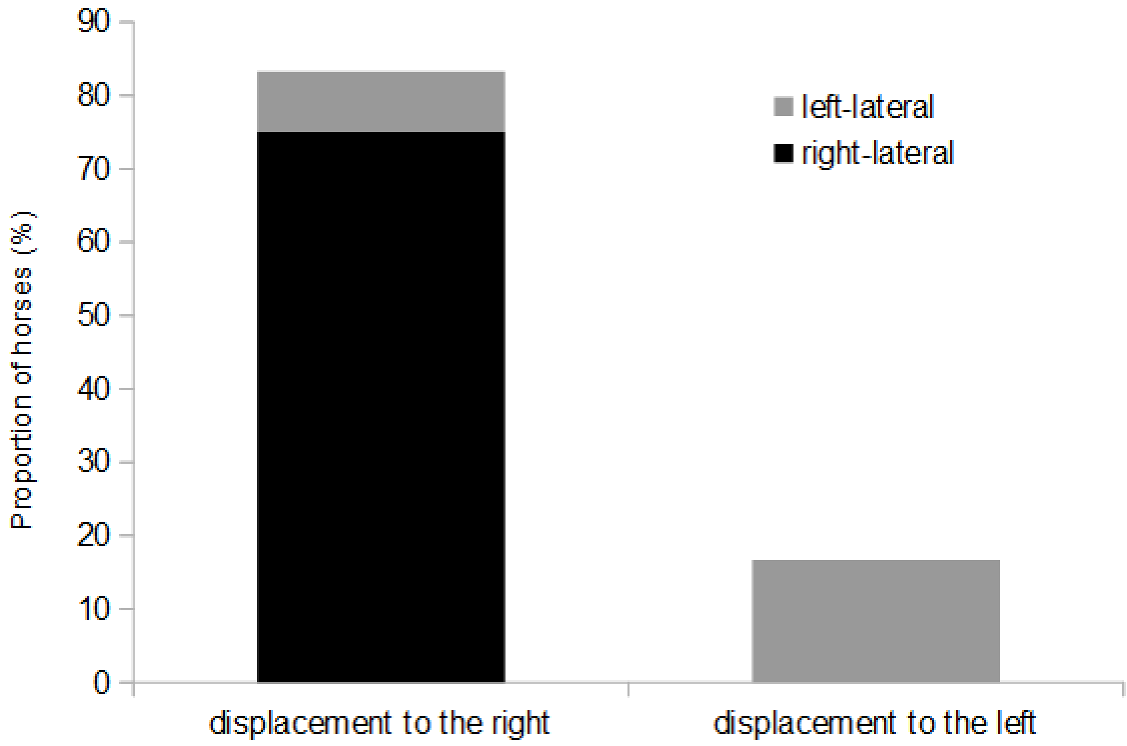


Figure 36: The relationship of riders' assessment of their horse's laterality during riding and the lateral displacement of the hindquarters (%, sample A, n=12, p=0.007).

Rein tension tended to be higher in horses with their hindquarters displaced to the left (18.57 ± 4.6 N vs. 9.77 ± 2.3 N, p = 0.077). Asymmetry of rein tension patterns seemed to be influenced by laterality of both, horses and riders. Riders applied higher mean rein tension with their dominant, right hand (14.2 ± 1.5 N right hand vs. 13 ± 1.5 N left hand, p=0.044; Figure 37). Mean rein tension applied to the left-lateral horses was higher than in right-lateral horses (mean of both reins: 17.6 ± 2.5 N LL vs. 9.5 ± 1.5 N RL, p=0.02, Figure 38).

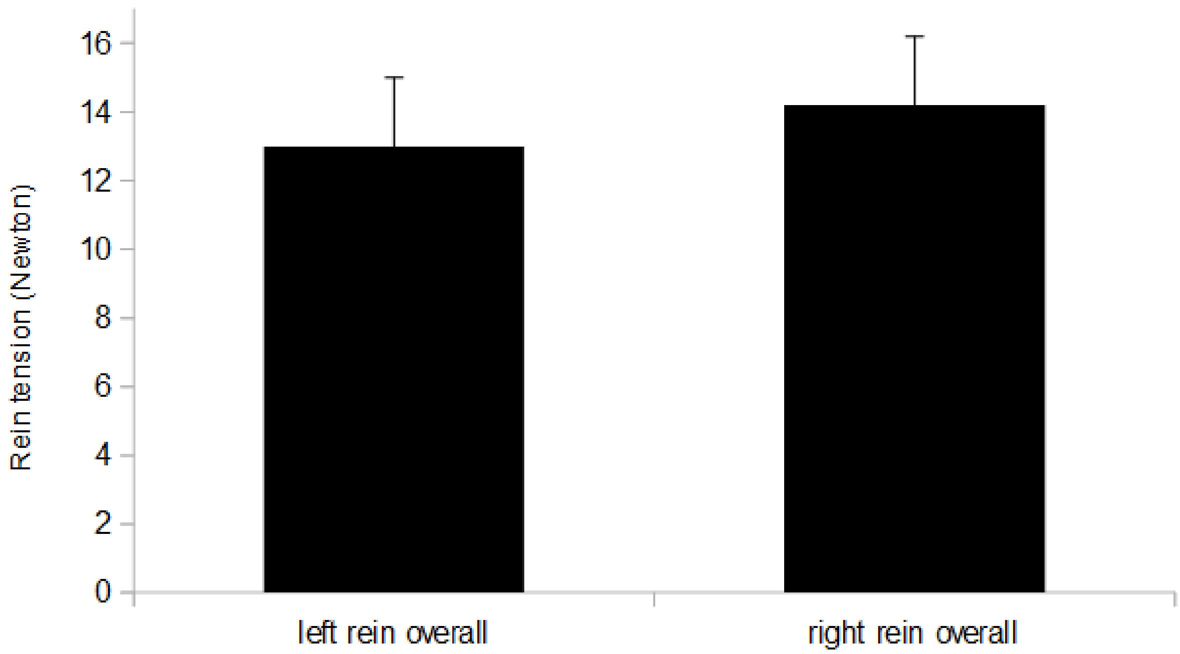


Figure 37: Mean rein tension (N) of the left and right rein. Riders applied higher mean rein tension with their dominant, right hand (p=0.044).

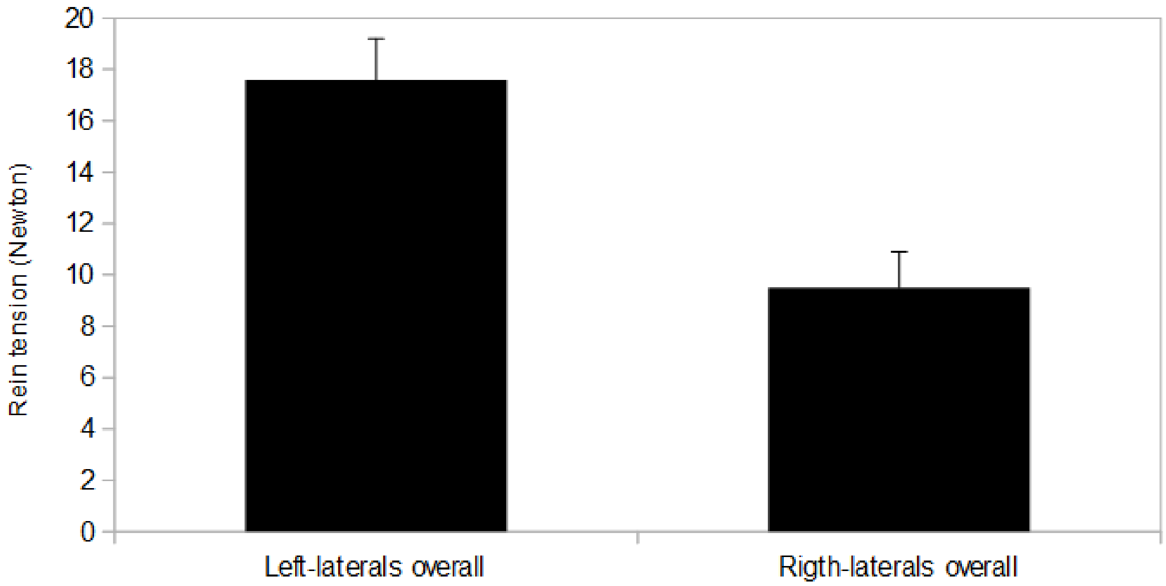


Figure 38: Mean rein tension (N) in relation to horse's laterality assessed by the riders. Mean of both reins was higher in left-lateral horses (p=0.02).

The difference between tension in the left and right rein was higher when riding in direction of the rider's non-dominant hand (counter-clockwise) with all horses (p = 0.02, Figure 39). Rein tension was more stable when riding in the direction of the rider's dominant hand (clockwise) (Mean standard deviation as an indicator of stability, p<0.0001, Figure 40). The mean difference of left and right rein tension as a measure of quantitative symmetry correlated with mean tension (r=0.6, p<0.05) and standard deviation (r=0.65, p<0.05).

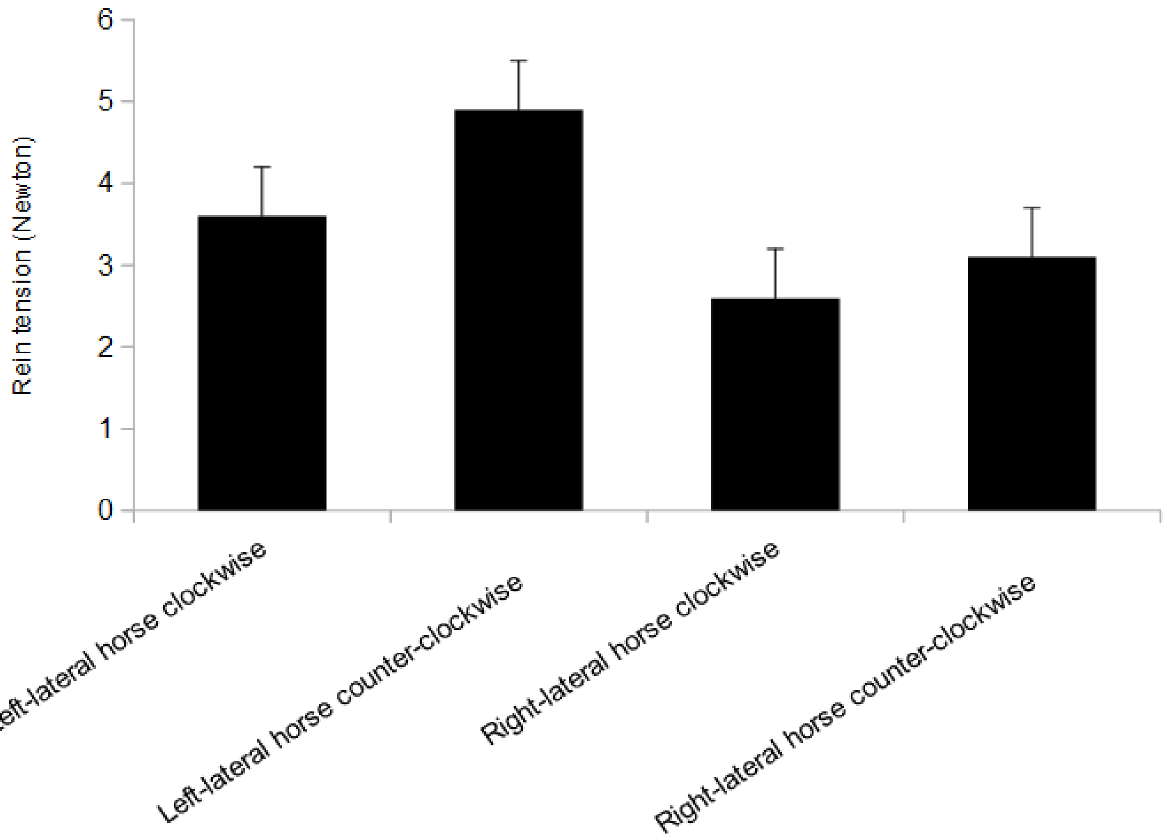


Figure 39: The difference of mean tension between left and right rein (N) in clockwise and counter-clockwise directions in relation to horse's laterality (sample A, n=12, p=0.02).

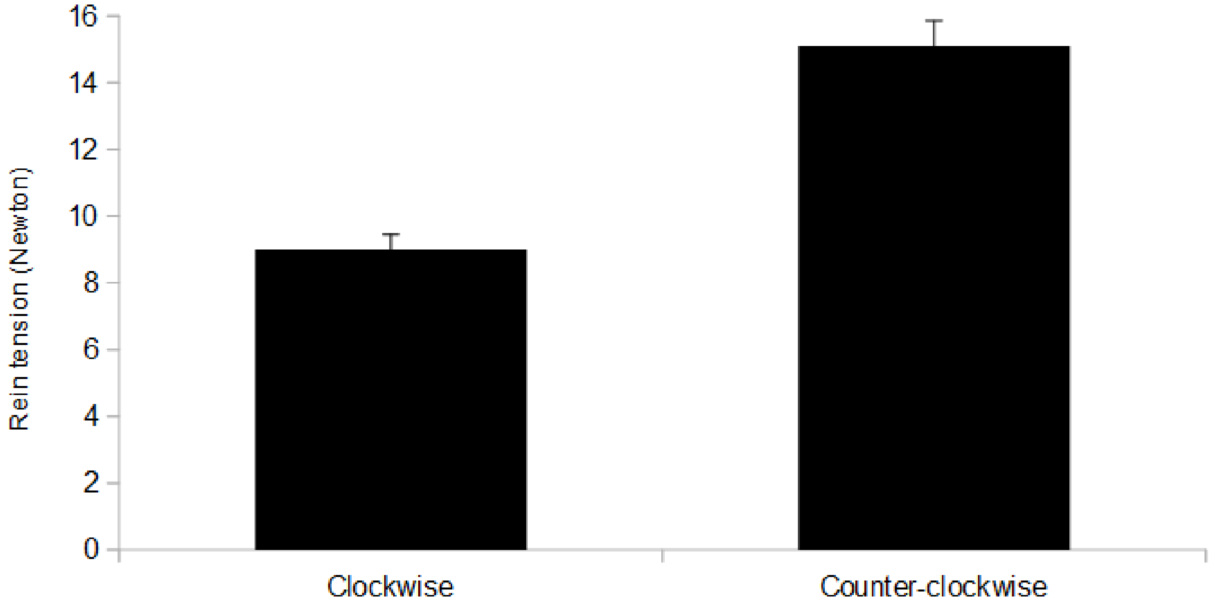


Figure 40: Mean standard deviation (SD) of rein tension (N) as an indicator for the stability of rein contact during riding clockwise vs. counter-clockwise (sample A, n=12, p<0.0001).

5.4 Discussion

A variety of different tests has been used to determine horse's laterality (Murphy *et al.* 2005, McGreevy & Rogers 2005, Murphy & Arkins 2008, Van Heel et al. 2006, Williams & Norris 2007, Larose et al. 2006). Results have varied between the studies. Significantly lateralized behaviour was found with most methods. However, results varied for the main direction of laterality (McGreevy & Rogers 2005, Williams & Norris 2007) and between different breeds (McGreevy & Thomson 2006, Osterholz 2016). In some studies a small number of up to three test methods have been compared (Murphy *et al.* 2005, Van Heel et al. 2006), but not all relations between test methods have been evaluated yet. Especially, with sensory and motor laterality, results varied and relationships between parameters of the two different domains could not be proven in all samples (Larose et al. 2006, De Boyer Des Roches *et al.* 2008, Carey & Hutchinson 2013). Strong motor laterality does not seem to increase sensory laterality (Carey & Hutchinson 2013). No test method had been tested for its relation and agreement with laterality assessed during riding so far.

Laterality is proven to vary between horses of different age groups and changes from one preference to the other during maturation have been observed (Podhajsky 1968, McGreevy & Rogers 2005, McGreevy & Thomson 2006, Van Heel *et al.* 2006). Therefore a large sample containing horses of all ages was chosen. The majority of horses in sample E did not show any leg preferences, which is most likely due to the fact that it consisted of mostly young horses. The majority of horses in sample A were not ridden, mainly due to young age. The sample of ridden horses for the collection of rein tension data contained all age groups from young horses (7 years) that have been trained for several years up to senior horses (23 years). With neither sample a relation of age to any laterality method or rein tension could be identified.

For some studies with smaller sample sizes laterality seemed to be biased by sex (Murphy *et al.* (2005). However, in the current study, this was found for only one test method exclusively in a smaller sample of Thoroughbreds (sample E). Similar to the results of sample E, male horses of other sample populations exhibited mostly left-biased behaviour, in contrast to female horses which were reported to show a bias to the right most often (Murphy et al. 2005). The present results of sample E differs from previous reports for female horses, which in the actual sample showed mostly no laterality or a left-bias. This could be either due to young age, the left-bias in the total population of the breed or possibly due to the direction of laterality of their parents. The sire of most young horses, as well as some of the dams showed a left-bias throughout all test methods. In humans, left-handed parents, especially females, are more likely to have a left-handed child (Annett 1978, McManus 1985). However, the mechanism behind the inheritance of left-handedness remains unclear (Annett 1978, McManus 1985, McKeever 2004, Ocklenburg et al. 2017) and environmental factors most likely play a role as well (Jones & Martin 2008). In horses, a genetically predetermination might be possible that appears and increases with age and might also be influenced by environmental factors (Murphy et al. 2005). The fact that the occurrence and direction of laterality of the parents did not significantly relate to their offspring's laterality in this sample, rejects a theory of either genetics or environmental influences being the single trigger for laterality. A possible explanation for breed differences of lateralized behaviour was suggested to be training and selection of horses for different purposes (McGreevy & Thomson 2006).

5.4.1 The direction of mane and facial hair whorls

Probably due to the smaller sample size compared to the sample in chapter 2, a relation of the direction of mane to the rider's assessment of their horse's laterality could not be documented in the warmbloods of sample A. Most Thoroughbreds in sample E carried their mane on the right side, which according to the results of the investigation in chapter 4, might be a possible indicator of laterality during riding. However, the results of any other method to determine laterality showed a bias to the opposite side in this sample.

In previous research, a relation of laterality during riding and the direction of facial hair whorls has been documented (Elworthy 2004, Murphy & Arkins 2008, Shivley et al. 2016). In other studies, however, these methods did not agree (Pywell 2005). In the present study the direction of facial hair whorls was randomly distributed and did not match with the results of any other method, neither in warmbloods nor in Thoroughbreds. One could argue that the sample of ridden horses with known laterality as assessed by their riders might have been quite small. However, other methods such as the lateral displacement of the hindquarters differed from a normal distribution without significant relation to laterality during riding throughout all comparisons. Furthermore, even the rather small sample of horses displayed a clear side bias that could be documented with several other methods such as rein tension and to some extent the lateral displacement of the hindquarters. The correlation of a flighty temperament with the position of facial hair whorls has been reported for horses and cattle too (Grandin *et al*. 1995, Larose *et al.* 2006, Austin & Rogers 2007, Gorecka *et al*. 2007). However, hair whorl position did not always deliver reliable results during these assessments (Grandin *et al*. 1995, Olmos & Turner 2008), which might explain why results did not correlate in the present study either.

5.4.2 Visual laterality (Preferred eye for investigation)

Visual laterality was not related to any other method applied in the present study. Young Thoroughbreds of sample E were more likely to show a biased reaction during investigation of a ball. If a biased reaction was found, the left eye was used almost exclusively. Breeds such as Thoroughbreds have been identified to be more emotionally reactive and fearful (Mader & Price 1980, Hausberger *et al.*1998, Lloyd *et al.* 2008, Larose *et al.* 2006,). The use of the left eye correlates with negative emotions about novel objects or objects that are associated with fearful situations (Austin & Rogers 2007, Larose *et al.* 2006, de Boyer des Roches *et al.* 2008, Osterholz 2016). Since the majority of horses in sample E was younger than the horses in sample A, and Thoroughbreds might tend towards fearful reactions more easily than warmbloods, this could explain the greater number of left-biased reactions in the Thoroughbred sample. Accounting for the fact, that the offspring of the Thoroughbred stud has been described as brave, friendly, and curious in general, the number of horses not showing a biased reaction might actually be closer to the sample of warmbloods than to another sample of Thoroughbreds with more diverse parentage.

5.4.3 The preferred forelimb during grazing during 30 second vs. 60 second scan sampling

The preferred advanced forelimb has been most commonly used to determine horse's laterality (McGreevy & Rogers 2005, McGreevy & Thomson 2006, Warren-Smith & McGreevy 2010, Austin & Rogers 2012). As a scan sampling test, 60 second intervals have been applied in most cases. In order to test possible variations in results with different intervals, scan sampling has been applied for 30 second intervals, thus counting every other value to receive a 60 second interval. Significant side bias has been detected with both intervals. In order to be able to record a decrease or increase in preference between the two test- intervals, a z-value of +/- 1 was chosen to determine a tendency towards a certain preference. For the individual horses, the associated significance levels remained, increased or decreased between both samples but never changed direction. The majority of horses that showed a tendency or in some cases even a significant preference in the 30 second scan did not show any tendency or significant preference with the 60 second interval. Mainly horses tending to or preferring their left foreleg showed this side bias throughout both recording intervals. This indicates that the advanced foreleg during grazing might be more reliable in left-lateral horses. However, the sample size of horses with a significant preference is rather small. Since only the results of the 60 second interval correlated with the results of other methods, it is suggested that this interval should be chosen when using this method to determine horse's laterality.

5.4.4 The preferred forelimb during grazing and the preferred eye

Most horses did not show any biased reaction towards any of the objects used for the determination of the preferred eye. Two objects (ball and toy) were chosen as they were expected to be entirely unknown or without any specific meaning to the horses. The third object (plastic bag) was chosen as an object that might have the positive correlation of food, if familiar to the horses. This approach was chosen according to Larose et al. (2006) and de Boyer des Roches *et al.* (2008), who found a side bias that was related to objects connected with positive or negative emotions and the character of the horses. Every horse in this sample that showed a reaction during investigation at all used its left eye regardless of the object, which supports the hypothesis that more fearful characters tend to use their left eye (Larose et al. 2006). The few horses of the present study using their left eye exclusively preferred their left forelimb too, but this relationship may have to be validated in a larger sample of horses with sensory laterality. A lack of lateralized behaviour based on eye preference has been reported by Larose et al (2006) for some horses, too. A possible explanation might be that some horses are not sensory biased or only show a sensory biased reaction when the object triggers a strong emotional reaction. It seems that different types of laterality developed in horses on different levels, so tests based on sensory laterality such as eye preference, do not seem to be useful to conclude on motor laterality. Similar results have been reported earlier by McGreevy & Rogers (2005) leading them to the same conclusion.

5.4.5 The preferred forelimb during grazing and the rider's assessment of their horse's laterality

Horses perceived as right-lateral during riding did not show any preferred foreleg during grazing with 30 or 60 second scan sampling. One could argue that the purpose of the limbs during grazing is to support the horse's weight and allowing it to reach food compared to locomotion whilst keeping their own balance and that of the rider during riding, thus explaining the lack of agreement between test methods. However, with left-lateral horses a relation towards the preference of the left foreleg exists. It seems that the advanced foreleg during grazing might only be useful to predict laterality in left-lateral horses.

5.4.6 The lateral displacement of the hindquarters from the median plane

Results of the present study showed that the lateral displacement of the hindquarters could be assessed visually when standing behind a standing or walking horse and that the direction varies between horses.

Most of the warmbloods, ponies and Thoroughbreds had their hindquarters displaced to the right. This result is comparable to the observations of many experts on equitation throughout the centuries (De la Guérinère 1733, Steinbrecht 1901, Müseler 1933, Klimke 1985, Hinnemann & van Baalen 2004, Loch 2000, Miesner *et al.* 2000). Differences of the occurrence and main direction of sensory and motor laterality between horse breeds have been documented before, using other test methods (McGreevy & Rogers 2005, Murphy *et al.* 2005, Van Heel *et al.* 2006, Larose *et al.* 2006, Austin & Rogers 2007). The lateral displacement of the hindquarters was related to the rider's assessment of their horse's laterality and rein tension symmetry only. However both methods were not applicable for the sample of Thoroughbreds.

Comparisons of methods applied for the different samples produced the same results, indicating that the different methods for assessment of laterality are not related, regardless of the breed of horses. Still, the results of the different methods might vary between horse breeds regarding the occurrence and directions of laterality. This further supports the theory of different levels of laterality in individuals that developed separately and do not allow conclusions among different tests based on results of one test method.

Evaluating the lateral displacement of the hindquarters, no horse was entirely straight, therefore every warmblood and pony breed included in the present study, contained either right- or left-lateral horses. These results come close to findings of other studies that revealed the majority of their rather small samples being either left- or right-lateral. However, similar to other vertebrates, such as gorillas (Christel 1993, Christel et al. 1998, McManus 2002, Vallortigara 2006, Hopkins et al. 2011, Tabiowo & Forrester 2013), both directions of laterality exist in horses, even though one direction of laterality is most frequent at the population level. Furthermore, regarding the different incidence of left-laterality in Oldenburgs bred for either dressage or show jumping it seems that the lateral displacement of the hindquarters is genetically correlated to certain performance traits.

5.4.7 The lateral displacement of the hindquarters in Thoroughbreds determined in situ compared to results obtained during video analysis

In order to be able to collect data from a large test group for the estimation of genetic parameters, video analysis can be a helpful tool. However, available videos of flat races do not deliver a clear view of all horses straight from behind while standing or walking. Therefore, the results of video analysis had to be compared to those assessed while standing behind the horse for the same sample of horses (sample C) in order to validate the adaptation of the method.

Comparing both methods revealed a significant agreement of the results for 79% of the total sample. Agreement was higher for horses that were right-lateral. However, the majority of the sample was categorized as right-lateral during evaluation on site. For both groups, a change of direction of the lateral displacement for the results of video analysis was recorded for some horses, indicating that the methods might not be reliable in all cases. During video analysis some horses showed a lateral displacement to both sides, so that it was impossible to categorize them as either left or right. This included both, horses changing the direction of displacement within the same race or between races in two different directions. Therefore, it seems necessary to compare the lateral displacement of the hindquarters clockwise and counter-clockwise, to identify ambidextrous horses. Furthermore, in canter and galopp as an asymmetric gait (Hildebrandt 1985, Falaturi 1998), the side to which the hindquarters are displaced might likely be identical to the lead. However, some horses displayed both a left lead and a right lead and still showed a consistent displacement of their hindquarters to the same side with varying angles.

In order to look at all the horses, which most of the time galloped in a close group blocking each other from view, different shots had to be used. Most useful were the sequences right after the start from the starting machine and right after the finish, as both shots showed the horses from straight behind, so except for the difference in gait (gallop vs. walking or standing), no adaptations of the method were required. Also valuable to some extent were shots of the horses from behind when about to enter one of the bends. However, attention had to be paid to distinguish whether the particular horse was still on a straight part of the track or bending already. Very useful, even though adaptations of the method were required, was the shot showing the horses approaching the finish line frontally. Here, the position of the horses' hindquarters in relation to the shoulders could be used in order to distinguish between left- and right-displacement. Most videos contained a sequence of the horses approaching the finish line in slow-motion viewed from the side of the track. This shot focussed on the first horses in a broad group and did not show every horse equally long or with good visibility. Also, it did not prove to be useful to evaluate the lateral displacement of the hindquarters. Still, it allowed to determine the lead when exiting the last bend and when crossing the finish line or in many cases showed the horses changing their lead.

5.4.8 The lateral displacement of the hindquarters assessed during video analysis compared to the preferred lead

Race horses most commonly prefer the same hind limb for push off at the starting gate as well as the same lead for their racing performance (Deuel & Lawrence 1987, Williams & Norris 2007). The preferred lead has been regarded as a sign of laterality in horses. However, differences according to the direction of preference can be found between racing Thoroughbreds and Quarter Horses on shorter and straight tracks (Deuel & Lawrence 1987, Williams & Norris 2007). The preferred lead shows slightly different movement patterns compared to the non preferred lead, which might be a decisive advantage during racing (Deuel & Lawrence 1987, Williams & Norris 2007).

The majority of horses seemed to prefer the outside lead regardless of the direction of the racetrack. The opposite has been reported before. However, it remains unclear whether data were collected at the start or finish of the race (Biewener *et al.* 1983, Deuel & Lawrence 1987, Davies 1996, Barrey

2001). Performance in the outside lead (i.e. the direction of gallop in relation to the direction of the racetrack e.g. left lead on a clockwise track) could mean both that horses have already changed their lead due to fatigue before the finish line and that using the outside lead might provide an advantage for their performance. While running on bended tracks, horses shift their body at the median plane towards the direction of bend, thus shifting their center of mass and being forced to slow down due to fraction (Tan & Wilson 2011). During bends a longer stance phase of the inside limbs compared to the outside limbs can be observed (Falaturi 1998, Chateau et al. 2013). Furthermore, horses increase their speed with increasing the duration of their swing phase and reducing the duration of their stance phase (Streitlein & Preuschoft 1987, Falaturi 1998). When using the inside lead (i.e. left lead on counter-clockwise track) therefore, the leading forelimb is the inside limb which assumingly shows a longer stance phase possibly also carrying more weight and being restricted during its swing phase in comparison to the leading (outside) limb when using the outside lead. When using the outside lead however, the leading (outside) limb is able to elongate the swing phase without restriction and assumingly carries less weight than the opposite limb, thus enabling the horse to pass the bend at a faster speed.

In both right-lateral and left-lateral horses, the majority chose the lead according to the direction their hindquarters were displaced to, thus mainly preferring the inside lead in one direction and the outside lead in the other direction. It seems that matching patterns of asymmetry might improve performance. Ambidextrous horses were mostly inconsistent or showed left-displacement of their hindquarters in a left-lead in clockwise and right-displacement in a right-lead in counter-clockwise races, thus preferring the outside lead regardless of the direction. Laterality i.e. the overall lateral displacement of the hindquarters was weakly related to the chosen lead. Therefore, inconsistent lateral displacement could indicate that they are unbalanced and suffering from fatigue more often than right-lateral or left-lateral horses or they adapted their hindquarters according to the respective lead they changed to. Agreement of results for the lateral displacement of the hindquarters in situ versus during video analysis was generally good. The definition of horses being ambidextrous, if they show deviating results in more than one race seems to be an indicator that might be useful for future research.

In clockwise races, most horses used the left lead, which was the inside lead for left-lateral horses as expected (Biewener *et al.* 1983, Deuel & Lawrence 1987, Davies 1996, Barrey 2001) and the outside lead for right-lateral horses. In counter-clockwise races more right-lateral horses used the outside (right) lead than in clockwise races, which however matches their direction of laterality. Fewer ambidextrous horses seem to use the outside lead in counter-clockwise compared to clockwise races, indicating that they might be more similar to left-lateral than right-lateral horses. Left-lateral horses in contrast mainly used the inside (left) lead, thus indicating that both ambidextrous and right-lateral Thoroughbred race horses seem to be more flexible and able to adapt their lead to the direction of the race track. In contrast, left-lateral horses seem to be less likely to use a lead that differs from their direction of lateral displacement.

Lead changes during racing and especially at the finish line have been reported as a sign of fatigue and the attempt to change loading and use the muscles differently in order to keep up speed (Williams & Norris 2007), however this study did not evaluate the position of the hindquarters. In the present study, no significant relation of the change from one lead to the other and other parameters was found. With all directions of laterality some horses, however, changed the direction of lateral displacement of their hindquarters without a lead change being observed. It seems that fatigued horses in the present study seek relief in changing the position of their hindquarters rather than in changing to their non-preferred lead, in contrast to previous findings (Williams & Norris 2007). Still with video analysis of official racing videos the observation of lead changes and thus the value as an indicator is limited. In sample E, only 50% of horses (i.e. the offspring's sire and dams for which previous races were available on video) remained in their preferred left lead in a counter-clockwise direction. Since in that direction the preferred lead was the inside lead which might have been harder for the horses to remain in until the finish line, more horses either changed to their non-preferred lead or changed lead multiple times. However, the sample of active race horses was rather small and possibly biased to one side on a genetic basis, since all had the same, left-lateral sire.

5.4.9 The lateral displacement of the hindquarters and the rider's assessment of their horse's laterality

In contrast to the preferred foreleg, the displacement of the hindquarters is easy to assess and clearly visible in all horses. Slightly different approaches to determine the lateral displacement of the hindquarters in other studies showed variation between the horses of the respective samples (Lerbs et al. 2014, Lucidi et al. 2013). According to the results in the present study, the lateral displacement of the hindquarters seems to be a reliable indicator for laterality during riding in left-lateral horses. Hindquarters that deviate to the right occurred mainly in horses described as right-lateral, but also in a small number of left-lateral horses. Mixed information that is found exclusively in left-lateral horses with their hindquarters displaced to the right, might indicate that, similar to humans (Goble & Brown 2008, Rousson et al. 2009), left-lateral individuals might be less lateralized. Further investigations of the lateral displacement of the hindquarters according to laterality during riding and the muscular system are required to support this hypothesis.

5.4.10 Rider's assessment of their horse's laterality compared to rein tension and the lateral displacement of the hindquarters

In contrast to other methods to determine horse's laterality, only the rider's assessment of the horse's preferred side during riding and to some extent the lateral displacement of the horses' hindquarters related to rein tension symmetry. For the comparison of the rider's assessment of their horse's laterality with the symmetry of rein tension, twelve ridden horses (10 right-lateral; 2 left-lateral) and ten right-handed riders were available, which resembles the majority of the horse-rider combinations in equestrian sports (see chapter 4). Full insights to the rein tension patterns and correlations of these methods including left-handed and ambidextrous riders are provided in chapter seven.

Rider handedness showed a strong influence of the dominant hand on the rein tension and the symmetry of the outside versus the inside rein between both directions, which has been reported in a previous study, too (Kuhnke et al. 2010). The horses' laterality as assessed by their riders seemed to be related to the magnitude and symmetry of rein tension. As previously reported (Kuhnke et al. 2010), higher rein tension was applied to left-lateral horses by their right-handed riders throughout. A higher magnitude of rein tension was also observed in horses with a displacement of the hindquarters to the left. According to the results of the current sample, symmetry and stability of rein tension seems to be related to the magnitude of mean rein tension and the horse's preferred side. Thus a symmetric and stable rein contact seemed to be easier to achieve with the right-lateral horses that were ridden with lower mean rein tension and that preferred the side of the rider's dominant hand. Riding counter-clockwise, their non-preferred left side that is associated with less symmetric and less stable rein tension patterns and their rider's dominant right hand with stronger rein tension meet the demands of the riding literature to ride with more contact (i.e. higher tension) on the outside rein (Steinbrecht 1901, Müseler 1933, Miesner et al. 2000). In a clockwise direction, the rider's dominant hand applies stronger rein tension to the inside rein, thus making rein tension of the inside and outside rein appear almost equal in contrast to demands of the riding literature. However, since this occurs on the horse's dominant side e.g. the side on which dressage tasks and turns are easier to ride, the horse seems to compensate the rider's mismatching rein tension signals for the same task in both directions. On the other hand, the theories and demands of the riding literature have been established based on the subjective experiences and impressions of the old riding masters (e.g. De la Guérinère 1733). Both handedness and laterality influence rein tension and riders are often unaware about the magnitude and symmetry of their rein tension even on a model horse (Stahlecker 2007, Hawson et al. 2010). The demand to ride with stronger contact on the outside rein could therefore also be based on a compensatory mechanism that has been perceived as supportive for horse-rider-communications by the riders, but is actually an unclear signal and counterproductive for horse learning.

5.5 Conclusion

5.5.1 The direction of facial hair whorls and the direction of mane

The direction of facial hair whorls was randomly distributed in all samples and did not relate to laterality during riding. The direction of mane was not related to laterality during riding either. Considering previous results, it seems that the direction of mane and the direction of facial hair whorls might agree with some horse's preferred side during riding. However, it is not a reliable method to conclude to the results of laterality based on other test methods.

5.5.2 The lateral displacement of the hindquarters

The lateral displacement of the hindquarters did not relate to age or sex. Only young, male Thoroughbreds were more likely to show biased behaviour. The lateral displacement of the hindquarters varied at the population basis among breeds. In warmbloods and ponies, it seems to be genetically correlated to traits such as coat colours or grades for show jumping and the incidence of left-laterality in the population could be modified through phenotypic selection of these traits. If lateralized motor or sensory behaviour occurred in Thoroughbreds, there seemed to be a left-bias. However, laterality does not seem to be influenced by parental laterality, since there was no relation between the results of the mares, stallion and their offspring in sample E. Considering that ambidexterity occurs in Thoroughbred racehorses and might be beneficial for performance, selection based on racing success seems to play a bigger role than training.

Agreement of the direction of lateral displacement of the hindquarters when assessed on track and during video analysis was generally good. Even though video analysis did not allow accurate classification of the lateral displacement of the hindquarters for some horses due to restricted visibility when galloping in a group, the method seems to be reasonably reliable to obtain data for a large sample of horses.

5.5.3 The preferred lead during flat racing

In racing Thoroughbreds the preferred lead mostly agreed with the lateral displacement of their hindquarters during races in both directions. Overall in left-lateral and right-lateral horses the preferred lead agreed with the direction of laterality too. It seems that matching patterns of asymmetry improve performance and might be based on the horses adapting their lead to match the direction of their hindquarters. The outside lead seems to enable horses to pass the bends at a faster speed. Right-lateral horses seem to be superior in clockwise races, since they perform better with the preferred inside (right) lead and benefit from the non-preferred outside (left) lead. Left-lateral horses in contrast, seem to perform better in counter-clockwise races. Still, since the majority of races are clockwise and horses are traditionally trained more often in a clockwise direction, right-lateral horses might be better trained in using the outside lead, thus reducing the advantage of left-lateral horses in counter-clockwise races. Ambidextrous horses seem to be closer to left-lateral than right-lateral horses, however they appear to be little lateralized and able to adapt to any direction.

Horses showing inconsistent lateral displacement might either be fatigued or ambidextrous. Ambidextrous horses preferring the outside lead regardless of the direction of race track are able to perform more successfully than left-lateral horses. Therefore, assessment of this parameter while standing or moving in one direction only might not be sufficient to identify ambidextrous horses. Comparison of the results in both directions seems to be more advisable to distinguish ambidextrous horses from left- or right-lateral horses.

5.5.4 The preferred forelimb

The preferred left foreleg during grazing seems to relate to the preference of the left eye and the left side during riding. However, these relationships are not mirrored in horses preferring the right leg during grazing. Motor laterality during grazing seems to be accurate according to the direction, but not the degree or presence of laterality. Laterality can be more accurately determined in left-lateral horses. Significance levels remained, increased or decreased between both sampling intervals of leg preference but never changed direction. Only results of the 60 second scan sample were related to other methods, therefore it is suggested that this interval should be chosen when using this method to determine horse's laterality. Different levels of laterality – even within the area of motor laterality- seem to exist, that are not necessarily related to each other. Thus, the agreement between different aspects of laterality in horses seems to be limited to specific measures and outcomes. Attention should be paid to the desired information when selecting methods for assessment of laterality.

5.5.5 Rider's assessment of their horse's laterality

Laterality test results obtained on the ground do not appear to predict laterality during riding. Only the lateral displacement of the hindquarters can give a hint on the direction of laterality during riding for many, but not all horses. However, only the riders' assessment of their horse's laterality agreed significantly with the laterality patterns detected in rein tension. Both horse's laterality and human handedness have an impact on the magnitude and symmetry of rein tension. Horse-rider-combinations with the same direction of laterality seemed to be better coordinated and showed more stable rein contact. Matching horses and riders according to their laterality might be beneficial for the stability of rein tension and thus improve training.

6. Genetic parameters for motor laterality and sport success in warmbloods and Thoroughbreds

6.1 Aim

Results of chapter four and five indicated that a possible relation of horse's laterality and other genetically determined traits such as e.g. coat colour exist. This leads to the hypothesis that there is also a genetic basis for laterality in horses. Apart from the rider's assessment of the horse's preferred side during riding, only the the lateral displacement of the horses' hindquarters related to rein tension symmetry (chapter five). It was the only indicator tested in chapter five that is easy, reliable and repeatable to assess on the ground for both horses with known laterality during riding and horses with unknown laterality (i.e. horses that have not yet been ridden or e.g. racehorses that have not been assessed by their riders). The present study aimed to investigate the heritability of the lateral displacement of horse's hindquarters and evaluated the influence of the direction of the lateral displacement of horse's hindquarters on their sport success.

6.2 Material & Method

6.2.1 Samples and test methods

The present study used samples B, D and E described in chapter five. Sample B consisted of 3973 warmbloods (aged 0.5 – 20 years, 2379 male, 1594 female) that were identified and classified according to the lateral displacement of their hindquarters during breed shows, as well as local and international competitions. Horses were observed either on site or during video analysis of competitions that were available via live streams, as validated in chapter five. The horse's main discipline was determined as the one they mostly competed in or the one they were categorized in by their breed association (e.g. "bred for show jumping"). Disciplines included in the study were dressage (n= 2166), show jumping (n=2122) and eventing (n=53). Additionally, the riding level the horses competed at, and the pedigree information, which included three paternal generations (i.e. sire, grandsire and great-grandsire) were obtained, resulting in a total of 16901 animals in the pedigree. The annual earnings (i.e. total earnings of the prior year) and lifetime earnings (i.e. all earnings gathered so far) were obtained from the German database of sport horses.

In sample D a total of 1822 Thoroughbreds (aged 2 – 15 years, 1003 male, 819 female) were identified and observed during video analysis of flat races. The horse's laterality was determined according to the direction of the lateral displacement of their hindquarters during races in both directions (left-lateral = 383; right-lateral = 778, ambidextrous =661) or multiple races in one direction, as validated in chapter five. The horse's pedigree information (three maternal and paternal generations, n=7463 horses in total) as well as their competition-related data such as their handicap and best distance (i.e. the distance in which they achieved the highest number of wins and placings), the number of wins and placings in total, their annual (i.e. earnings of the year prior to laterality observation) and lifetime earnings (i.e. all earnings in total) were obtained from the database of the German Association for Thoroughbred breeding and racing. The victory rates (wins only) and success rates (wins and placings) were calculated according to the number of wins and placings in relation to the number of starts recorded.

Sample E was a group of 61 Thoroughbreds (age 0.003–19 years) observed at pasture. It consisted of one Thoroughbred stud and his offspring (n=42) over five consecutive years with the same 13 Thoroughbred brood mares, as well as 5 additional, unrelated Thoroughbreds. Additionally, 18 horses were either by another stallion or out of a different mare. Laterality was classified according to the lateral displacement of the hindquarters. The horse's pedigree information (three maternal and paternal generations) were obtained from the stud farm and double-checked with the database of the German Association for Thoroughbred breeding and racing.

6.2.2 Statistical and genetic analysis

Data was tested for normal distribution using chi-square tests in SPSS. Crosstabulations of two characteristics with 2-30 values (e.g. laterality and riding levels with their respective directions and classes) were investigated for random distribution using chi-square tests, phi and Cramer's-V in SPSS for all samples. In addition, for each sample the relation of laterality with the handicap, number of wins and placings, the victory and success rates as well as the annual and lifetime earnings was investigated with Pearson correlations. Laterality was assumed to be a linear trait, i.e. coded -1 for left-lateral horses and 1 for right-lateral horses. Horses that were considered ambidextrous were coded 0. Significance of fixed effects and covariables was tested with mixed (Gaussian data) or generalized linear mixed models (binary or poisson-distributed data) using SAS 9.4. If an effect was significant at the phenotypic level (i.e. competition class for warmbloods), it was included in the model for estimation of genetic parameters. Genetic parameters for both sample B and D for laterality as well as the respective traits related to sport success (annual and lifetime earnings (sample B +D) and handicap, number of wins and placings as well as victory and success rates (sample D only) were estimated via uni- and bivariate generalized linear mixed models using the software DMU6 (Madsen and Jensen, 2006).

6.3 Results

In the voluminous sample B, which contains a great number of warmbloods and racehorses, the lateral displacement of the hindquarters was not significantly related to age, sex, discipline, annual earnings and lifetime earnings (all p>0.05). However, significant differences in distribution of laterality were observed between horses of different competition levels as demonstrated below.

6.3.1 The lateral displacement of the hindquarters and its relation to competition level in warmbloods and riding ponies

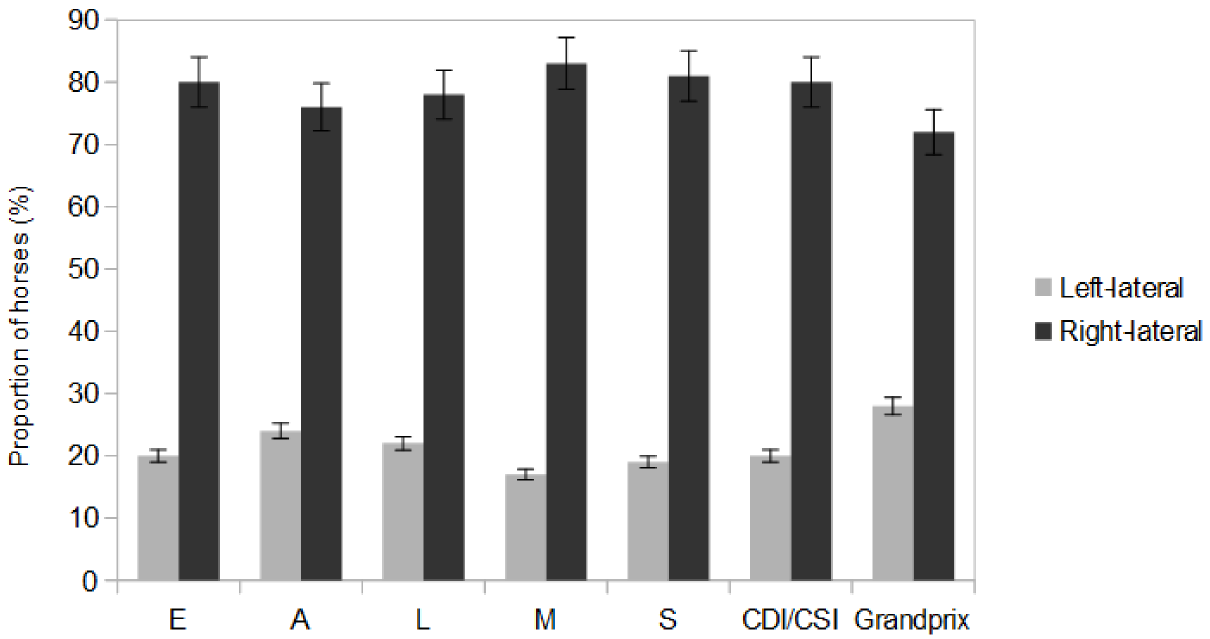


Figure 41: The lateral displacement of the hindquarters within competition levels of all disciplines combined (proportion of horses in % per competition level, sample B, p=0.039).

Horses with their hindquarters displaced to the left were represented with up to 20% at German competition levels E – L for all disciplines combined. At levels M and S the displacement of the hindquarters to the right was more common (17 – 19% left-displacement). At international dressage

(CDI) and show jumping (CSI) competitions (20%) and at Grand Prix level (28%) a displacement to the left was significantly more common again (p = 0.039, Figure 41).

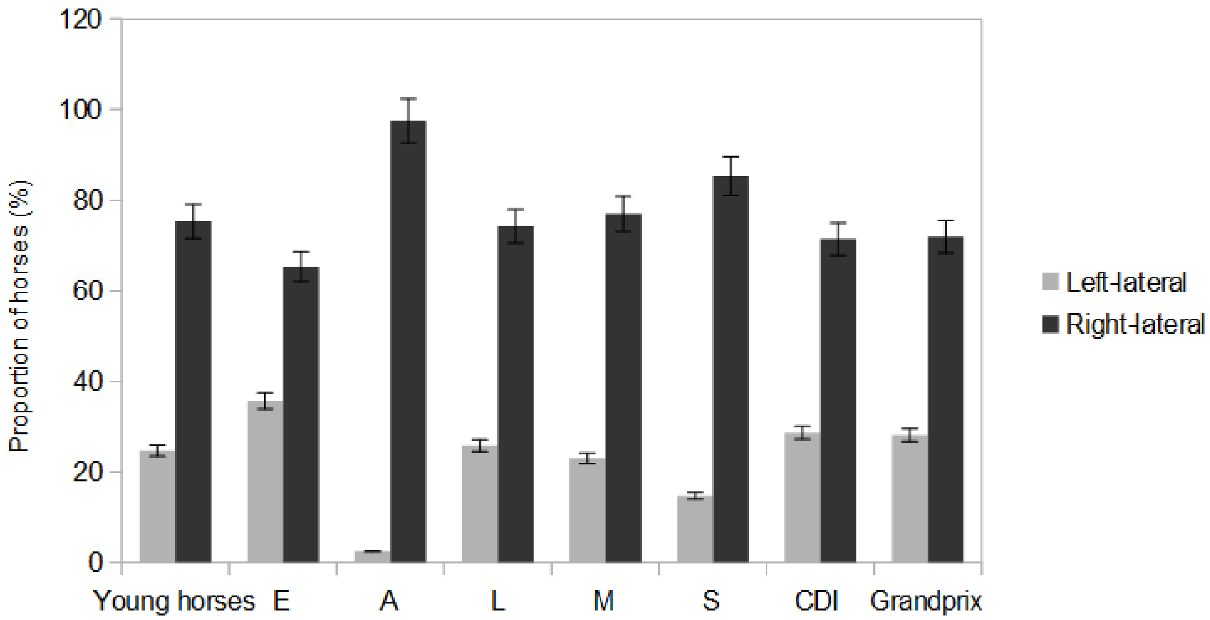


Figure 42: The lateral displacement of the hindquarters of dressage horses within different competition levels (proportion of horses in % per competition level, sample B, p=0.01).

Laterality of horses competing in show jumping was equally distributed within the different competition levels (p>0.05). In dressage horses, however, left lateral horses were more common at basic levels (competition for young horses= 24.7%, E=35.7%) and at the highest levels (CDI=28.6%, Grand Prix=28.1%, p=0.01, Figure 42). The percentage of left-lateral horses in classes A – S showed large variations.

6.3.2 The lateral displacement of the hindquarters in Thoroughbreds and their offspring

No relationship of the phenotypic occurrence of lateralized behaviour or the direction of laterality between the stallion and brood mares and their offspring was found (p>0.05).

6.3.3 The lateral displacement of the hindquarters and its relation to competition level in racing Thoroughbreds

The horse's best racing distance and handicap, as well as the victory rates and success rates were not significantly related to the lateral displacement of their hindquarters or preferred lead in either clockwise or counter-clockwise races (p>0.05).

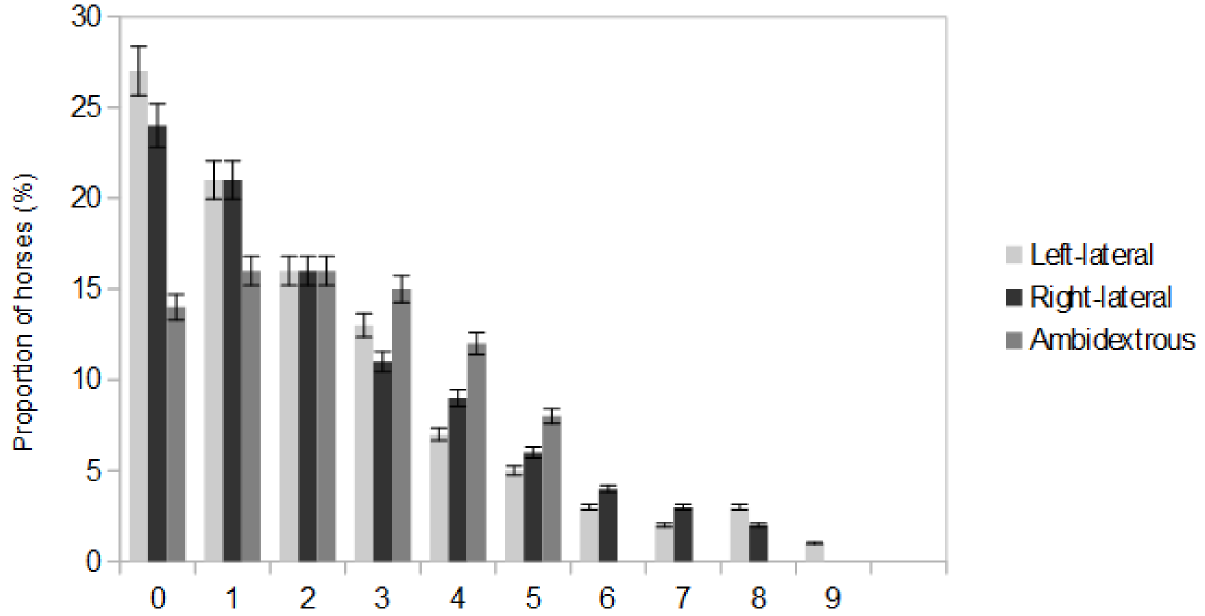


Figure 43: The number of wins in relation to the number of horses and their laterality based on the lateral displacement of the hindquarters (proportion of horses in % per number of wins, sample D, p<0.0001).

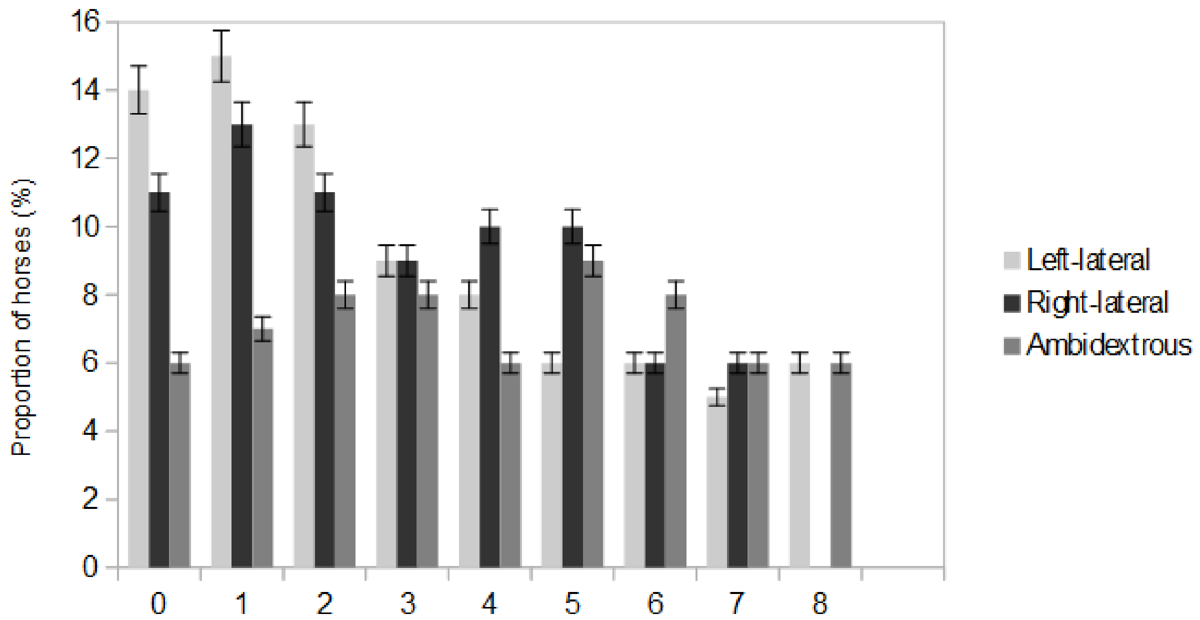


Figure 44: The number of placings in relation to the number of horses and their laterality based on the lateral displacement of the hindquarters (proportion of horses in % per number of placings, sample D, p<0.0001).

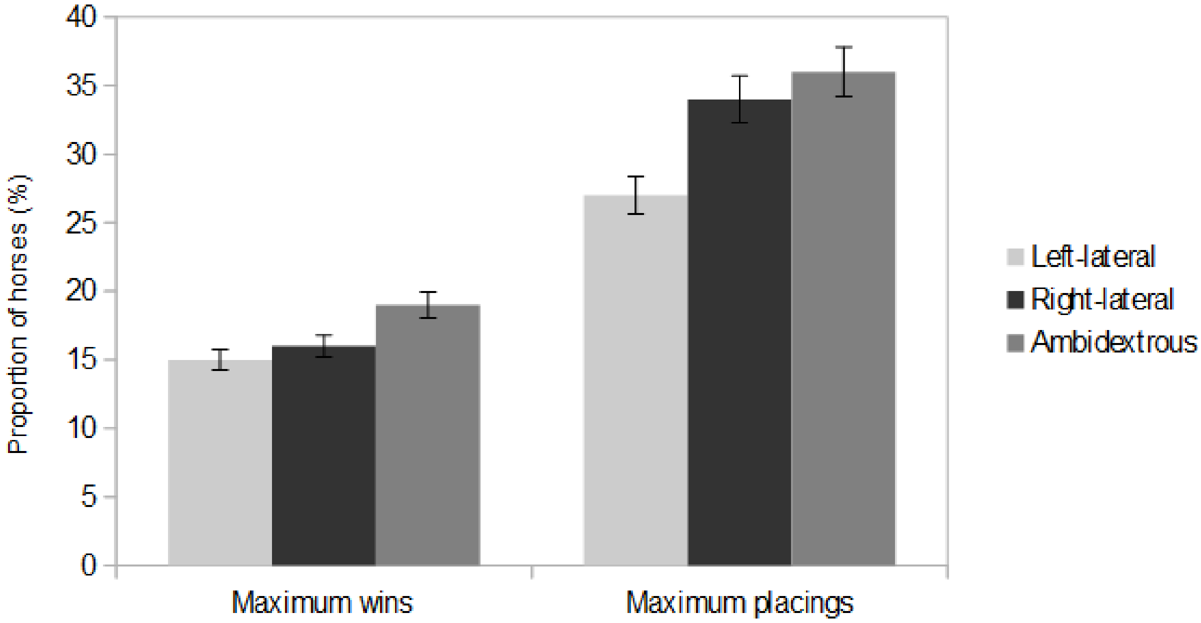


Figure 45: The number of maximum wins and placings in relation to laterality (sample D, $p<0.0001$). Laterality was based on the lateral displacement of the hindquarters. Maximum wins and placings were based on the horse with the highest number per direction of laterality.

Based on the lateral displacement of the hindquarters, horses classified as left-lateral remained without wins (27%) or placings (14%) more often than right-lateral horses (no wins 24%, unplaced 11%, all $p<0.0001$, Figures 43 and 44). Ambidextrous horses appear to be more successful (no wins 14%, unplaced 6%, all $p<0.0001$, Figure 43 & 44). Left-lateral and right-lateral individuals had single wins or placings more often than ambidextrous horses (Figures 43 and 44). The maximum number of wins and placings was achieved by ambidextrous horses (19 wins, 36 placings) in comparison to right-lateral (16 wins, 34 placings) and left-lateral horses (15 wins, 27 placings, $p<0.0001$, Figure 45).

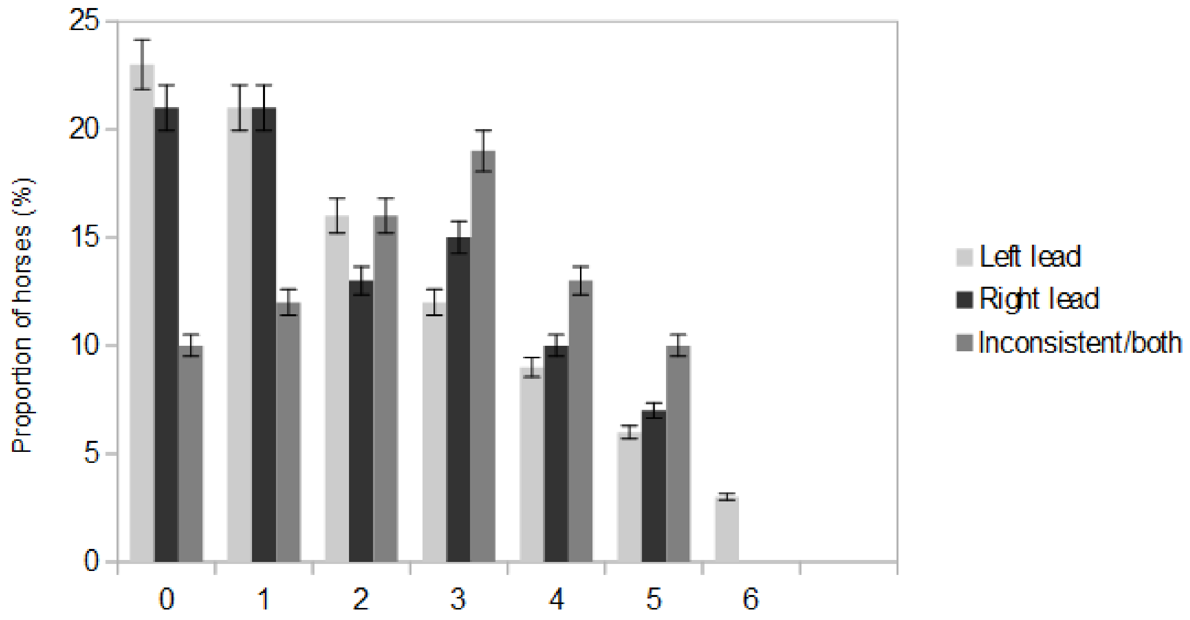


Figure 46: The number of wins in relation to the number of horses and their preferred lead during clockwise races (proportion of horses in % per number of wins, sample D, p<0.0001).

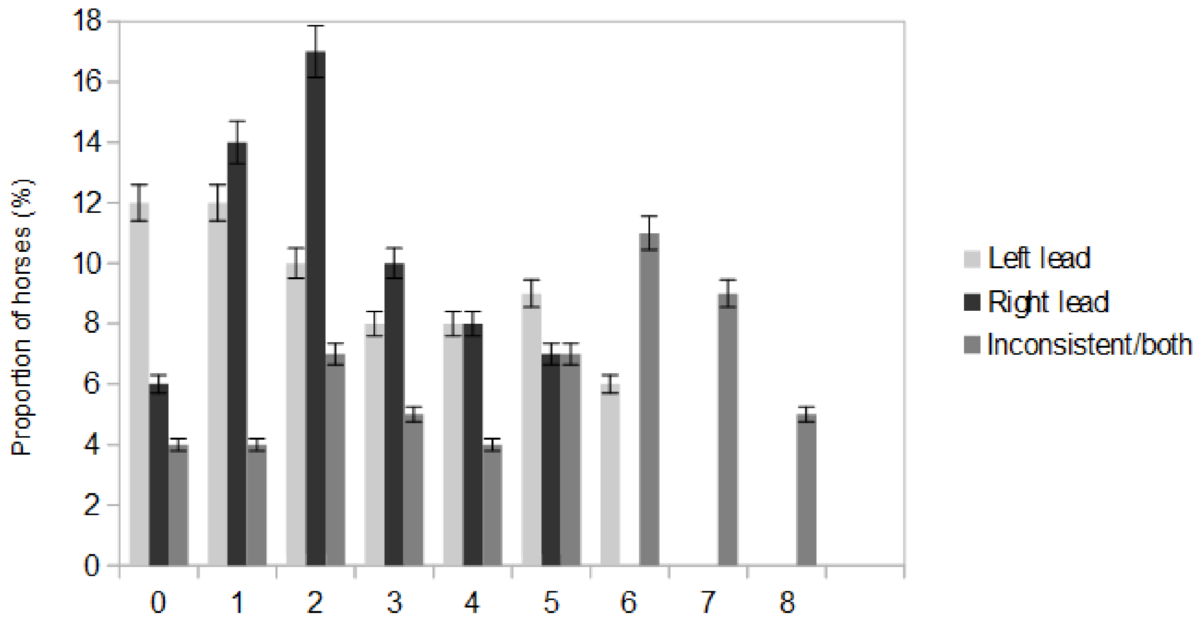


Figure 47: The number of placings in relation to the number of horses and their preferred lead during clockwise races (proportion of horses in % per number of placings, sample D, p<0.0001).

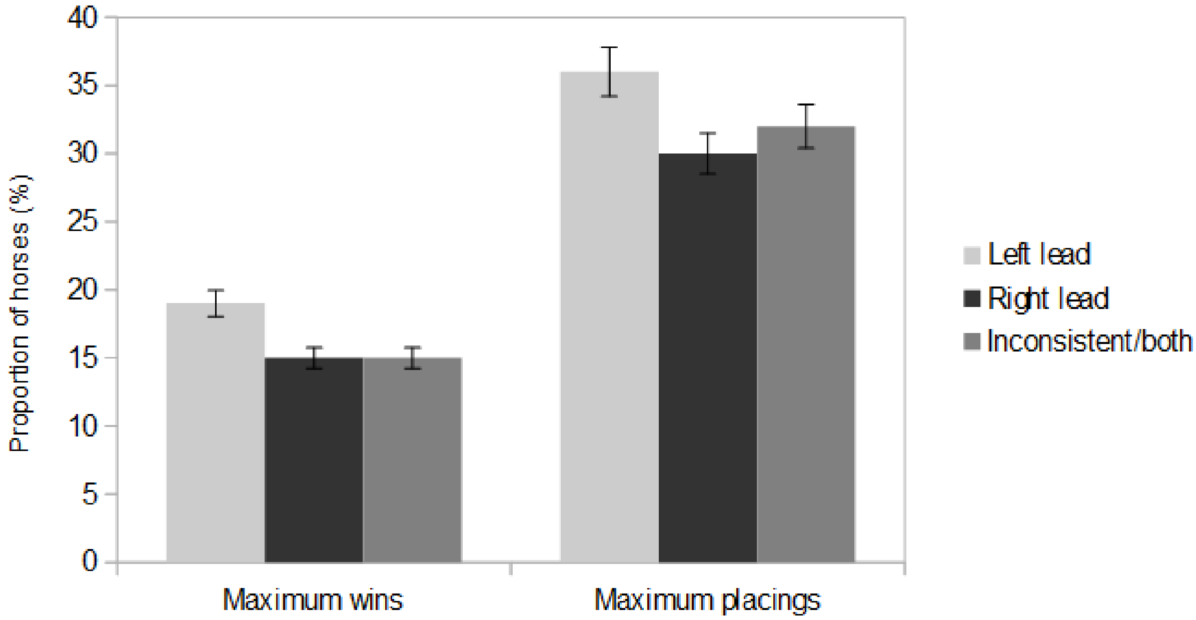


Figure 48: The number of maximum wins and placings in relation to the preferred lead during clockwise races (sample D, p<0.0001). Maximum wins and placings were based on the horse with the highest number per lead preference.

In clockwise races, horses that preferred the outside (left) (23%) or inside (right) (21%) lead remained unplaced more often or achieved just one win (21% respectively) compared to horses that showed no preference (10% unplaced, 12% one win, p<0.0001, Figure 46). The majority of horses without a preference achieved up to 6 wins (67%, p<0.0001, Figure 46). Horses preferring the inside (45%) or outside (43%) lead achieved mostly up to 5 wins (p<0.0001, Figure 46). Horses without a preference were more successful (4% unplaced) and mostly achieved up to 8 placings (52%, p<0.0001, Figure 47). Horses preferring the outside lead achieved the maximum number of wins and placings compared to horses preferring the inside lead or horses without a preference (p<0.0001, Figure 48).

In counter-clockwise races, horses with a preference for the inside (left) lead were more successful and mostly achieved up to 6 wins (51%, p=0.022, Figure 49). However, horses that preferred the outside (19%) or inside (20%) lead remained unplaced more often than horses that showed no preference (7%, p=0.022, Figure 49). The number of maximum wins was higher in horses preferring the outside (right) lead or showing no preference (p=0.02, Figure 50). No significant relation of the preferred lead and the number of placings was found (p>0.05).

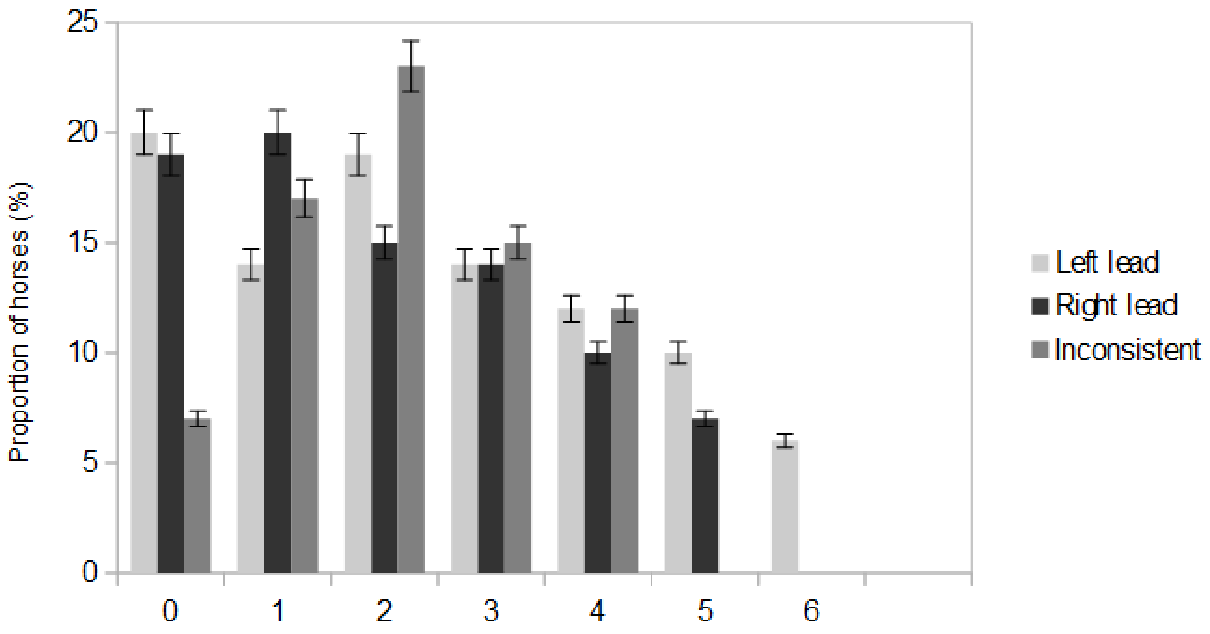


Figure 49: The number of wins in relation to the preferred lead during counter-clockwise races (proportion of horses in % per number of wins, sample D, p=0.022).

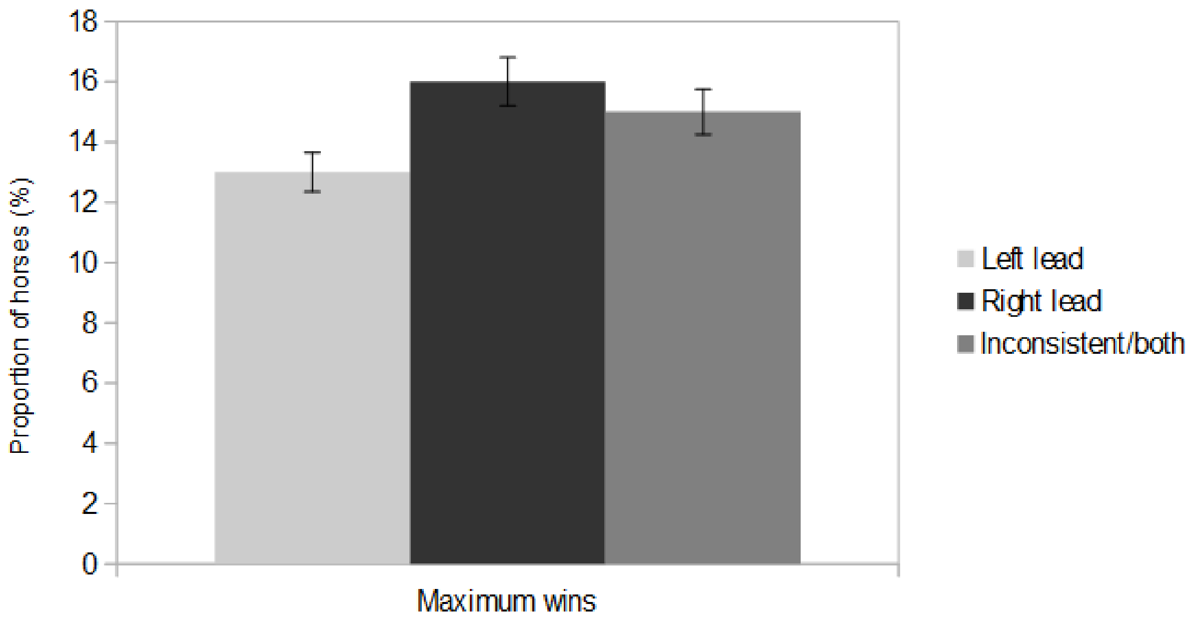


Figure 50: The number of maximum wins in relation to the preferred lead during counter-clockwise races (sample D, p=0.02). Maximum wins were based on the horse with the highest number per lead preference.

6.3.4 Genetic parameters for the lateral displacement of the hindquarters in racing Thoroughbreds

Heritabilities from univariate models were laterality: h^2=0.19, placings: h^2=0.72 and wins: h^2=0.66. Phenotypic correlation between laterality and number of wins and placings was low (all r_p=0.13). Genetic correlations, however, were high (laterality and number of wins: r_g=0.82±0.19; laterality and number of placings: r_g=0.70±0.16).

6.3.5 Heritability of the lateral displacement of the hindquarters in warmblood sport horses

Heritability for laterality in warmbloods was high on the observed scale (h^2= 0.51), but unfortunately, no results could be obtained for annual and lifetime earnings as models did not converge. Thus, genetic correlations between laterality and sport succsss were unavailable for the warmbloods.

6.4 Discussion

6.4.1 Laterality and its phenotypic relation to competition level in warmbloods and riding ponies

In the current sample, a larger population of warmbloods and ponies has been investigated for their lateral displacement of the hindquarters. This trait can easily and objectively be assessed in order to determine the heritability of laterality and its relation to variables indicating sport success. Also, since only part of the horses was assessed at the competition sites and riders were usually too busy to answer a questionnaire between competitions the rider’s assessment of their horse’s laterality was not a useful method for the present study. Results of the determination of the lateral displacement of the hindquarters obtained with video analysis are reliable and comparable to those obtained when standing straight behind the horse on site (chapter five). Using their official sport names, all registered horses could easily and unambiguiously be identified in the German sport horse database, thus ensuring that no horses were entered into the study multiple times and providing access to reliable information on lifetime and annual (i.e. of the year prior to laterality observation) earnings.

Most of the horses had their hindquarters displaced to the right. Based on the results of the survey (chapter four) left-handed riders had more wins and were over-represented at higher German riding levels (M & S) compared to right-handed riders. No relation to the direction of horse's laterality as assessed by the riders could be found in chapter four. Using a different test method however, the current sample reveals a comparable relationship of left-laterality in horses and their competition level. Horses with their hindquarters displaced to the left, even though being in the minority, were over- represented at the highest competition levels in dressage (CDI & Grand Prix) and in the overall sample which contained a majority of dressage horses. In contrast, the largest proportion of right-lateral dressage horses was documented at level A competitions. The number of left-lateral horses was large at lower levels (competitions for young horses & E) too. Since the sample of horses competing at lower levels was the largest in the present study, the chances of left-lateral horses competing at level E are higher and even high-level horses have to start their career at the lower classes, though they will usually start at the A, rather than E level. Tasks at higher riding levels are more demanding when it comes to balance and symmetry in horse-rider-pairs, especially in dressage (Steinbrecht 1901, Klimke 1985, Miesner *et al.* 2000) and horse-rider-pairs with matching directions of laterality seem to achieve symmetric rein tension more easily (chapter five). Therefore, one possible reason for the variation in proportions at the different competition levels of this sample, especially in level A-S, could be that horse-rider-combinations played a larger role with the majority of riders at this level being right-handed according to the overall distribution of handedness in the human population (McKeever 2004) and possibly preferring right-lateral horses. The direction of the lateral displacement of horse's hindquarters did not correlate with the horse's annual or lifetime earnings, indicating that the horse-rider-combination might be a more important factor to sport success than the horse's laterality alone.

6.4.2 The lateral displacement of the hindquarters in Thoroughbreds and their offspring

The sample size of this group of Thoroughbreds was too small to draw conclusions on the heritability of laterality as such. However, due to the composition of a large number of closely related horses (full- and half-siblings) with information on the laterality of both parents the sample size allowed reliable conclusions on inheritance of laterality from parents to their offspring. The sire as well as some of the mares showed a left-bias throughout all test methods. In humans, left-handed parents, especially females, are more likely to have a left-handed child (Annett 1978, McManus 1985). However, the mechanism behind the inheritance of left-handedness remains unclear (Annett 1978, McManus 1985, McKeever 2004, Ocklenburg et al. 2017) and environmental factors most likely play a role as well (Jones & Martin 2008). In horses, a genetical predetermination might be possible that appears and increases with age and might also be influenced by environmental factors (Murphy et al. 2005). The fact that the phenotypic occurrence and direction of laterality of the parents did not significantly relate to their offspring's laterality in this sample, rejects a theory of either genetics or environmental influences being the single trigger for laterality. A possible explanation for breed differences of lateralized behaviour was suggested to be training and selection of horses for different purposes (McGreevy & Thomson 2006), e.g. warmbloods being bred for dressage or Thoroughbreds being bred for flat racing.

6.4.3 The lateral displacement of the hindquarters and its relation to competition level in racing Thoroughbreds

In the present sample of racing Thoroughbreds, the majority of horses were right-lateral or ambidextrous. The majority of races and training sessions took place in a clockwise direction, too. A larger number of right-lateral and ambidextrous individuals in a population bred based on successful performance mainly in a clockwise direction might indicate that these traits could be beneficial for performance and that selection on a phenotypic level might have taken place, thus changing the structure of the population. In Thoroughbreds and standardbred trotters, variables of body symmetry e.g. bone length were related to risk of injury (Anderson et al. 1999, Ramzan & Palmer 2011) as well as racing success (Smith et al. 2006, Leleu et al. 2005) in previous studies. Laterality as an indicator of performance symmetry as well as the outside lead during races in both directions was related to racing success in the present study. Ambidextrous and right-lateral horses were more successful overall. Horses preferring the right lead counter-clockwise or the left lead clockwise showed the highest number of wins and placings. In clockwise races the majority of horses without a specific preference were more successful than horses preferring either lead. In counter-clockwise races however, the majority of horses preferring the left (inside) lead performed more successfully. Even though no direct influence of the direction of laterality on the parameters of success was found, the preferred lead in relation to the direction of racetrack therefore seems to be a decisive matter too.

6.4.4 Genetic parameters for the lateral displacement of the hindquarters in Thoroughbreds and its relation to sport success

Phenotypic correlation between laterality based on the lateral displacement of the hindquarters and the number of wins and placings was low and parameters of success did not directly relate to laterality or the preferred lead. However, genetic correlations in the sample of racing Thoroughbreds were high. A high genetic correlation suggests that laterality might be useful as an indicator for genetic merit for racing success. In the present sample it appears that horses with a right-displacement might be genetically more prone to finish a larger number of races at the first to fourth place. However, when interpreting the results, the relatively low sample size for estimation of genetic parameters needs to be kept in mind, which might explain the high heritability for placings and wins. Several genetic models have been suggested to explain and predict the inheritance of left-handedness in humans and other species (Annett 1978, McManus 1985, McKeever 2004, Dragovic *et al.* 2008, Ocklenburg et al. 2017). However, the genetics behind laterality might be more complex (Armour et al. 2014) and a laterality gene as such might not exist after all (Ocklenburg et al. 2017). Lateralized behaviours seem to be diverse, even within the same individual for identical tasks (Christel 1993) suggesting that laterality might be influenced by more than just genetic factors (Jones & Martin 2008) and distinct lateralized behaviour might not be beneficial for all aspects of life (Christel 1993).

6.4.5 Heritability of the lateral displacement of the hindquarters in warmblood sport horses

Information on the number of starts per year was not available, so a reliable success rate could not be determined for this sample. Since the pedigree included only three paternal generations, genetic connectedness between individuals was limited. This may have contributed to the fairly high values for heritability as well as to the convergence problems with the analysis of success data. Should this value proof to be a reliable estimate, it would indicate that selection against laterality could be successful. Future investigations should look into this aspect and the relationships to sport success at the genetic level.

6.5 Conclusion

6.5.1 Competition results in warmbloods and ponies

Similar to the proportion of left-lateral humans in several types of competitions, dressage horses with their hindquarters displaced to the left were over- represented at the highest competition levels. Considering the fact that the direction of laterality varied among different horse breeds and also with regard to the breed's main discipline (chapter five), evaluation of laterality within competition levels seems advisable. Still, the horse-rider combination seems to be more important to sport success than the direction of the horse's laterality as such.

6.5.2 Competition results in Thoroughbreds

Laterality based on the lateral displacement of the hindquarters, as an indicator of performance symmetry as well as the outside lead during races in both directions was related to racing success. In a population bred for and selected according to performance in mostly clockwise races, a shift towards a higher percentage of right-lateral and especially ambidextrous horses seems to have taken place.

6.5.3 Influence of parental behaviour

Even though one sample of the present study consisted of mostly full- or half- siblings, there was no relation between the results of the mares, stallion and their offspring. Therefore, laterality does not seem to be influenced by parental behaviour.

6.5.4 Heritability of laterality in Thoroughbreds and warmbloods

Laterality might be useful as an indicator for genetic merit for racing success. Horses with a right-displacement might be genetically more prone to obtain a larger number of wins and placings. Especially in warmbloods, laterality seems to be highly heritable, and the phenotypic analysis suggests a link to sport performance. Future analyses should investigate different trait definitions and assumptions of genetic architecture such as, for example, considering different thresholds for the binary or three-level trait trait (e.g., ambidextrous vs. either right or left lateral).

7. The magnitude and symmetry of rein tension in conventional European and Western riding in relation to laterality of horses and riders

7.1 Aim

Asymmetric rein tension has repeatedly been documented (Herde 2005, Warren-Smith et al. 2007, Kuhnke et al. 2010, Hawson et al. 2010, Eisersiö et al. 2013, Eisersiö et al. 2015a). Results revealed a possible influence of both human handedness and horse's laterality on the symmetry of rein tension in right-handed riders (Kuhnke et al. 2010). However, the hypothesis of a relationship between the laterality of horses and their rider's with regard to the symmetry of rein contact has not been entirely investigated with all combinations of horse-rider laterality and the mechanisms behind asymmetric rein tension remain unclear. In chapter four, a possible relation of laterality to injuries and sport success was documented based on an online survey, which will be further examined via attestable and direct data. Therefore, the present study aimed to:

- Examine how laterality of horses and their riders affect rein tension in different riding styles and disciplines and investigate the influence of horse –rider-laterality on communication and training (7.3).
- Investigate the influence of horse –rider-laterality on sport success, risk of injury and the horse's muscular system (7.4).
- Identify other factors that might influence rein tension, symmetry and performance in horse-rider combinations (7.5)
- Investigate the influence of different equipment used for communication and different ways of rein handling on rein tension parameters (7.6)

7.1.1 Hypothesis

The rider's handedness as well as the horse's laterality influence horse-rider communication, as well as sport success and the incidence of injuries. Horse-rider combinations with matching directions of laterality are hypothesized to exhibit more symmetric rein tension patterns.

7.2 Materials and Methods:

7.2.1 Handedness test

Sixty-five riders (females n=59, males n=6) aged 10 - 63 years from different yards throughout Germany took part in the study. Riders were asked to fill out a questionnaire containing a modified version of the "Edinburgh Handedness Inventory" which was adopted from Westerhausen *et al.* (2003) (Appendix 13.1.2). The handedness test included three additional questions about the preferred hand for writing, hammering and unscrewing a bottle. It consisted of ten questions with five possible answers each. The maximum points were +20 (right-handed) and -20 (left-handed) respectively. The participating riders were right-handed (scoring from + 20 to + 7 in the handedness test; n= 49), ambidextrous (scoring from +1 to -1; n=2) and left-handed (scoring from -6 to -20; n= 11). Three additional participants with inconsistent handedness, who identified themselves as being left-handed (scoring +14, +13 and +7) were categorized as left-handers. Additional questions about their horse's and their own riding habits, injuries and sport successes and the equipment that was used were added in order to be able to describe and compare the sample of participants.

7.2.2 Laterality test methods

Eighty-eight horses (47 male, 41 female) aged 3 -25 years took part. In the present study, horse's laterality was classified by their owner based on their performance in several tasks with a questionnaire. Whilst 12 horses were perceived as performing equally well in both directions, 35 horses were considered as left-biased and 41 horses as right-biased by their riders. Additionally, the lateral displacement of the hindquarters from the median plane while standing was evaluated for each horse (left-displacement n=48, right-displacement n=40).

7.2.3 Horse-rider combinations

The laterality of the horse and the rider's handedness was represented with almost every possible combination in the sample. Left-lateral horses were ridden by right- (n=34 rides) and left-handed (n=8 rides) riders. Right-lateral horses were ridden by right-(n=40 rides) and left-handed (n=10 rides), as well as ambidextrous riders (n=4 rides). Horses without a preference were ridden by right- (n=12 rides) and left-handed (n=2 rides) riders.

7.2.4 Riding styles and disciplines

The sample of horses and riders resulted in 106 horse-rider combinations in conventional European riding (51 rides) and Western riding (59 rides). Conventional "European" riding is based on the riding theories of European riding masters (e.g. de la Guérinière 1733, Steinbrecht 1901) as well as riding instructions for military purposes (H.Dv. 12 1937). It includes the olympical disciplines "dressage", "show jumping" and "eventing", as well as horse riding in terms of a leisure activity ("leisure riding") with the equipment conventionally used for these purposes. Riders were either active at Western (30 riders) or conventional European riding (35 riders) riding, however, 7 riders were occasionally active at both riding styles. Most disciplines of both riding styles were represented in the study (Western: Allaround n= 21, Cutting n= 1, Reining n= 8; conventional European riding: Dressage n= 18, Show jumping n= 2, Leisure riders n= 14, Racing n= 1). While some horses were not being ridden on a regular basis at the time of the study, others were being ridden for up to 7 hours per week. Some horses had up to 20 different riders, the majority, however, was being ridden by one or two riders only. A total of 49 horses was used for Western riding (Allaround n=26, Cutting n=6, Pleasure n=2, Reining n=15) and 39 horses for conventional European riding (Dressage n=22, Leisure riding n=13, Show jumping n= 4).

7.2.5 Riding levels and sport results

Whilst 22 participants were professional riders, who had made at least part of their living through competition, training horses and teaching riders, 42 riders were amateurs and one rider was at beginner level. The riders had three month - 44 years of experience with riding. Some amateur riders did not ride at all at the time of the study, while some professional riders rode up to 70 hours per week. Due to the different riding styles, a variety of riding- and competition levels were stated in the questionnaire. Riding levels contained the levels E (n=14), A (n=7), L (n=7), M (n=3), S (n=5) in conventional European riding and the levels "beginner" (n=1), "basic" (n=1), "Amateur" (n=2), "advanced" (n=11) and "professional" (n=14) as self-assessed by the riders in Western riding. The levels of both riding styles were combined into one system consisting of 1 "beginner", 22 riders at "basic" level, 27 "advanced" and 15 "professional" riders, to enable statistical comparisons of rider skill level across disciplines. Thirty-three participants stated that they compete at horse shows in their discipline at least occasionally, whilst the other participants do not compete at all. To improve comparison, the competitions were split up according to the system of Western Horse Shows, dividing the sample into "amateur" (i.e. classes for non-professional riders only; n=14) and "open" (i.e. both, professional and non-professional riders competing; n=19) at national (n=18) and international level (n=15). Twenty-five participants were active in other sports in addition to riding. The current riding levels in conventional European riding and Western riding as assessed by their riders (conventional European riding: E n=13, A n=7, L n=8, M n=4, S n=5; Western: “basic” n=17, “amateur” n=3, “advanced” n=23, “fully trained” n=3; both: “just started” n=5) were combined into one system consisting of 5 horses that had “just started” their training, 40 horses at “basic” level, 35 “advanced” and 8 “fully trained” horses, thus aiming to improve statistical comparison. Thirty-nine horses compete at horse shows in their discipline at least occasionally, whilst the other horses do not compete at all. To improve comparison, the competitions were split up according to the system of Western Horse Shows, dividing the sample into “amateur” (i.e. classes for non-professional riders only; n=17) and “open” (i.e. both, professional and non-professional riders competing; n=20) at national (n=25) and international level (n=12).

7.2.6 Previous injuries

A total of 8 participants stated to have sustained an injury of their hand, arm or shoulder region within the last 3 years (left n= 7, both n= 1). In horses, a total of 24 horses had sustained an injury of the locomotory system within the last 3 years (left n= 4, both n= 17, unknown n=3). The evaluation of this sample of horses and riders aims to verify results obtained via the online questionnaire (chapter four).

7.2.7 Horse breeds

Horses were considered as either a breed mainly used for Western riding (6 Paint Horses, 34 Quarter Horses, 1 Appaloosa) or for conventional European riding (27 Warmbloods, 4 Haflinger, 3 PRE, 2 Freiberger, 1 Friesian, 1 Knabstrup) or as horses of mixed breeds (7 Ponies, 1 Standardbred Trotter, 1 Arabian). Still some horses of either category were used for the other riding style by their owner on a regular basis.

7.2.8 Muscular system

Figure 51: Overview of the 25 regular "trigger point" locations (yellow dots) and 3 additional locations (red dots) used for evaluation

A total of 28 muscle "trigger points" were assessed bilaterally. The chosen "trigger points" (irritable areas of the musculotendinous junction at the origin of the muscle) were the 25 locations most commonly used by Jack Meagher. Additionally, three different locations on the M. masseter were tested, which might be tensed up when horses clench their mouths or grind their teeth due to inappropriate bit pressure (Meagher 1985, Teslau 2006; Appendix 13.1.3; Figure 51). The "trigger points" were categorized according to the reaction to manual pressure (reaction level 0-3, where 0= no reaction and 3= strong avoidance reaction) in 86 horses. Additionally, the magnitude of pressure necessary to evoke a twitch reaction was measured using an algometer (Wagner Instruments, USA). Due to technical failure, only 30 horses could be assessed with this device. The sum, mean, standard deviation and difference between mean reaction level of each side was evaluated, as well as the difference between left and right reaction level for each trigger point individually.

7.2.9 Familiarity of horse-rider combinations

Most riders took part on horses, which they ride on a regular basis (82 horse-rider combinations), however, some riders participated with an unfamiliar horse (24 horse-rider combinations).

7.2.10 Rider's impression of symmetry and harmony

The questionnaire contained a section with questions investigating the test ride. Riders had to describe their session according to symmetry and strength of rein contact, as well as symmetry and harmony of the test ride as such, in order to identify and statistically analyse handedness and its possible influence on rein tension.

7.2.11 Equipment

Laterality and handedness in relation to rein tension was investigated separately according to the use of snaffle bits and curb bits. For 11 rides in Western riding (5 right-handed riders with 5 left-lateral horses, 4 right-lateral horses, 2 horses without preference) reins were held both bimanually and one-handed, either with the preferred-hand or with each hand. Most horses were ridden with their usual bits and bridles. In Western riding, horses were ridden with snaffle bits, wherever possible and a separate cavesson was used additionally, if the attachment of the recording device on the throat latch interfered with the device's cables and no chin piece (Figure 55) was provided. In total, horses wore Cavessons (n=24), flash nosebands (n=15), drop nosebands (n=2), grackle nosebands (n=4) or no cavesson at all (n=40, Figure 52). Horses were bitted with snaffle bits (n=68), curb bits (n=16), mullen mouth bits (n=1) or wore bitless bridles (n=3). Snaffle bits were either single-jointed (conventional European riding: n=16; Western: n=16, Figure 53) or double-jointed (conventional European riding: n=18; Western: n=18, Figure 53). Curb bits were either fixed (Bit, n=3) or jointed (Correction n=5, snaffle with shanks n=8, Figure 54). In order to compare rein tension of snaffle bits and curb bits, mean and peak rein tension were converted into the amount of pressure expected at the horse's mouth with the specific type of bit according to factors previously published by Preuschoft (Preuschoft 1990a, b; Preuschoft *et al.* 1999a, c; Preuschoft 2000, Herrmann 2011).

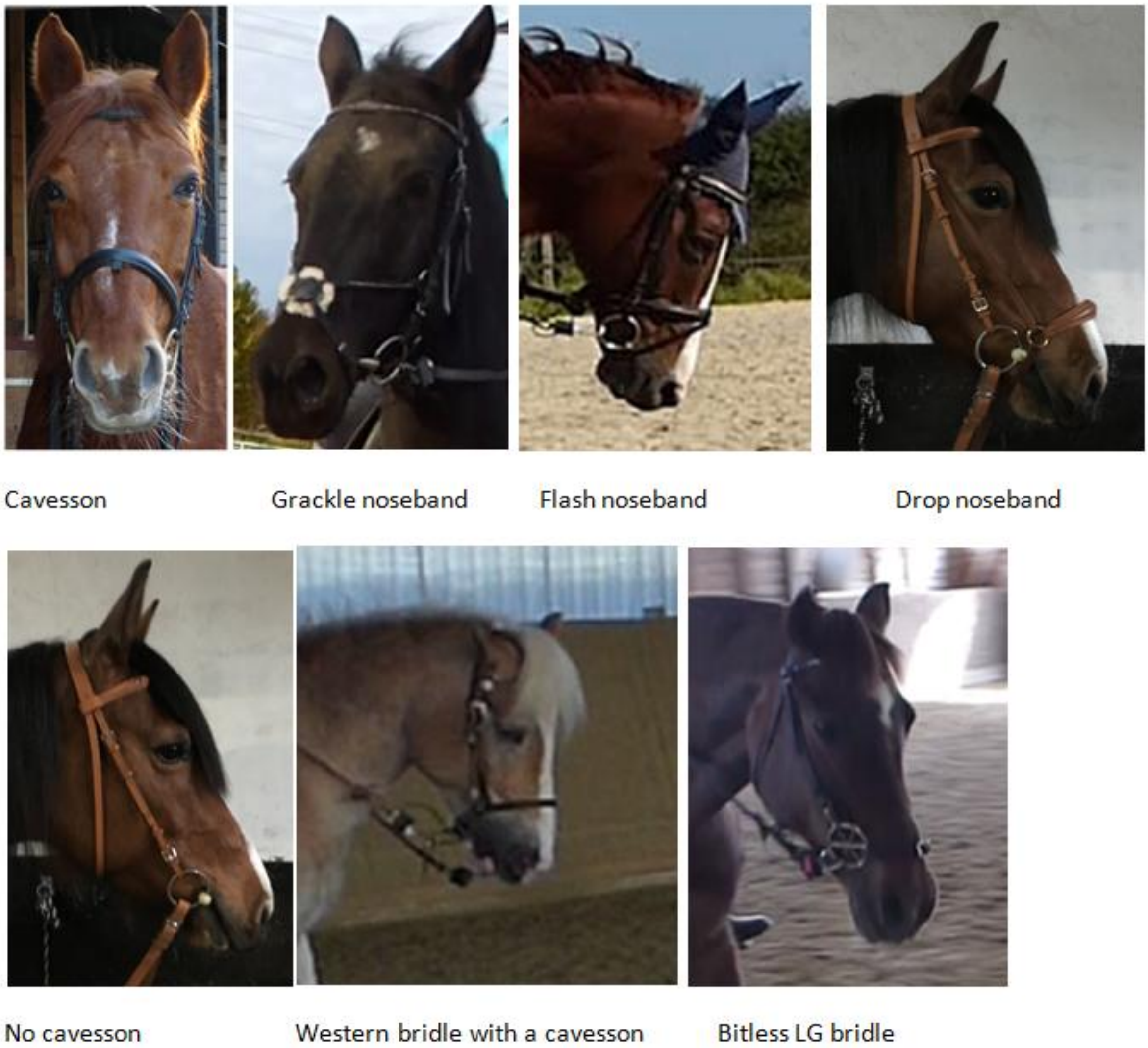


Figure 52: Example photos of the different types of bridles used in the present study (A French cavesson resembles a bitted bridle with a noseband only, in contrast to the bitless version traditionally used for lunging, which is commercially available under the name "cavesson" too (i.e. German: Kappzaum)).

Figure 53: Example photos of the different types of snaffle bits used in the present study (left: single jointed, middle: double-jointed, right: single-jointed used in Western riding)

Figure 54: Example photos of the different types of curb bits (fixed and jointed) used for Western riding in the present study (left to right: fixed curb bit, baby bit, snaffle with shanks, correction bit; curb bits were used with curb chains)

7.2.12 Collection of rein tension data

Rein tension was recorded continuously using the Rein Tension Device by Centaur, Netherlands (Figures 55 and 56). The data were sampled at a frequency of 100 Hz. The data logger was attached to the throat lash or the chin strap (Figure 56) with velcro strips. It was connected to the sensors with two inserted cables. Two lightweight tension cells were connected to the reins with a snap hook on one end and connected to the bit with a snap hook on the other end. This construction allowed attaching the device to different horses quickly however, the connection was flexible on two points through the snap hooks which created instability and some reactions of unwillingness or irritation from the horses. In all test rides the same pair of reins was used, which was either a pair of 290 cm (total length) web reins for conventional European riding or a pair of 245 cm (length of single rein) leather split reins for Western riding. Data were collected using the Centaur Software. Data were transferred from the data logger to the programme with a wireless connection through the usb-stick provided with the device. The Rein Tension Device was calibrated for each horse-rider pair.


Figure 55 (left): The rein tension device attached to a horse for Western riding using a bridle without a cavesson

Figure 56 (right): The rein tension device attached to a horse for conventional European riding using a bridle with a cavesson

Data collection took place in indoor and outdoor arenas of various sizes. The assignment consisted of 3 circles (20 – 30 m in diameter) and 3 straight lines (30 – 60 m long) in each gait (walk, rising trot, sitting trot and canter) and each direction (clockwise and counter-clockwise), as well as transitions (canter-trot, trot-walk, walk-halt). Sessions contained both sitting and rising trot (n=28), however, some riders felt uncomfortable or do not usually ride in both versions of trotting and therefore chose to ride in rising (n=43) or sitting trot (n=38) only. Riders were allowed a warm-up period before data collection started. Some riders used a fixed order of the assignment starting either left or right, while others, especially the professional riders, requested to integrate the demanded tasks into their usual training routine. In doing so, some riders added various manoeuvres to the assignment such as transitions canter-walk and canter-halt, as well as sliding stops, spins and backing up. Since each horse-rider pair chose to ride at a speed that suited them best and the arenas varied in size, total time of data collection for each rider varied. Each test ride was videotaped, starting with a shot at the computer screen showing the programme recording the data in order to ensure correct assignment of each task to the associated rein tension data.

7.2.13 Statistical analysis

For each rein in each gait and direction mean, standard deviation, maxima, minima and range of tension were calculated, as well as the difference between the mean of the left and right rein (= mean of left rein – mean of right rein) and the mean of the left and right rein difference (mean difference = mean (left rein – right rein); Figure 57).

Furthermore, an Excel file was used to identify the peaks of rein tension (consecutive maxima only) for each rein through comparison of each data with the subsequent data for increase or decrease via macros. For distinguishing actual rein tension initiated from a contact of the rider with the horse's mouth in contrast to the reins swinging loosely, a threshold of 5 N was identified in both riding styles. This threshold resembles the tension previously reported for sagging reins (Stahlecker 2007, Preuschoft (personal communication)). Using the identified peaks as a new data set, mean, mean standard deviation, the number of peaks left and right, the mean difference between left and right rein for left and right peaks, as well as the deviation in time between a left and right peak ("time shift", Figure 57) was determined. Mean standard deviation served as a parameter to measure stability of rein contact.

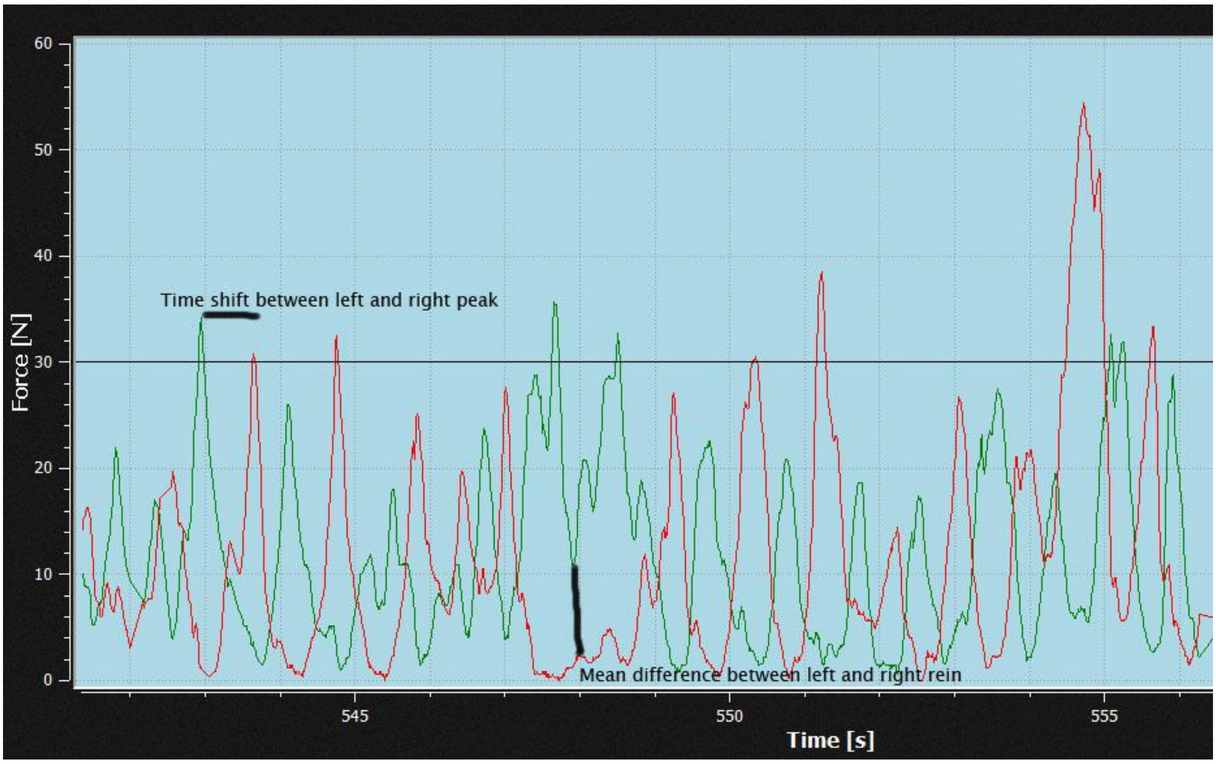


Figure 57: The mean difference of rein tension and the time shift between left and right rein tension peaks in an example sequence

In order to compare the rein tension of the different types of bits, rein tension was converted to the magnitude of rein tension that would be expected at the horse's mouth. According to Preuschoft (Preuschoft 1990b, Preuschoft *et al.* 1999a & c) rein tension was converted using different factors for single-jointed (factor 1.4) and double-jointed snaffle bits (factor 3.6), mullen mouth bits (factor 1), curb bits with short shanks (factor 5.9), curb bits with long shanks (factor 8), correction bits (factor 8.1) and snaffle with shanks (factor 9.4), as well as the bitless LG bridle (factor 3). For this new data set for each rein in each gait and direction mean and mean peak tension were calculated.

SAS (SAS Institute Inc., Cary, NC, USA) and SPSS (IBM, Armonk, NY, USA) were used for data analysis. If necessary, data were logarithmized and outliers removed to achieve a Gaussian distribution. Rein tension was analysed using a mixed model, considering gait (G), direction (D), task (T) and reins (Z) and their interactions as fixed effects, and rider (R), horse (H) and horse*rider as random effects. Additional variables were consecutively added to or exchanged in the term. The model was reduced again if a variable was not significant. Consequently the model was e.g.

"mean rein tension = R + H + H*R + G + D*T*Z + further variables + error"

Additionally Pearson correlations were used to compare relations of different influencing factors and rein tension wherever possible. Previous injuries in horses and riders, as well as indicators of success were investigated for normal distribution using chi^2-tests.

7.3 The influence of laterality of horses and their riders on rein tension in different riding styles and disciplines

7.3.1 Results

7.3.1.1 Rein tension parameters in different gaits, transitions and manoeuvres

The magnitude of mean tension and mean standard deviation as well as mean peak tension varied between and within the different gaits and transitions (Table 4, Figure 58). Mean peak tension was overall between 0.1 N and 2.2 N higher than mean rein tension (Table 4, Figure 58). In contrast, converted mean tension (i.e. tension was converted into the amount of pressure expected at the horse's mouth) was higher than converted peak tension (Figure 59). Quantitative asymmetry of rein tension (mean difference between left and right rein tension) was highest at canter and canter-trot transitions and lowest at walk (Table 4, Figure 60). Temporal asymmetry (mean time shift between peaks of the left and right rein) was highest at canter and walk compared to sitting trot and rising trot (Table 4, Figure 61). The sample consisted of 106 horse-rider combinations with all types of bits (Table 4).

Table 4: Rein tension parameters at different gaits, transitions and manoeuvres in both riding styles combined

Rein tension was compared between the different gaits, transitions and manoeuvres within each parameter. (Sample: 106 horse-rider combinations with all types of bits. Mean peak tension= mean of tension peaks only; Converted rein tension = rein tension was converted into the amount of pressure expected at the horse's mouth with the specific type of bit according to factors previously published by Preuschoft; time shift = mean time shift between peaks of the left and right rein; Mean SD= mean standard deviation as a measure of stability of rein contact; N=Newton, [1]p-values of pairwise comparisons of effect level are available on request.

	Horse-rider combinations	Mean peak tension (N)	Mean tension (N)	Converted mean tension (N)	Converted mean peak tension (N)	Time shift (sec.)	Mean difference of left and right rein tension (N)	Mean SD (N)
Spin	8	10.5±1.4	12±2.3	25.2±3.5	25.1±2.9		6.1±0.7	7.6±1.4
Rollback	3	11.5±1.5	10.1±1.2	33.4±4.3	26.5±2.4		5.8±0.8	7.8±1.8
Rein back	23	10.1±0.9	9.5±0.9	25.3±3	25±2.1		5.3±0.6	7.2±1
Sliding stop	11	10.1±0.9	10.6±1.3	30.1±3.2	24.9±2.3		6.2±0.6	8±1.2
Canter-halt	15	13.9±1.2	11.7±1	31.9±3.1	28.7±2.2		6.1±0.6	8.4±1.1
Canter-walk	6	16.8±2	14.6±2.2	24.9±3.1	31.8±3.8		5.4±0.7	8±1.5
Canter-trot	74	14.1±1.1	12.5±0.7	35.1±2.7	32.1±1.7		7.1±0.5	9.6±0.8
Trot-walk	83	11.5±0.9	10.7±0.7	30.4±2.7	26.3±1.7		5.4±0.5	7.5±0.9
Walk-halt	33	9.6±0.8	8.7±0.8	26.4±2.9	22.3±2	0.03±0.2	5.1±0.6	5.9±1
Canter	101	14±1	12.4±0.7	34.2±2.6	32±1.7	0.1±0.03	6.8±0.5	10.2±0.8
Sitting trot	65	10.2±0.8	10.1±0.7	27.8±2.7	25.1±1.7	0.01±0.003	5.6±0.5	8±0.8
Rising trot	68	9.1±0.7	8.4±0.7	23.2±2.6	21.3±1.7	0.01±0.003	5.2±0.5	6.2±
Walk	106	7.1±0.5	6.7±0.7	18.6±2.6	18.4±1.7	0.08±0.02	4±0.5	4.9±0.8
P[1]		<0.0001	<0.0001	<0.0001	<0.0001	<0.01	<0.0001	<0.0001

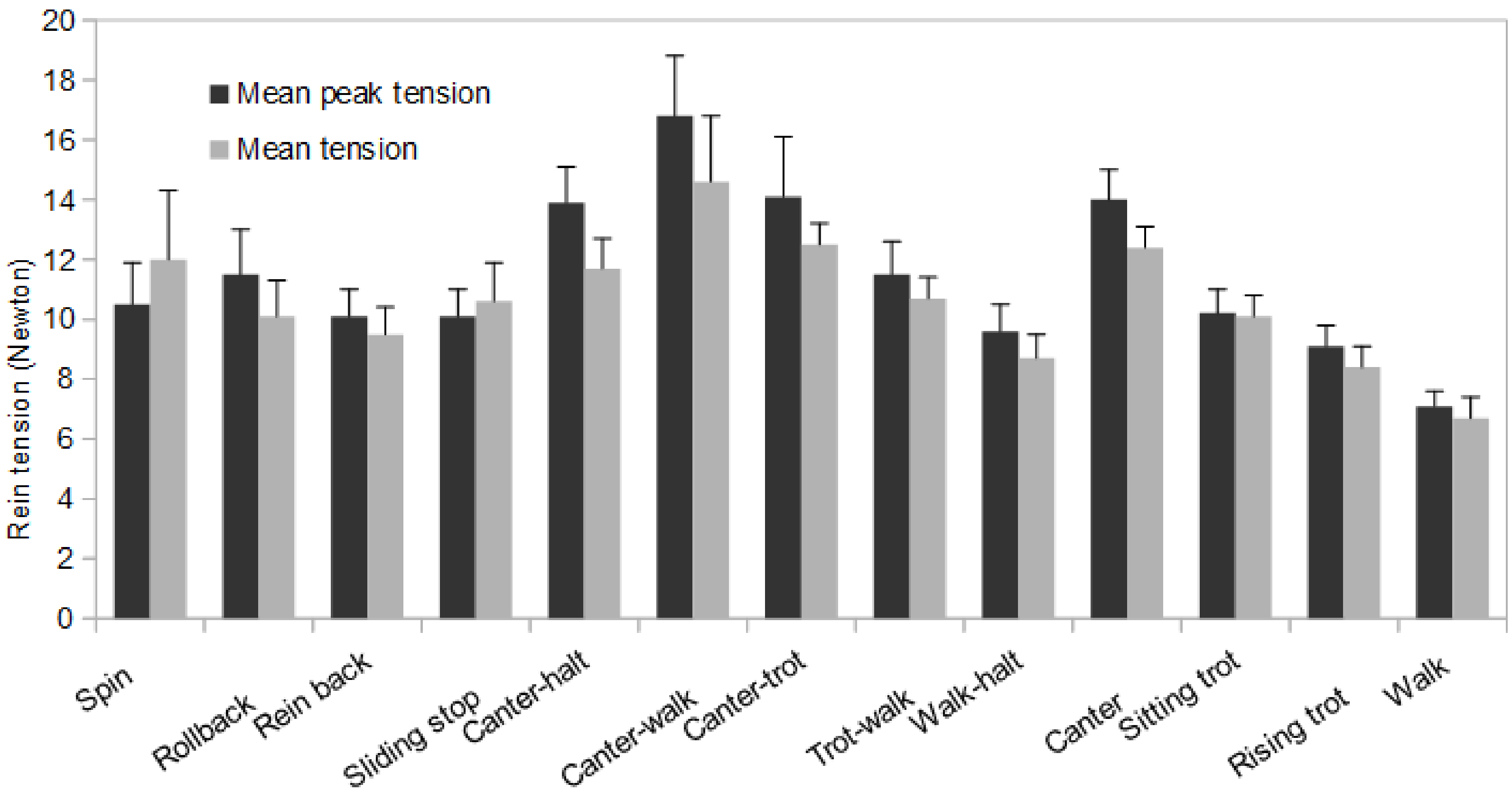


Figure 58: The magnitude of rein tension (mean and mean peak tension in Newton[1], $p<0.0001$) during different gaits, transitions and manoeuvres in both riding styles combined (sample: 106 horse-rider combinations with all types of bits, see Table 4). [1]p-values of pairwise comparisons of effect level are available on request.

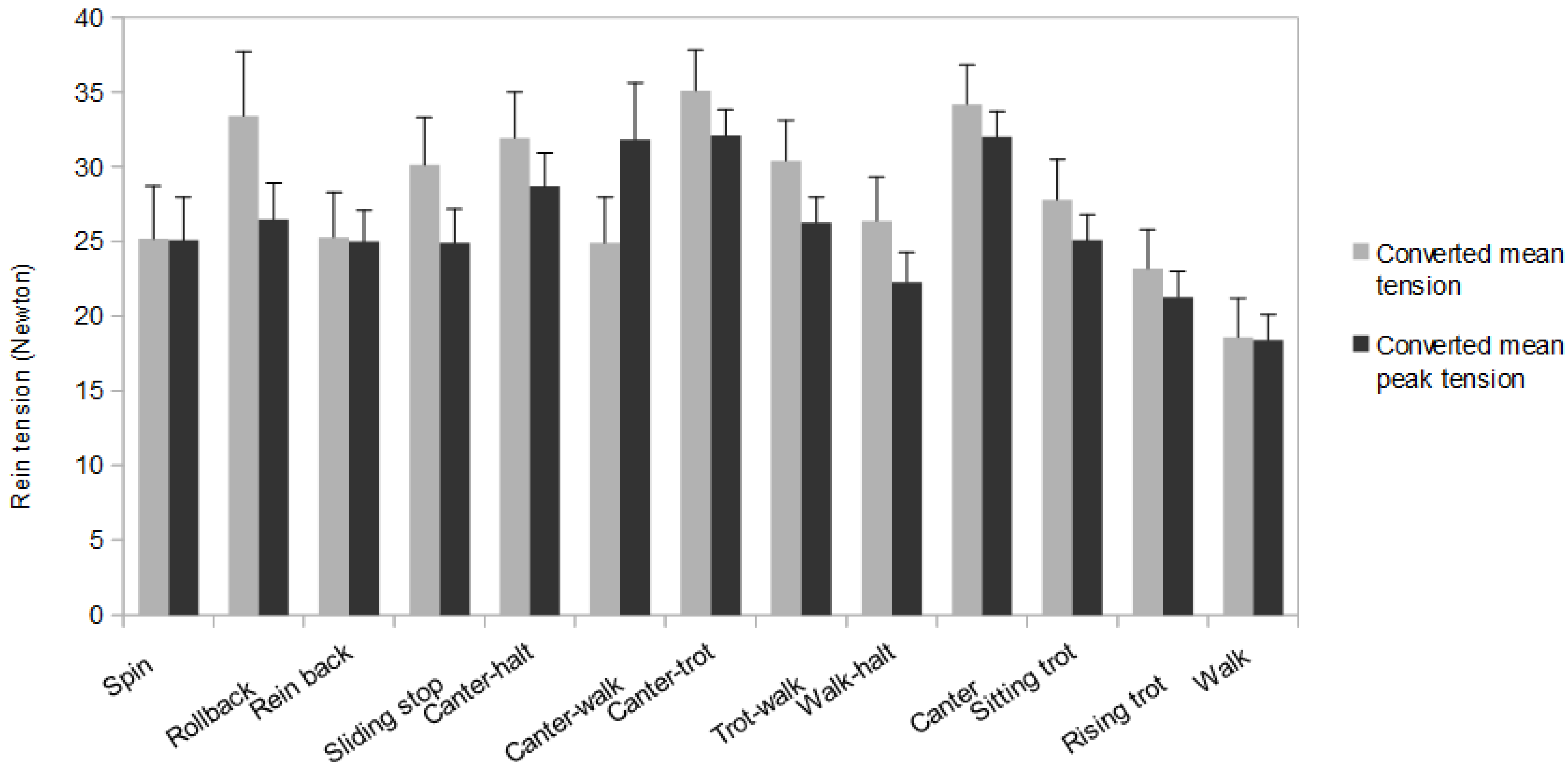


Figure 59: The magnitude of rein tension converted to the amounts of pressure expected at the horse's mouth (converted mean and mean peak tension in Newton[1], $p<0.0001$) during different gaits, transitions and manoeuvres in both riding styles combined (sample: 106 horse-rider combinations with all types of bits, see Table 4). Converted values exceeded mean values in almost every gait and manoeuvre.

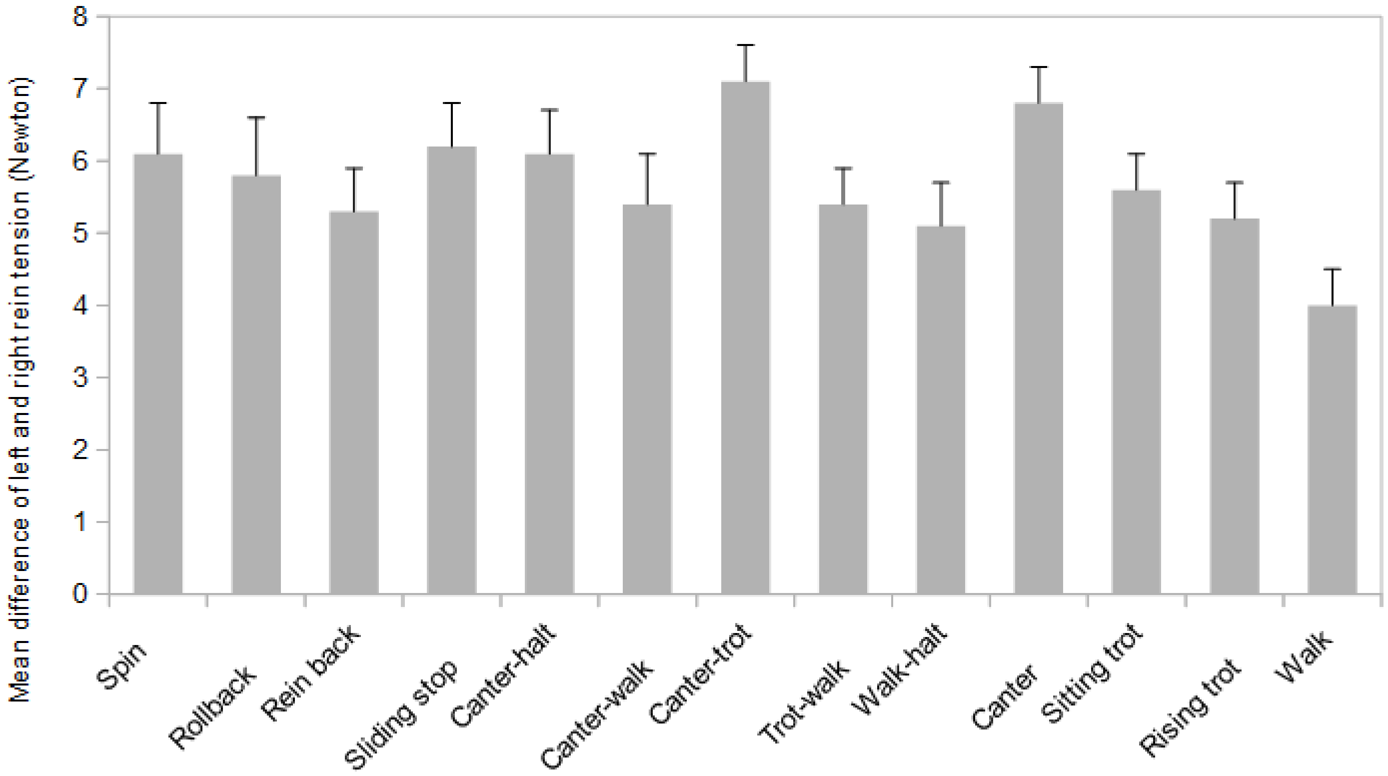


Figure 60: The symmetry of rein tension (mean difference of left and right rein tension in Newton[1], $p<0.0001$) during different gaits, transitions and manoeuvres in both riding styles combined (sample: 106 horse-rider combinations with all types of bits, see Table 4).

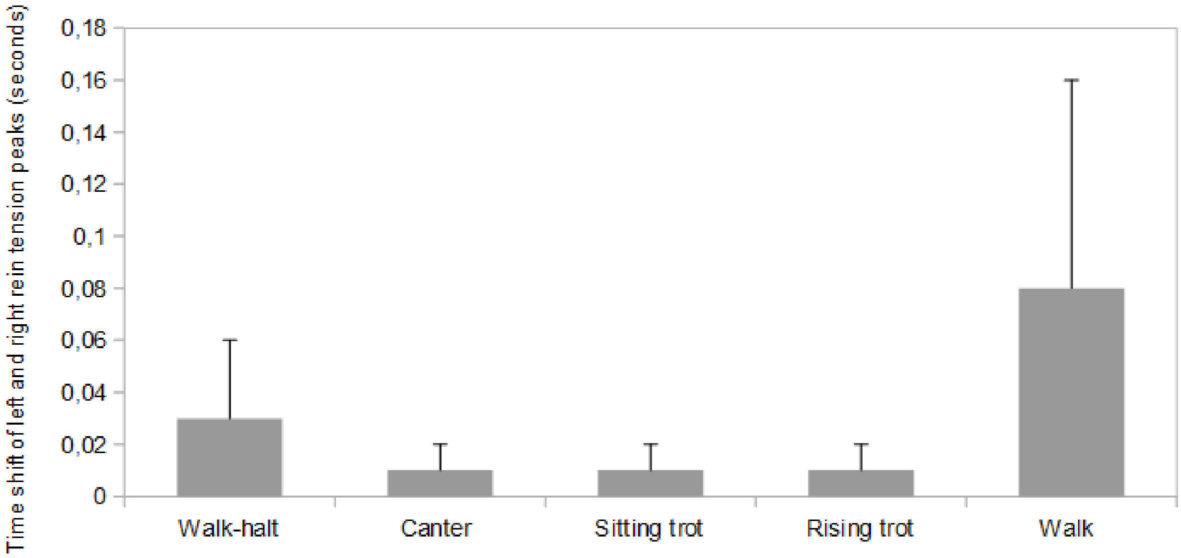


Figure 61: Time shift[1] (seconds, $p<0.01$) between peaks of the left and right rein during different gaits and transitions in both riding styles combined (sample: 106 horse-rider combinations with all types of bits, see Table 4).

7.3.1.2 Rein tension parameters in conventional European riding vs. Western riding

Conventional European riders applied higher mean rein tension, mean standard deviation, spread of tension and mean peak rein tension overall and within different gaits compared to Western riders (Table 5) (Figures 62 and 63, snaffle bits only). Rein tension in Western riding showed a smaller mean difference between the left and right rein (Figure 64). Smaller time shift was found in Western riding (Figure 65) compared to conventional European riding, however, the time shift did not differ significantly between the different disciplines of both riding styles.

Table 5: Rein tension parameters in different gaits and transitions with regard to riding style and type of bit

Rein tension was compared between the different gaits, transitions and riding styles within each parameter. (Mean SD=Mean standard deviation as a measure of stability of rein contact; Mean peak tension= mean of tension peaks only; N=Newton)[1]

conventional European riding with snaffle bits or bitless bridles (47 horse-rider combinations)				
Gait	Mean tension (N)	Mean SD (N)	Mean peak tension (N)	Mean difference of left and right rein tension (N)
Canter-trot	16.3±0.8	12.6±0.9	27.7±1.1	9.7±0.5
Trot-walk	14±0.8	10.4±0.9	23.9±1.1	7.6±0.5
Walk-halt	11.3±0.9	7.7±1.1	20.6±1.3	7.1±0.6
Canter	16.3±0.8	13.6±0.9	28.6±1.1	9.2±0.5
Sitting trot	12.9±0.8	9.8±0.9	22.6±1.1	7.6±0.5
Rising trot	10.6±0.8	8±0.9	18.3±1.1	7±0.5
Walk	8.5±0.8	6.5±0.9	23.9±1.1	5.4±0.5
P[1]	<0.0001	<0.0001	<0.0001	<0.0001
Western riding with snaffle bits (43 horse-rider combinations)				
Gait	Mean tension (N)	Mean SD (N)	Mean peak tension (N)	Mean difference of left and right rein tension (N)
Canter-trot	6.9±0.9	6.4±1	17.3±1.2	4.1±0.6
Trot-walk	5.4±0.9	4.3±1	12.7±1.3	3±0.6
Walk-halt	5±1.1	4±1.4	10.3±1.7	2.8±0.7

Canter	7.4±0.8	7.3±0.9	17.3±1.1	4.6±0.6
Sitting trot	6.2±0.8	6.6±0.9	13.3±1.2	3.8±0.6
Rising trot	5.4±0.8	4.9±1	13.2±1.2	3.5±0.6
Walk	3.8±0.8	3±0.9	10.3±1.7	2.4±0.6
P[1]	<0.0001	<0.0001	<0.0001	<0.0001
Western riding with curb bits (16 horse-rider combinations)				
Gait	Mean tension (N)	Mean SD (N)	Mean peak tension (N)	Mean difference of left and right rein tension (N)
Canter-trot	4.4±0.5	4.2±0.7	12.3±2.6	3.4±0.5
Trot-walk	2.8±0.5	2.7±0.7	8.3±2.5	1.8±0.5
Walk-halt	3.4±0.5	3.8±0.7	8.1±3.2	2.8±0.5
Canter	2.8±0.3	3.2±0.6	11.1±1.7	1.8±0.3
Sitting trot	2.1±0.3	1.9±0.6	8.9±1.9	1.1±0.3
Rising trot	1.9±0.3	2±0.6	8.2±1.9	1.2±0.3
Walk	1.7±0.3	1.4±0.6	7.2±1.8	1±0.3
P[1]	<0.0001	<0.0001	<0.0001	<0.0001

Figure 62: Example sequence of rein tension (N) of conventional European riding at canter (snaffle bit; Screenshot of the data recording software by Centaur, which indicates a mean tension level (black line) and scales the diagramme automatically. Therefore the scales used in Figures 62 and 63 are different.)

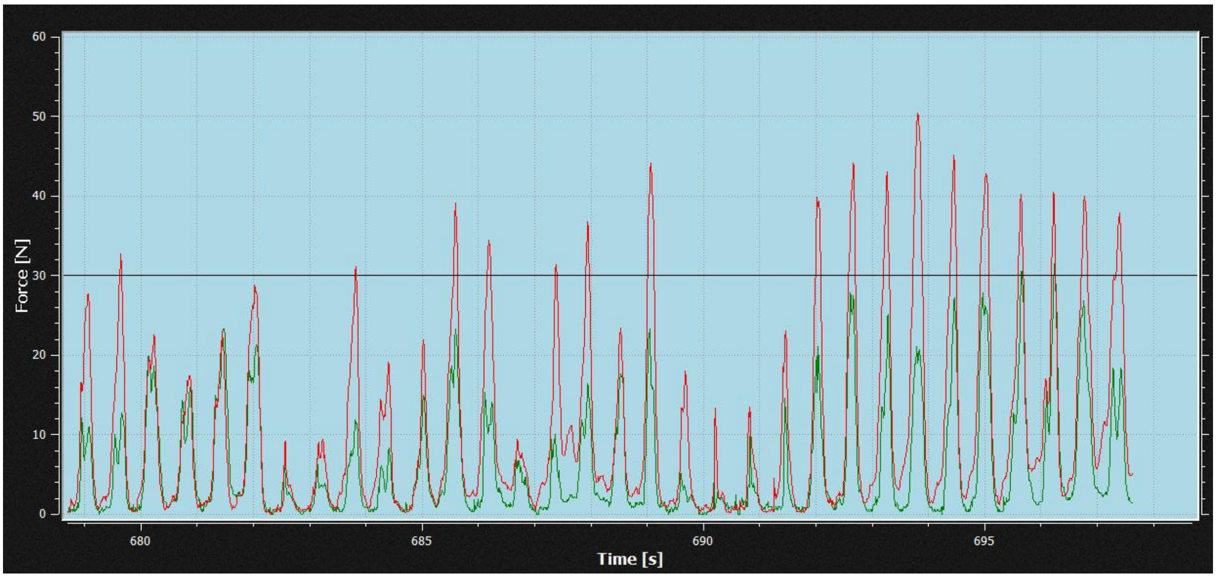


Figure 63: Example sequence of rein tension (N) of Western riding at canter (snaffle bit; Screenshot of the data recording software by Centaur, which indicates a mean tension level (black line) and scales the diagramme automatically. Therefore the scales used in Figures 62 and 63 are different.)

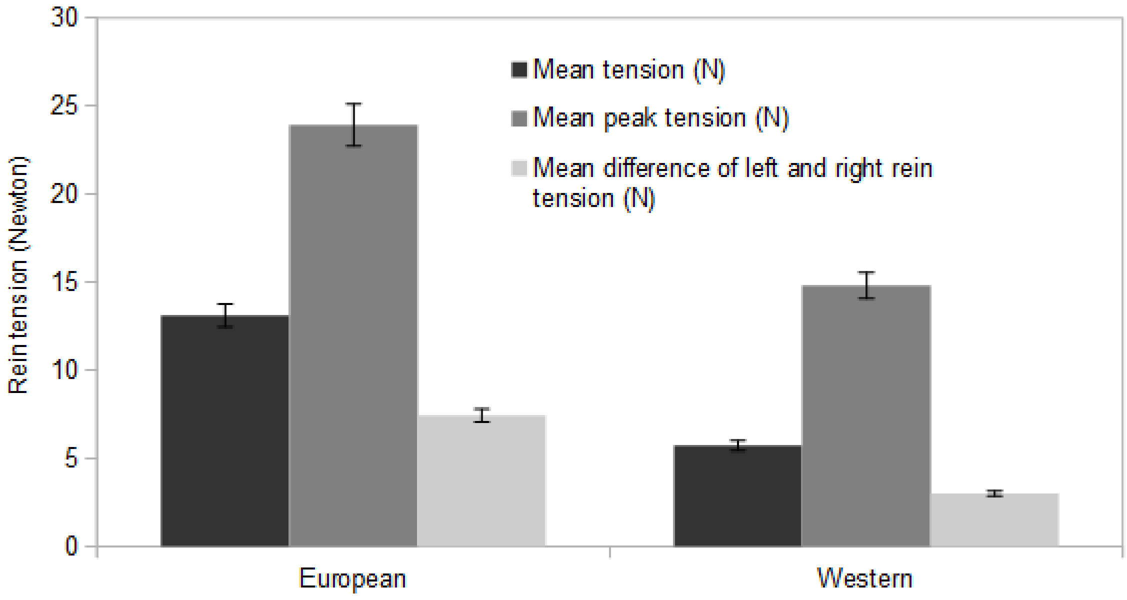


Figure 64: Rein tension parameters (Newton) compared between conventional European riding (47 horse-rider combinations) and Western riding (43 horse-rider combinations, all p <0.0001, Mean peak tension= mean of tension peaks only, all snaffle bits).

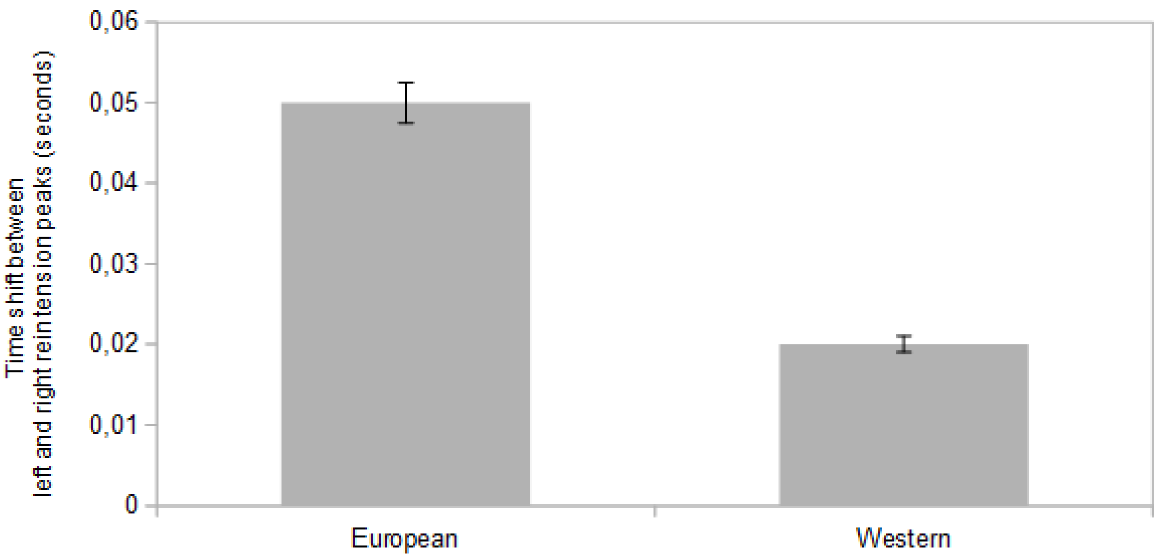


Figure 65: Mean time shift of peaks (seconds) between left and right reins compared between rein tension in conventional European riding (47 horse-rider combinations) and Western riding (43 horse-rider combinations) overall (all p=0.038, all snaffle bits).

7.3.1.3 Rein tension parameters within different disciplines of conventional European riding and Western riding

Mean rein tension, mean standard deviation, spread of tension and mean peak tension differed within the specific disciplines with snaffle bits or bitless bridles (Table 6, Figure 66). Peak tensions showed little difference between manoeuvres and directions (generally p>0.05). Quantitative asymmetry of rein tension (mean difference between left and right rein tension) was highest for show jumping in conventional European riding and lowest for reining in Western riding (Table 6, Figure 66). Rein tension was more symmetric (time shift between peaks of the left and right rein) in allaround, reining and leisure riders than in the disciplines show jumping, dressage and cutting (Figure 67).

Table 6: Rein tension parameters of different disciplines in conventional European riding and Western riding
Rein tension was compared between the different disciplines within each parameter. (Mean SD= Mean standard deviation as a measure of stability of rein contact; Spread of rein tension = Mean (max-min); Mean peak tension= mean of tension peaks only; N=Newton, mostly snaffle bits and bitless bridles)[1]

Discipline	Horse-rider combinations	Mean tension (N)	Mean SD (N)	Spread of rein tension (N)	Mean peak tension (N)	Mean difference between left and right rein tension (N)
show jumping	4	19.7±4.3	14±2	4.2±0.3	23.1±5	11.2±1.9
dressage	25	12.5±1.4	10.2±1	3.7±0.1	17.3±2.9	7.6±1.4
leisure riding	18	11.2±1.3	10.7±1.1	3.8±0.1	17.6±3	7.8±1.2
reining	18 (11 curb bits)	6.5±1.3	4.4±1.4	2.9±0.2	12.9±2.1	2.4±0.9
cutting	5	5.3±1.3	5.8±2.2	3.2±0.2	14.8±2.4	4.2±1
allaround	36 (5 curb bits)	4.9±1.2	6.2±1	3.2±0.2	12.4±2	3.5±0.8
P[1]	106 (16 curb bits)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

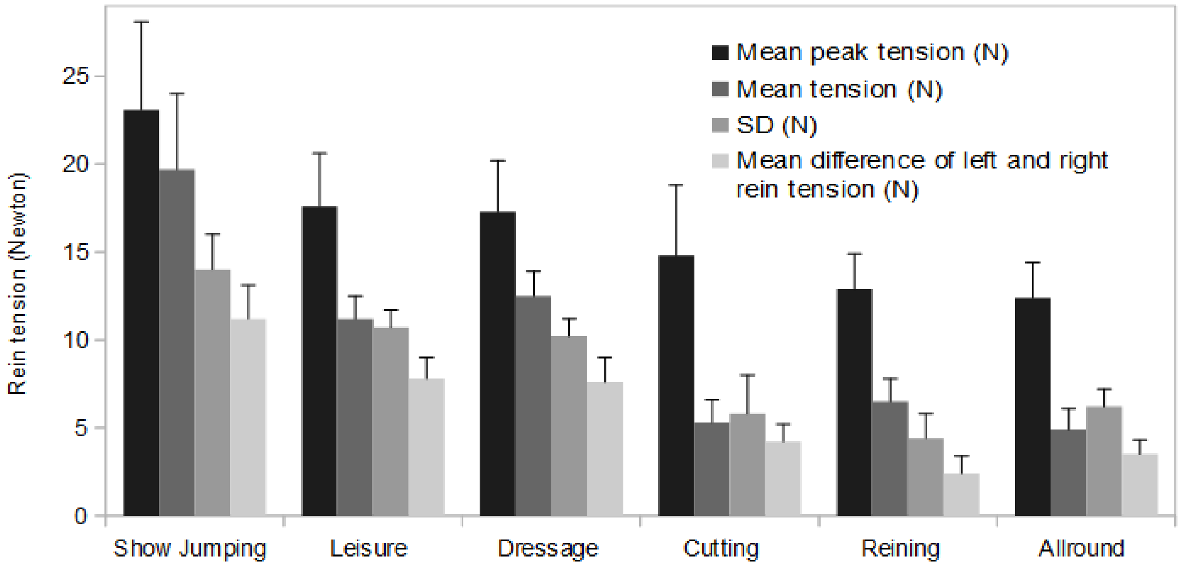


Figure 66: Rein tension parameters[1] (Newton) compared between different disciplines in conventional European riding and Western riding (all p<0.0001; use of bits: compare Table 6)

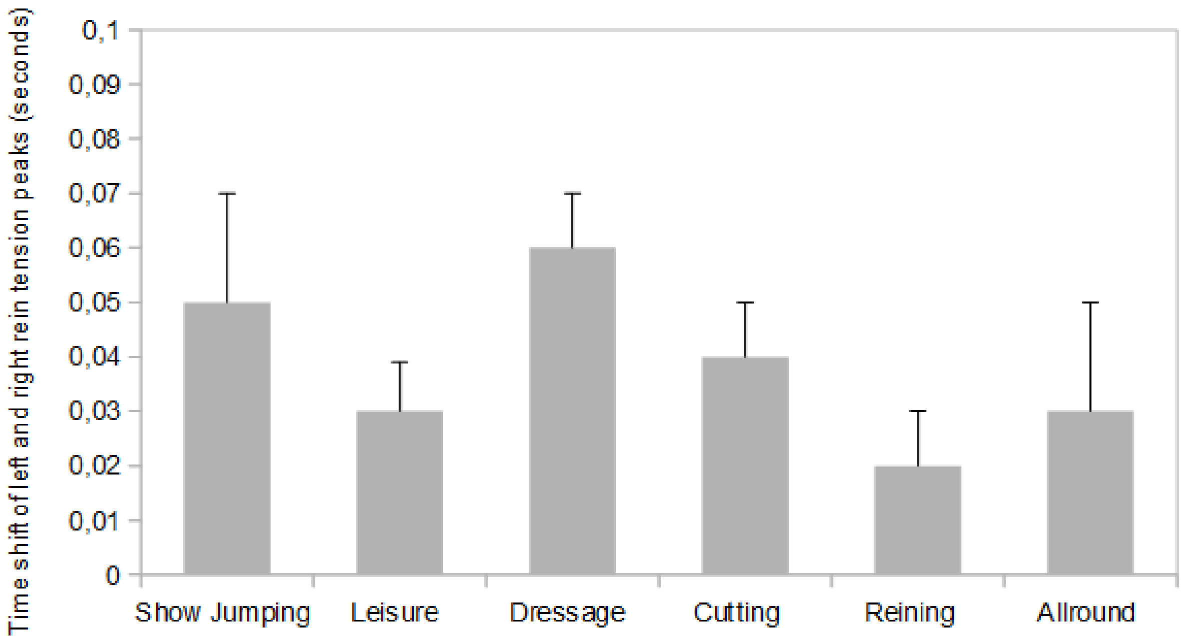


Figure 67: Time shift[1] (seconds) between peaks of left and right rein tension compared between different disciplines in conventional European riding and Western riding (p=0.0007, use of bits: compare Table 6)

7.3.1.4 Rein tension parameters in relation to rider handedness

Table 7: The distribution of handedness and laterality in the horse-rider combinations with regard to riding style and different bits

	Riding styles		Bits	
	Western riding	European riding	Snaffle bits& bitless	curb bits
Left-lateral &Left-handed	1	8	9	0
Left-lateral & Right-handed	19	15	26	8
Right-lateral & Left-handed	6	4	9	1
Right-lateral & Right-handed	23	16	34	5
Right-lateral & Ambidextrous	2	2	4	0
No laterality & Left-handed	2	0	2	0
No laterality & Right-handed	6	6	10	2
Total	59	51	94	16

In rides with snaffle bits and bitless bridles (overview of sample in Table 7), human handedness alone did not influence mean rein tension, standard deviation, mean peak tension, minimum tension and the mean difference of left and right rein tension (all p>0.05). The time shift between peaks of the left and right rein, however, revealed a tendency towards lower time shift in left-handed and ambidextrous riders in comparison to right-handed participants (Figure 68).

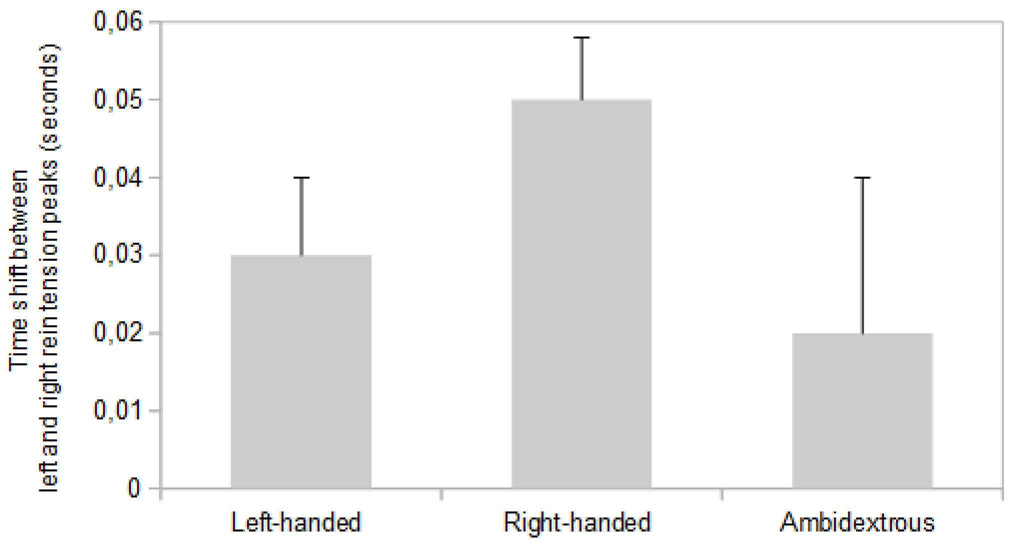


Figure 68: Time shift[1] (seconds) between left and right peaks of rein tension in relation to rider handedness (p=0.05, 94 rides)

7.3.1.5 Rein tension parameters in relation to horse's laterality (based on the assessment of their riders)

In the sample of rides with snaffle bits and bitless bridles (94 rides), higher mean tension was applied to the reins of left-lateral horses (11.6± 1.0 N) and horses without laterality (8.8± 1.1N) than to right-lateral horses (7.9± 1.1N, Figure 69, p=0.04). Horse's laterality did not influence standard deviation, mean peak tension, minimum tension and the mean difference of left and right rein tension (all p>0.05). Time shift did not differ significantly between the different directions of horse's laterality (p>0.05).

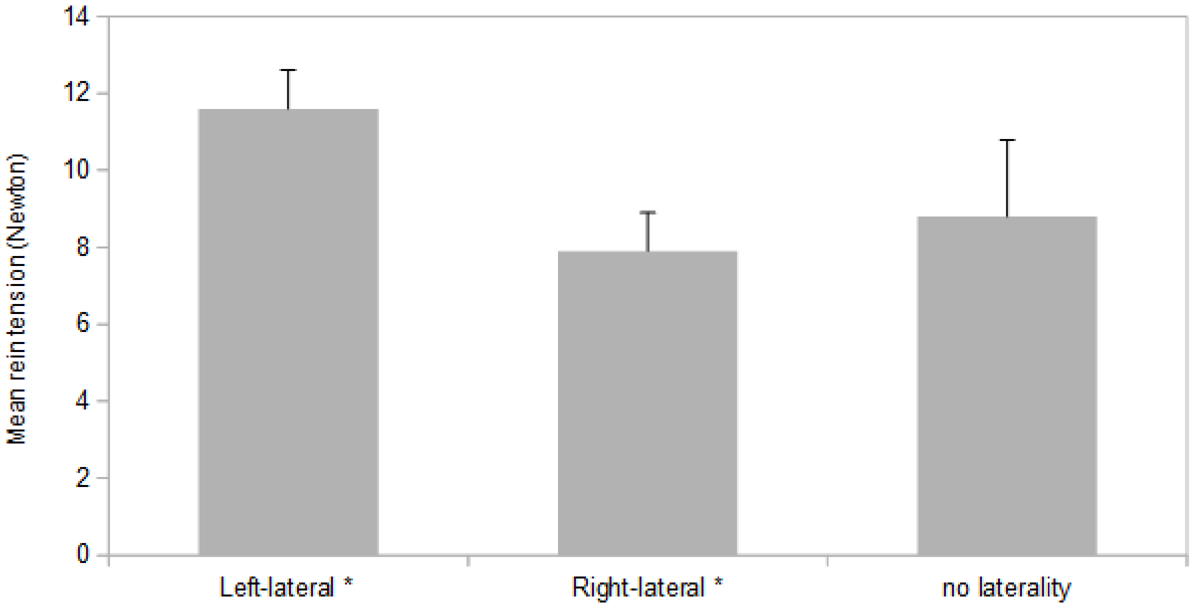


Figure 69: Mean rein tension (Newton) overall of different directions of laterality in horses based on their rider's assessment (p=0.04, * indicate a a significant difference at p<0.05, all other comparisons p>0.05, 94 rides)

Mean tension was highest in horses without laterality in total and especially in the right rein and lowest in right-lateral horses with slightly higher tension in the left rein (Figure 70). Mean tension was asymmetric in left-lateral horses and horses without laterality (Figure 70).

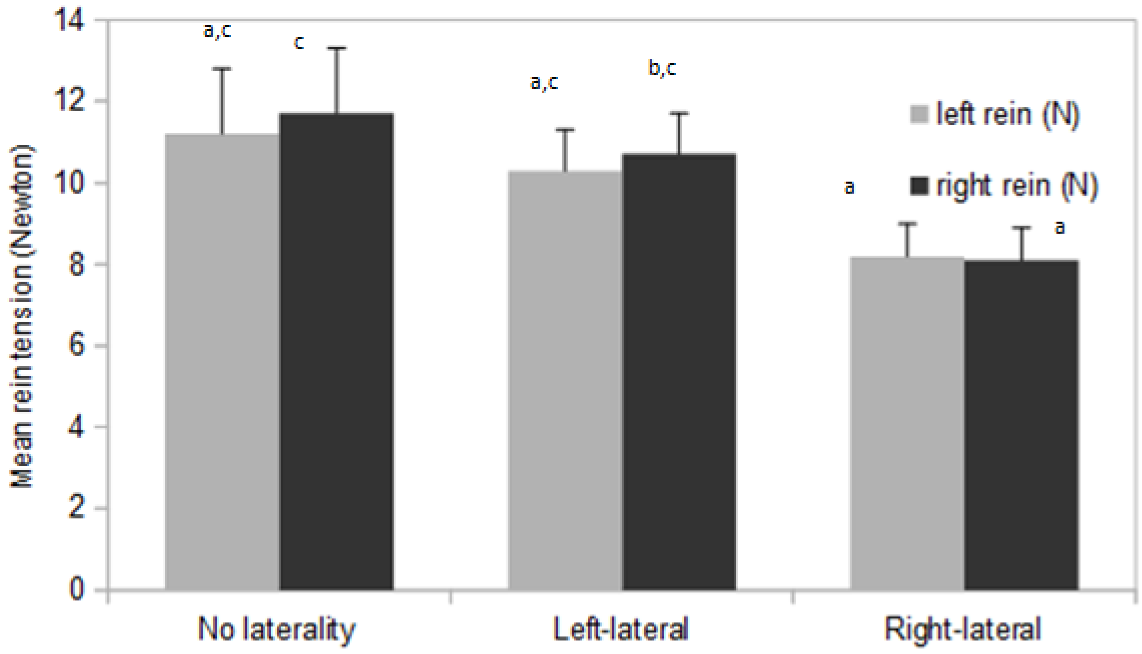


Figure 70: Comparison of mean tension (N) of the left and right rein in relation to horse's laterality based on their rider's assessment (p=0.04, 94 rides with snaffle bits and bitless bridles, unadjusted p-values; After adjustment for multiple comparisons, none of the pairwise comparisons were significant any longer).

7.3.1.6 The influence of horse's laterality (based on the assessment of their riders) and rider's handedness on rein tension parameters overall

The combination of left-lateral horses with right-handed riders (23 horse-rider combinations with 26 rides) resulted in lower mean tension overall compared to the combination with left-handed riders (9 horse-rider combinations, Figure 71, p=0.04). Mean peak tension was higher for the combination of left-lateral horses and left-handed riders too (Figure 72, p=0.03). Horses without laterality received lower mean peak tension combined with left-handed riders (Figure 72). In contrast left-handed riders applied lower mean tension and mean peak tension overall to right-lateral horses compared to right-handed riders (Figures 71 and 72). Mean peak tension was higher for horses without laterality combined with right-handed riders, as well as horse-rider combinations with matching directions of laterality (Figure 72). Ambidextrous riders rode right-lateral horses exclusively (4 horse-rider combinations) and applied overall mean tension that was comparable to right-handed riders (8.3±2.6N, Figure 71) and mean peak tension that was comparable to left-handed riders (15.1±3.2N, Figure 72). No significant influence of horse-rider combinations on standard deviation, minimum tension, the mean difference of tension and time shift could be found (all p>0.05).

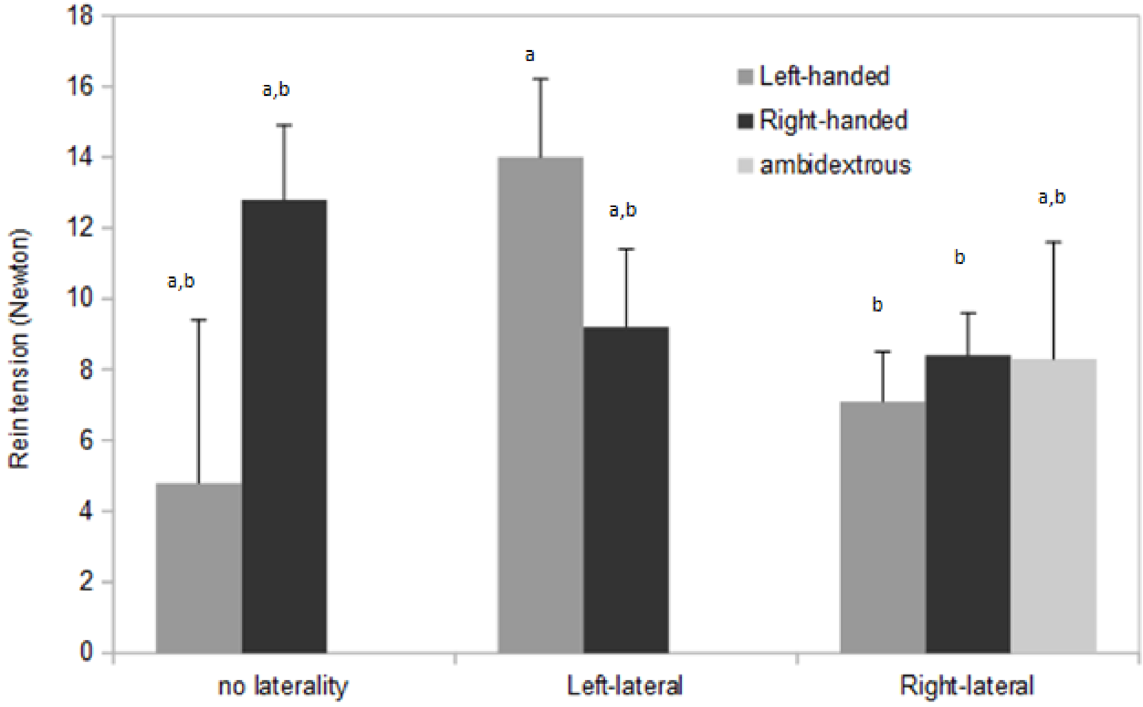


Figure 71: Comparison of mean rein tension overall (Newton) between the different directions of horse's laterality based on their rider's assessment and rider handedness in 90 different horse-rider combinations with snaffle bits and bitless bridles in 94 rides ($p=0.04$; different letters indicate a tendency towards a significant difference at $p<0.1$)

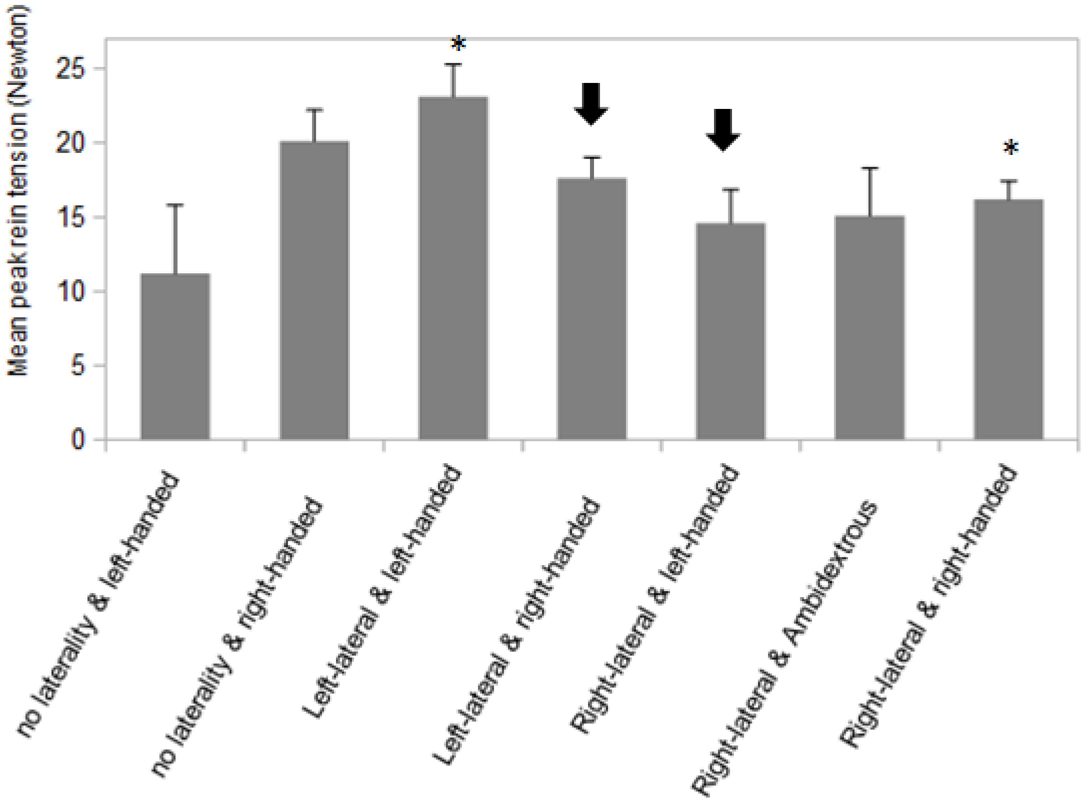


Figure 72: A comparison of mean peak tension[1] (Newton) in 94 rides of 90 different horse-rider combinations (p=0.03). Higher tension peaks seem to occur with left-laterality in horses and riders. Laterality was assessed by the riders based on the horse's suppler side during riding tasks. Horse-rider combinations with matching laterality are marked with stars and combinations with opposite laterality are marked with arrows.

Based on variance components from the mixed model analysis, both the rider and the horse explained with 33.2±0.0% each a significant (Likelihood Ratio Test, p<0.05) proportion of the total variance in mean rein tension. Specific horse-rider combinations however, did not contribute significantly to the total variance. In contrast, with SD of rein tension, the rider (14.9±5.8%, p<0.05) but neither the horse nor the horse-rider combination explained significant proportions of the total variance.

7.3.1.7 Rein tension parameters in relation to symmetry of the inside versus the outside rein

In this chapter, rein tension is regarded in relation to the direction of riding in the arena, i.e. in a clockwise direction the right rein is regarded as the inside rein and the left rein as the outside rein, whereas the opposite is true for riding in a counter-clockwise direction. Riders applied higher mean tension to the inside rein regardless of the direction (Figure 73). The asymmetry was stronger on a circle compared to riding on straight lines (Figure 73). Mean standard deviation of the rides (Figures 74 and 75) and mean peak tension (Figure 76) were higher on the inside rein on a circle regardless of the direction and the riding style.

Mean standard deviation of the rides served as a parameter to measure stability of rein contact, which was almost symmetric on straight lines and larger on the inside rein on circles and straight lines counter-clockwise with European and Western riding (Figures 74 and 75). Rein tension was least stable in the left (outside) rein on straight lines counter-clockwise in Western riding and in the right (outside) rein on circles clockwise in European riding. Mean peak tensions were slightly higher in the right rein on straight lines, regardless of the direction (Figure 76). Overall, riders reached higher peak tension in the inside rein. No significant results for minimum tension and the mean difference of left and right rein tension could be documented (all p>0.05). Larger time shift was found counter-clockwise (circle: 0.15±0.02 sec., straight: 0.04±0.007 sec., clockwise, circle: 0.01±0.003 sec. straight: 0.02±0.004 sec., p<0.0001).

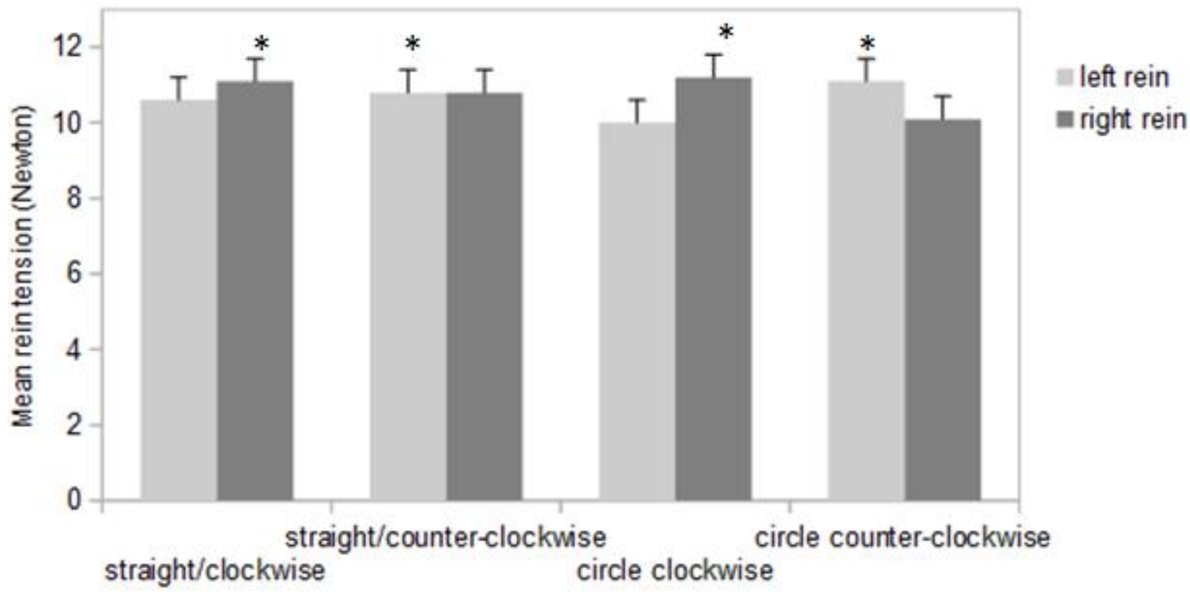


Figure 73: Comparison of mean rein tension[1] (Newton, based on 94 rides with snaffle bits and bitless bridles) of the left and right rein in relation to the direction of the straight lines and circles. Higher mean tension was applied to the inside (*) compared to the outside rein (p=0.0003).

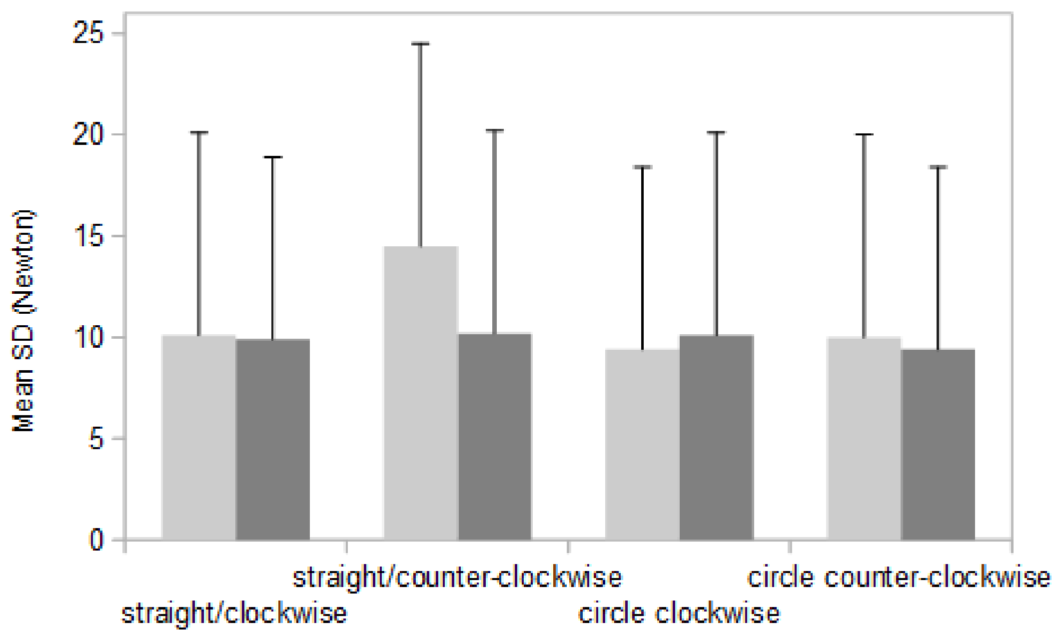


Figure 74: Comparison of mean SD[1] (Newton, based on 94 rides with snaffle bits and bitless bridles) of the inside and outside rein on straight lines and circles in both directions ($p<0.0001$) in European riding. Mean standard deviation served as a parameter to measure stability of rein contact.

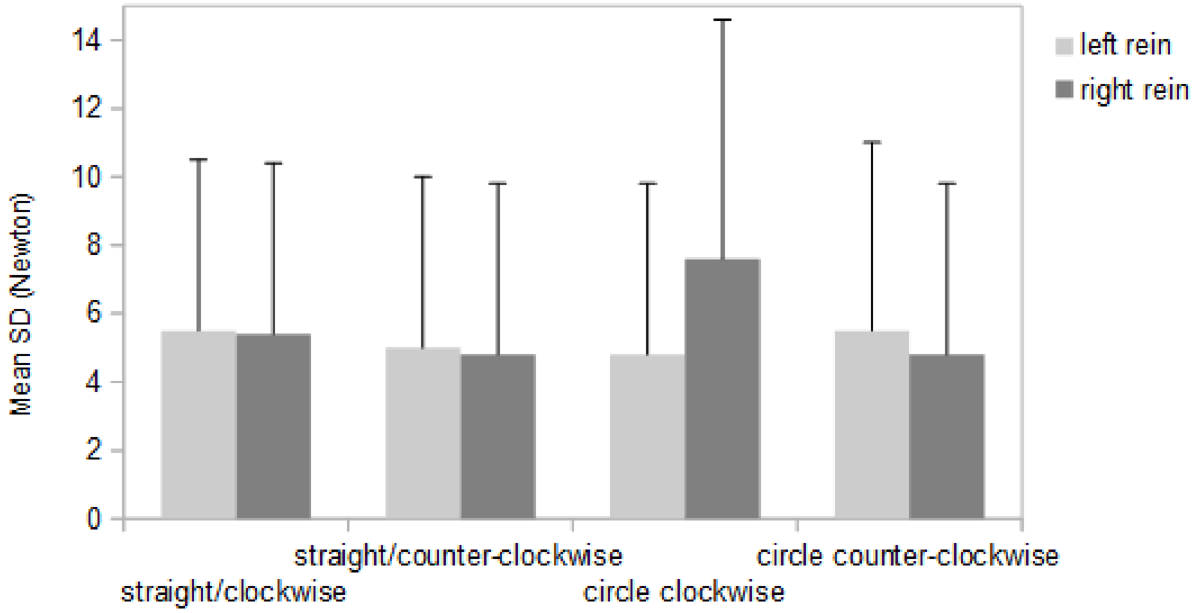


Figure 75: Comparison of mean SD[1] (Newton, based on 94 rides with snaffle bits and bitless bridles) of the inside and outside rein on straight lines and circles in both directions ($p<0.0001$) in Western riding. Mean standard deviation served as a parameter to measure stability of rein contact.

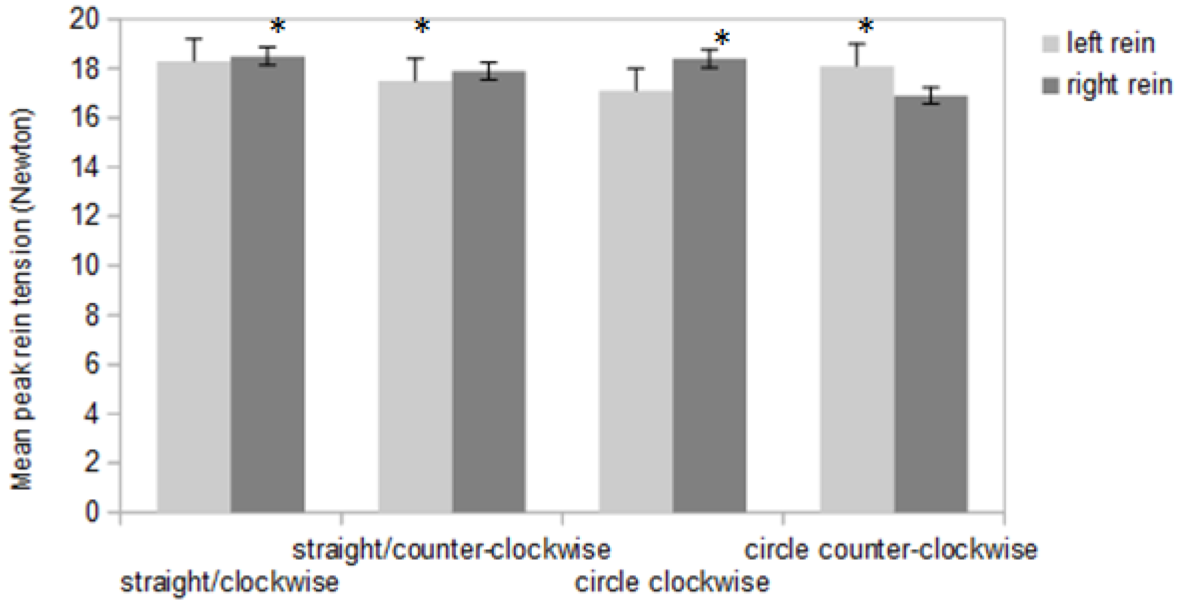
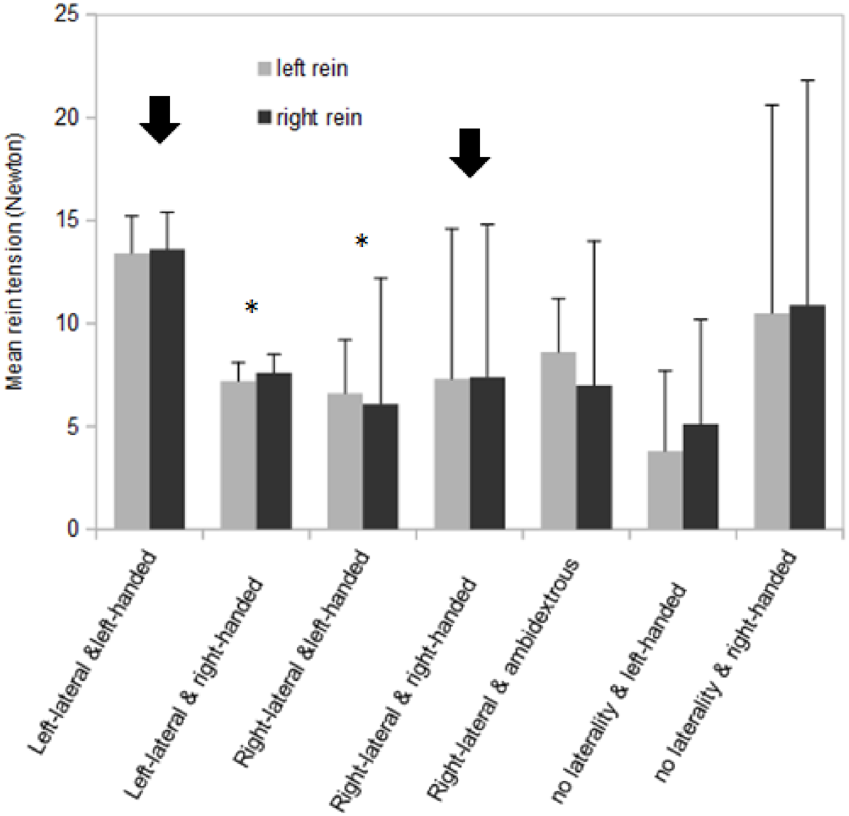


Figure 76: Comparison of mean peak tension[1] (Newton, based on 94 rides with snaffle bits and bitless bridles) of the inside (*) and outside rein on straight lines and circles in both directions (p=0.03). In contrast to mean rein tension, peaks are never symmetrical.

7.3.1.8 The symmetry and stability of left and right rein tension in different horse-rider combinations

Contact of the right rein was most often stronger (Figure 77, p=0.003) and less stable (Figure 78, p=0.02) with left-laterality in both, horses and riders, compared to right-lateral individuals. Ambidextrous riders seem to be more comparable to left-handed riders (Figures 77 & 78). Horses without laterality were ridden with higher mean tension and mean standard deviation in the right rein (Figures 77 & 78). Right-handed riders showed the most asymmetric mean rein tension in the right rein with left-lateral horses or horses without laterality (Figure 79). Left-handed riders showed the strongest mean tension in the right rein with left-lateral horses (Figure 80). Rein tension was less stable but more symmetric with matching directions of laterality in horses and riders (Figures 79 & 80). Mean peak tension was higher in the right than the left rein for all horse-rider combinations (Figure 81).



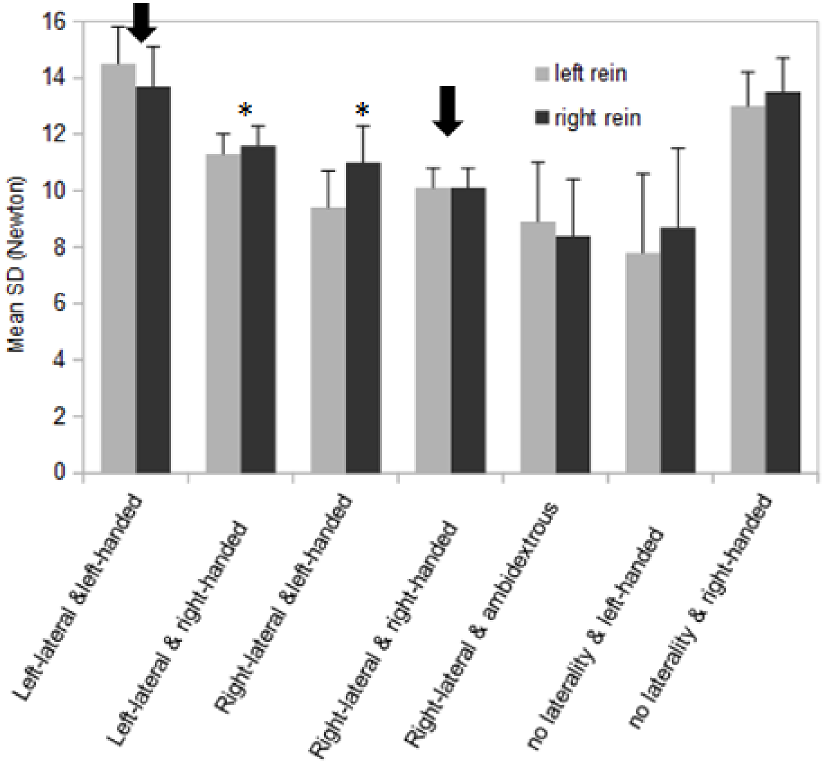


Figure 77 (left): A comparison of mean rein tension[1] (Newton) in 110 rides of 106 different horse-rider combinations (p=0.003). Laterality was assessed by the riders based on the horse's suppler side during riding tasks. Right rein contact was stronger in most combinations. Horse-rider combinations with matching laterality are marked with arrows and combinations with opposite laterality are marked with *.

Figure 78 (right): A comparison of mean standard deviation[1] (Newton) as a measure to determine stability of rein contact in 94 rides of 90 different horse-rider combinations (p=0.02). Laterality was assessed by the riders based on the horse's suppler side during riding tasks. Stability of rein contact was asymmetric. Stronger rein contact was identical with higher mean SD (less stability) in all horse-rider combinations, except left-lateral riders with either left- or right-lateral horses. Horse-rider combinations with matching laterality are marked with arrows and combinations with opposite laterality are marked with *.

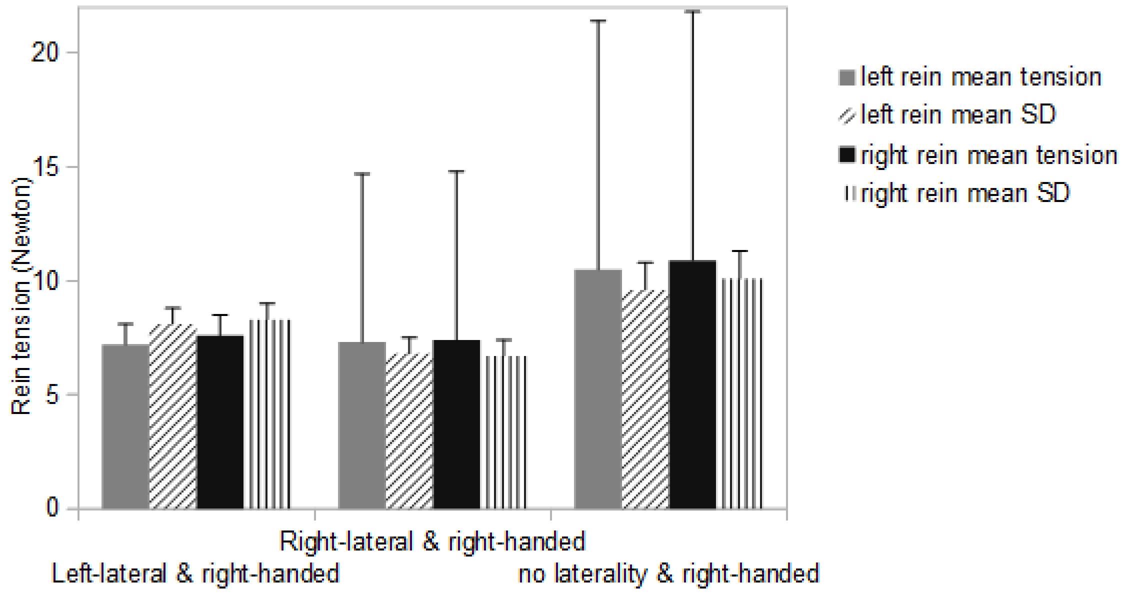


Figure 79: Comparison of mean rein tension[1] (Newton, p=0.003) and mean standard deviation[1] (Newton) as a measure to determine stability of rein contact in 70 rides of combinations with right-handed riders. Laterality was assessed by the riders based on the horse's suppler side during riding tasks.

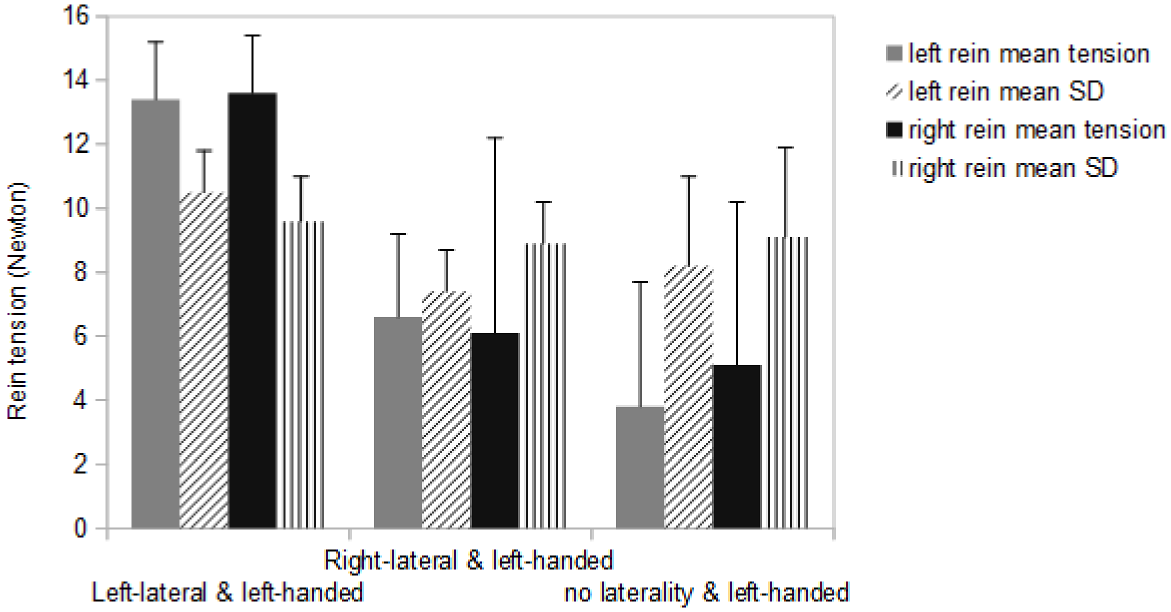


Figure 80: Comparison of mean rein tension[1] (Newton, p=0.003) and mean standard deviation[1] (Newton, p=0.02) as a measure to determine stability of rein contact in 20 rides of combinations with left-handed riders. Laterality was assessed by the riders based on the horse's suppler side during riding tasks.

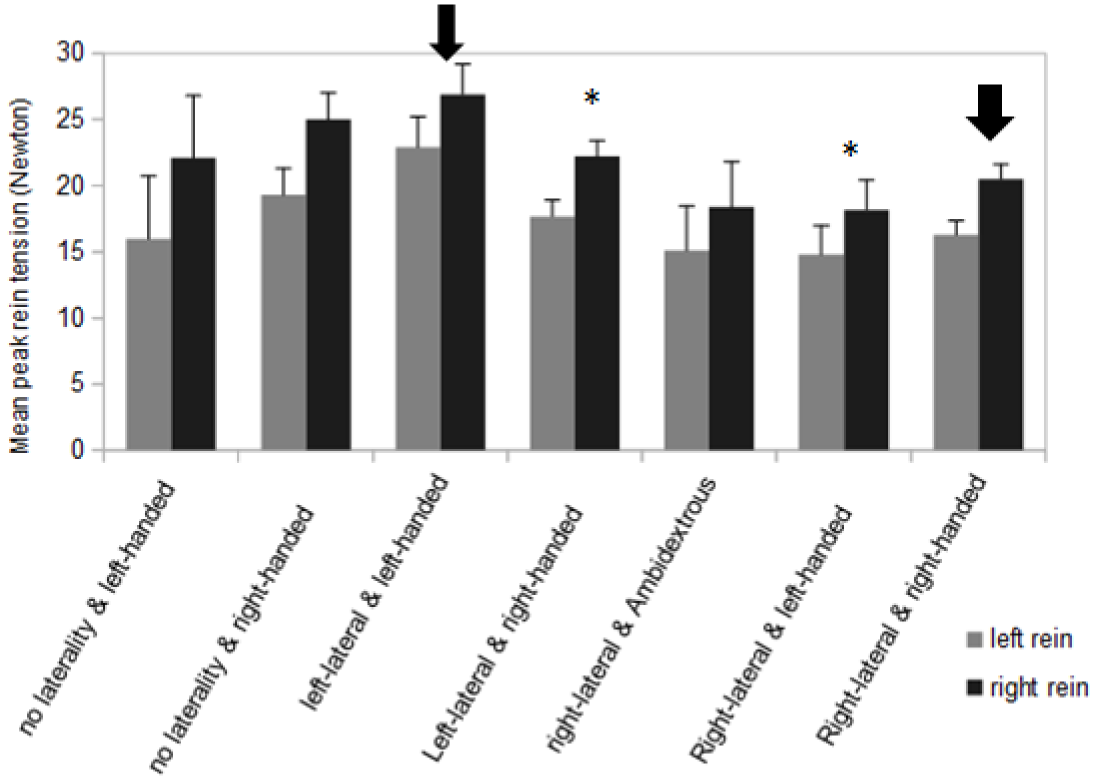


Figure 81: Comparison of mean peak tension (Newton)[1] in the right versus the left rein of 90 different horse-rider combinations with 94 rides (p=0.04). Laterality was assessed by the riders based on the horse's suppler side during riding tasks. Horse-rider combinations with matching laterality are marked with arrows and combinations with opposite laterality are marked with *.

7.3.1.9 Rein tension symmetry in relation to the direction of reported difficulties of horses to bend

Only rides of horses with reported difficulties to bend clockwise (i.e. to the right), showed asymmetric rein tension overall (Figure 82, p=0.04). Difficulties to bend counter-clockwise (i.e. to the left) resulted in lower, but almost equal rein tension. Mean rein tension overall was symmetric but rather high in horses with overall and without reported difficulties bending compared to those with reported problems clockwise or counter-clockwise (Figure 82). The mean difference of left and right rein tension was largest for rides without reported problems in comparison to rides with reported problems to bend clockwise, counter-clockwise or in both directions (Figure 83, p=0.0005). No relation of difficulties bending and mean peak tension, standard deviation, minimum tension and time shift could be found (all p>0.05).

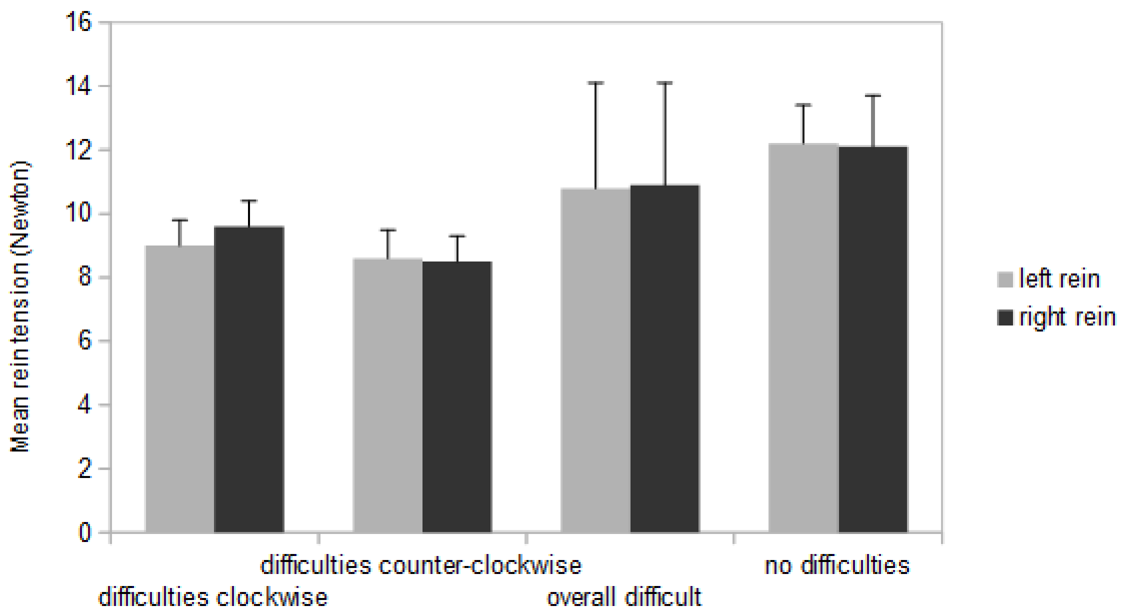


Figure 82: Mean rein tension[1] (Newton) of the left vs. the right rein, based on 94 rides with snaffle bits and bitless bridles in relation to the side to which horses had difficulties bending to as reported by their riders (p=0.04). Rein tension was symmetrical, except for horses with difficulties to bend clockwise.

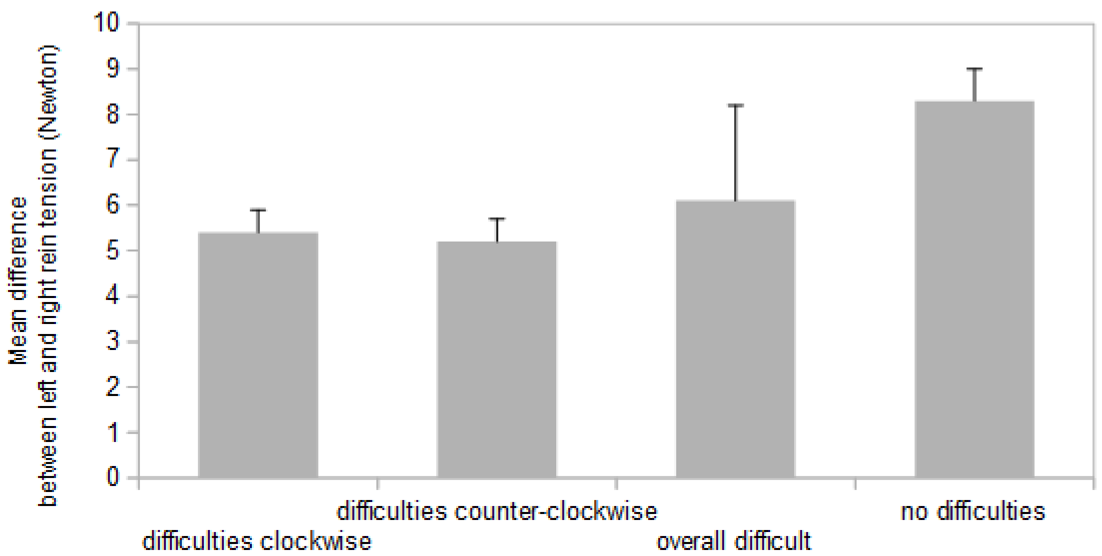


Figure 83: Mean difference between left and right rein tension[1] (Newton), based on 94 rides with snaffle bits and bitless bridles) in relation to the side to which horses had difficulties bending to as reported by their riders (p=0.0005). Rein tension was more symmetrical when rider's reported difficulties to bend in either direction for their horses.

Mean rein tension (Figure 84), mean peak tension (Figure 85) and the mean difference of left and right rein tension (Figure 86) according to reported difficulties bending were related to horse's laterality, but not to rider's handedness. No significant relation of difficulties bending and neither laterality, nor handedness were discovered for standard deviation, minimum tension and time shift (all p>0.05). In both right-lateral and left-lateral horses higher rein tension occurred with reported problems in the direction of the non-preferred side, whereas tension in direction of the preferred side was more stable (e.g. in right lateral horses: mean tension= 9±1N counter-clockwise (=non-preferred side) vs. 6.6±2.6N clockwise (=preferred side), Figure 84). In right-lateral horses rein tension was highest when difficulties occurred overall (Figure 84-86). The highest magnitude of mean tension was found in horses without reported problems and no laterality (14.5±1.7N). In horses without laterality only problems bending clockwise or overall were reported. Mean peak tension was highest for horses without reported difficulties in left-lateral horses and horses without laterality (i.e. no difficulties or overall difficult, Figure 85). Spread of tension was smallest for horses with difficulties bending to the right (3.5±0.1N) and left (3.8±0.1N) and identical for horses without difficulties and with difficulties bending to either side (3.9±0.1N, p<0.0001). The mean difference of left and right rein tension was highest for horses without laterality and no reported difficulties (Figure 86). In right-lateral horses, rein tension was most asymmetric with reported difficulties in both directions (7.3±2.6N) in comparison to left-lateral horses which showed almost equal asymmetry regardless of the reported problem (clockwise: 6.9±0.8N, counter-clockwise: 6.9±1N, none: 6.5±2.1N).

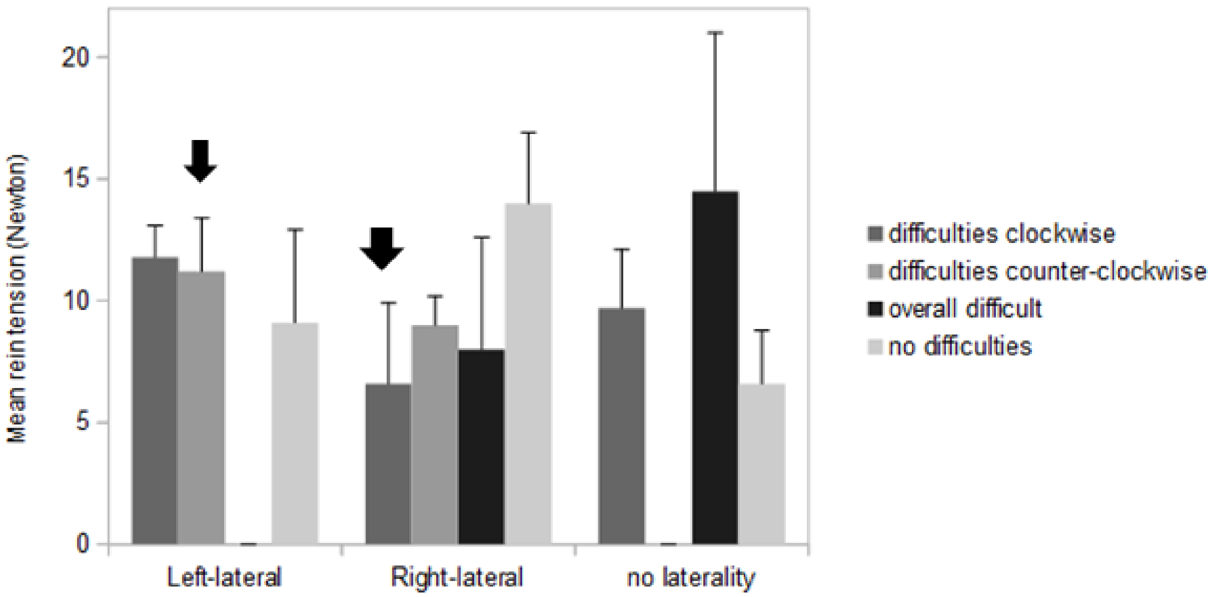


Figure 84: Mean rein tension[1] (Newton) in relation to the horse's laterality and their difficulties bending, both as assessed by their riders (p=0.0066, 94 rides with snaffle bits and bitless bridles). "No difficulties bending" was not reported for left-lateral horses. Horses without laterality were not perceived as difficult to bend counter-clockwise. Arrows indicate the horse's preferred side.

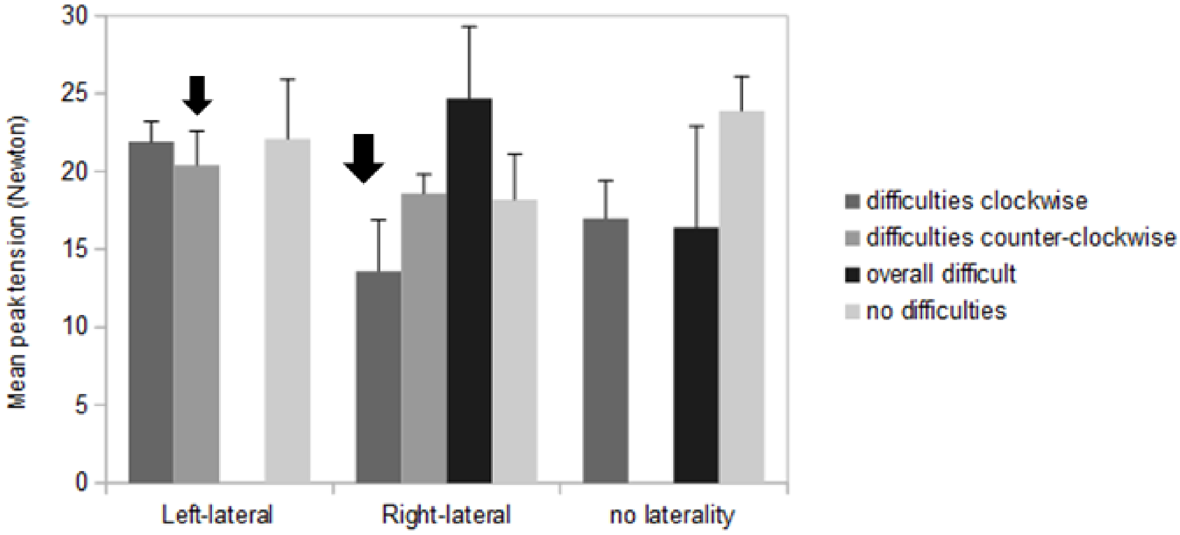


Figure 85: Mean peak tension[1] (Newton) in relation to the horse's laterality and their difficulties bending, both as assessed by their riders (p=0.0014, 94 rides with snaffle bits and bitless bridles). "No difficulties bending" was not reported for left-lateral horses. Horses without laterality were not perceived as difficult to bend counter-clockwise. Arrows indicate the horse's preferred side.

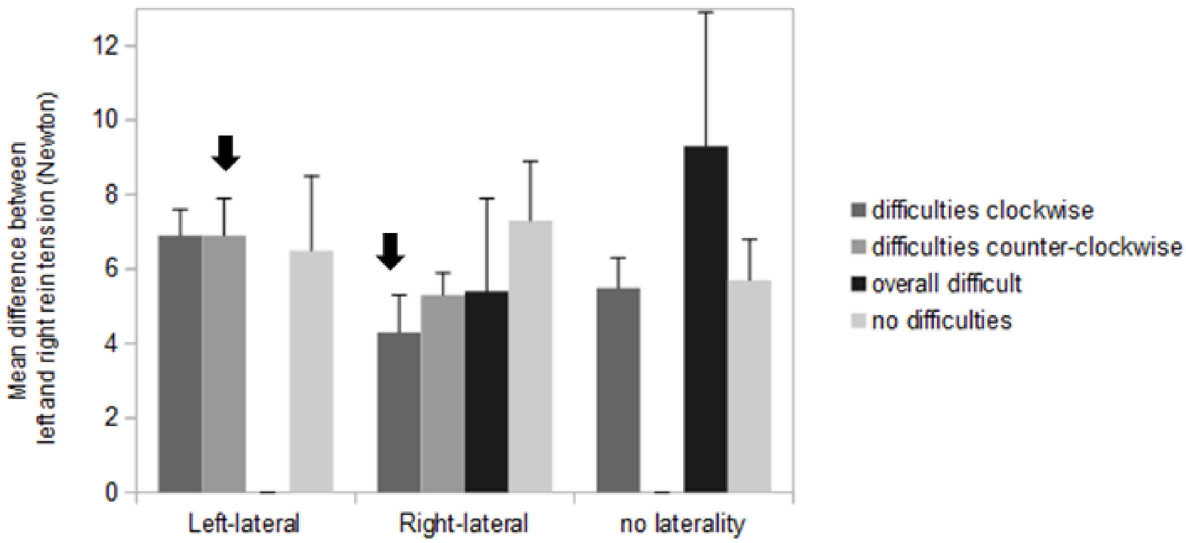


Figure 86: Mean difference of left and right rein tension[1] (Newton) as a measure of symmetry in relation to the horse's laterality and their difficulties bending, both as assessed by their riders (p=0.003, 94 rides with snaffle bits and bitless bridles). "No difficulties bending" was not reported for left-lateral horses. Horses without laterality were not perceived as difficult to bend counter-clockwise. Arrows indicate the horse's preferred side.

7.3.1.10 Rein tension parameters in relation to the lateral displacement of the hindquarters

The lateral displacement of the hindquarters as such did not influence mean rein tension. However, horses of any direction of laterality as assessed by their riders, that had their hindquarters displaced to the left, received higher mean tension than those with a right displacement of their hindquarters (Figure 87, p=0.04). No influence was found for the mean difference of tension, mean peak tension and mean standard deviation. The lateral displacement of the hindquarters in combination with horse's laterality did not influence the side to which difficulties bending were reported (p>0.05). Larger time shift was found in horses with right-displaced hindquarters (0.04±0.01 sec. right vs. 0.02±0.005 sec. left, p=0.046).

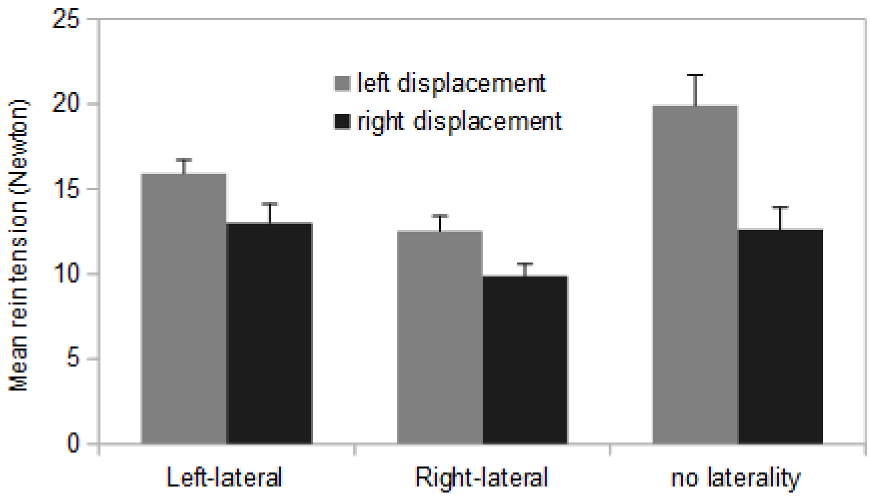


Figure 87: Mean rein tension (Newton) in relation to horse's laterality as assessed by their riders and the lateral displacement of their hindquarters in 90 horse-rider combinations with 94 rides (p=0.04). Rein tension was higher in horses with left-displaced hindquarters, regardless of their rider's assessment of their laterality.

7.3.2 Discussion

Horse-rider-communication, especially with regard to rein tension, has often been investigated. Even though asymmetric rein tension has been discovered before (Warren-Smith et al. 2007, Hawson et al. 2010, Eisersiö et al. 2015a, Eisersiö et al. 2013), studies focusing on the possible impact of laterality on rein tension are scarce. However, Kuhnke et al. (2010) documented a possible influence of horse's laterality and rider's handedness on the symmetry of rein tension.

7.3.2.1 Rein tension parameters in different gaits, transitions and manoeuvres

The magnitude and standard deviation of rein tension differed between gaits in previous studies too (Preuschoft et al. 1999a , Clayton *et al.* 2003, 2005, 2011, Herde 2005, Warren-Smith *et al.* 2005, 2007, Kuhnke et al. 2010, Randle et al. 2011). Regarding mean peak tension which considered consecutive maxima only in contrast to mean tension containing the full sequence with values decreasing to minimum and increasing to maximum values, it seems a logical consequence for mean peak tension to reach higher values. When it comes to converted rein tension values though (i.e. rein tension was converted into the amount of pressure expected at the horse's mouth with the specific type of bit according to factors previously published by Preuschoft), in most gaits, transitions and manoeuvres, as well as regarding different bits and bridles, converted mean tension was higher than converted peak tension, indicating that the minima must have been quite high. Mean peak tension for canter in conventional European riding of mostly leisure riders was 28.6N in this sample, which is less than the values reported for canter in professional riders (70-109N for a comparable task and position, Egenvall et al. 2015b). Previous research found that riders mainly influenced the amount of minimum and mean rein tension, whereas the horses seemed to determine the range and maximum rein tension applied (Eisersiö et al. 2015, Egenvall et al. 2015b). With a much larger sample investigated in all gaits, the present study revealed equal contributions of horses and riders to the variance of mean rein tension overall. Stability of rein tension in the present study seemed to be solely determined by the rider, which could be explained by previous findings of the rider almost exclusively determining minimum tension (Egenvall et al. 2016a).

The mean difference of left and right rein tension and thus quantitative asymmetry of rein tension was larger with gait transitions and faster gaits suggesting a relation of symmetry with speed. The rein tension patterns vary according to the different gaits (Preuschoft *et al*. 1999a, Clayton *et al.* 2005) and the associated movements of the horse (Preuschoft 1999a, b & c). An increase of rein tension has been reported with faster gaits (Preuschoft et al. 1999a). Speed is the only influencing factor of the gait (Falaturi 1998). Horses increase their speed by increasing the duration of their swing phase and reducing the duration of their stance phase (Streitlein & Preuschoft 1987, Falaturi 1998). Speed has a direct impact on the vertical force components of the ground reaction force due to gravity acting on the rider. They differ between the gaits being lower at walk (1.2g) than at canter and trot (approx. 2 g) (Preuschoft 2011). Therefore a relation of speed and symmetry seems to be a logical consequence.

Time shift between the peaks of the left and right rein was ten times higher in canter and seven times higher in walk compared to sitting or rising trot. Temporal asymmetry might be influenced by the horse's footfall pattern as such and the associated forces acting on the rider (Preuschoft *et al*.

1999a, Clayton *et al.* 2005, Preuschoft 2011). Since less time shift would have been expected to be produced in walk than trot, symmetry and the movement pattern of the gait as such rather than speed might be more important. Trot has been described as a highly symmetric gait (Falaturi 1998, Hildebrandt 1985) providing stability to the rider especially in rising trot (Peham et al. 2009). In contrast to walk, horses show a suspension phase and compress their limbs like springs during ground contact at trot (Witte et al. 1995, Preuschoft 1993). Furthermore movement cycles in trot are shorter (0.65 – 0.9 seconds) than in walk (1- 1.5 seconds) (Streitlein & Preuschoft 1987, Falaturi 1998). In walk however, horses "nod" their heads while protracting their front limb due to the contraction of the M. brachiocephalicus, thus possibly increasing rein tension and also asymmetry (Preuschoft 2008).

7.3.2.2 Rein tension parameters in conventional European riding vs. Western riding

Rein tension in conventional European riding with snaffle bits or bitless bridles was higher and less stable throughout all gaits, transitions and manoeuvres compared to Western riding. The reason lies most obviously in the different aims and techniques of the two riding styles. Western riding, which developed according to the necessities of ranch and cattle work, aims to have the horses work independently on a loose rein with minimum contact (Holm 2008, Schmid 2014) as opposed to conventional European riding where a "light" but constant contact between horse and rider via the reins is desired (De la Guérinère 1733, Steinbrecht 1901, Müseler 1933, Podhajski 1967, Miesner *et al.* 2000). Furthermore, the reins in Western riding are bridged with bimanual contact and rein signals e.g. for bending are supposed to be given with both hands simultaneously with a gliding movement (Holm 2008, Schmid 2014). Rein tension with bridged reins showed improved stability and temporal symmetry of rein contact in the present study. Still, the skill level of the horse-rider combinations seems to be more important for performance and horse learning, than the difference between Western and conventional riding styles (König von Borstel et al. 2013).

7.3.2.3 Rein tension parameters within different disciplines of conventional European riding and Western riding

The rein tension of show jumpers was higher than those of leisure or dressage riders, which were quite comparable. A possible explanation might be that leisure riders and dressage riders are more focused towards improving their horse's balance and suppleness, thus training their horse to obey to lighter signals. Suppleness and prompt reactions are essential in dressage competitions (Steinbrecht

1901, Müseler 1933, Miesner et al. 2000) or as a simple necessity for a reliable horse that is pleasant to ride (Holm 2008, Schmid 2014), whereas show jumpers might be more focused on improving their horses jumping ability and speed (Miesner et al. 2000). When it comes to symmetry however, show jumpers and leisure riders might give less frequent signals to their horses, thus improving temporal symmetry with smaller time shift between the left and right rein. Another possible factor might be that especially dressage horses moved with more impulsion thus leading to larger amplitudes of movement inducing a slight alternating shift of the horse's head with every contraction of the M. brachiocephalicus (Preuschoft 2008). However, absolute temporal symmetry was not only documented in Western breeds with little impulsion during their gaits, but also in some of the warmbloods and riding ponies throughout entire Western rides and for shorter periods of time during conventional European riding. In Western riding, higher rein tension values were found in cutters than in reining or allaround riders. Time shift was higher for cutters than for any other discipline. However, especially for disciplines asking horse-rider-combinations to work with cattle, a horse that works independently on a very loose rein is essential (Holm 2008). Thus some riders of cutting horses in this sample reported that their horses were upset with them keeping more rein contact than usual and tried to pull against the reins, which might explain the differences especially in mean peak tension and time shift. Since the number of horse-rider combinations for show jumpers and cutters was rather low, these results need to be investigated again with a larger sample. Rein tension values of different gaits and transitions showed large differences between the disciplines of one riding style compared those of the other riding style. However, the differences among the disciplines of the same riding style were rather small, indicating that the riding style rather than the demands of different disciplines influences rein tension values.

7.3.2.4 Rein tension parameters in relation to rider handedness

Human handedness alone did not influence the magnitude of rein tension. However, temporal asymmetry was greater in right-handed than left-handed participants. Advantages of left-handed humans e.g. when it comes to reaction times and skill of their non-dominant hand (Steenhuis & Bryden 1999, Rousson et al. 2009) and in different sport disciplines (McManus 2002) have been reported. Furthermore, left-handers often perform superiorly in bimanual tasks (Judge & Stirling 2003) and perceive grip force more accurately, thus being able to perform more symmetrically (Adamo et al. 2012). A possible advantage of left-handed and ambidextrous individuals has been suggested by the results of chapter four in equestrian sports, which might be based on the improved symmetry and accuracy shown in this sample of horse-rider combinations.

7.3.2.5 Rein tension parameters in relation to horse's laterality (based on the assessment of their riders)

and

7.3.2.6 Rein tension parameters in relation to horse's laterality (based on the assessment of their riders) and rider handedness in different horse-rider combinations

When it comes to horse's laterality, the magnitude of rein tension but not temporal symmetry differed significantly between the directions of laterality. Also a significant proportion of the variance of mean standard deviation of rein tension was explained by the rider, thus indicating that the rider, but not the horse or horse-rider-combination influence the stability and temporal symmetry of rein tension. The total variance of mean rein tension in the present study was equally influenced by the horse and the rider, indicating that quantitative asymmetry might be related to different directions of laterality in horse-rider-combinations. As documented in previous studies (chapter 5, Kuhnke et al. 2010) higher rein tension was applied to left-lateral compared to right-lateral horses or individuals without reported laterality. Right-handed riders applied lower mean and peak tension to horses with matching (right-) laterality than to left-lateral horses and horses without reported laterality in the present study as well as in previous research (Kuhnke et al. 2010). However, left-handed riders applied higher mean and peak tension to left-lateral compared to other horses, contradicting the first impression that matching directions of laterality in horse-rider combinations might be an advantage according to the magnitude, symmetry and stability of rein tension (chapter 5, Kuhnke et al. 2010). The present study seems to support these results for right-handed riders on right-lateral horses only. In contrast, rein tension seemed to be increased with left-laterality in horses and riders, especially in the combination of left-handed riders and left-lateral horses. Regarding rein tension variables overall based on the direction of horse's laterality, contra-lateral combinations produced lower rein tension. These results might mirror the findings of chapter 4, indicating that the handedness of the rider might be more important to success and safety than horse's laterality. Ambidextrous riders seemed to be comparable to right-handed riders for mean tension and to left-handed riders for mean peak tension. However, results have to be regarded carefully, since only two ambidextrous riders participated and only rode right-lateral horses.

7.3.2.7 Rein tension parameters in relation to symmetry of the inside versus the outside rein

Results of the present study revealed higher peak tension in the right rein on straight lines in both directions. Since the majority of riders were right-handed females and attributes such as muscle strength and grip force in these groups have repeatedly been documented to be larger in the dominant hand (Steele 2000, Klum et al. 2012), a possible relation to human handedness is suggested. For straight lines counter-clockwise, higher mean peak tension was applied to the outside (right) rein as demanded by the riding literature (De la Guérinère 1733, Steinbrecht 1901, Miesner *et al.* 2000, Müseler 1983). In contrast, mean peak tension was asymmetric and stronger on the inside rein on circles counter-clockwise (left rein) and on circles and straight lines clockwise (right rein) even in advanced and professional riders, further supporting the hypothesis of a relation to handedness and previous results (Kuhnke et al. 2010, chapter 5).

Asymmetry was stronger on a circle especially when it comes to the stability of rein contact revealing higher mean standard deviation and thus less stability in the inside rein, regardless of the direction. This might be caused by the longer stance phase of the inside limbs compared to the outside limbs on a circle (Falaturi 1998, Chateau et al. 2013). Accounting for this fact and the relation of rein tension to the horse's movement pattern, asymmetric rein tension might be unavoidable. Stability might also be further reduced when riders cannot use the arena's walls as a boundary and orientation, while trying not to ride with their inside rein (Miesner et al. 2000, Kapitzke 2001). Depending on the direction of the circle and the horse's laterality this might either add in to the horse's own preference or oppose the horse's preference (Müseler 1933) and animate the rider to "correct" the horse with stronger rein tension signals of the inside rein. This situation might be the reason behind the impression that the horse performs easier in one direction than the other. However, the theories and demands of the riding literature have been established based on the subjective experiences and impressions of the old riding masters (e.g. De la Guérinère 1733). The demand to ride with stronger contact on the outside rein could therefore also be based on a compensatory mechanism, whereas stronger tensions on the inside rein might be more natural according to the horse's movement patterns. However, the present results might explain and further support the results of chapter 5, that only the rider's assessment of the horse's side preference showed a significant relation to rein tension symmetry. Even though stability of rein tension is determined by the riders, their horse's laterality seems to influence the basic situation the rider has to deal with.

7.3.2.8 The symmetry and stability of left and right rein tension in different horse-rider combinations

Mean peak tension was higher in the right than the left rein for all horse-rider combinations. This has been potentially explained with the strength of the dominant hand in right-handed riders before (Steele 2000, Hobbs et al. 2014, Klum et al. 2012). Even though left-handed subjects seem to perform more symmetrically when it comes to grip force (Adamo et al. 2012), they use their non-dominant hand more intensively than right-handed subjects (Steenhuis & Bryden 1999, Rousson et al. 2009). Therefore, one possible explanation for stronger tension of the right rein in left-handed riders could be overcompensation with their non-dominant right hand when riding right-lateral horses which avoid contact to the right rein. Horses without laterality showed higher mean tension and less stability, especially in the right rein with all riders, indicating that they might not be truly symmetric and well -balanced in both directions, even though no laterality has been perceived by their riders. However, many riders perceived a rather high rein tension as “light” or “medium” whereas the lightest contact was described as “strong”. These difficulties to assess their own rein contact appropriately further indicate that these horses might not be truly balanced after all. According to the riding literature, horses would tend to lean on the rein of their non-preferred side, thus avoiding contact with the rein of their preferred side (e.g. the left-lateral horse would tend to avoid contact with the left rein and lean on the right rein overall; Klimke 1985, Müseler 1933). In fact, in left-handed riders, rein tension was higher on the horse’s non-preferred side and less stable on the horse’s preferred side with all combinations of horses, supporting this theory. Combinations of horses with right-handed riders, however, showed stronger interaction of horse’s laterality and human handedness. In left-lateral horses with right-handed riders, rein tension was higher in the rider’s dominant (right) hand and least stable in the rein held by the rider’s dominant hand on the horse’s non-preferred side (i.e. right rein of a right-handed rider on a left-lateral horse). In contrast, almost symmetric tension of the left and right rein according to mean tension and mean standard deviation was found in combinations of right-lateral horses and right-handed riders. The right-handed rider seems to be able to maintain contact with his/her dominant right hand, thus the right-lateral horse does not lean as much on the left rein which creates the impression of symmetric and more stable rein tension. These results once again indicate that the rider determines the stability of rein tension, which is based on the situation created by horse’s laterality. Right-handed riders seem to depend upon their dominant hand while trying to compensate their horse’s laterality, suggesting a strong influence of human handedness on rein tension. Left-handed riders in contrast seem to be independent of their dominant hand thus supporting the theory of left-handed individuals being less lateralized (Goble & Brown 2008, Rousson et al. 2009, Michałowski & Króliczak 2015). The right-handed sample contained a broad number of any riding level, in contrast to the left-handed riders in the present study, which were riding mostly at basic and advanced level. Therefore it seems that left-handedness rather experience might indeed enable the rider to act more independently of their own handedness when attempting to "correct" their horse's laterality patterns and improve their balance.

7.3.2.9 Rein tension symmetry in relation to the direction of reported difficulties of horses to bend

Riders assessed their horse's laterality based on the direction in which dressage tasks such as riding circles are easier to perform. Therefore, the horse's laterality is related to the horse's "hollow" side and the reported difficulties that are expected in the opposite direction during the rides analysed in the present study. However, since some riders did not perceive their horses to be lateralized overall and performance might vary between different days and circumstances, comparing the assessed direction of laterality (i.e. the side preference overall) to the perception of difficulties for the recorded ride seemed advisable. Rides with difficulties to bend horses clockwise showed asymmetric rein tension (i.e. quantitative asymmetry), whereas rein tension in rides with reported difficulties to bend counter-clockwise was highest. Those rides contained both right-lateral and left-lateral horses, however most horses of the present study were assessed as right-lateral. The results of the present study seem to support the theory of horses flexing more easily to one side and thus tending to decrease or increase the diameter of a circle depending on the direction (De la Guérinère 1733, Steinbrecht 1901, Müseler 1933, Miesner *et al.* 2000). While some riders might perceive their horse as being difficult in both directions, others might handle one situation better than the other and report a problem to one side. Problems bending counter-clockwise might therefore most likely consist of mainly right-lateral horses drifting towards the inside and being "pulled over" by the outside right rein. However, some left-lateral horses might increase the circle over their outside shoulder being ridden with more tension in general and especially on the inside left rein, thus resulting in symmetric, but rather high rein tension for the situation "difficulties bending counter-clockwise". "Difficulties bending clockwise" however resulted in asymmetric rein tension possibly because the majority of right-lateral horses increasing the circle were attempted to be "corrected" with the inside right rein, which was associated with higher rein tension of the majority of rider's dominant hand (right hand in right-handed riders) and reached higher tensions than the outside left rein of most left-lateral horses being prevented from drifting towards the inside of the circle. The mean difference of left and right rein tension was highest for rides without reported problems, even though mean tension overall was symmetric. Those horses might actually have been ridden with higher tension on the outside rein as demanded by the riding literature (Steinbrecht 1901, Müseler 1933, Miesner *et al.* 2000, Kapitzke 2011), thus creating quantitative asymmetry of rein tension throughout the ride, but not overall. Regarding the horse's laterality, in fact less mean and peak tension was found with rides for which difficulties were reported in the direction of the horse's preferred side, when it tends to increase the circle and creates the impression of being naturally flexed ("hollow") (Müseler 1933, Klimke 1985). The mechanism behind higher rein tension with difficulties in the direction of the horse's non-preferred side might be its tendency to drift towards the inside and "ignore" the rider's leg signals. The horse creates the impression of being flexed towards the opposite side (Müseler 1933, Klimke 1985) and animates the rider to use the inside rein in order to support the inside leg signals with rein signals. The highest magnitude and asymmetry of tension was found in horses that were difficult to ride in both directions and in those without reported difficulties. Horses that are difficult to ride in both directions might be unbalanced and perceived as not supple to the rider's signals at all (Klimke 1985). In contrast, horses that perform equally "well" in both directions might also be ridden with higher rein tension because they either perform actually equally "poor" in both directions or the rider might cover the horse's difficulties with strong rein contact and an altered head and neck position (Kienapfel 2011, Kienapfel & Preuschoft 2016). Rein tension was more asymmetric in left-lateral compared to right-lateral horses. Asymmetric and strong rein tension signals given over a prolonged period of time might negatively affect horse's learning and training and jeopardize horse welfare (Zeitler-Feicht 2001, McGreevy 2004).

7.3.2.10 Rein tension parameters in relation to the lateral displacement of the hindquarters

In previous research the direction of the lateral displacement of the hindquarters, but not the forelimb preference was related to the rider's assessment of their horse's laterality (chapter 5) and results seemed to be more reliable in left-lateral horses. In the present study, neither method was related to laterality during riding and rein tension symmetry. The hindquarters were displaced to either the left or right side in both right-lateral and left-lateral horses of the present sample. Furthermore, trigger point reactions were not directly related to laterality or the lateral displacement of the hindquarters, even though muscles involved in lateral flexion (Budras & Röck 2017, Kienapfel et al. 2017) contributed to the sum of trigger point reactions of both sides with different proportions (See 7.4). Therefore it seems that in contrast to common assumptions in the riding literature (De la Guérinère 1733, Steinbrecht 1901, Müseler 1933, Podhajski 1967, Klimke 1985, Miesner *et al.* 2000), the lateral displacement of the hindquarters and the rider's assessment of the horse's preferred side are not directly related. Still, the rider's assessment of their own rein contact varied between horses with their hindquarters displaced to the left or right, indicating that the lateral displacement to either side might contribute to the rider's perception of the horse's asymmetry in a way more subtle than it has been assumed so far.

7.3.3 Conclusion

7.3.3.1 Rein tension parameters in different gaits, transitions and manoeuvres

Minima of rein tension seemed to be been quite high in the total sample, thus leading to higher mean tension at the horse's mouth (converted mean tension) compared to peak forces. Considering horse's welfare, it seems to be more important to achieve a light and soft rein contact overall than to focus on reducing tension peaks alone. The mean difference of tension and thus quantitative asymmetry seem to be related to speed, whereas temporal asymmetry might be influenced by the horse's footfall pattern and symmetry of gait as such. The rider and human handedness seem to influence the stability and temporal symmetry of rein tension. The magnitude and quantitative symmetry of rein tension in contrast varies according to horse's laterality in horse-rider-combinations. Therefore, it seems that symmetry is influenced by several variables and at least two different aspects of symmetry exist. Overall rein tension seemed to be increased and less stable with left-laterality in horses and riders, especially in the combination of left-handed riders with left-lateral horses. Ambidextrous riders seem to be more comparable to left-handed riders overall, which might support previous findings of similar advantages of both left-handed and ambidextrous riders.

7.3.3.2 Rein tension parameters in conventional European riding vs. Western riding

Rein tension in Western riding compared to conventional European riding is lower, more stable and symmetric throughout the different gaits and transitions. The riding style rather than the demands of different disciplines influences rein tension values. Horses that were difficult to ride in both directions might be unbalanced and not supple for the rider's signals at all. In contrast, horses that performed equally "well" in both directions might actually perform equally unbalanced.

7.3.3.3 Rein tension parameters in different horse-rider combinations

Higher peak tensions were documented in the right rein in all horse-rider combinations. Asymmetry was stronger on a circle with higher and less stable tension in the inside reins, regardless of the direction. Asymmetric rein tension seems to be natural on curved tracks. However, the demands of the riding literature to keep a stronger contact to the outside rein might be counter-active. Even though stability of rein tension is determined by the rider, the horse’s laterality seems to influence the basic situation the rider has to react to. Right-handed riders seem to be depending upon their dominant hand while trying to compensate their horse’s laterality, suggesting a strong influence of human handedness on rein tension. Matching directions of laterality in horse-rider combinations seems to be beneficial in right-handed riders. Left-handed riders in contrast seem to be independent of their dominant hand thus supporting the theory of left-handed individuals being less lateralized.

7.3.3.4 Rein tension parameters in relation to the lateral displacement of the hindquarters

The lateral displacement of the hindquarters and the rider’s assessment of the horses’ preferred side do not seem to be related. However, the lateral displacement of the hindquarters to either side might still contribute to the rider’s perception of the horse’s asymmetry in a more subtle way as it has been assumed so far.

7.4 The influence of horse –rider-laterality on sport results, risk of injury and the horse’s muscular system

7.4.1 Results

7.4.1.1 The magnitude and symmetry of rein tension in relation to horse’s sport results

The mean rein tension of right-lateral horses was lower with international competition horses in contrast to national competition and leisure horses (Figure 88, p<0.0001). In left-lateral horses more than twice as much rein tension was applied to leisure and national competition horses than to horses competing on international level (Figure 88). In horses without laterality mean rein tension was increased at national competitions compared to leisure horses (Figure 88). Mean peak tension tended to be highest for national competition horses without laterality (25.4±2.9N), as well as left-lateral (23.2±1.7N) and right-lateral (19.8±1.6N) leisure horses (p=0.05). Asymmetry of rein tension (i.e. a larger mean difference of left and right rein tension) was highest for national competition horses without laterality, as well as for right-lateral leisure and national competition horses (Figure 89, p<0.0001). No significant relation of rein tension and the number of wins and placings, lifetime earnings, success and competition level was found (p>0.05).

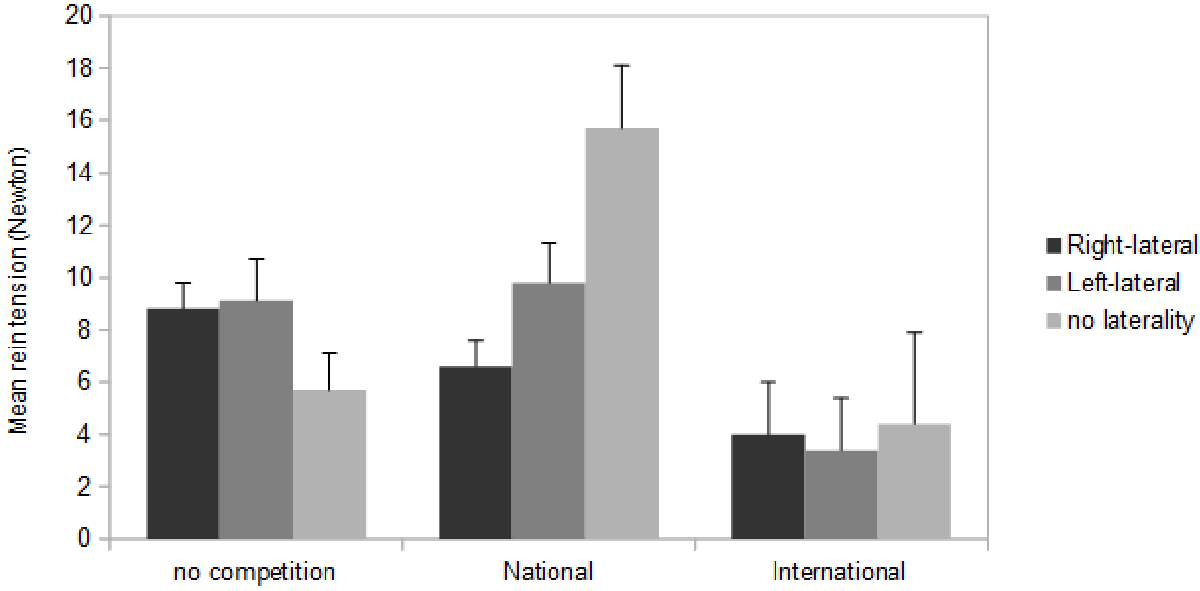


Figure 88: Comparison of mean rein tension[1] (Newton) at different competition levels of horse’s in relation to their laterality based on their rider’s assessment (106 horse-rider combinations, all types of bits, p<0.0001). [1]p-values of pairwise comparisons of effect level are available on request.

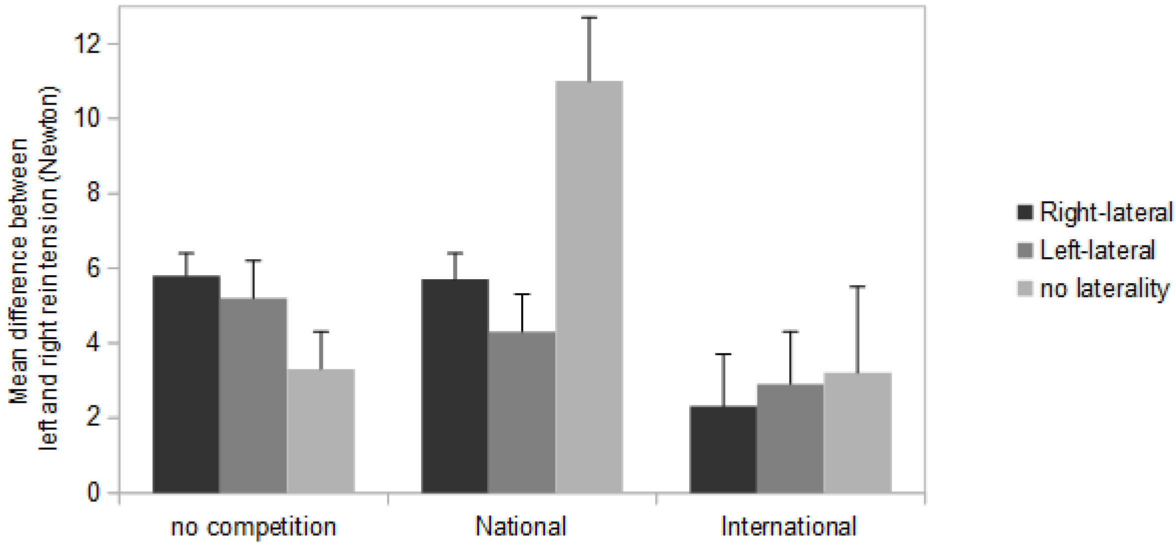


Figure 89: Mean difference of left and right rein tension[1] (Newton) as a measure to determine asymmetric rein tension at different competition levels of horse's in relation to their laterality based on their rider's assessment (106 horse-rider combinations, all types of bits, p<0.0001).

7.4.1.2 Rein tension parameters in relation to rider handedness, horse's laterality and previous injuries

Considering mean rein tension, rider handedness was significantly related to the side horses sustained injuries in (Table 8). Furthermore, regarding the mean difference of left and right rein tension, the different directions of laterality in horse-rider combinations were related to rider injuries (Table 9). However, numbers were low, especially when considering laterality in different horse-rider combinations (Tables 9 & 10), therefore results need to be re-evaluated with a larger sample size.

With horse injuries to the right side mean tension (Figure 90) was higher with left-handed riders. With horse injuries to the left side mean tension was similar between the directions of human handedness. With bilateral injuries of horses mean tension was lowest for ambidextrous riders (however, p>0.05; Figure 90) and similar for left-handed and right-handed riders. For mean peak tension, mean SD and the mean difference of left and right rein tension, no significant differences were found considering horse injuries (p>0.05).

Table 8: Mean rein tension[1] (Newton) in relation to rider handedness and previous horse injuries. Rein tension was compared between the different sides of injury within each direction of rider handedness. Horse injuries were defined as injuries to the locomotory system sustained within the past three years. [1]p-values of pairwise comparisons of effect level are available on request.

Handedness & horse injuries	Horse-rider combinations	Mean tension (N)
Left-handed		
none	11	7±1.5
bilateral	4	8.9±2.5
left	1	12.2±5.1
right	5	18.7±2.5
Right-handed		
none	53	8.9±0.8
bilateral	14	9±1.4
left	3	11.9±2.9
right	11	9.7±1.8
Ambidextrous		
none	1	3.5±5
bilateral	1	5.5±5
left	2	12±3.6
right	-	-
P[1]		0.02

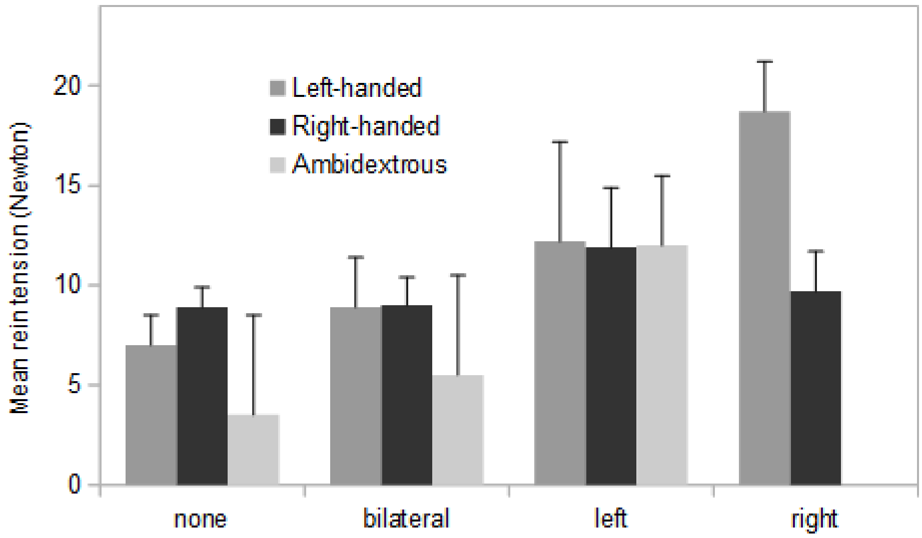


Figure 90: Comparison of mean rein tension[1] (Newton) to the side of reported previous injuries in horse's in relation to their rider's handedness (106 horse-rider combinations, all types of bits, p=0.02,). Horse injuries were defined as injuries to the locomotory system sustained within the past three years.

Injuries to the right hands, arms or shoulders as well as bilateral injuries occurred exclusively with combinations of right-handed riders, whereas rider injuries to the left were only detected in any combinations with left-handed riders, as well as right-handed riders and left-lateral horses (Table 9). Rein tension was most unstable in uninjured riders (spread of tension: 3.9±0.1N) compared to riders who sustained an injury to either the left or right side (both 3.5±0.1N). Spread of tension was smallest for riders with reported bilateral injuries (3.3±0.1N, p<0.0001). Rein tension was most asymmetric in right-handed riders with injuries to the left or right side (Figure 91).

Mean rein tension was highest with left-handed riders and left-lateral horses for bilateral injuries and injuries to the right (Table 10, Figure 92). Injuries to the left only occurred in combinations of right-lateral horses with right-handed and ambidextrous riders (Figure 92). In uninjured horses mean tension was highest for right-handed riders and horses without laterality and lowest for ambidextrous riders and right-lateral horses (Table 10, Figure 92).

Table 9: Rein tension parameters (Newton)[1] of different horse-rider combinations in relation to previous rider injuries. Rein tension was compared between the different sides of injury within each direction of rider handedness (Mean peak tension= mean of tension peaks only). Rider injuries were defined as injuries to the hands, arms or shoulder region sustained within the past three years.

Horse-rider combination & rider injury	Horse-rider combinations	Mean difference of left and right rein tension (N)
Ambidextrous & Right-lateral		
none	4	4.1±1.7
bilateral	-	-
left	-	-
right	-	-
Left-handed & Right-lateral		
none	7	4.7±1.4
bilateral	-	-
left	3	4.1±2
right	-	-
Left-handed & Left-lateral		
none	8	7.8±1.2
bilateral	-	-
left	1	5.3±3.5
right	-	-
Left-handed & no laterality		
none	1	2.5±3.5
bilateral	-	-
left	1	4.2±3.5
right		-
Right-handed & Right-lateral		
none	34	5±0.8
bilateral	2	3.7±3.5
left	-	-
right	2	11.6±2.4
Right-handed & Left-lateral		
none	20	5.9±1
bilateral	2	3.7±2.4
left	6	9.5±2

right	3	7±2
Right-handed & no laterality		
none	10	7.8±1.3
bilateral	-	-
left	-	-
right	2	11±2.4
P[1]		0.03

Table 10: Rein tension parameters (Newton)[1] of different horse-rider combinations in relation to previous horse injuries. Rein tension was compared between the different sides of injury within each direction of rider handedness (Mean peak tension= mean of tension peaks only). Horse injuries were defined as injuries to the locomotory system sustained within the past three years.

Horse-rider-combination & horse injury	Horse-rider combinations	Mean tension (N)
Ambidextrous & right-lateral		
none	1	4.2±4.9
bilateral	1	6.2±4.8
left	2	12.7±3.4
right	-	-
Left-handed & Right-lateral		
none	6	7.5±2.2
bilateral	3	6.6±2.8
left	1	12.8±4.8
right	-	-
Left-handed & Left-lateral		
none	4	9±2.5
bilateral	1	18.3±4.8
left	-	-
right	4	19.4±2.5
Left-handed & no laterality		
none	2	5.5±3.4
bilateral	-	-
left	-	-
right	-	-
Right-handed & Right-lateral		

none	26	8.5±1.2
bilateral	8	8.6±1.8
left	2	11.6±3.5
right	3	8.6±2.8
Right-handed & Left-lateral		
none	19	8.6±1.4
bilateral	6	11.5±2.2
left	-	-
right	5	11.5±2.2
Right-handed & no laterality		
none	11	13.4±1.7
bilateral	-	-
left	1	14.4±4.8
right	-	-
P[1]		0.02

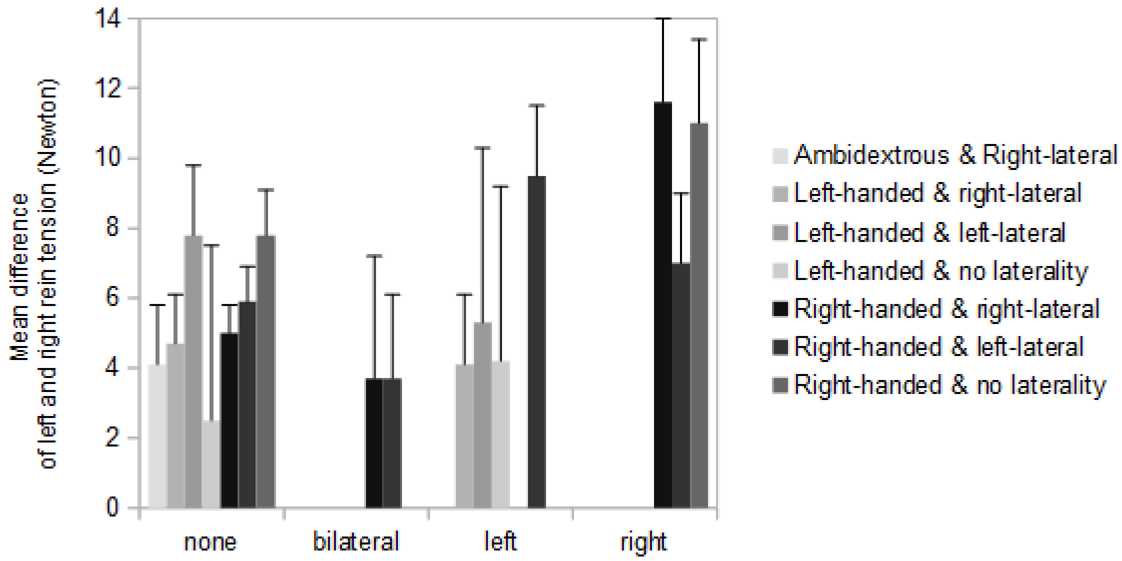


Figure 91: Comparison of the mean difference of left and right rein tension[1] (Newton) to the side of reported previous injuries in riders in relation to the direction of laterality in horse-rider combinations (106 horse-rider combinations, all types of bits, p=0.03). Rider injuries were defined as injuries to the hands, arms or shoulder region sustained within the past three years.

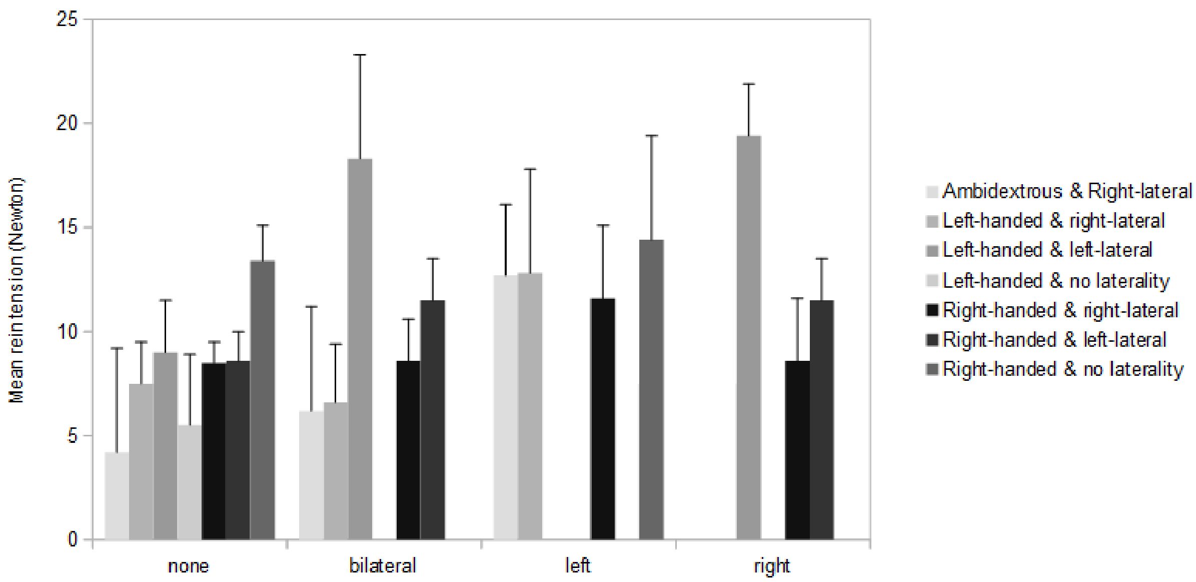


Figure 92: Comparison of mean rein tension[1] (Newton) to the side of reported previous injuries in horses in relation to the direction of laterality in horse-rider combinations (106 horse-rider combinations, all types of bits, p=0.02). Horse injuries were defined as injuries to the locomotory system sustained within the past three years.

7.4.1.3 The relation of trigger point reactions to the rider's perception of rein contact and harmony of the ride

Left-right difference of trigger point reactions (see chapter 3.9) was asymmetric in horses ridden with "instable" rein contact (0.1±0, p=0.03, Figure 93). Horses with tensed or very unharmonious rides showed indeed stronger trigger point reactions compared to harmonious rides (Figure 94). Strangely, strong trigger point reactions were also related to rides described as very harmonious, whereas horses with unharmonious rides showed less trigger point reactions than harmonious rides (p=0.04, Figure 94).

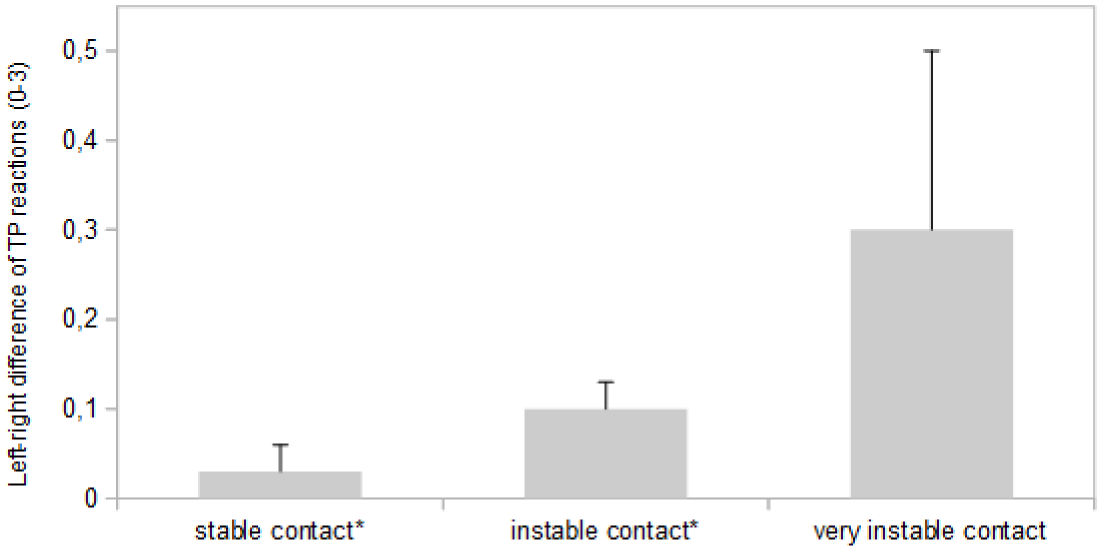


Figure 93: Left-right difference of trigger point reactions (Scale 0-3; 3= strong avoidance reaction) in relation to the rider's assessment of rein contact (110 rides with 88 horses, p=0.03, * indicate a significant difference at p<0.05, all other pairwise comparisons p>0.05).

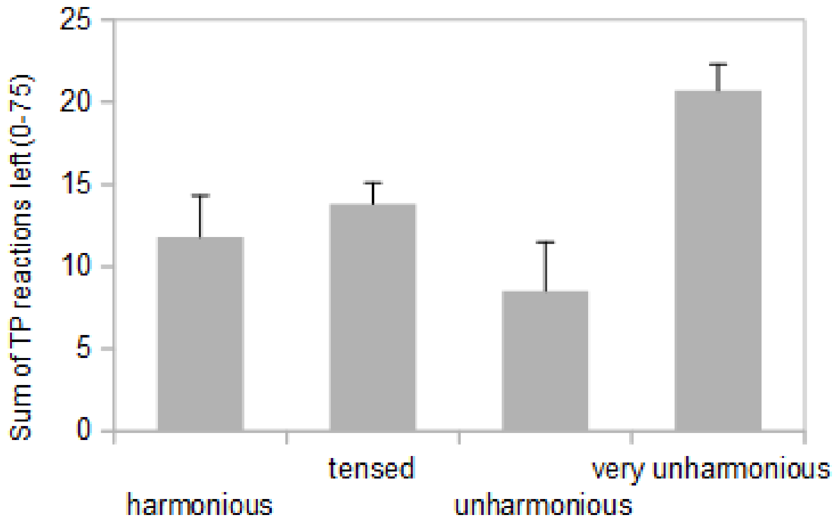


Figure 94: Sum of trigger point reactions for 25 "trigger points" on the horse's left side (Scale 0-3; 3= strong avoidance reaction)[1] in relation to the rider's assessment of harmony of the test ride (110 rides with 88 horses, p=0.04).

7.4.1.4 The relation of trigger point reactions to previous horse injuries

The sum of trigger point reactions of the horse's right side (p=0.047), but not of the horse's left side (p>0.05) was related to horse injuries. Horses that sustained bilateral injuries showed stronger trigger point reactions on the right side compared to horses with injuries to the left and right side only (Figure 95).

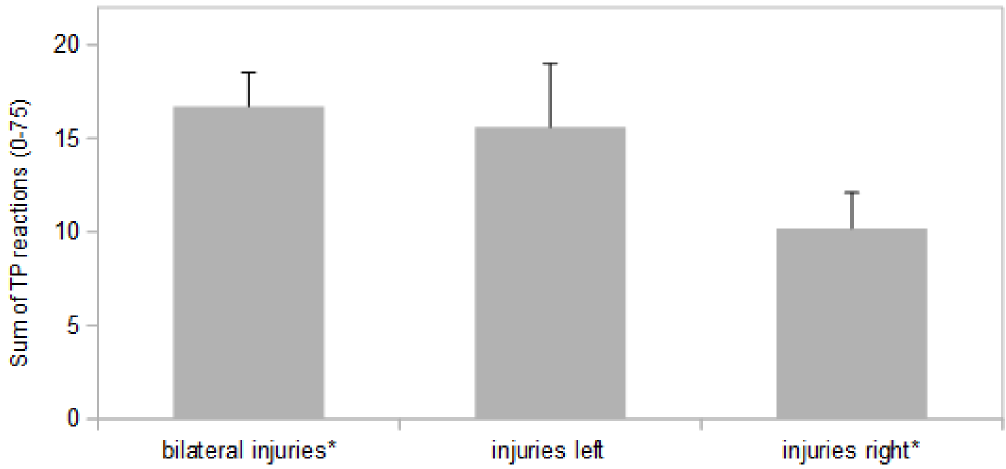


Figure 95: Sum of trigger point reactions of horse's right side (Scale 0-3; 3= strong avoidance reaction, maximum of 75) in relation to previous horse injuries (88 horses, p=0.047, *p=0.02, all other pairwise comparisons p>0.05). Horse injuries were defined as injuries to the locomotory system sustained within the past three years (bilateral n=19, left n=8, right n=18). * indicate a significant difference at p<0.05, all other pairwise comparisons p>0.05.

7.4.1.5 The relation of trigger point reactions to body symmetry in horses

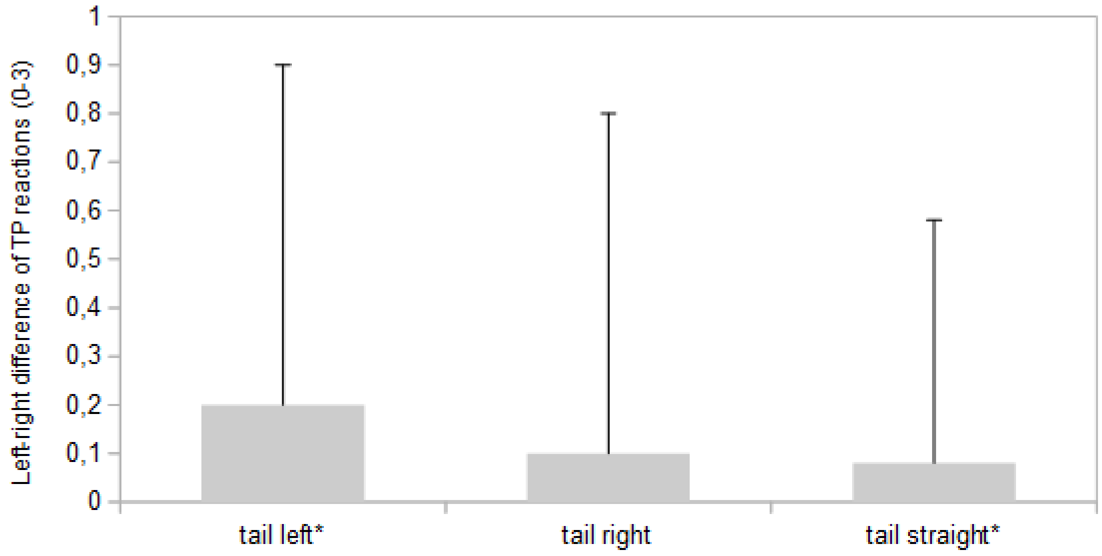


Figure 96: Left-right difference of trigger point reactions (mean of differences between individual trigger points, scale 0-3; 3= strong avoidance reaction) in relation to tail carriage (88 horses, p=0.03, *p=0.01, all other pairwise comparisons p>0.05). Asymmetric body postures (e.g. tail) is related to asymmetric tension in the muscles of the left vs. the right body side. * indicate a significant difference at p<0.05, all other pairwise comparisons p>0.05.

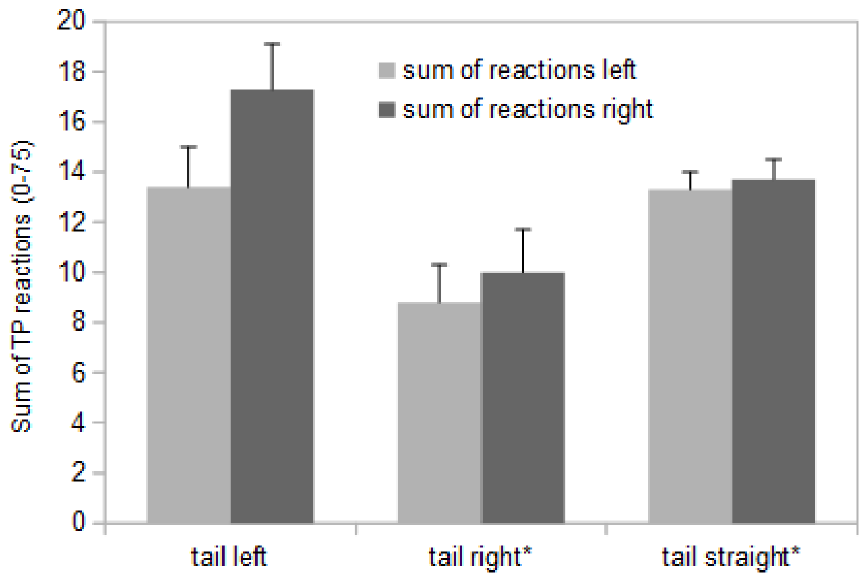


Figure 97: The sum of trigger point reactions of the left (p=0.01, + p=0.01, ° p=0.04, all other comparisons p>0.05) and the right body side (p=0.03, all other pairwise comparisons p>0.05) in relation to tail carriage. Tail asymmetries to either side were related to stronger muscle tension of the right body side. * indicate a significant difference at p<0.05 for sum of reactions left only, all other pairwise comparisons p>0.05.

Horses carrying their tail to the left showed less symmetric trigger point reactions compared to horses carrying their tail straight or to the right (p=0.03, Figure 96). Horses carrying their tail either left or right showed stronger trigger point reactions on the right body side (p=0.01) compared to the left (p=0.0.3, Figure 97), whereas trigger point reactions in horses carrying their tail straight were strong, but more symmetric (Figure 97).

7.4.1.6 The contribution of individual trigger point reactions to the total sum of trigger point reaction

The sum and symmetry of trigger point reaction was not related to riding style, laterality of horses or riders, the lateral displacement of the hindquarters, type of bit or bridle, rein handling, difficulties bending, the magnitude or symmetry of rein contact, the symmetry or stability of the rider's hands, age of horse or rider, rider experience, the horse's engagement of the hindquarters or either head or neck carriage (p>0.05).

Contribution of sensitive trigger points to the sum of reaction varied between both sides and individual trigger points. Sensitive trigger points of muscles associated with the movement of the limbs and lateral flexion showed the largest variation. Consequently, they were correlated highly with a large sum of reactions (Table 11).

The sum of trigger point reactions left and right were highly correlated (r=0.77, p<0.0001) indicating that most trigger points were sensitive bilaterally. A large sum of trigger point reaction on the left body side was mainly influenced by trigger points TP 9, 10, 14, 15, 16 (r>0.6, Figure 98, red dots) and TP 2-6, 8, 12, 13, 19-24 (r =0.4-0.6, p<0.0001, Figure 98, yellow dots).

A large sum of trigger point reaction on the right body side was mainly influenced by trigger points TP 9, 10, 14, 15, 21, 22 (r>0.6, p<0.0001, Figure 99, red dots) and TP 1-4, 7, 8, 12, 13, 16, 17, 19, 20, 23, 24 (r=0.4-0.6, p<0.0001, Figure 99, yellow dots).

Sensitive trigger points TP 1-3, 13, 15, 19, 23, 24, k1-k3 (r=0.3-0.5, Table 10, Figure 100, yellow dots) were weakly correlated to the left-right difference of trigger point reactions. Especially trigger points TP 7-10, 14, 20-22 (r>0.5, Table 12, Figure 100, red dots) contributed significantly to a larger left-right difference of trigger point reactions overall.

Figure 98: Individual trigger points of the left body side that showed large variation (Scale 0-3; 3= strong avoidance reaction) and thus correlated significantly with the total sum of trigger points of the left body side. Red dots = locations of trigger points with r>0.6; yellow dots = locations of trigger points with r=0.4 -0.6.

Figure 99: Individual trigger points of the right body side that showed large variation (Scale 0-3; 3= strong avoidance reaction) and thus correlated significantly with the total sum of trigger points of the right body side. Red dots = locations of trigger points with r>0.6; yellow dots = locations of trigger points with r=0.4 -0.6.

Figure 100: Individual trigger points that showed large variation bilaterally (Scale 0-3; 3= strong avoidance reaction) and thus correlated significantly with the left-right difference of trigger point reactions. Red dots = locations of trigger points with r>0.5; yellow dots = locations of weakly correlated trigger points with r=0.3 -0.5.

Table 11: Correlations of individual trigger points with the total sum of trigger point reaction. Individual trigger points of muscles associated with the movement of the limbs and lateral flexion (marked *) that showed the largest variation (Scale 0-3; 3= strong avoidance reaction) and contributed significantly to the total sum of trigger point reaction.

Trigger Points		**1**	**2***	**3**	**4***	**5***	**6***	**7***	**8***	**9***	**10***
Correlation to sum of trigger point reaction of the left side	r	0,245	0,384	0,453	0,497	0,439	0,449	0,318	0,388	0,639	0,583
	p	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Correlation to sum of trigger point reaction of the right side	r	0,373	0,510	0,405	0,395	0,346	0,250	0,440	0,463	0,624	0,564
	p	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Trigger Points		**11**	**12***	**13***	**14***	**15***	**16***	**17**	**18**	**19***	**20***
Correlation to sum of trigger point reaction of the left side	r	0,201	0,457	0,391	0,696	0,709	0,563	0,259	0,333	0,386	0,413
	p	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Correlation to sum of trigger point reaction of the right side	r	0,148	0,423	0,477	0,671	0,633	0,448	0,440	0,345	0,518	0,542
	p	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Trigger Points left		**21***	**22***	**23***	**24**	**25**	**k1**	**k2**	**k3**		
Correlation to sum of trigger point reaction of the left side	r	0,536	0,504	0,513	0,370	0,338	0,165	0,269	0,193		
	p	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001		
Correlation to sum of trigger point reaction of the right side	r	0,714	0,641	0,49	0,4	0,309	0,269	0,329	0,2		
	p	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001		

Table 12: Correlations of individual trigger points with the left-right difference of trigger point reactions. Individual trigger points (marked *) showed the larger variation (Scale 0-3; 3= strong avoidance reaction) and contributed significantly to the total sum of trigger point reaction.

Trigger points		**1**	**2**	**3**	**4**	**5**	**6**	**7***	**8***	**9***	**10***	**11**
Left-right difference (LRD) of trigger point reaction	r	0,319	0,391	0,379	0,079	0,080	0,181	0,536	0,545	0,509	0,470	-0,015
	p	0,001	0,000	0,000	0,416	0,410	0,061	0,000	0,000	0,000	0,000	0,877

Trigger points		**12**	**13**	**14***	**15**	**16**	**17**	**18**	**19**	**20***	**21***
Left-right difference (LRD) of trigger point reaction	r	0,119	0,300	0,525	0,433	0,227	0,140	0,113	0,430	0,509	0,464
	p	0,219	0,002	0,000	0,000	0,018	0,149	0,243	0,000	0,000	0,000

Trigger points		**22***	**23**	**24**	**25**	**K1**	**K2**	**K3**
Left-right difference (LRD) of trigger point reaction	r	0,474	0,355	0,260	-0,011	0,366	0,413	0,332
	p	0,000	0,000	0,007	0,914	0,000	0,000	0,001

7.4.2 Discussion

7.4.2.1 The magnitude and symmetry of rein tension in relation to horse's sport results

Previous research has indicated that similar to other sports (McManus 2002, Raymond & Pontier 2004, Clotfelter 2008) left-handed and ambidextrous humans might be more successful and compete at higher level than right-handed individuals (chapter 4). With the present sample however, this hypothesis could not be supported since indicators of sport success, such as the number of wins and placings and the competition level, were not significantly related to handedness, laterality, specific horse-rider-combinations or rein tension as such. Horses competing at international level were ridden with less, and more symmetric rein tension compared to horses at national competitions and leisure horses. However, significant differences were only observed for right-lateral horses and seem to be more influenced by riding style. The majority of horse-rider combinations competing especially on international level were Western riders, whereas most conventional European riders of this sample did not compete at all. A study by König von Borstel et al. (2013) supports this assumption, since in that study, conventional European riders showed lower rein tension the higher the competition level was, whereas rein tension of Western riders remained at approximately the same low to medium level regardless of competition level. Furthermore, some of horse-rider combinations at international competition level also used curb bits including curb chains during data collection (Data were not converted for this specific analysis). Both, the magnitude and symmetry of rein tension are influenced by the riding style (See 7.3) and the type of equipment used (See 7.3 and 7.6). Horses without reported laterality were ridden with the highest rein tension, regardless of competition level, further supporting the hypothesis that these horses seem to perform equally asymmetric and unbalanced (See 7.3). The large number of horses without laterality in the sample of competition horses, especially at national level might be explained by the fact, that the majority of competition horses were Western horses. In these horses riders perceived an absence of laterality more often than in those of the conventional European riding style.

7.4.2.2 Rein tension parameters in relation to rider handedness, horse's laterality and previous injuries

Previous research (chapter 4) has provided data leading to the assumption that the incidence of musculoskeletal injury in the human hands, arms and shoulder region and the horse's locomotory system might be related to laterality. This information was based on subjective reports of 686 riders and could not be reproduced with the present, much smaller sample. In the present study, the incidence of musculoskeletal injury in horses and riders was not related to laterality and handedness nor did injuries influence rein tension directly. However, human handedness and the direction of laterality in horse-rider-combinations seemed to influence rein tension in relation to injuries especially in horses. Rider injuries seem to be related to rider handedness and matching directions of laterality, since rider-injuries-right and rider-injuries-bilaterally occurred with combinations of right-handed riders only, whereas rider-injuries-left only occurred in combinations with left-handed riders and right-handed riders on horses without laterality. Mean tension was higher with horse injuries on the side of the rider’s non-dominant hand. With right-laterality in riders and horses an injury to any side or bilaterally could be observed. A horse injury on the left however, was not documented for any combination of left-lateral horses or riders. It seems that risk of injury in horses and riders is influenced to some extent by the combinations of laterality. The non-dominant side might be at higher risk in individual horses, whereas the opposite might be true for riders, contradicting previous results (chapter 4). Uninjured riders showed less stability and larger range of rein tension than riders who sustained unilateral or bilateral injuries. Riders who sustained unilateral injuries on either side showed asymmetric rein tension. One possible reason for the deviation of rein tension patterns in uninjured riders could be that those riders might be leisure riders who take less risk in general, however injuries in riders and horses was not related to their riding level. Another explanation could be that the injured structures might have forced the riders to adopt a persisting relieving posture (Wallden 2011). Musculoskeletal injuries have been linked to laterality in humans and horses in many studies (Stashak 1995, Pugh & Bolin 2004, Williams & Norris 2007). While the present results indicate that the laterality of horse-rider-combinations might be important, too, further research with larger samples of horses and riders with previous injuries is needed to identify influencing factors in horse-rider-communication affecting risk of musculoskeletal injury other than rein tension. Furthermore the present sample included several types of bits. The incidence of injuries to one side or the other is not affected by the type of bit used in the study. However, since rein tension values are lower with curb bits and the number of reported injuries was rather low, the relation of rein tension values should be evaluated on a larger sample with similar bits.

7.4.2.3 The relation of trigger point reactions to the rider's perception of rein contact and harmony of the ride

and

7.4.2.4 The contribution of individual trigger point reactions to the total sum of trigger point reaction

The muscle chains of the large muscle groups of the neck, abdomen and hindquarters enable the "collection" of the horse, which includes the horse going on the bit (Preuschoft 1976, Preuschoft et al. 1994a). Therefore, a balanced muscle state seems to be essential for horse's performance and health. In the present study, horses with rein contact that was perceived as "stable" showed more symmetric trigger point reactions as horses of rides with "instable" or "very instable" rein contact. A balanced muscle state rather than the absence of muscular tension and "trigger point reactions" seems to be required for a stable connection between the horse's mouth and the rider's hands and thus for horse-rider communication. In fact, the muscle groups responsible for protraction and retraction of the limbs were correlated with the sum of "trigger point reactions". Especially the muscles moving the shoulder and hip joint, stabilizing the spine and enabling lateral flexion (Budras & Röck 2000, Kienapfel et al. 2017) contributed most to the sum of "trigger point reactions" on both body sides and were most strongly correlated with asymmetric "trigger point reactions" indicating that quality of movement might influence muscular health and vice versa.

Horses with both "very harmonious" and "very unharmonious" rides showed stronger trigger point reactions on the left than "unharmonious" or "tensed" rides indicating that the rider's perception of "harmony" might have been more focused on rein tension than on the suppleness of the horse. Therefore, rein contact might be a more suitable variable to assess horse-rider communication.

7.4.2.5 The relation of trigger point reactions to previous horse injuries

Horse injuries were related to the sum of trigger point reactions of the right side. Especially with bilateral injuries the sum of trigger point reactions of the right side was higher than with an injury to either side alone. Since mean peak tension was higher in the right rein in all horse-rider-combinations (See 7.3), a larger sum of trigger point reaction might be supported by high rein tension. Muscle state has been reported as a factor influencing horse's health and especially lameness before (Dyson & Murray 2003). Tensed and asymmetric muscle chains lead to compensative changes in posture and possible overload of structures in humans and horses (Dyson &

Murray 2003, Wallden 2011). Testing “trigger point reactions” might therefore be a measure to detect and treat possible issues and prevent injuries.

7.4.2.6 The relation of trigger points to body symmetry in horses

One-sided tail carriage in horses is a situation that is well-known to many horse owners and has often been discussed e.g. in common horse riding magazines. However, scientific research is scarce. Tail carriage to one side was associated with a higher sum of trigger point reactions on the right body side and horses carrying their tail to the left showed a larger difference of left and right trigger point reactions. These results suggest again that muscle balance might be more important for performance than the absence of sensitive muscle trigger points. Asymmetric muscles seem to be directly related to the horse’s posture. Correlations of single trigger points with tail carriage were very low. However, the muscles moving the horse’s tail were not included in the sample of tested trigger points. Still, the cause of horse’s carrying their tail to one side might not only be the muscles as such. Tension and asymmetries of muscle chains as a result of osteopathic lesions have been reported for humans before (Wallden 2011) and might be another possible explanation.

The hindquarters were displaced to either the left or right side in both right-lateral and left-lateral horses of the present sample (See 7.3). However, trigger point reactions were not directly related to laterality or the lateral displacement of the hindquarters, even though muscles involved in lateral flexion (Budras & Röck 2017, Kienapfel et al. 2017) contributed to the sum of trigger point reactions of both sides with different proportions. A good muscular state could be affected by a large variety of influencing factors. However, no significant difference of muscle state according to handedness, equipment, riding style and different attributes of horse-rider communication was documented, indicating that the horse’s muscular system might also have the ability to compensate negative influences to some extent. Especially with regard to horse-rider-communication and the identification of possible influencing factors for risk of musculoskeletal injury, muscle state and trigger point reactions should be included in future research.

7.4.3 Conclusion

7.4.3.1 The incidence of injuries

It seems that musculoskeletal injuries in horses and riders are supported by matching directions of laterality. The non-dominant side might be at higher risk in horses, whereas the opposite might be true for riders. Injuries were related to laterality in horse-rider-combinations and higher rein tension e.g. with horse injuries on the rider's non-dominant side. However, further evaluations with larger numbers of previously injured individuals and similar equipment are required.

7.4.3.2 The horse's muscular system

Quality of movement seems to influence the horse's muscular system and vice versa. The results of testing trigger points suggest that muscular balance is important for horse's health and performance as well as for horse-rider-communication. Muscles which are tensed up asymmetrically may lead to horses being tensed overall, thus adopting asymmetric postures, diminishing horse-rider-communication and increasing the risk of musculoskeletal injury. Checking the horse's muscular health should be regarded with higher priority in order to improve communication and horse's health, thus possibly preventing horse injuries. Rein contact might be a more suitable variable to assess horse-rider communication than the perception of a "supple" horse. To improve rider's subjective assessment of rein tension, as well as to increase symmetry, the regular use of a rein tension device for self-control during training seems advisable. Monitoring rein tension might help to improve training and reduce the risk of musculoskeletal injury in horses and riders.

7.5 Other factors that might influence rein tension, symmetry and performance in horse-rider combinations

7.5.1 Results

7.5.1.1 Rein tension parameters in relation to different riding styles and horse breeds

Mean rein tension of horses bred for Western riding was lower compared to breeds for conventional European riding (i.e. a variety of mostly warmblood and pony breeds , Figure 101, p<0.0001).

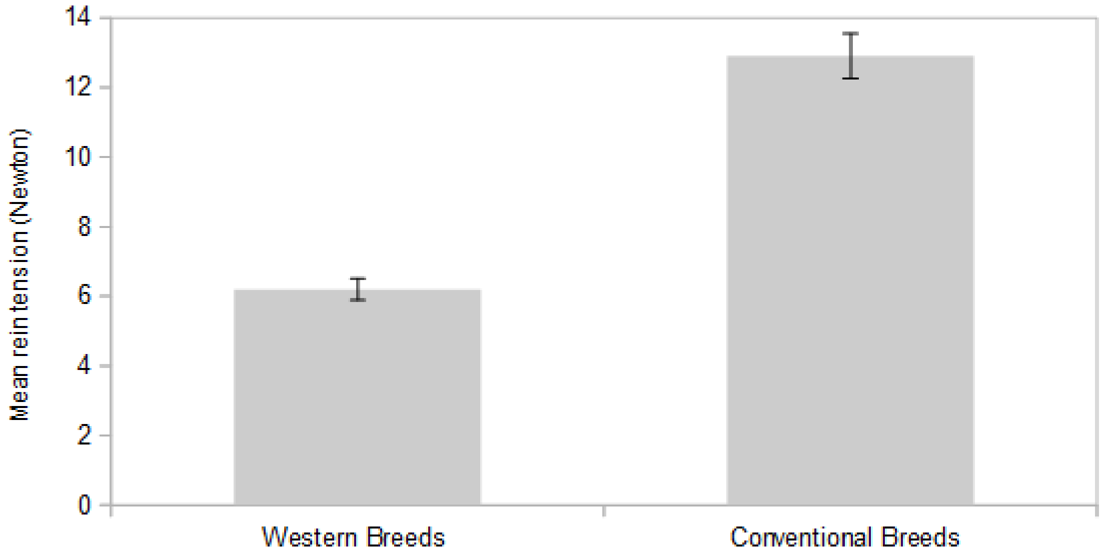


Figure 101: Comparison of mean rein tension (Newton) in Western (n=50 rides) versus breeds for conventional European riding (n=60 rides, all p<0.0001).

Rein tension of American Quarter Horses was lower and more symmetric in Western riding, compared to warmbloods and other mixed breeds (Figure 102, p=0.03) in either Western or conventional European riding (Figure 103, p=0.0004).

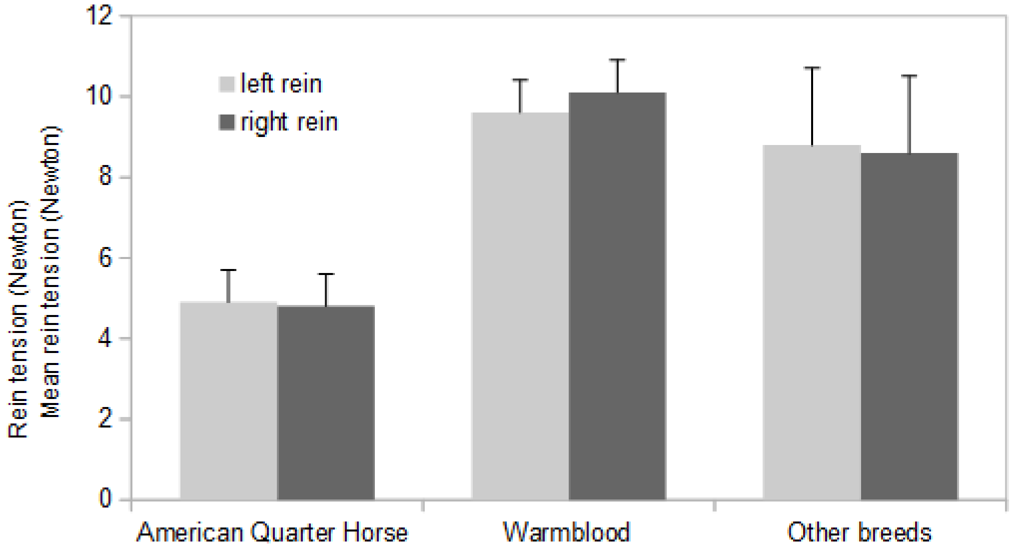


Figure 102: Comparison of the symmetry of mean rein tension[1] (left versus right rein; Newton) in American Quarter Horses (n=44 rides), warmbloods (n=36 rides) and other breeds (n=30 rides, p=0.03). [1]p-values of pairwise comparisons of effect level are available on request.

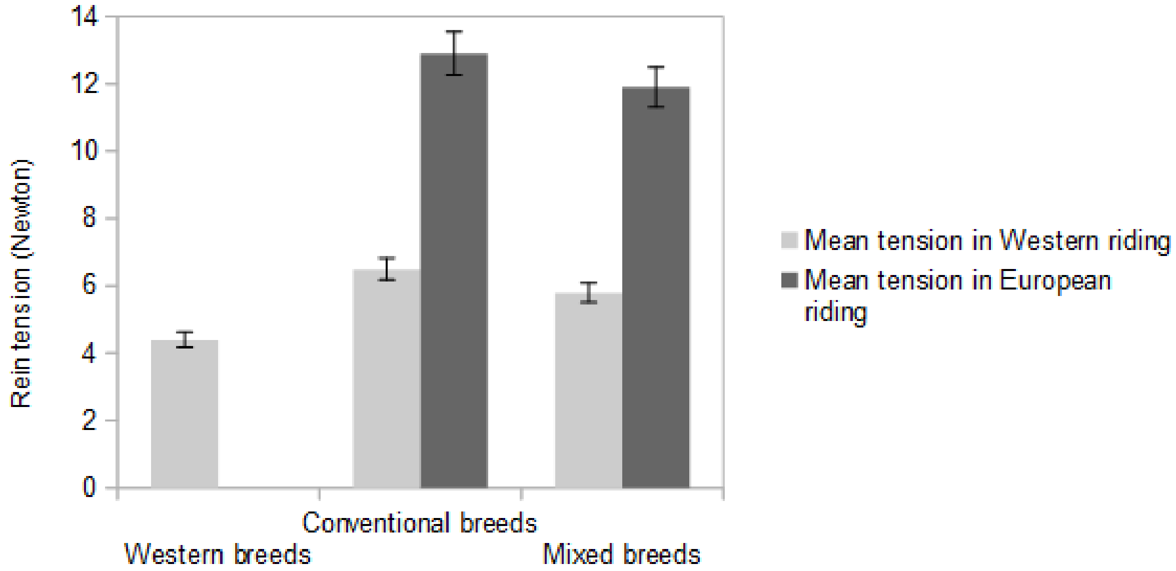


Figure 103: Comparison of the magnitude of mean rein tension overall[1] (Newton) in Western breeds (n=51 rides), breeds for conventional European riding (n=48) and horses of mixed breeds (n=11) in Western versus conventional European riding (p=0.0004).

Horses bred for western riding revealed lower spread of tension (p=0.003, Table 13) compared to breeds used mainly for conventional European riding and mixed breeds in conventional European riding. Even though mean tension did not differ significantly in Western riding, mean SD was lower for breeds used mainly for conventional European riding and horses of mixed breeds in Western riding compared to Western breeds (p=0.003, Table 13). Mean tension was most symmetric with any laterality in American Quarter Horses and most asymmetric in mixed breeds without reported laterality (Figure 104).

Table 13: Comparison of mean standard deviation, mean spread of rein tension (mean tension of left rein – mean tension of right rein) and mean difference of left and right rein tension (Newton) as measures to determine stability and symmetry of rein tension in Western breeds, breeds used mainly for conventional European riding and horses of mixed breeds in Western versus conventional European riding. [1]p-values of pairwise comparisons of effect level are available on request.

	Number of rides	Mean SD (N)	Mean spread of tension (N)	Mean difference of left and right rein tension
Western breed in Western riding	51	2.1±0.1	2.9±0.1	3±0.4
Conventional breed in Western riding	5	1.7±0.5	3.2±0.5	2.8±2.9
Conventional breed in conventional European riding	43	2.1±0.1	3.8±1.1	8±0.5
Mixed breeds in Western riding	3	1.4±0.2	3±0.1	1.7±2.9
Mixed breeds in conventional European riding	8	2.1±0.2	3.7±0.2	8.5±1.5
P[1]		p=0.003	p=0.003	p<0.0001

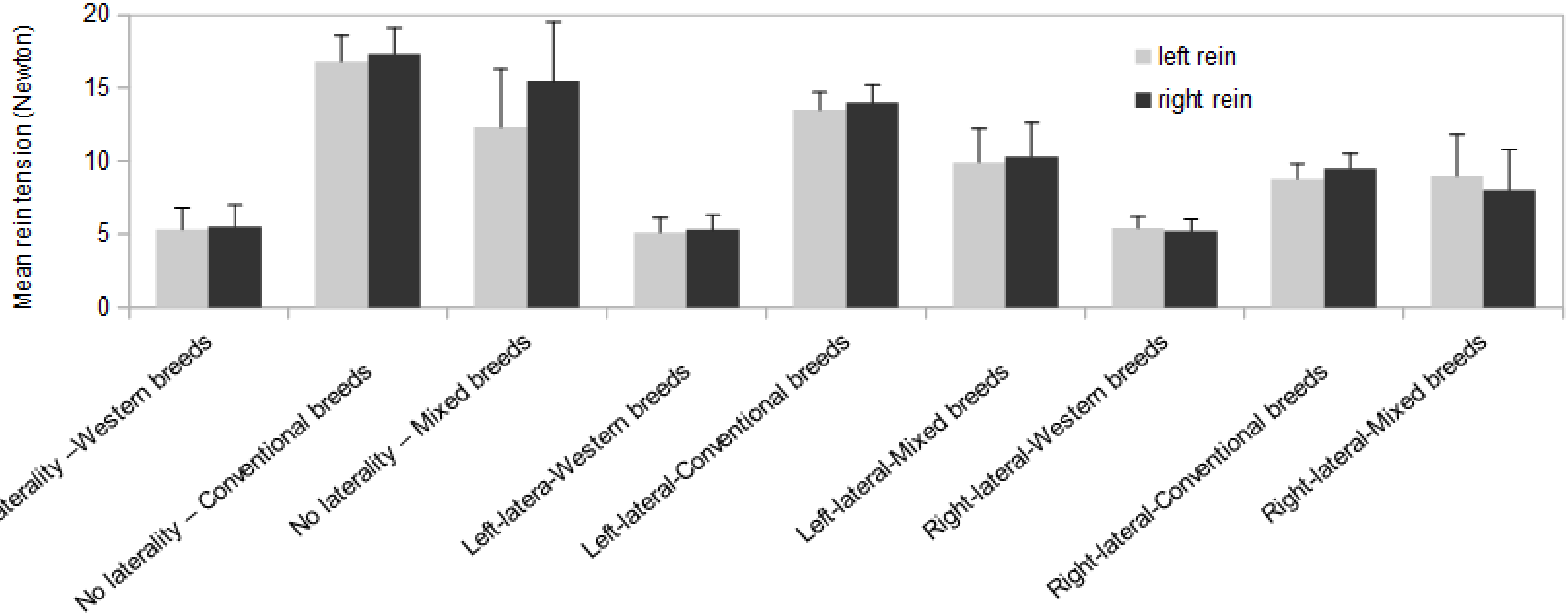


Figure 104: Comparison of mean tension in the left and right rein[1] (Newton) of Western breeds (n=51 rides), breeds used mainly for conventional European riding (n=48 rides) and mixed breeds (n=11 rides) in relation to horse's direction of laterality (all p<0.0001).

7.5.1.2 The magnitude and symmetry of rein tension in riders performing additional sports

Rein tension revealed a smaller spread of tension in riders who were active in equitation only (35.4±7.5N vs. 48.9±8.8N additional sports, p=0.046). Mean standard deviation as a measure to determine stability of rein contact as well as mean rein tension did not reveal a significant difference between riders who were active in additional sports vs. equitation only (p>0.05).

7.5.1.3 The magnitude and symmetry of rein tension in relation to rider's familiarity with the horse

Riders who were unfamiliar with the respective horses applied less mean tension (Figure 105, p=0.049) and more symmetric tension (mean difference of left and right rein tension, Figure 105, p=0.032) than riders who were well-acquainted with their horse. Time shift was lower in familiar horse-rider combinations too (0.02±0.03 sec. vs. unfamiliar: 0.05±0.07 sec., p=0.005). Mean standard deviation as a measure to determine stability of rein contact did not reveal a significant difference between well-acquainted horse-rider combinations and riders who were unfamiliar with their horse (p>0.05).

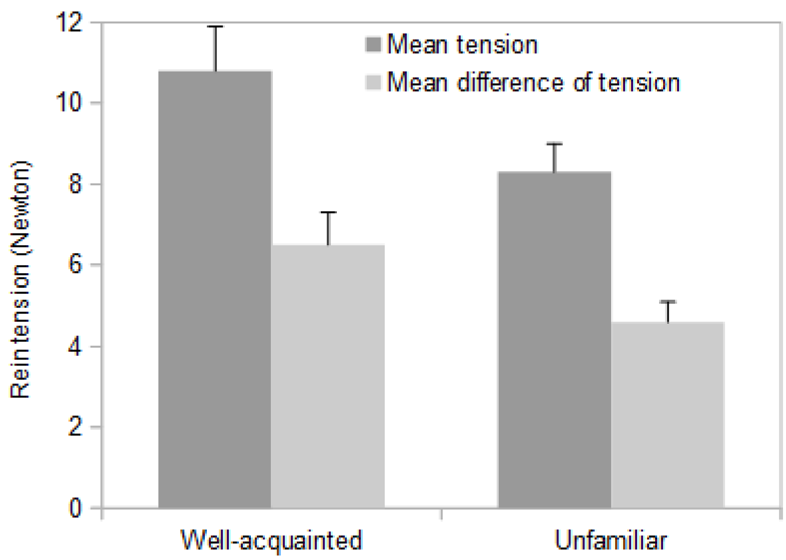


Figure 105: Comparison of mean rein tension (Newton, all p=0.049) and mean difference of left and right rein tension (Newton, all p=0.032) as a measure to determine symmetry between well-acquainted horse-rider combinations (82 combinations) and riders who were unfamiliar with their horse (24 combinations).

7.5.1.4 Rein tension parameters in relation to the rider's assessment of the magnitude of their own rein contact

Riders assessing their own contact as "very strong" had indeed significantly higher rein tension (e.g. mean tension) compared to strong or light contact (Table 14, Figure 106, p<0.0001). No significant difference of mean standard deviation according to rider's assessment of their own rein contact was found (p>0.05). Rein tension was most symmetric with contact assessed as "light" compared to medium or strong contact. Rein contact that was assessed as "very strong" was most asymmetric (Figure 106). The stronger rider's assessed their own contact, the greater the spread of rein tension and the higher mean and mean peak tension were recorded (Table 12, p<0.0001).

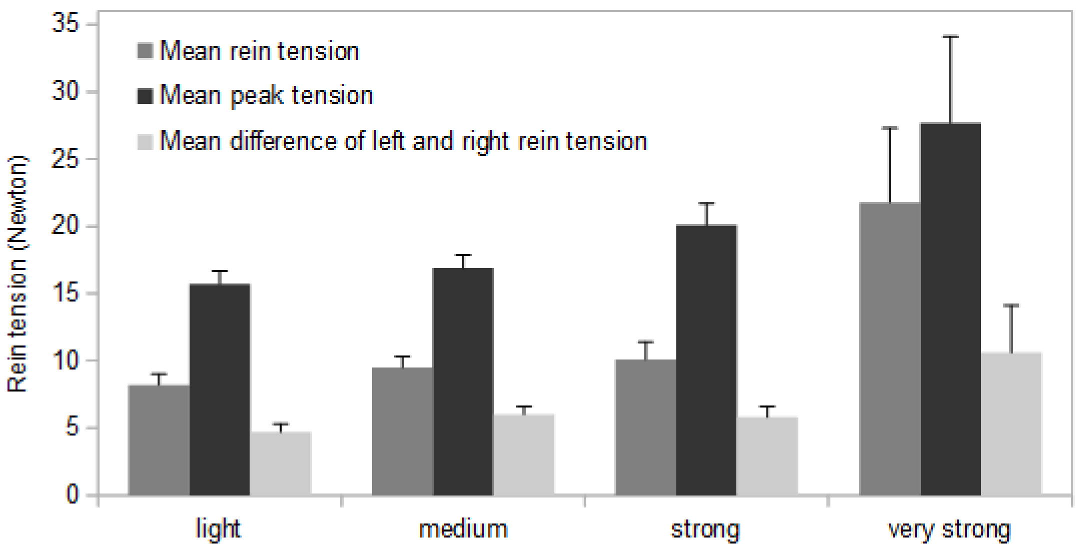


Figure 106: A comparison of rein tension parameters[1] (Newton) with the rider's assessment of their own rein contact overall (94 rides with snaffle bits and bitless bridles, mean tension p=0.0007, mean peak tension p<0.0001, mean difference of left and right rein tension p=0.001)

Table 14: A comparison of rider's assessment of their own rein contact overall (94 rides with snaffle bits and bitless bridles) and in relation to their handedness and their horse's laterality with rein tension parameters (Newton)[1].

Rider's assessment of their own rein contact overall	Number of rides	Mean tension (N)	Mean peak tension (N)	Mean difference of left and right rein tension (N)	Spread of tension (N)
Light	40	8.2±0.8	15.7±1	4.7±0.6	28.1±8.8
Medium	34	9.5±0.8	16.9±1	6±0.6	29.7±8.9
strong	19	10.1±1.3	20.1±1.6	5.8±0.8	53.4±10.5
very strong	1	21.8±5.5	27.7±6.4	10.6±3.5	55±29.6
P[1]		0.007	<0.0001	0.001	<0.0001
Rider's assessment of their own rein contact with left-lateral horses					
light	14	9.8±1.3	17.3±1.6	5.7±0.8	
medium	14	11.2±1.3	18.2±1.6	8.4±0.8	
strong	7	16.6±2.8	30.1±3.3	8.3±1.8	
very strong	-	-	-	-	
Rider's assessment of their own rein contact					

with right-lateral horses					
light	20	7.7±1.2	13.8±1.5	3.7±0.8	
medium	17	8.9±1.2	18.2±1.6	5.5±0.8	
strong	11	9±1.5	17.3±1.8	5.8±1	
very strong	1	21.3±4.1	27.7±5.8	10.8±2.5	
Rider's assessment of their own rein contact with horses without laterality					
light	6	12.2±2.3	19.7±2.6	7.9±1.5	
medium	3	9.7±2.3	16.1±3.4	5.2±1.5	
strong	1	6.9±3.4	12.3±4.3	4.1±2.4	
very strong	-	-	-	-	
P[1]		0.039	0.0002	<0.0001	>0.05
Left-handed rider's assessment of their own rein contact					
light	8	10.9±1.8	17.5±2	4.6±1.1	
medium	7	12.5±1.8	21.1±2	8.3±1.2	
strong	4	8.6±1.8	17.6±3.2	4.7±1.6	
very strong	-	-	-	-	

Right-handed rider's assessment of their own rein contact					
light	32	8.3±1.1	15.2±1.4	4.8±0.7	
medium	24	9.6±1.1	16±1.5	5.7±0.7	
strong	14	11.2±1.5	20.8±1.8	6.3±1	
very strong	1	21.3±3.9	27.7±6.3	10.6±3.5	
Ambidextrous rider's assessment of their own rein contact					
light	-	-	-	-	
medium	3	7.2±3.7	15.2±1.1	3.5±2.3	
strong	1	14.3±4.4	22.1±6.3	5.9±3.5	
very strong	-	-	-	-	
P[1]		0.03	0.03	<0.0001	>0.05

Regarding the horse's laterality, riders were able to assess differences of the magnitude of rein tension for left-lateral horses but showed difficulties in differentiating between "strong" and "medium" contact in right-lateral horses. "Light" rein contact in horses without reported laterality was assessed incorrectly as "strong" and vice versa (Table 14, Figure 107 & 108). Rein tension peaks of left-lateral horses with "strong" rein contact were actually higher than those of "very strong" contact (Figure 108). In horses without reported laterality, rein tension was more symmetric, the stronger the rein contact was perceived by the riders (mean difference of left and right rein tension, Table 14).

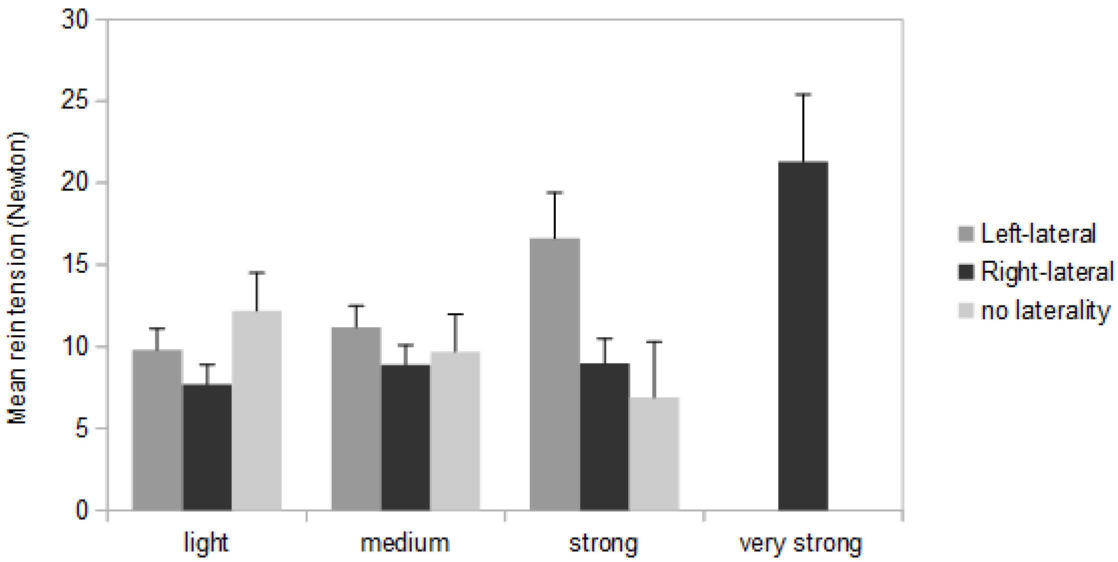


Figure 107: A comparison of mean rein tension[1] (Newton) with the rider's assessment of their own rein contact in relation to their horse's laterality based on the rider's assessment (94 rides with snaffle bits and bitless bridles, p=0.039).

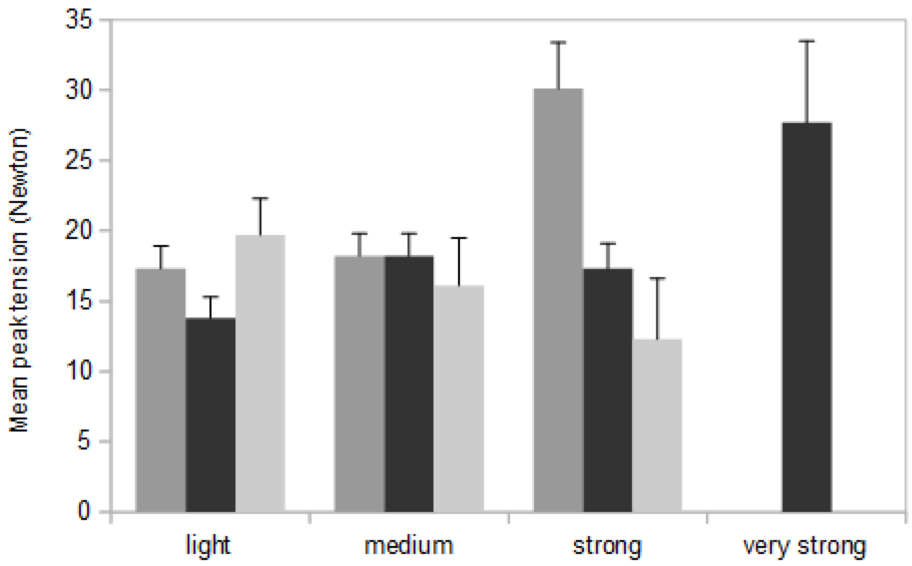


Figure 108: A comparison of mean peak rein tension[1] (Newton) with the rider's assessment of their own rein contact in relation to their horse's laterality based on the rider's assessment (94 rides with snaffle bits and bitless bridles, p=0.0002).

Right-handed and ambidextrous riders assessed their own mean rein tension appropriately (Figure 109). In contrast, left-handed riders showed mismatching assessments of their own rein contact (e.g. the lightest mean tension was found with rider's assessing their own rein contact as "strong", Figure 109, p=0.0008). Regardless of their handedness, all riders assessed their own mean peak tension appropriately (Table 14, p=0.03).

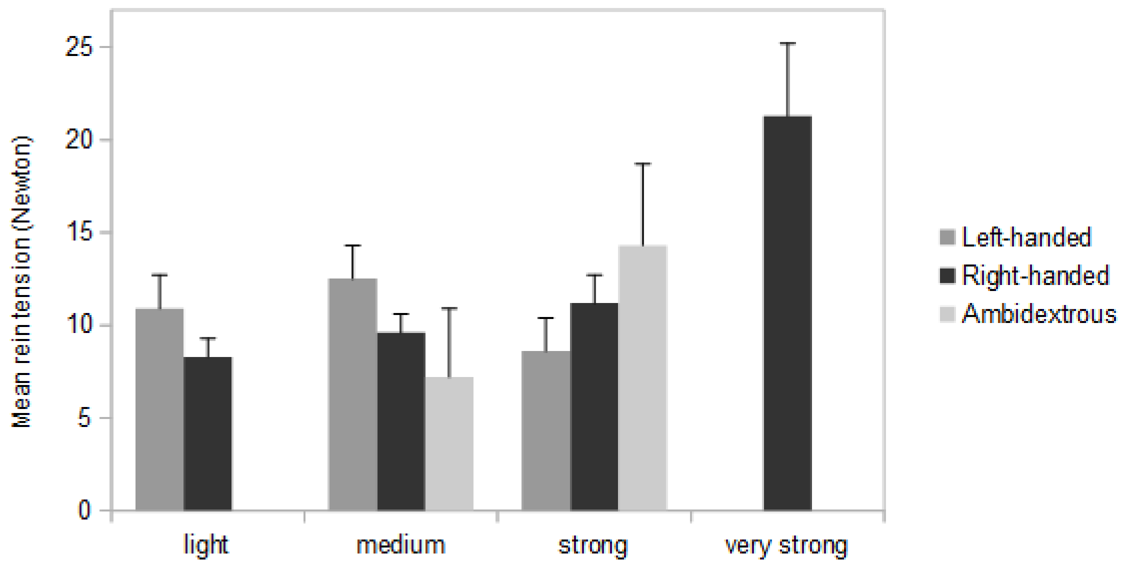


Figure 109: A comparison of mean rein tension[1] (Newton) with the rider's assessment of their own rein contact in relation to their handedness (94 rides with snaffle bits and bitless bridles, p=0.03).

7.5.1.5 Rein tension parameters in relation to the rider's assessment of symmetry

Performances perceived as symmetric showed higher mean tension (Figure 110) and larger spread of tension than asymmetric performances (spread of tension: symmetric= 42.3±5.7N versus asymmetric= 36.2±4.9N, p<0.0001). Except for horses without reported laterality, mean rein tension did not differ between symmetric and asymmetric performances (Figure 110) and the quantitative asymmetry (i.e. the mean difference of left and right rein tension) was actually higher in rides described as asymmetric (Figure 111, p=0.04).

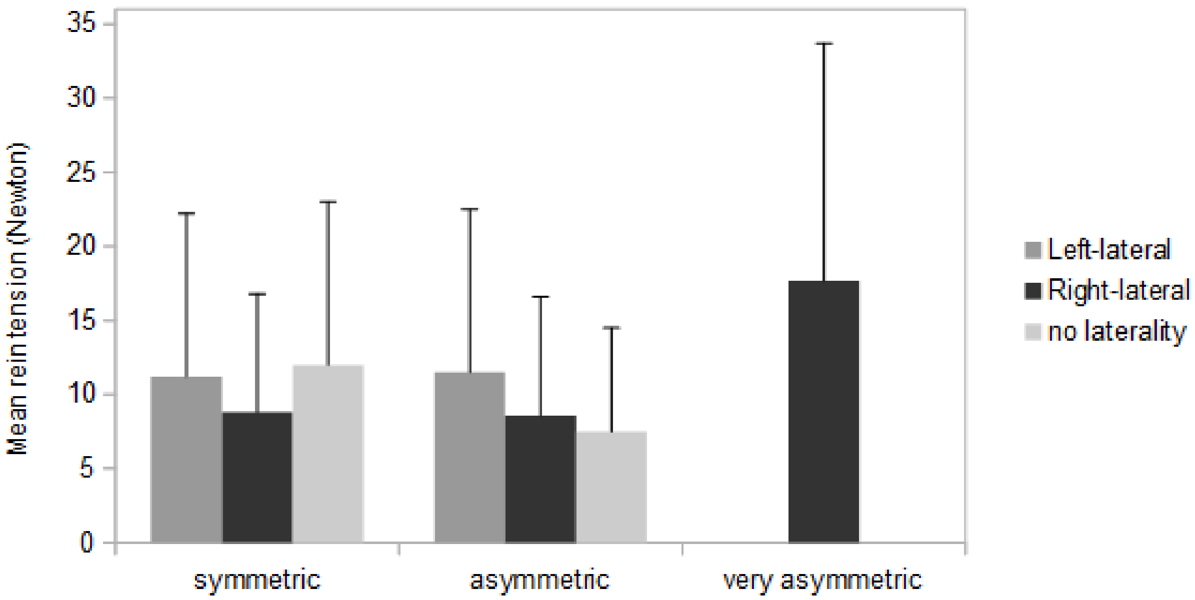


Figure 110: A comparison of mean rein tension[1] (Newton) with the rider's assessment of the test ride's symmetry of rein tension in relation to their horse's laterality based on the rider's assessment of the horse's suppler side (94 rides with snaffle bits and bitless bridles, p=0.03)

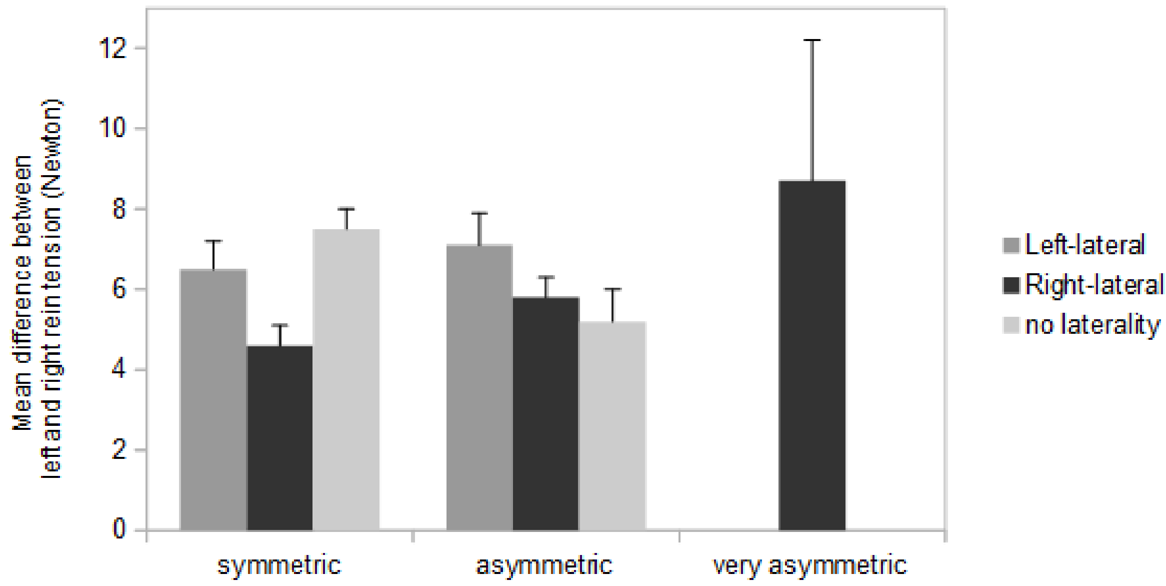


Figure 111: A comparison of the mean difference of left and right rein tension[1] (Newton) with the rider's assessment of the test ride's symmetry of rein tension in relation to their horse's laterality based on the rider's assessment (94 rides with snaffle bits and bitless bridles, p=0.04)

7.5.1.6 Rein tension parameters in relation to the rider's assessment of stability of their own rein contact

Mean rein tension (p=0.0005) and mean peak tension (p=0.005) increased with decreasing stability of rein contact overall as assessed by the riders (Figure 112). The spread of rein tension hardly differed between stable and unstable rein contact, but was distinctly larger in contact assessed as "very unstable" (Figure 113). Rein contact was more asymmetric the less the rein contact was perceived as stable (Figure 114).

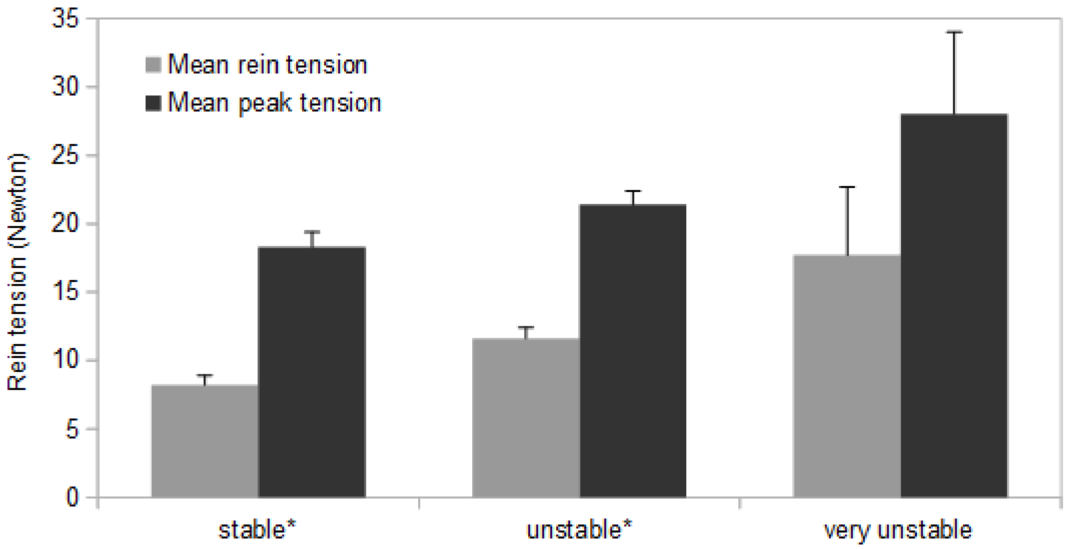


Figure 112: Rider's assessment of the stability of their own rein contact (94 rides with snaffle bits and bitless bridles) in relation to mean rein tension (Newton, p=0.0005, *p<0.05, all other pairwise comparisons p>0.05) and mean peak tension (Newton, p=0.005, * p<0.05, all other pairwise comparisons p>0.05)

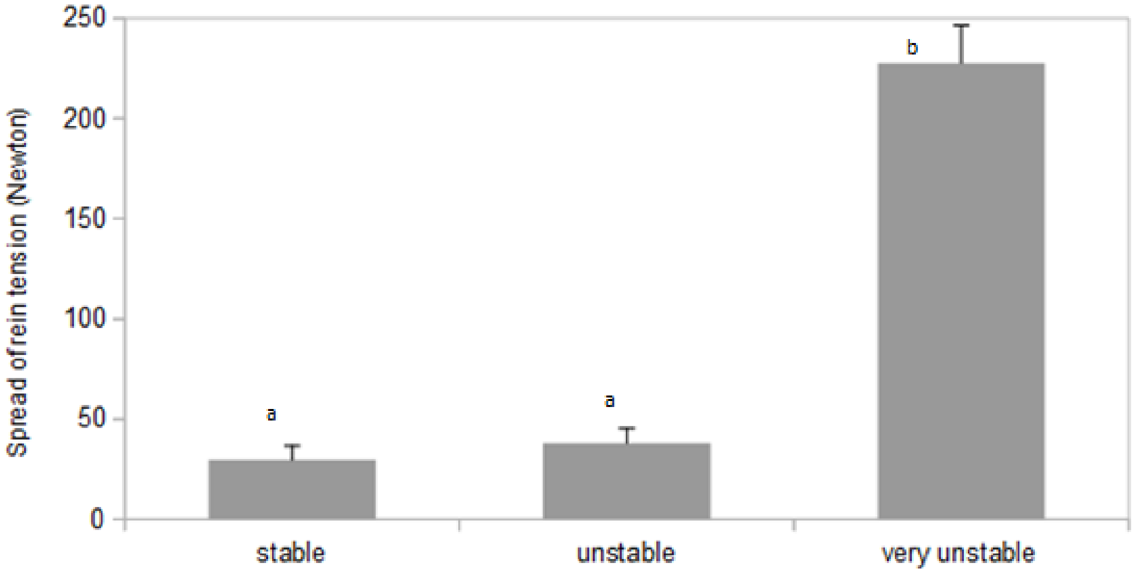


Figure 113: Rider's assessment of the stability of their own rein contact (94 rides with snaffle bits and bitless bridles) in relation to the spread of rein tension (p<0.0001), different letters indicate a significant difference at p<0.05

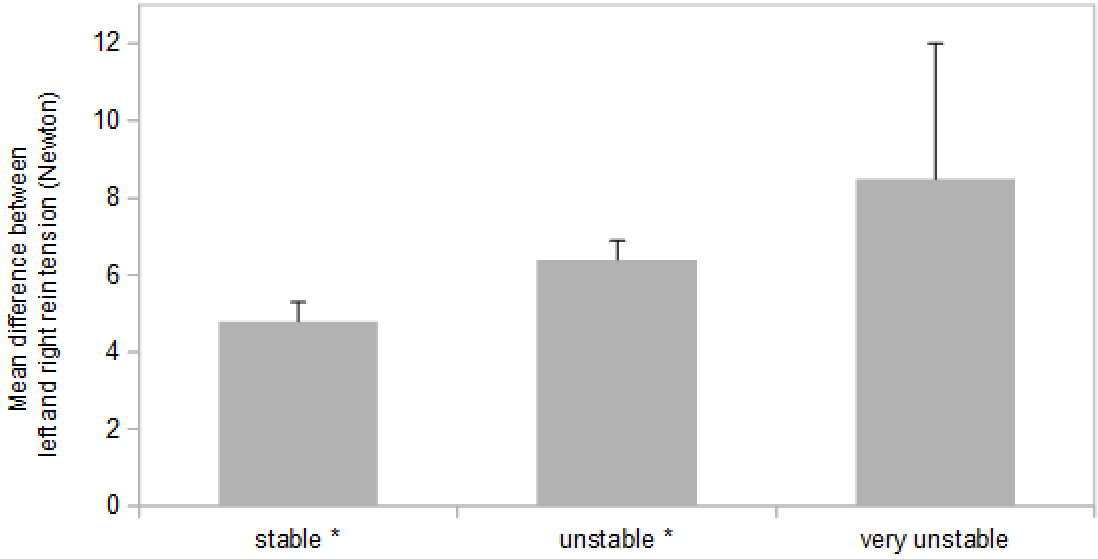


Figure 114: Rider's assessment of the stability of their own rein contact (94 rides with snaffle bits and bitless bridles) in relation to the quantitative symmetry (mean difference of left and right rein tension, p=0.02). * indicate a significant difference at p<0.05, all other pairwise comparisons p>0.05

Except for horses without reported laterality, mean tension increased with decreasing stability of rein contact for left-lateral and right-lateral horses (Figure 115, p=0.0009). The same was observed in left-handed, right-handed and ambidextrous riders (Figure 116, p=0.01). Spread of tension was larger for unstable contact in relation to rider handedness as well as horse's laterality and indeed almost quadrupled for contact perceived as "very unstable" (Figures 117 & 118).

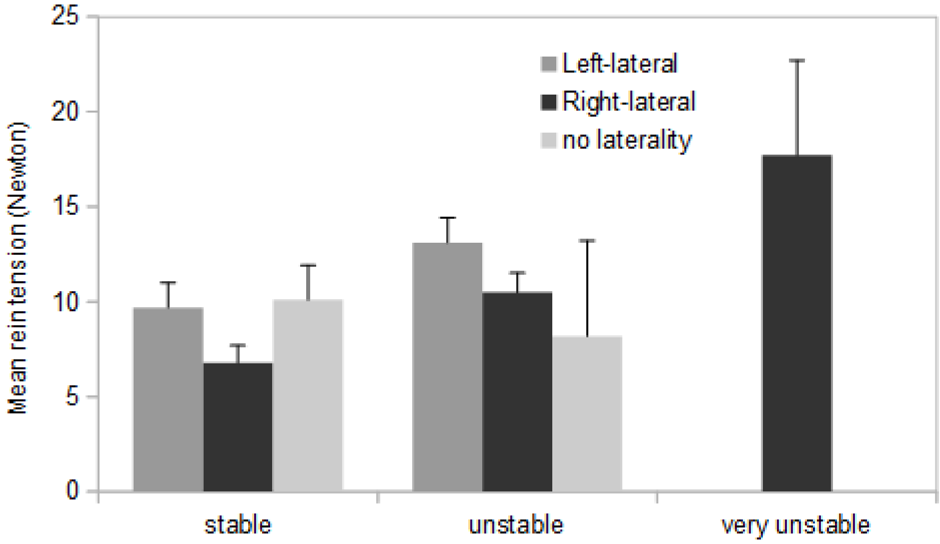


Figure 115: A comparison of the mean rein tension[1] (Newton) with the rider's assessment of the stability of rein tension in relation to their horse's laterality based on the rider's assessment (94 rides with snaffle bits and bitless bridles, p=0.0009)

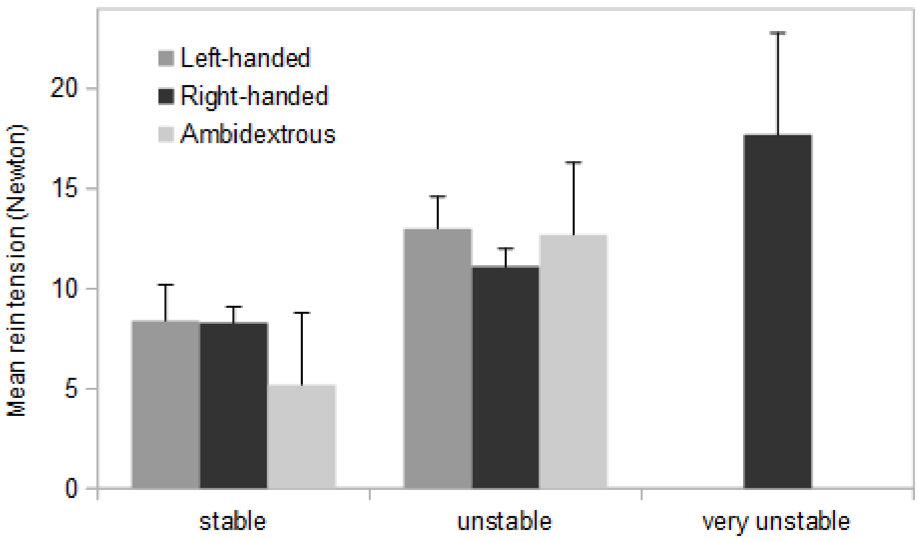


Figure 116: A comparison of mean rein tension[1] (Newton) with the rider's assessment of the stability of rein tension in relation to their own handedness (94 rides with snaffle bits and bitless bridles, p=0.01)

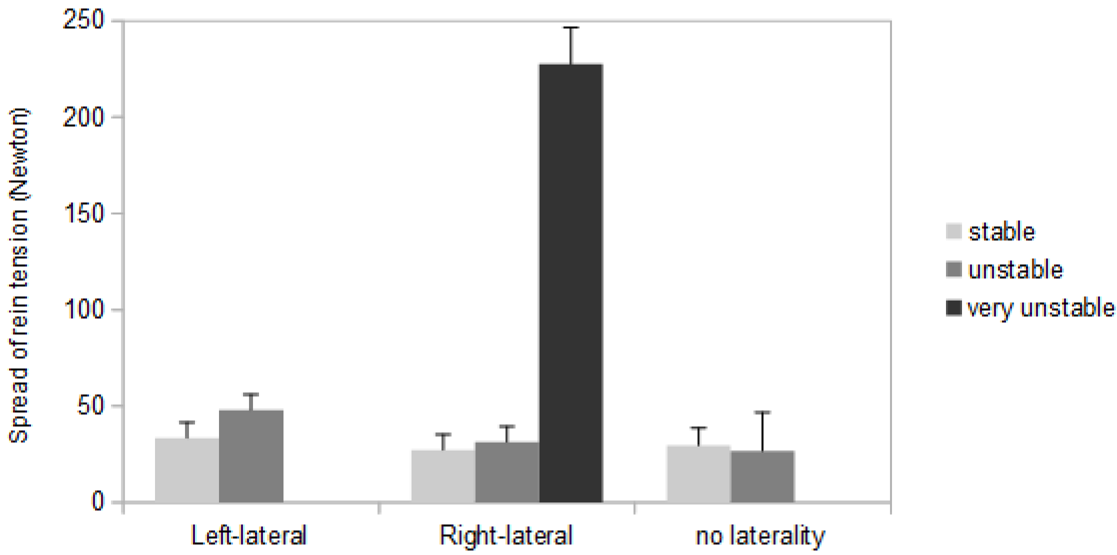


Figure 117: A comparison of the spread of rein tension[1] (Newton) with the rider's assessment of the stability of rein tension in relation to their horse's laterality (94 rides with snaffle bits and bitless bridles, p<0.0001).

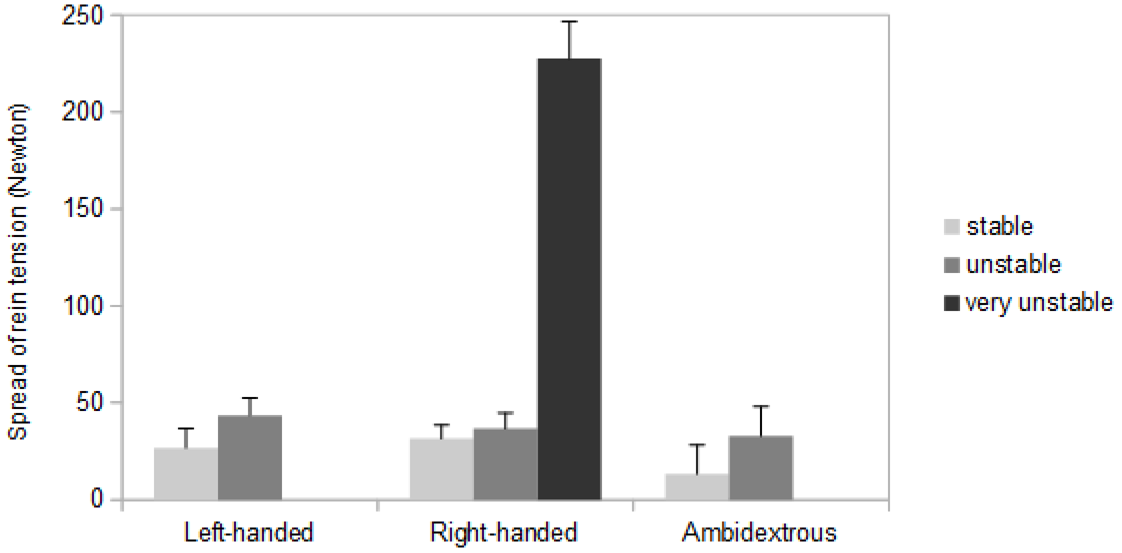


Figure 118: A comparison of the spread of rein tension[1] (Newton) with the rider's assessment of the stability of rein tension in relation to their own handedness (94 rides with snaffle bits and bitless bridles, p<0.0001).

In horses with their hindquarters displaced to the right, mean tension of "stable" contact was lower and of "unstable" contact higher as opposed to a displacement of the hindquarters to the left (Figure 119, p=0.0008). The highest mean tension was recorded in horses with their hindquarters displaced to the left and rein contact that was assessed as very unstable (Figure 119).

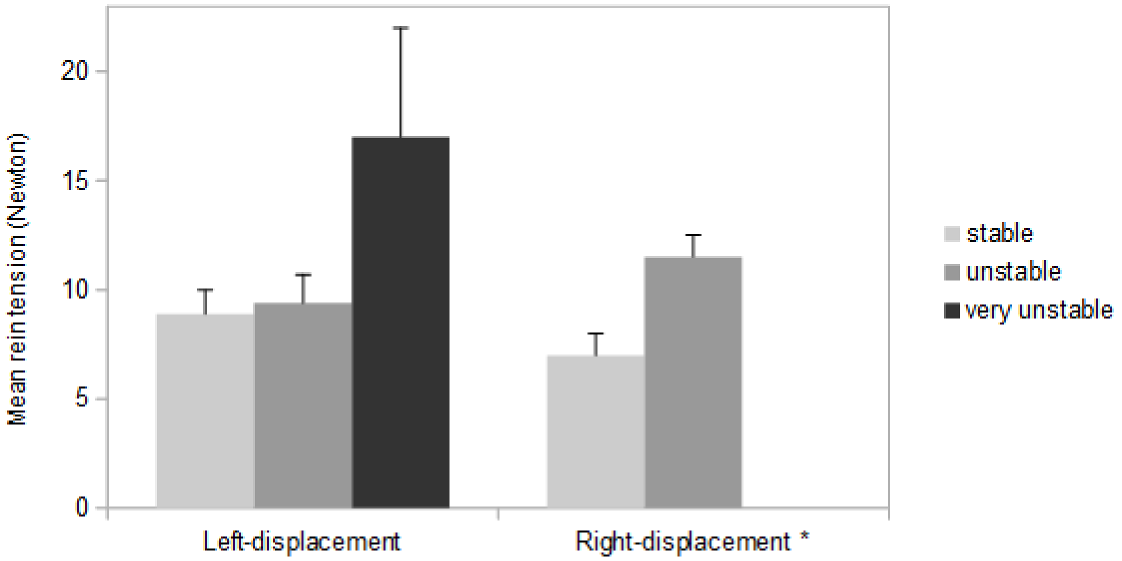


Figure 119: A comparison of mean rein tension (Newton) in horses with their hindquarters displaced either left or right to the rider's assessment of the stability of rein tension (94 rides with snaffle bits and bitless bridles, p=0.0008, *p=0.0005 for effect levels within right-displacement, all other pairwise comparisons p>0.05).

Mean rein tension in relation to the rider's assessment of magnitude of rein contact increased more in horses with a left- displacement (Figure 120) compared to horses with a right- displacement of the hindquarters (Figure 120, p=0.01). Very strong rein tension was only perceived in horses with their hindquarters displaced to the right and resulted indeed in the highest tension (Figure 120).

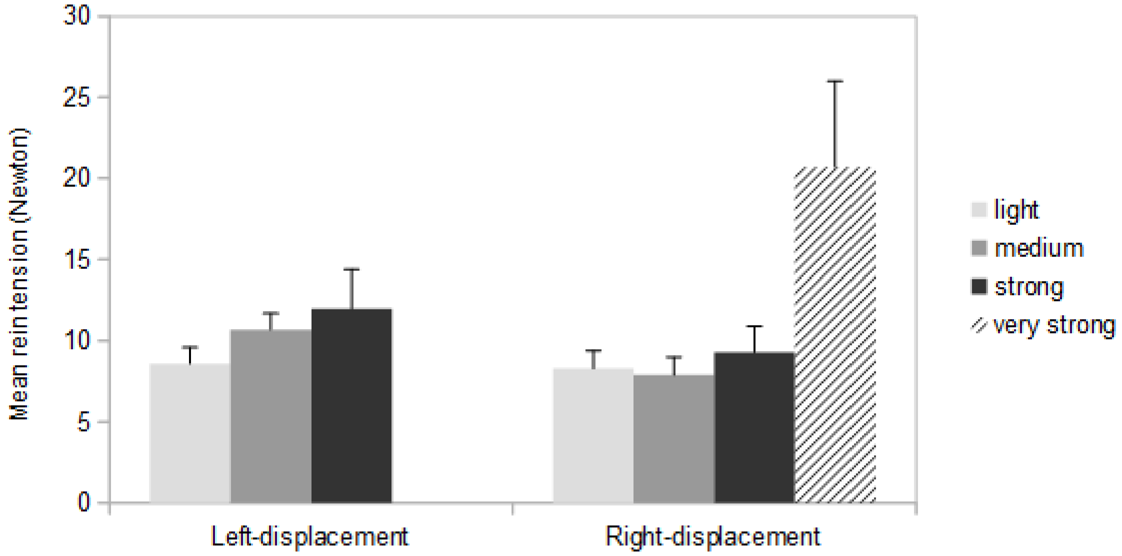


Figure 120: A comparison of mean rein tension[1] (Newton) in horses with their hindquarters displaced either left or right to the rider's assessment of the magnitude of rein contact (94 rides with snaffle bits and bitless bridles, p=0.01).

Factors such as age, sex, lateral displacement of the hindquarters, direction of mane, forelimb-preference and former injuries in horses and riders did not influence rein tension or relate to laterality (all p>0.05).

7.5.1.6 Rein tension parameters in relation to the rider's assessment of "harmony" of the test ride

Spread of tension was highest for rides described as "unharmonious" (43±3N) and lowest for horses perceived as tensed (harmonious: 37.2±2.5N, very harmonious: 36.5±2.8N, tensed: 30.5±2.3N, p<0.0001). Contact in "very harmonious" and "very unharmonious" rides was exclusively assessed as "stable" (mean: 9.5±1.3N, p=0.016) and "light" (10.2±1.2N, p=0.014) vs. "unstable" (7.2±3.7N) or "very unstable" (17.3±5.8N) and "strong" (17.3±5.8N) contact in "unharmonious" or "tensed" rides.

7.5.2 Discussion

7.5.2.1 Rein tension parameters in relation to different riding styles and horse breeds

Horses bred for Western riding revealed lower and more stable rein tension in both riding styles compared to warmbloods or other breeds. It might be hard to differentiate the influence of the riding style and breed. Still, especially in American Quarter Horses, rein tension was lower and more symmetric as opposed to warmbloods and mixed breeds. The aim of Western horse breeders and breed associations worldwide when it comes to their horse's gaits is to breed a horse with flat gaits showing little impulsion (AQHA, DQHA), which is argued to improve the rider's comfort and save the horse's energy when working on a ranch all day (DQHA). Horses bred for conventional European riding such as warmblood breeds however, are supposed to show movement patterns with impulsion and active front limbs (Müseler 1933, Miesner et al. 2000). Since rein tension values seem to be related to speed and the horse's pattern of movement (Preuschoft 1999a, b & c), the different breeding aims and their resulting difference in the horse's pattern of movement might explain why different rein tension values can be found between different horse breeds. Additionally, when it comes to symmetry, American Quarter Horses used for reining seem to be less lateralized at the population basis (Whishaw 2015, Whishaw & Kolb 2017), even though most horses performed individual tasks better in one direction than the other (Whishaw 2015) and lateralized behaviour on different levels such as leg preference has been documented (Siniscalchi et al. 2014). Since a preferred side for bending has been declared for almost every American Quarter Horse by their rider in the present study and still horse-rider-pairs of this breed produced more symmetric rein tension patterns than other horse-rider-combinations regardless of the horse's laterality or rider's handedness, the present study seems to support these previous results.

7.5.2.2 The magnitude and symmetry of rein tension in riders performing additional sports

Rein tension of riders who were active in additional sports did not differ from those who were active in equitation only. Additional sports are commonly discussed and recommended among riders for a balanced training and improvement of health and performance. The present results do not support this hypothesis. Furthermore riders who were active in equitation only applied a lower range of rein tension suggesting improved coordination whereas the majority of additional sports the present participants have chosen seem to aim to improve strength and stamina instead of coordination. However, a larger sample might be needed for investigation.

7.5.2.3 The magnitude and symmetry of rein tension in relation to rider's familiarity with the horse

Similar to previous results (Kuhnke et al. 2010), riders who were unfamiliar with the horse ridden during the session applied less mean tension more symmetrically compared to riders participating with horses they ride on a regular basis. The reason behind that remains unknown. It seems possible though that unfamiliar riders act more carefully since they cannot anticipate their horse's reactions as well as riders who were familiar with the horse and might have focused more on the performance of the actual task. Furthermore, riders were reported to perform differently with unfamiliar tack e.g. saddles, even without the influence of a horse (Biau & Debrils 2016).

7.5.2.4 Rein tension parameters in relation to the rider's assessment of the magnitude of their own rein contact

In the present study, most riders were able to assess the magnitude of mean and peak rein contact overall appropriately on a subjective basis. However, riders showed more accurate assessments when it comes to peaks as opposed to mean tension. Difficulties of riders to correctly assess their own rein contact during equitation and on a model horse have been reported before (Stahlecker 2007, Clayton et al. 2013, Hawson et al 2014). With rein contact perceived as "stable", rider's perception of the magnitude of contact showed little difference in actual mean tension. Riders seemed to have individual interpretations of the magnitude of tension e.g. "strong" and "medium" contact, which actually did not differ in magnitude for right-lateral horses and "light" or "medium" contact, which in left-handed riders actually showed higher magnitudes than "strong" contact. Differences in rein tension were reported between types of rein and materials (Randle et al. 2011). However, the same pair of reins was used for each riding style. The reason behind these deviations of perception and actual tension might therefore be the applied grip force. Differences between left- and right-handed participants (Flanagan 1996, Flanagan & Wing 1997) and their perception of their dominant vs. non-dominant hand (Weber 1978) have been reported before and might be a result of human handedness.

7.5.2.5 Rein tension parameters in relation to the rider's assessment of symmetry

Rides described by the riders as symmetric showed higher mean tension and less stability (tension spread more widely). However, this did not seem to be directly related to horse's laterality as only horses without reported laterality showed a difference in rein tension between symmetric and asymmetric rides. Quantitative asymmetry (higher mean difference of left and right rein tension) was indeed larger in asymmetric performances with all directions of horse's laterality and might be a better indicator for the assessment of asymmetry than mean or peak tension alone.

7.5.2.6 Rein tension parameters in relation to the rider's assessment of stability of their own rein contact

Except for horses without reported laterality rein tension increased with the rider's perception of instable rein contact. This result supports previous findings of lower rein tension being related to more stability (chapter 5). Riders perceiving their contact as instable might apply more tension in order to create more stability, however, in doing so further decreasing it. A stronger and less stable rein contact was revealed with left-laterality in both, horses and riders, compared to right-lateral individuals. Ambidextrous riders seem to be more comparable to left-handed riders overall, which might support the previous findings of similar advantages of both left-handed and ambidextrous riders (chapter 4).

7.5.2.7 Rein tension parameters in relation to the rider's assessment of "harmony" of the test ride

"Unharmonious" rides were related to less stable rein tension (larger spread of tension and rider's assessment of instable rein tension only). "Harmony" of the ride was related to the rider's perception of stable rein contact. However, rides with stable and light contact were perceived as either very harmonious or very unharmonious, indicating that the perception of "harmony" is very subjective and mostly reflects the impression of the stability and magnitude of rein contact. Since riders often showed inaccurate assessments of their own contact in the present study as well as in previous research (Stahlecker 2007, Clayton et al. 2013, Hawson et al 2014), assessment of the "harmony" of a ride seems rather subjective and unreliable.

7.5.3 Conclusion

7.5.3.1 Rein tension in relation to different horse breeds

American Quarter Horses showed almost symmetric rein tension regardless of their own laterality or their rider's handedness, supporting the hypothesis of no laterality at the population basis concluded in previous research. Even though the positive effects of the Western riding style cannot be entirely separated, rein tension of Western breeds is lower and more stable, possibly due to their breeding aim of flat gait patterns with little impulsion.

7.5.3.2 Rein tension in relation to familiarity of the horse-rider combination and additional sports

Riders who are unfamiliar with the horse might apply rein tension more carefully until they are able to anticipate the reaction of their horse better. Additional sports might not benefit equestrian performance, especially if they improve muscle strength rather than coordination.

7.5.3.3 The rider's assessment of his/her own rein tension

Quantitative asymmetry was larger in performances perceived as asymmetric with all directions of horse's laterality and might be a better indicator for the assessment of asymmetry than mean tension alone. The stability of rein contact seems to be directly related to the magnitude of rein tension and may deliver more reliable results when it comes to the subjective assessment of rider's own rein contact. Riders showed more accurate assessments when it comes to peaks as opposed to mean tension and seemed to have individual interpretations of the magnitude of tension. The harmony of a ride seems to reflect the impression of the stability and magnitude of rein contact and delivers rather subjective and unreliable results.

7.6 Rein tension parameters in relation to the type of equipment used for communication and different ways of rein handling

7.6.1 Results

7.6.1.1 Rein tension parameters in relation to the type of equipment used for communication

Mean rein tension ($p<0.0001$), mean peak tension ($p<0.0001$) and the mean difference of left and right rein tension as a measure to determine quantitative asymmetry of rein tension ($p<0.0001$) varied according to the different types of bits used in the sample of all rides (Figure 121). With mean rein tension converted to the amount of pressure expected in the horse's mouth or on the bridge of the horse's nose with bitless bridles ("converted rein tension"), tension did not differ between curb bits and snaffle bits ($p=0.05$). Converted mean peak tension was highest with bitless bridles as well as snaffle bits and lowest with curb bits (Figure 121, $p<0.0001$).

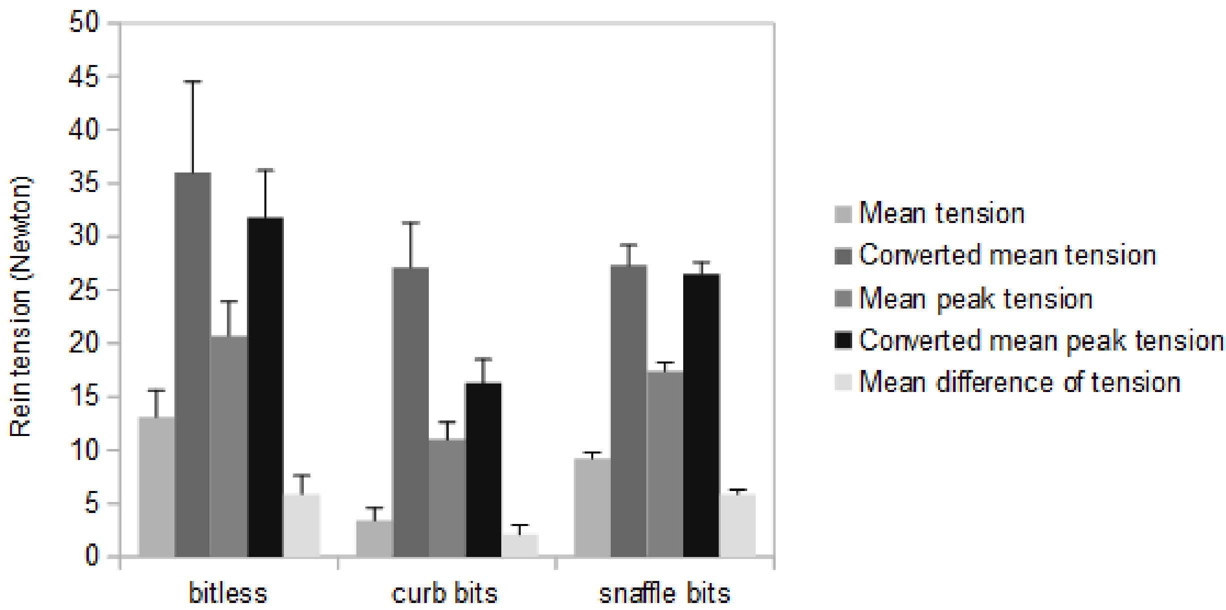


Figure 121: Comparison of various rein tension parameters[1] (Newton) in relation to the equipment used for communication. (Bitless: n=3, curb bits: n=16, snaffle bits: n=68; Parameters have been compared for the different types of equipment within each parameter; Mean peak tension= mean of tension peaks only; Converted rein tension = rein tension was converted into the amount of pressure expected at the horse's mouth with the specific type of bit according to factors previously published by Preuschoft 1990 a-c; converted mean tension: $p>0.05$) [1]p-values of pairwise comparisons of effect level are available on request.

7.6.1.2 Rein tension parameters in relation to different riding styles

Many riders used equipment that was comparable between the different riding styles (Tables 15 and 16, Figures 52-54). Regardless of the type of bridle, higher mean tension was found in conventional European riding with snaffle bits compared to snaffle bits and in particular jointed curb bits (snaffle with shanks and correction bit) as well as fixed curb bits in Western riding (Figure 122, $p<0.0001$). Mean tension differed for conventional European riding but not Western riding between single-jointed and double-jointed snaffle bits (Figure 123, $p=0.001$).

Table 15: Overview of the types of bits used with both riding styles

Type of bit	Western	European
Snaffle bit (single-jointed)	16	16
Snaffle bit (double-jointed)	18	18
Mullen mouth bit	0	1
Bitless (LG)	0	3
Fixed curb bit	3	0
Jointed curb bit (correction)	5	0
Jointed curb bit (snaffle with shanks)	8	0

Table 16: Overview of the types of bridles used with both riding styles

Type of bridle	Western	European
Cavesson	12	12
Flash noseband	0	15
Drop noseband	0	2
Grackle noseband	0	4
No cavesson	38	5

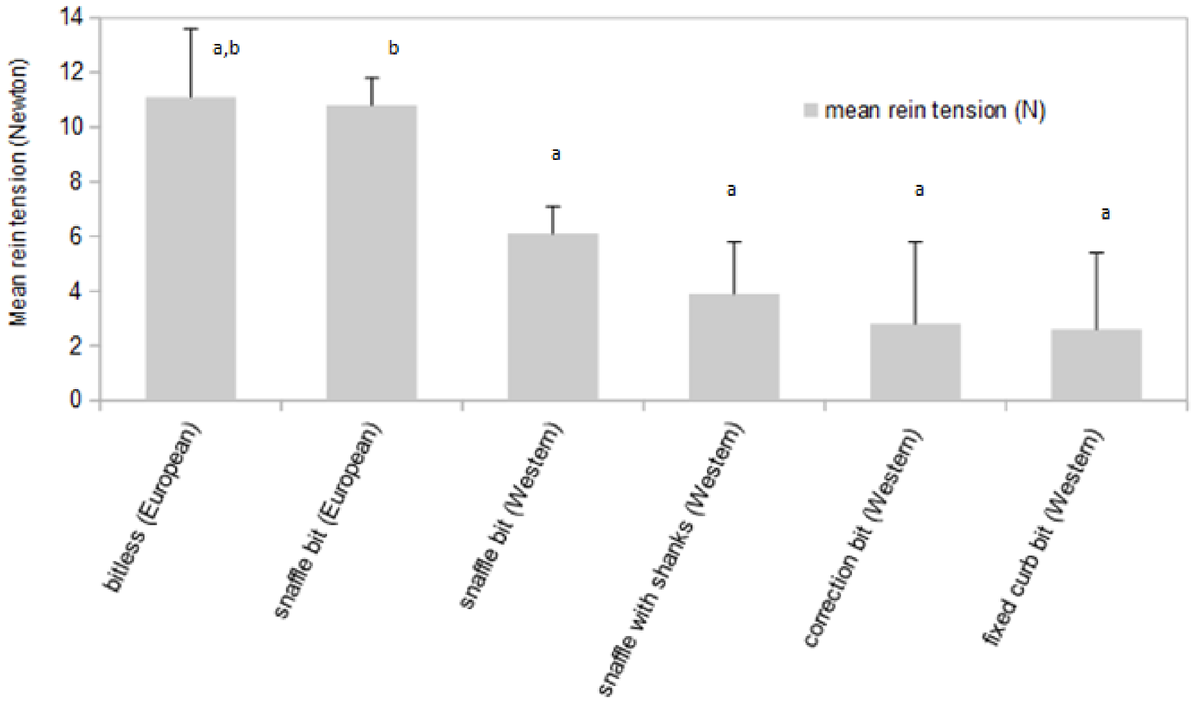


Figure 122: Mean rein tension (Newton) with regard to different bits used ($p<0.0001$). In Western riding all types of bits have been used, whereas conventional European riders chose snaffle bits only, different letters indicate a significant difference at $p<0.05$

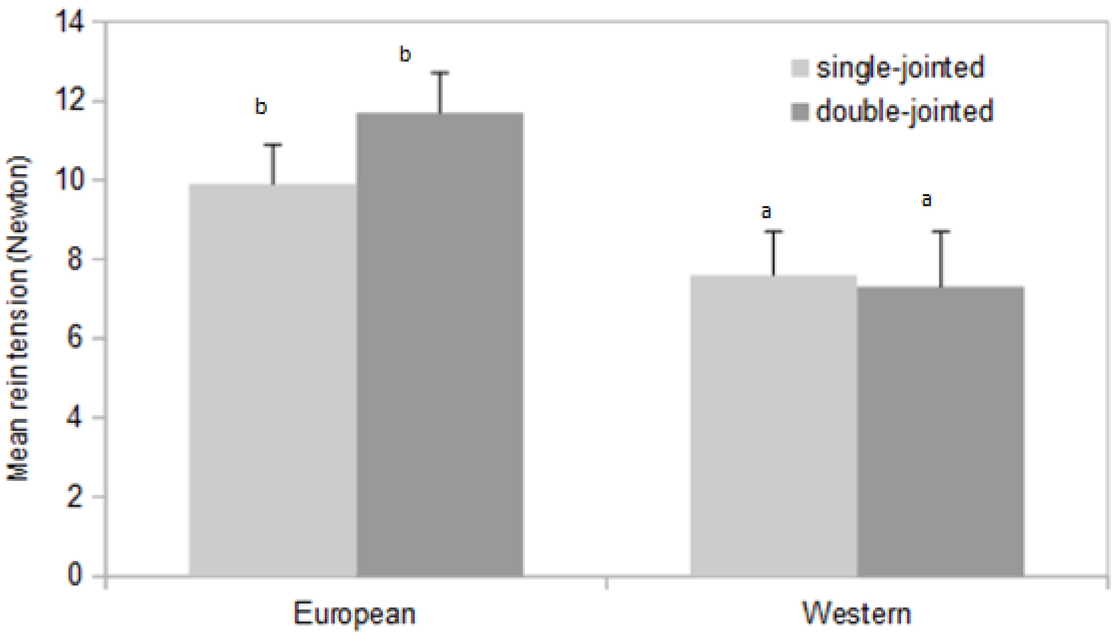


Figure 123: Comparison of mean rein tension (Newton) with single- and double-jointed snaffle bits in conventional European riding and Western riding ($p=0.001$). Riders used the bits that they chose for their horses and use on a regular basis, different letters indicate a significant difference at $p<0.05$

7.6.1.3 Rein tension parameters in relation to different combinations of bits and bridles used in both riding styles

Mean tension (p<0.0001), mean SD (p<0.0001), mean peak tension (p<0.0001), the mean difference of left and right rein tension (p=0.01), as well as converted (i.e. rein tension was converted into the amount of pressure expected at the horse's mouth) mean (p<0.0001) and mean peak tension (p<0.0001) differed significantly between the different bits used in both riding styles (Table 17, Figure 124). Mean peak tension was higher than mean tension with all bits, however, with converted tension mean tension was higher than mean peak tension with bitless bridles, double-jointed snaffle bits, snaffle with shanks and correction bits.

Mean tension (p<0.0001), SD (p=0.004), mean peak tension (p=0.001), the mean difference of tension (p<0.0001), as well as converted mean (p=0.026) and mean peak tension (p<0.0001) differed significantly between the different bridles types too (Table 18, Figure 125). Mean peak tension was higher than mean tension with all bridles types. Converted mean tension was higher than converted mean peak tension for all bridles except grackle nosebands and rides without a cavesson.

Mean rein tension also varied between combinations of bits and bridles. It was lowest for curb bits with or without a cavesson and grackle nosebands combined with snaffle bits compared to other combinations of snaffle bits with different cavessons (e.g. no cavesson, French cavesson, drop noseband, flash noseband; Table 19, Figure 126, p<0.0001). Converted mean and converted mean peak tension was higher in conventional European riding for snaffle bits with or without a cavesson compared to Western riding (Table 19, Figure 127, 128 & 129). Mean SD was lower for double-jointed snaffle bits in comparison to single-jointed snaffle bits with bridles restricting jaw opening (Table 19, Figure 130).

Table 17: Comparison of rein tension parameters overall (Newton, all gaits)[1] in relation to different bits used in conventional European riding and Western riding. Rein tension was compared between the different types of equipment within each parameter. (Mean peak tension= mean of tension peaks only; Converted rein tension = rein tension was converted into the amount of pressure expected at the horse's mouth with the specific type of bit according to factors previously published by Preuschoft 1990a-c; Mean SD= mean standard deviation as a measure of stability of rein contact). [1]p-values of pairwise comparisons of effect level are available on request.

	Number of horses	Mean tension (N)	Mean SD (N)	Mean peak tension (N)	Converted mean tension (N)	Converted peak tension (N)	Mean difference of tension (N)
bitless	3	12.2±2.5	9.8±1.7	22.7±3.1	37.4±7	32±4.2	6.6±1.7
Single-jointed snaffle bit (Western)	16	8.3±1.1	5.4±1	15.4±1.5	14.6±3.2	21.4±2.2	4.5±0.7
Double-jointed snaffle bit (Western)	18	6.9±1.4	6.8±1.1	16.6±1.7	24.7±4	23.1±2.5	5.1±1
Single-jointed snaffle bit (Conventional European)	16	10.8±1.1	8.9±1	20.7±1.5	18.9±3.1	28.3±2.1	5.8±0.7
Double-jointed snaffle bit (Conventional European)	18	12.9±1.1	10.2±1	22.9±1.5	46.2±3.3	33.3±2.1	8±0.8
Mullen mouth	1	17.3±4.6	14.4±3	27.4±5.6	20±13.3	38.3±7.7	8.6±3.2
Bit	3	3.1±2.8	3±2	12.5±3.5	17.7±8.2	17.3±4.9	1.7±2
Snaffle with shanks	8	4.2±1.9	3.6±1.4	11.4±2.3	33.3±5.4	16.1±3.3	2.4±1.3
Correction bit	5	3.3±2.3	2.9±1.6	12±2.9	23.6±6.7	16.7±4	2±1.6
P[1]		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.001

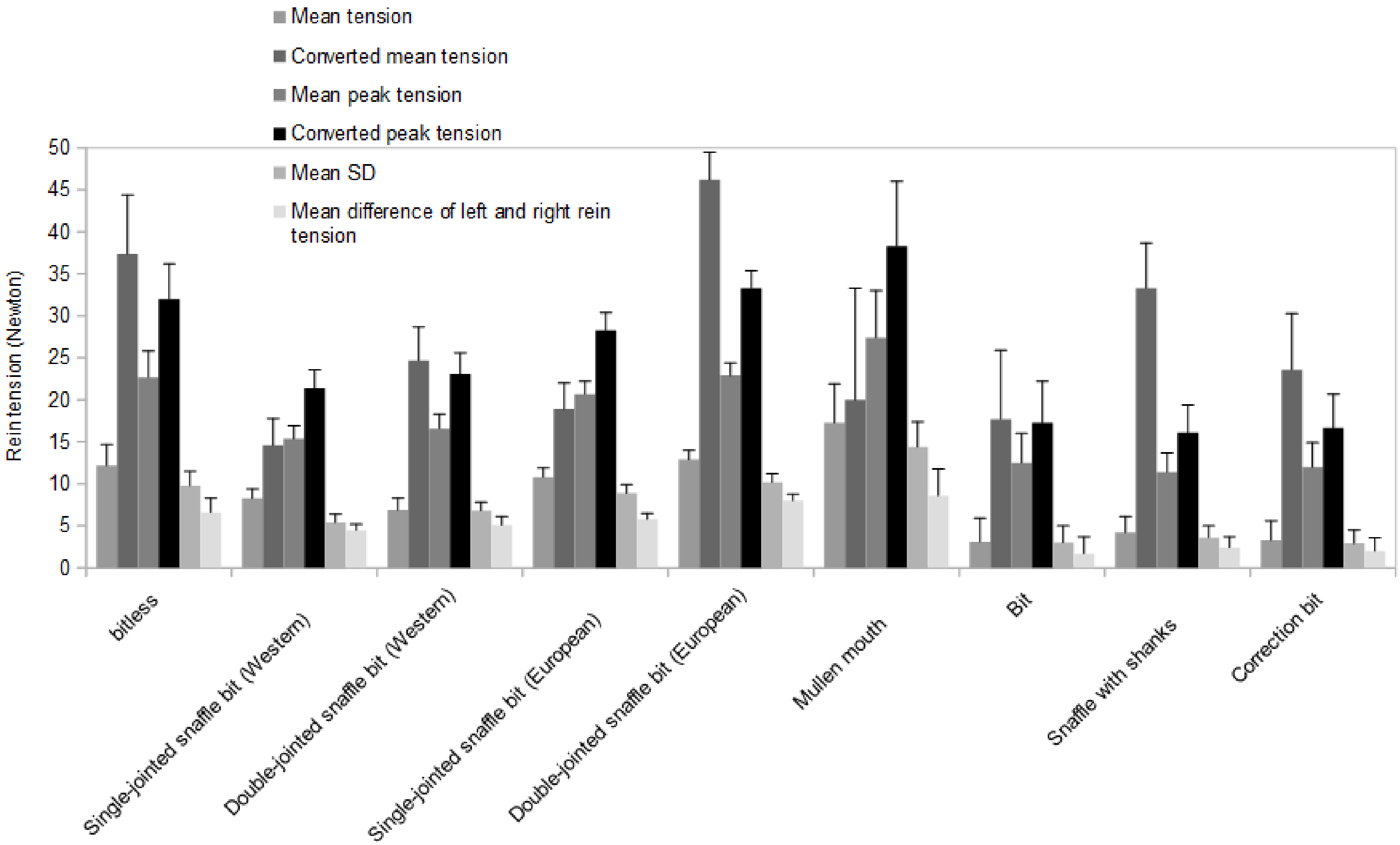


Figure 124: Comparison of rein tension parameters overall (Newton, all gaits)[1] in relation to different bits used in conventional European riding and Western riding. (Mean rein tension $p<0.0001$; Mean peak tension= mean of tension peaks only $p<0.0001$; Converted rein tension = rein tension was converted into the amount of pressure expected at the horse's mouth with the specific type of bit according to factors previously published by Preuschoft 1990a-c, converted mean tension: $p=0.026$, converted peak tension $p<0.0001$; Mean SD= mean standard deviation as a measure of stability of rein contact $p=0.004$, Mean difference of left and right rein tension $p=0.01$).

Table 18: Comparison of rein tension parameters overall[1] (Newton, all gaits) in relation to different bridles used in conventional European riding and Western riding. Rein tension was compared between the different types of equipment within each parameter. (Mean peak tension= mean of tension peaks only; Converted rein tension = rein tension was converted into the amount of pressure expected at the horse's mouth with the specific type of bit according to factors previously published by Preuschoft 1990a-c; Mean SD= mean standard deviation as a measure of stability of rein contact).

	Number of horses	Mean tension (N)	SD (N)	Mean peak tension (N)	Converted mean tension (N)	Converted peak tension (N)	Mean difference of tension (N)
Cavesson	21	8.7±1.1	6.4±1	16.8±1.6	27.4±3.9	23.4±2.2	4.8±0.7
Flash noseband	15	15.3±1.4	10.8±1.2	24.8±1.9	40.7±4.9	35.7±2.6	9.6±0.9
Drop noseband	2	10.8±3.4	10.5±2.6	20.3±4.4	39.3±12	28.4±6	7.9±2.3
Grackle noseband	4	9.2±2.1	8.2±1.6	19.2±2.9	23.3±7.2	26.9±3.9	5.9±1.4
Bitless bridle (with cavesson)	3	11.6±2.6	9.1±1.9	22.2±3.5	34.4±8.7	31.1±4.7	6±1.7
No cavesson	43	6.9±1	6.5±0.9	16±1.4	22.3±3.4	22.4±1.9	4.2±0.6
P[1]		0.004	0.05	0.03	0.02	0.02	0.01

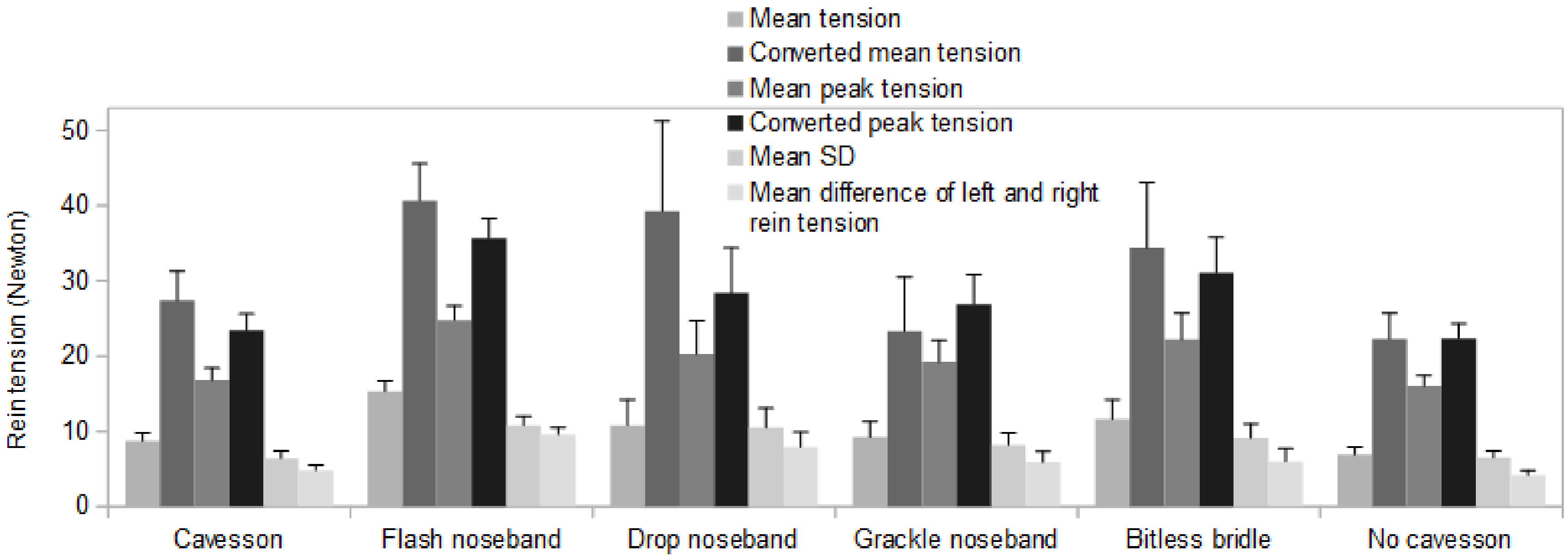


Figure 125: Comparison of rein tension parameters overall[1] (Newton, all gaits) in relation to different bridles used in conventional European riding and Western riding. (Mean rein tension p<0.0001; Mean peak tension= mean of tension peaks only p=0.001; Converted rein tension = rein tension was converted into the amount of pressure expected at the horse's mouth with the specific type of bit according to factors previously published by Preuschoft 1990a-c, all p<0.0001; Mean SD= mean standard deviation as a measure of stability of rein contact p=0.001, Mean difference of left and right rein tension p<0.0001).

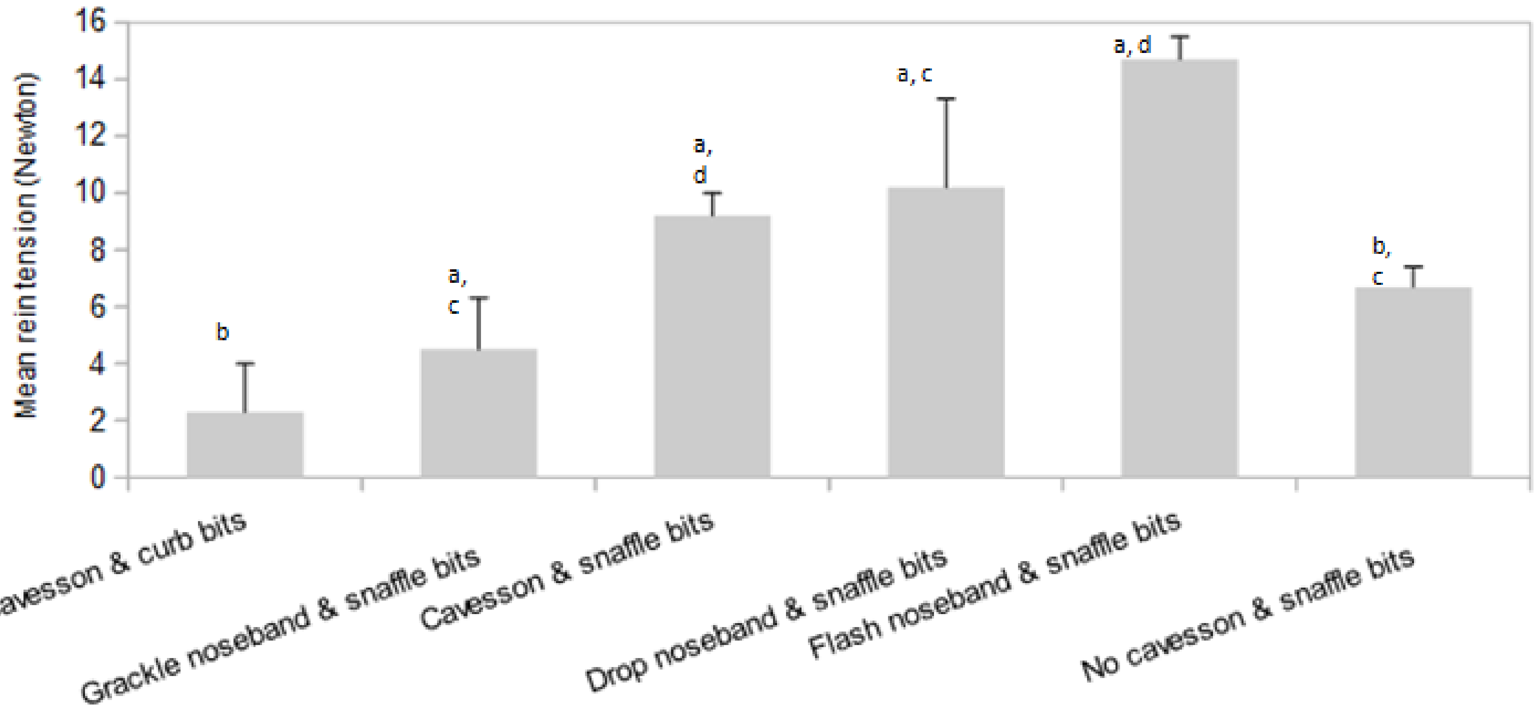


Figure 126: Mean rein tension overall (Newton) with different combinations of bits and bridles ($p<0.0001$), different letters indicate a significant difference at $p<0.05$

Table 19: Rein tension parameters overall[1] (Newton, all gaits) with different combinations of bits and bridles in conventional European riding and Western riding. Rein tension was compared between the different combinations of equipment within each parameter. (Mean peak tension= mean of tension peaks only; Converted rein tension = rein tension was converted into the amount of pressure expected at the horse's mouth with the specific type of bit according to factors previously published by Preuschoft 1990a-c; Mean SD= mean standard deviation as a measure of stability of rein contact).

	Number of horses	Mean tension (N)	Mean SD (N)	Mean peak tension (N)	Converted mean tension (N)	Converted peak tension (N)	Mean difference of left and right rein tension (N)
snaffle with shanks & no cavesson	2	5.9±2.8	5.4±2.1	14.2±3.7	47.8±8.8	19.9±4.9	4.2±2.1
Bit & no cavesson	3	3.2±2.4	3±1.9	12.6±3.2	17.9±7.6	17.6±4.3	1.8±1.8
Correction bit & no cavesson	4	2.9±2.2	2.8±1.9	13±3	20.6±7.1	18.3±3.8	1.8±1.7
single-jointed snaffle bit (Western) & no cavesson	10	6.5±1.2	5.3±1.1	14.2±1.8	11.6±4	20.1±2.4	3.2±0.9
double-jointed snaffle bit (Western) & no cavesson	18	6.8±1.1	6.8±1	16.5±1.6	24.8±3.5	23.1±2	5.1±0.8
bitless bridle	3	11.8±2.1	11.2±1.6	22.9±2.8	36.7±6.7	31.7±3.8	6±1.7
mullen mouth & no	1	17.3±3.9	14.4±2.9	27.4±5.1	20±12.3	38.4±6.8	8.6±2.9

cavesson							
single-jointed snaffle bit (European) & no cavesson	2	7.4±1.4	6.2±1.5	15.4±2.3	12.4±4.7	21.7±3.1	3.7±1
double-jointed snaffle bit (European) & no cavesson	1	13.9±3.2	15.8±2.2	29.4±4.3	49.9±10	41±5.8	5.9±2.7
Correction bit & cavesson	1	3.3±3.9	2±2.6	8.4±5	25.5±11.9	12.2±6.8	1.6±2.9
snaffle with shanks & cavesson	6	3.3±1.8	2.3±1.6	9.5±2.6	27.6±5	13.6±3.2	1.6±1.4
single-jointed snaffle bit (Western) & cavesson	6	5.4±1.7	4.3±1.4	12.4±2.3	9.9±5.4	17.4±3	2.7±1.3
single-jointed snaffle bit (European) & cavesson	5	10.9±1.6	8.2±1.3	20.8±2.2	22±5.2	29.4±3	7.3±1.2
double-jointed snaffle bit (European) & cavesson	5	13.9±1.7	9.5±1.3	23.4±2.3	49.7±5.3	32.6±3.1	7.4±1.3
single-jointed snaffle bit (European) & flash	7	17.3±1.6	11.4±1.3	26.2±2.2	27.5±5	35.8±2.9	8.8±1.2

noseband							
double-jointed snaffle bit (European) & flash noseband	8	14.3±1.4	10.8±1.2	24.2±1.9	51.4±4.4	36.5±2.6	10.7±1.1
double-jointed snaffle bit (European) & drop noseband	2	10.8±2.7	10.6±2.1	20.4±3.7	39.3±8.8	28.5±4.9	7.9±2.1
single-jointed snaffle bit (European) & grackle noseband	2	12.9±2.6	11.7±2	25.5±3.5	16.6±8.4	35.5±4.7	6.9±1.8
double-jointed snaffle bit (European) & grackle noseband	2	7.4±2.3	6.7±1.7	15.5±3.2	28.4±7.4	21±4.2	4.1±2
P[1]		<0.0001	<0.0001	<0.0001	0.0031	<0.0001	<0.0001

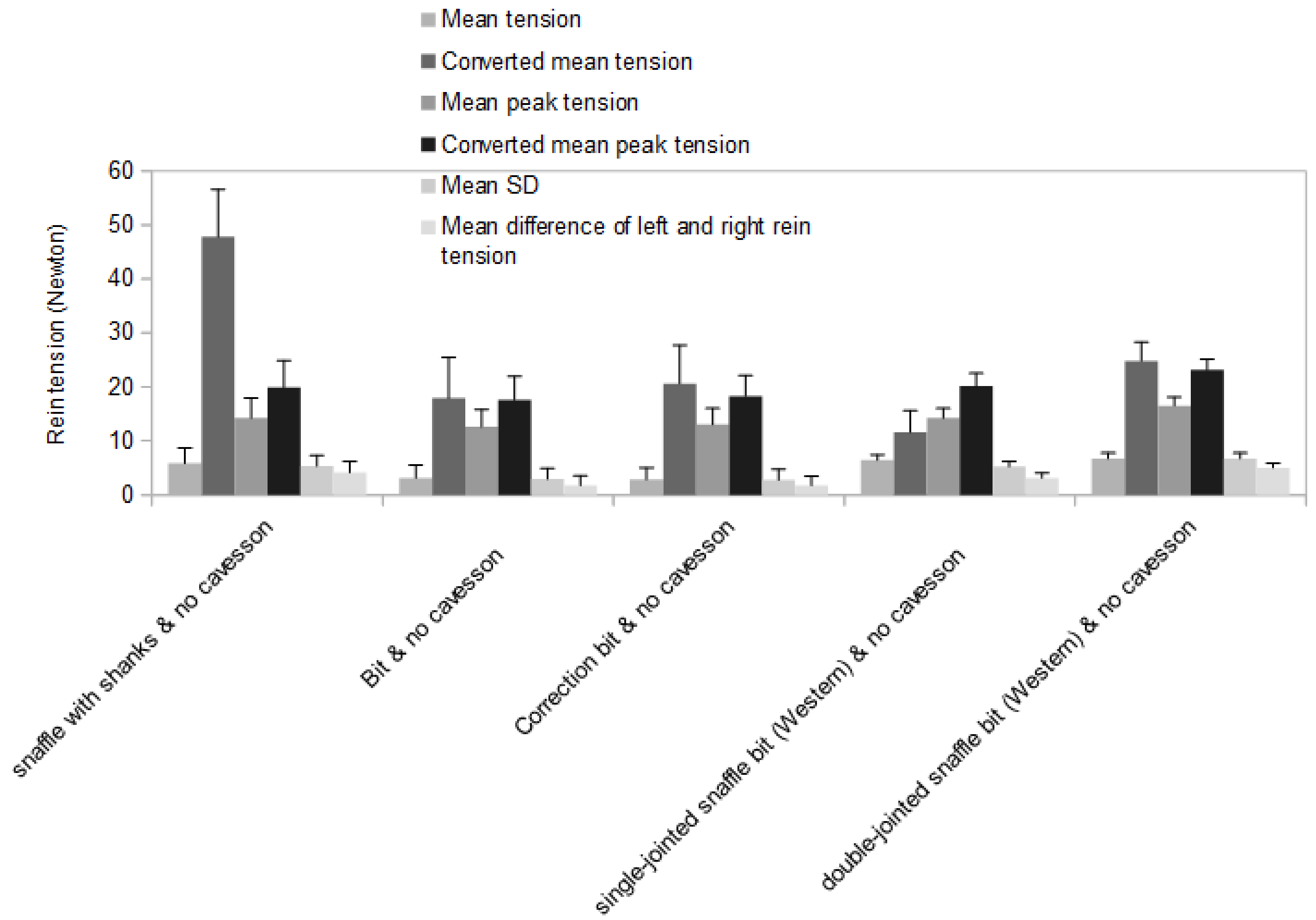


Figure 127: Rein tension parameters overall[1] (Newton, all gaits) with different combinations of bits and bridles without cavesson in Western riding. Rein tension was compared between the different combinations of equipment within each parameter. (Mean peak tension= mean of tension peaks only; Converted rein tension = rein tension was converted into the amount of pressure expected at the horse's mouth with the specific type of bit according to factors previously published by Preuschoft 1990a-c; Mean SD= mean standard deviation as a measure of stability of rein contact, all $p<0.0001$, converted mean tension: $p=0.003$).

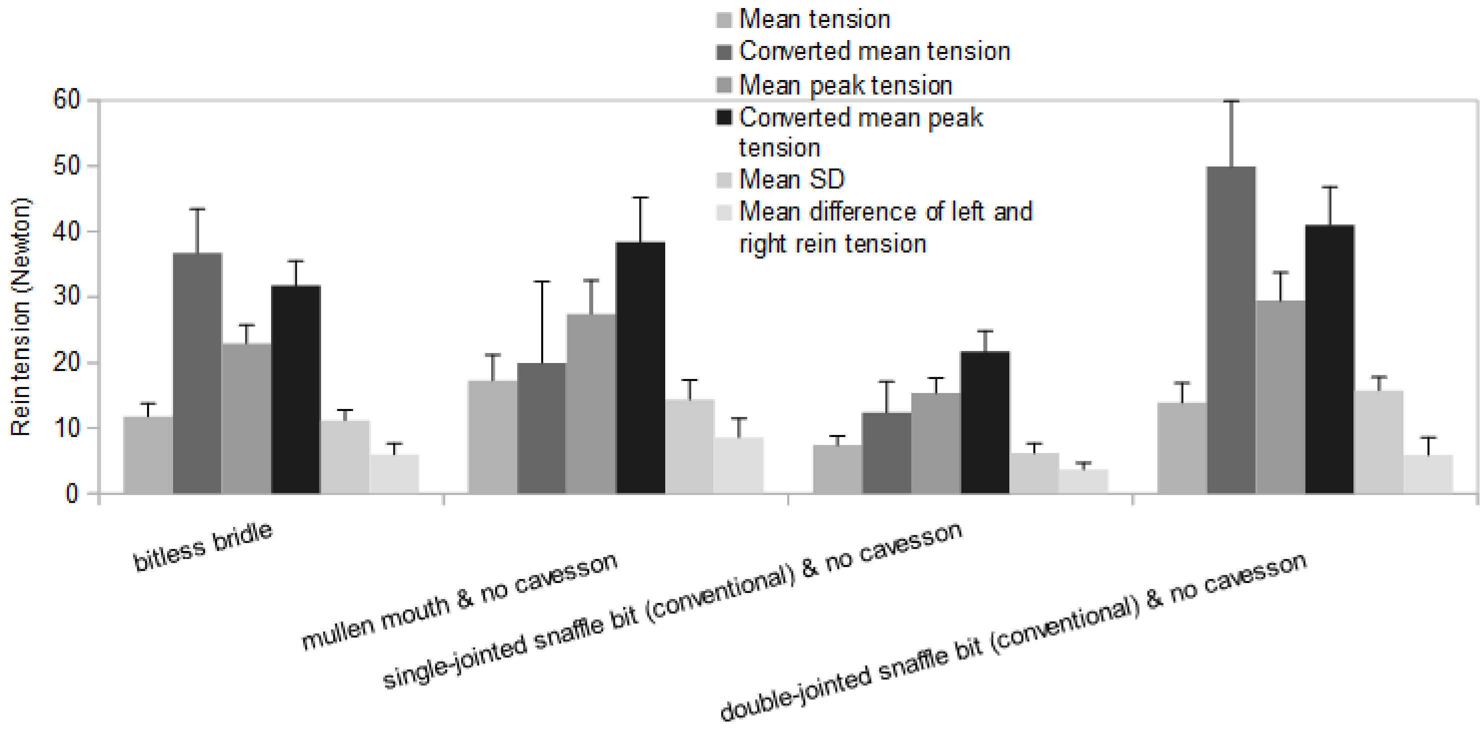


Figure 128: Rein tension parameters overall[1] (Newton, all gaits) with different combinations of bits and bridles without cavesson in conventional European riding riding. Rein tension was compared between the different combinations of equipment within each parameter. (Mean peak tension= mean of tension peaks only; Converted rein tension = rein tension was converted into the amount of pressure expected at the horse's mouth with the specific type of bit according to factors previously published by Preuschoft 1990a-c; Mean SD= mean standard deviation as a measure of stability of rein contact, all $p<0.0001$, converted mean tension: $p=0.003$).

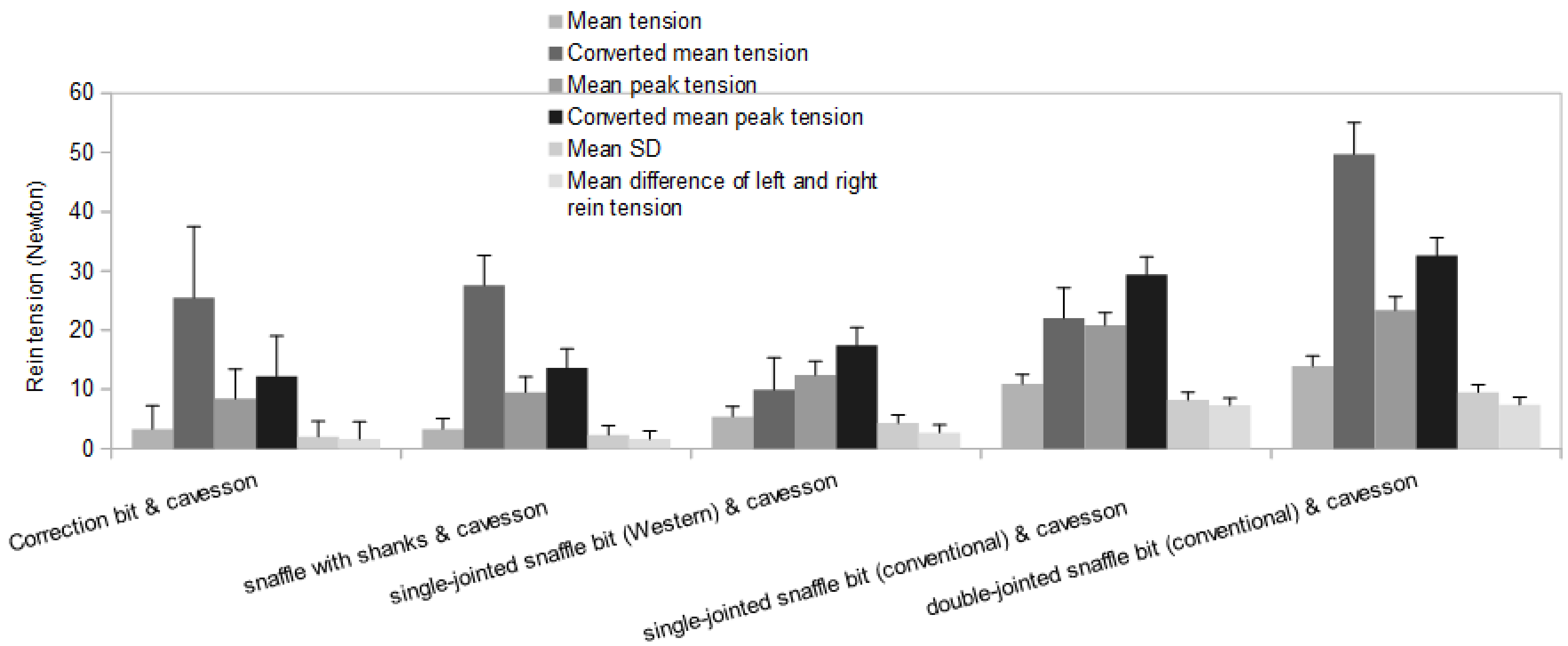


Figure 129: Rein tension parameters overall[1] (Newton, all gaits) with different combinations of bits and bridles with a cavesson in conventional European riding and Western riding. Rein tension was compared between the different combinations of equipment within each parameter. (Mean peak tension= mean of tension peaks only; Converted rein tension = rein tension was converted into the amount of pressure expected at the horse's mouth with the specific type of bit according to factors previously published by Preuschoft 1990a-c; Mean SD= mean standard deviation as a measure of stability of rein contact, all p<0.0001, converted mean tension: p=0.003).

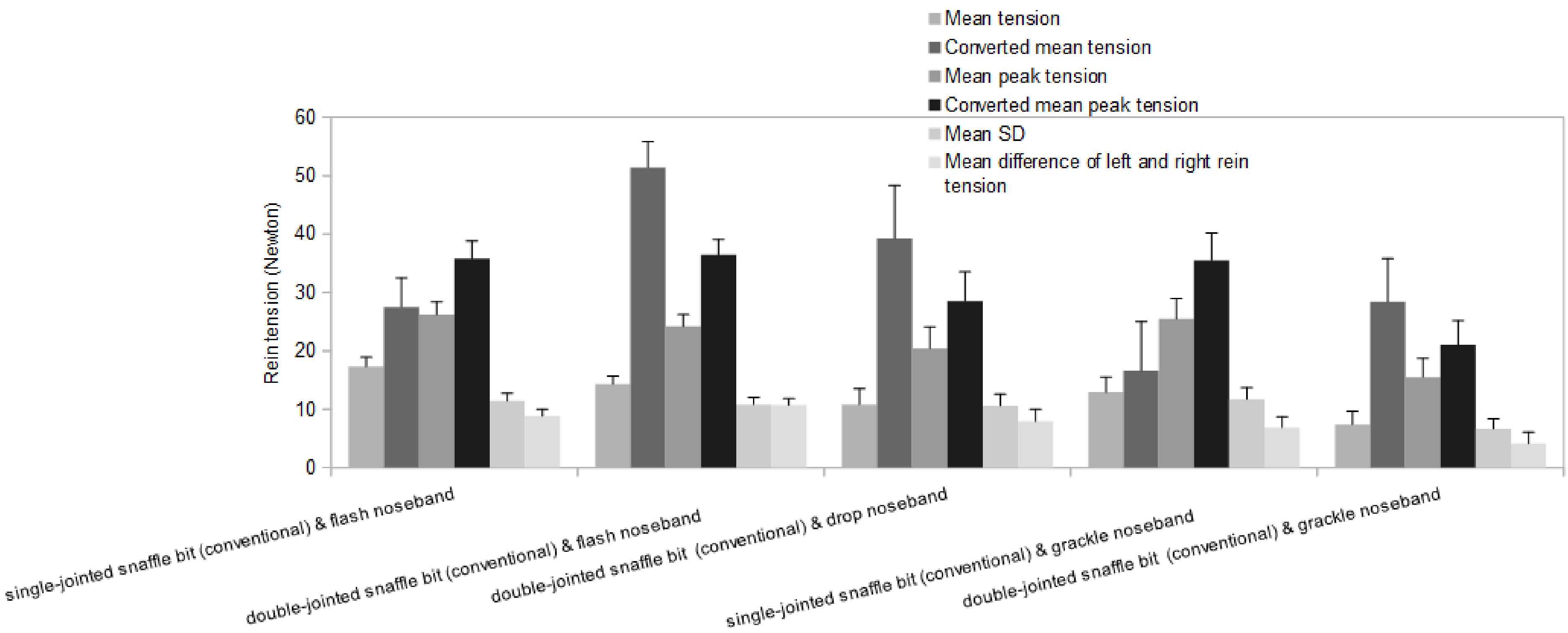


Figure 130: Rein tension parameters overall[1] (Newton, all gaits) with different combinations of bits and bridles restricting jaw opening in conventional European riding. Rein tension was compared between the different combinations of equipment within each parameter. (Mean peak tension= mean of tension peaks only; Converted rein tension = rein tension was converted into the amount of pressure expected at the horse's mouth with the specific type of bit according to factors previously published by Preuschoft 1990a-c; Mean SD= mean standard deviation as a measure of stability of rein contact, all p<0.0001, converted mean tension: p=0.003).

7.6.1.4 Rein tension parameters in relation to the type of equipment used for communication with regard to different ways of rein handling

In the present study the reins were handled mostly bimanually or bridged, however, a sample of five right-handed riders rode one-handedly as well (left-preference: 1 rider, right-preference: three riders, preference of bridged reins: 1 rider, Tables 20 and 21).

Table 20: Overview of the rides with regard to rein handling in the overall sample

Rein handling	Western	European
bimanual	0	51
bridged	54	0
left-handed	8	0
right-handed	11	0

Table 21: Overview of the rides with different ways of rein handling in a smaller sample of five right-handed riders with five left-lateral horses, four right-lateral horses and two horses without reported laterality

Rein handling	Number of rides
bimanual	6
left-handed	8
right-handed	11

Mean rein tension was higher with bimanual contact with either bitless bridles or snaffle bits in conventional European riding, compared to bridged reins with snaffle bits in Western riding (Figure 131, $p<0.0001$). Mean tension of one-handed rein contact with curb bits either left or right was lower compared to bridged reins (Figure 131, $p<0.0001$).

Converted mean tension revealed little difference between bimanual contact with bitless bridles and snaffle bits. Higher converted mean tension was found with bridged reins for curb bits vs. snaffle bits and left-handed vs. right-handed rein contact using curb bits (Figure 132, $p<0.0001$).

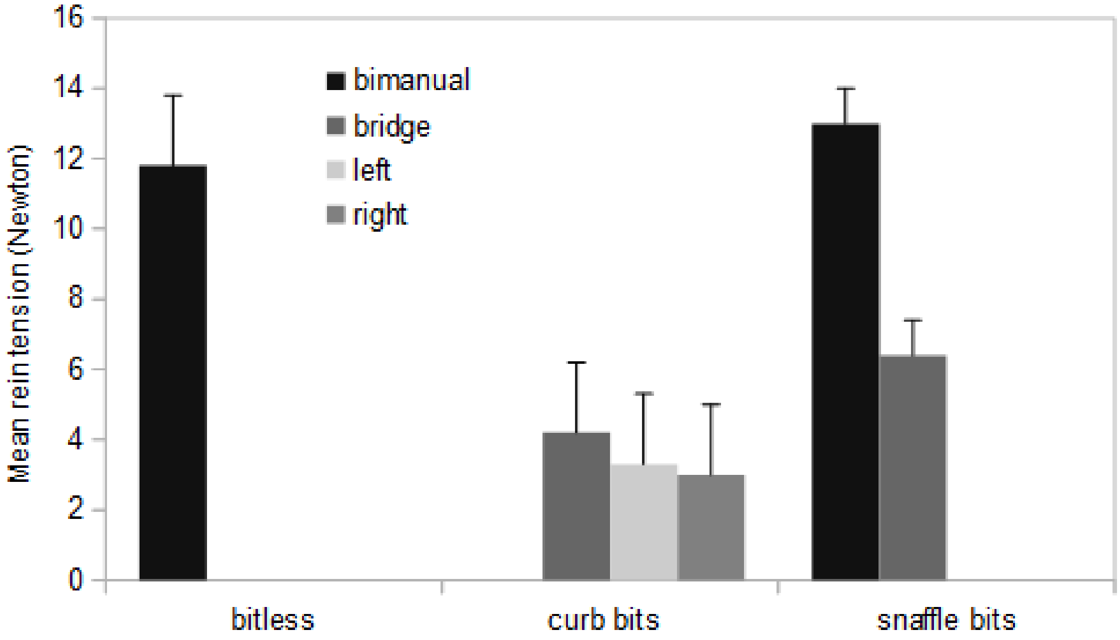


Figure 131: Comparison of mean rein tension[1] (Newton) in relation to the equipment used for communication with regard to different ways of rein handling (p<0.0001). Reins of bitless bridles were handled bimanually only. With snaffle bits, reins were used bimanually in conventional European riding and bridged in Western riding.

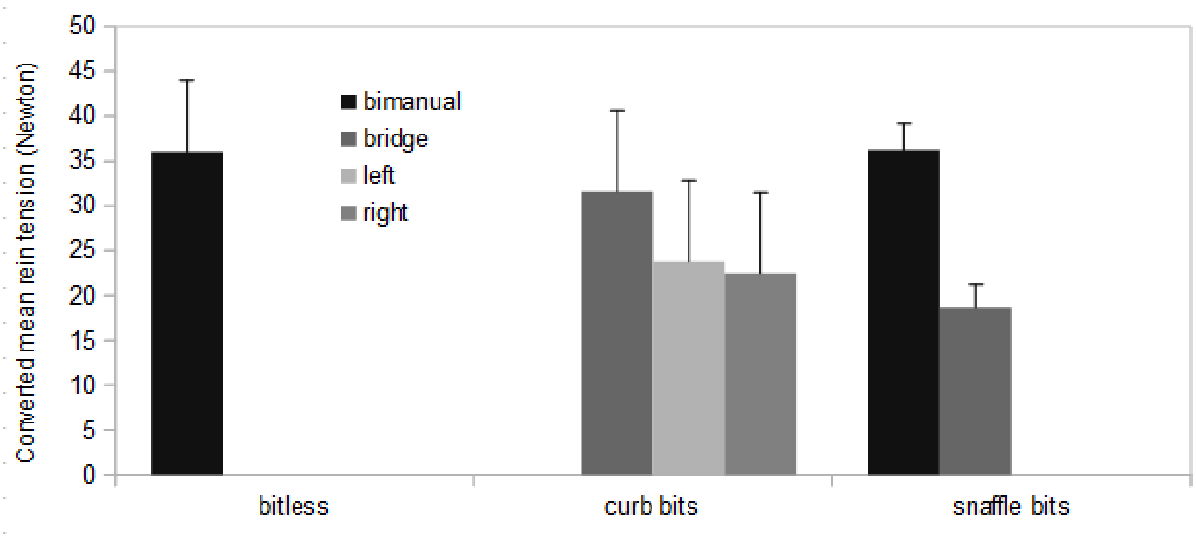


Figure 132: Comparison of converted mean rein tension[1] (Newton) in relation to the equipment used for communication with regard to different ways of rein handling (p<0.0001). Converted rein tension = rein tension was converted into the amount of pressure expected at the horse's mouth with the specific type of bit according to factors previously published by Preuschoft. Reins of bitless bridles were handled bimanually only. With snaffle bits, reins were used bimanually in conventional European riding and bridged in Western riding.

7.6.1.5 Rein tension parameters in relation to different ways of rein handling in conventional European riding and Western riding

With one-handed rein handling (Western riding, 11 horse-rider pairs) a slightly stronger mean tension overall was found when the reins were handled with the left hand compared to right-handed rein handling. The highest mean tension was found with bimanual rein contact (Figure 133, p<0.0001). Quantitative asymmetry of rein tension (mean difference of left and right rein tension) was increased with bimanual rein handling (bridged reins) and left-handed rein contact compared to right-handed rein handling (Figure 133, p<0.0001).

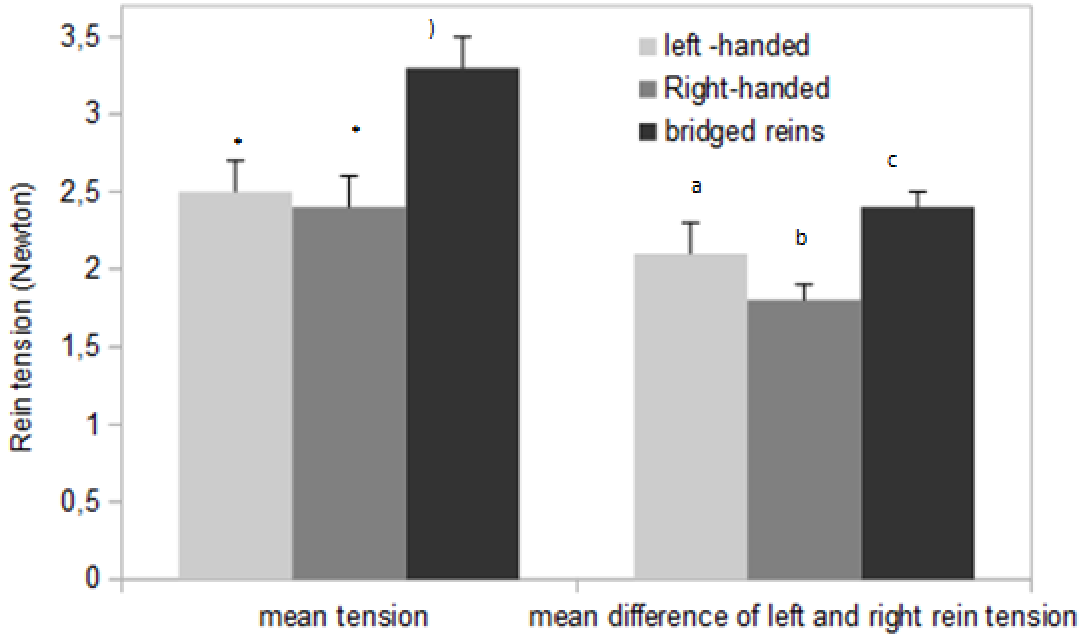


Figure 133: Comparison of the magnitude (mean tension, Newton) and symmetry (mean difference of left and right rein tension, Newton) of rein tension between one-handed rein handling (left-handed versus right-handed rein contact) and bridged reins in Western riding (p<0.0001), different letters indicate a significant difference at p<0.05, mean difference of left and right rein tension: pairwise comparison a-c: p=0.05

In Western riding with one-handed rein handling, slightly higher mean tension in the contra-lateral rein was found, whereas with bridged reins mean tension was slightly higher in the right rein (Figure 134, p<0.0001). In conventional European riding, mean tension in the right rein was higher than in the left rein with increased asymmetry when bridging the reins (Figure 134, p<0.0001).

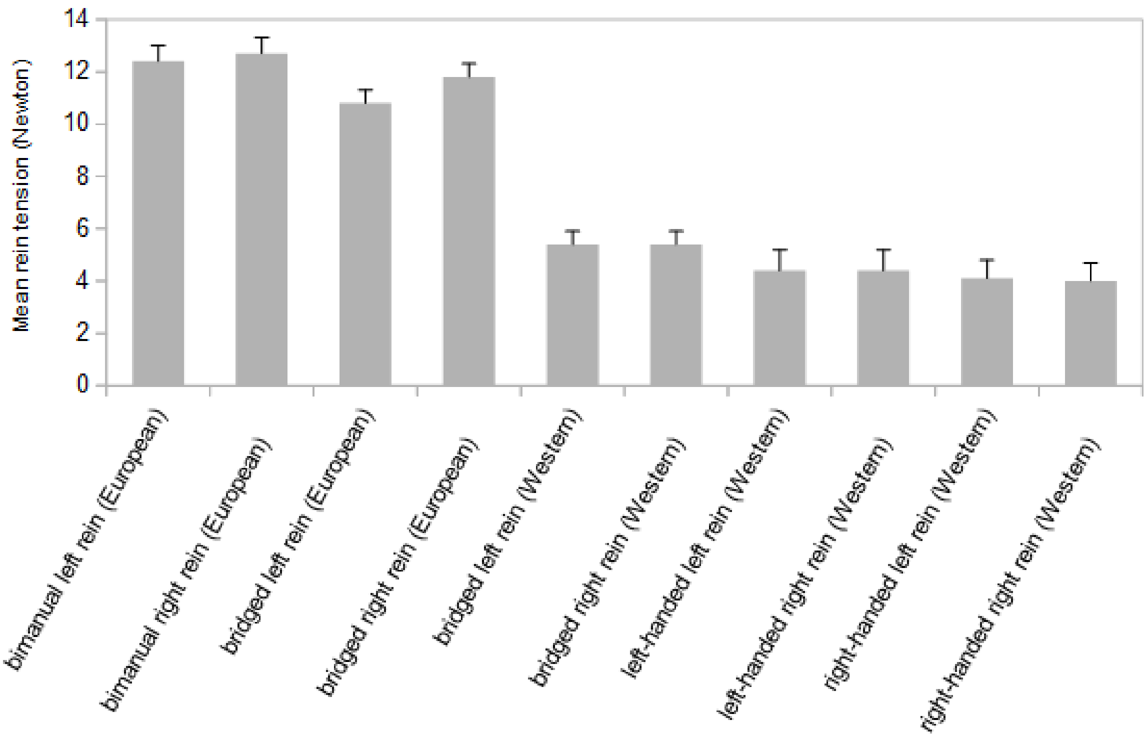


Figure 134: Comparison of mean rein tension[1] (Newton) of the left versus the right rein with one-handed rein handling (left-handed versus right-handed rein contact) and bridged reins in Western riding, as well as bimanual rein contact and bridged rein in conventional European riding (p<0.0001)

A larger spread of rein tension was found with conventional European riding with either bimanual rein contact or bridged reins compared to Western riding with bridged reins (Figure 135, p<0.0001). Regardless of riding style, spread of rein tension was higher in the left rein when both hands held the reins. With one-handed rein contact, spread of tension did not differ significantly between left and right reins (Figure 135).

Mean standard deviation as a measure to determine stability of rein contact was higher when the reins were held with both hands compared to one-handed rein contact (Figure 136, p<0.0001). Regardless of rein handling, mean SD was always higher in the right rein (Figure 136, p<0.0001).

Temporal asymmetry (time shift between left and right tension peaks) was highest for bimanual contact, lowest for left-handed rein contact and similar for bridged reins and right-handed rein contact (Figure 137, p=0.003).

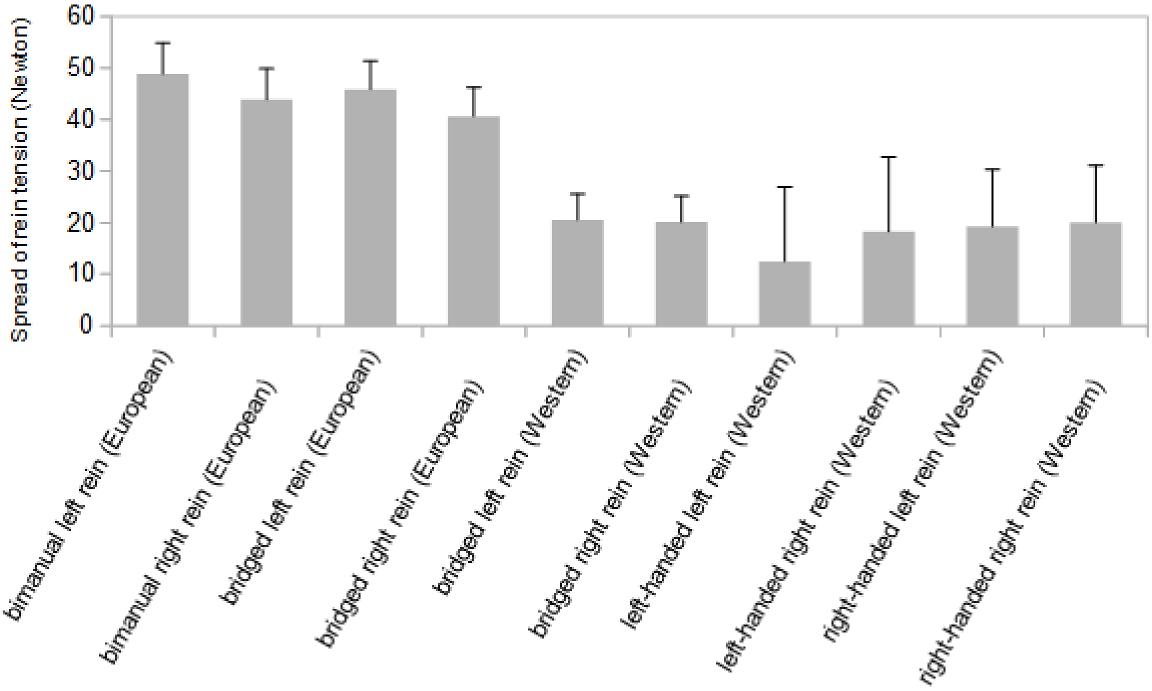


Figure 135: Comparison of the mean spread of rein tension[1] (Newton) of the left versus the right rein with one-handed rein handling (left-handed versus right-handed rein contact) and bridged reins in Western riding, as well as bimanual rein contact and bridged rein in conventional European riding ($p<0.0001$)

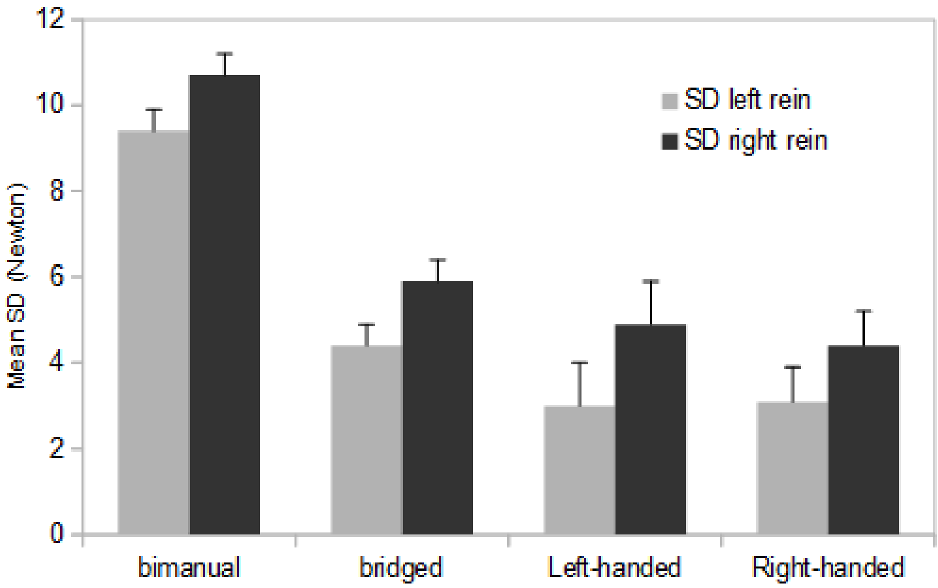


Figure 136: Comparison of the mean standard deviation of rein tension[1] (Newton) of the left versus the right rein with one-handed rein handling (left-handed versus right-handed rein contact), bridged reins and bimanual rein contact ($p<0.0001$)

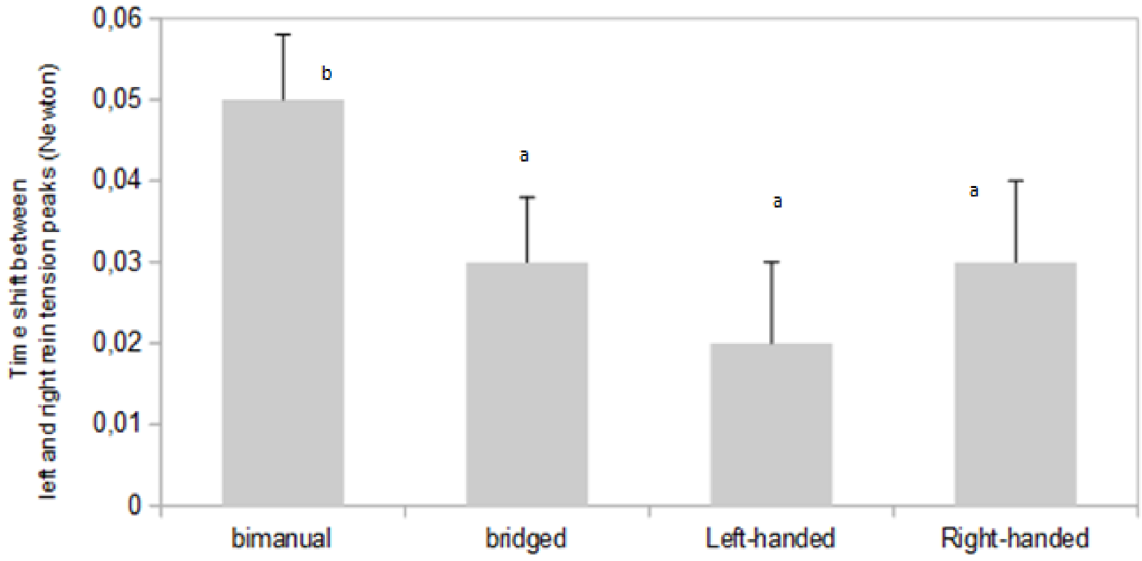


Figure 137: Comparison of time shift between left and right rein tension peaks (seconds) between one-handed rein handling (left-handed versus right-handed rein contact), bridged reins and bimanual rein contact (p=0.001), different letters indicate a significant difference at p<0.05

7.6.1.6 Rein tension parameters in relation to different ways of rein handling in Western riding with regard to laterality

Mean rein tension measured with different ways of rein handling was influenced by horse's laterality (p<0.0001). Higher mean tension was found in left-lateral horses, whereas the lowest mean tension was recorded in horses without reported laterality. The lowest magnitude of mean tension was found when the reins were handled with the left hand in left-lateral horses and with the right hand in right-lateral horses and horses without reported laterality (Figure 138, p<0.0001). Rein tension was symmetric in horses without reported laterality with one-handed rein contact and with right-handed rein contact in left-lateral horses (Figure 138, p<0.0001). Asymmetric rein tension was found with bimanual rein contact with all horses. With left-handed rein contact in left-lateral and right-lateral horses the rein of the horses preferred side revealed higher rein tension (Figure 138, p<0.0001).

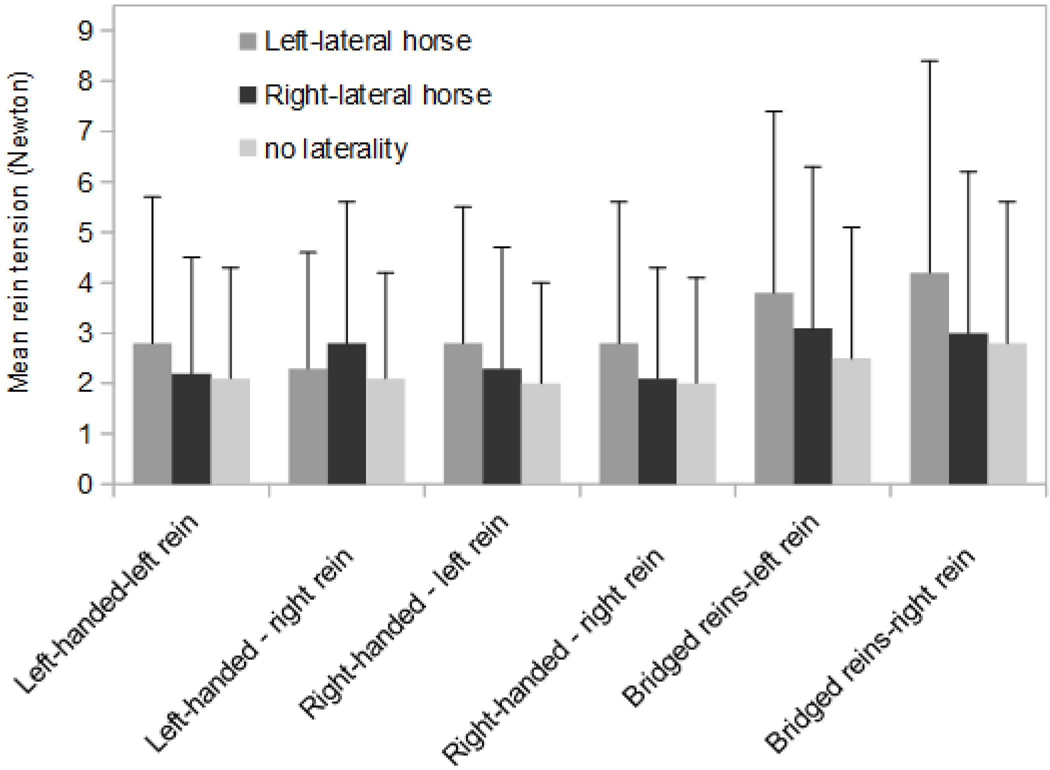


Figure 138: Comparison of mean rein tension[1] (Newton) of the left versus the right rein with one-handed rein handling (left-handed versus right-handed rein contact) and bridged reins with regard to the horse's laterality based on the rider's assessment of side preference for tasks (p<0.0001).

Mean tension, mean SD, mean peak tension and mean difference of left and right rein tension (all p<0.0001) varied according to the different combinations of actual rein handling in relation to preferred rein handling (Table 22, Figures 139 & 140). Rein tension of right-handed rein handling was higher for mean peak tension and lower for mean tension and mean difference of left and right rein tension in riders with a right-preference (Table 22). In riders with a left-preference, rein tension (e.g. mean peak tension) was lower with their non-preferred right hand compared to their preferred left hand (Table 22, Figures 139 & 140).

Table 22: Rein tension parameters[1] (Newton) with different ways of rein handling in relation to rider's rein handling preference. Rein tension during preferred rein handling is bolded.

Actual rein handling & rein handling preference	Number of rides	Mean tension (N)	SD (N)	Mean peak tension (N)	Mean difference of rein tension (N)
bimanual & bimanual	51	13.2±0.8	10.2±0.8	23.1±1.2	7.8±0.6
brigded & bridged	55	6.2±0.9	5.6±0.9	14.7±1.3	3.8±0.6
bridged & right-handed	5	4.8±1.7	4.1±1.5	12.5±2.2	2.5±1.4
bridged & left-handed	1	2.7±4.2	2.4±3.1	9.8±5.5	2±3.1
left-handed & bridged	1	5.3±1.5	4.9±2	15±2.9	3.3±0.9
right-handed & bridged	1	4.8±1.5	4±2.1	14.1±3.1	2.5±1
left-handed & left-handed	2	2.4±3.4	1.9±2.7	20.3±4.5	1.5±2.7
right-handed & left-handed	2	2±3.4	1.4±2.7	9.3±4.5	1.1±2.7
right-handed & right-handed	9	3.6±1.7	3±1.5	10.4±2.3	1.9±1.4
left-handed & right-handed	5	3.9±1.7	3±1.6	9.7±2.5	2.2±1.4
P[1]		<0.0001	<0.0001	<0.0001	<0.0001

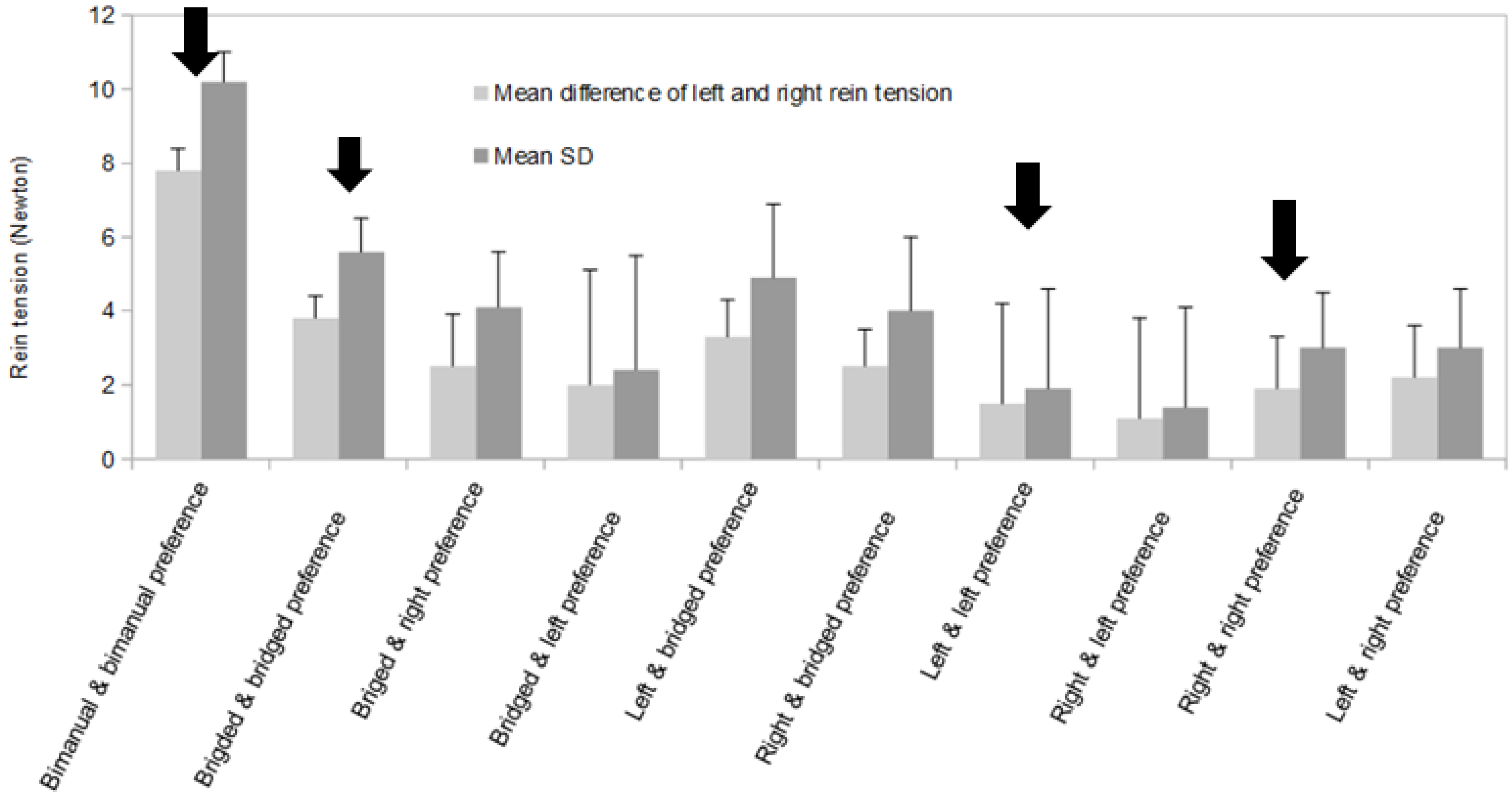


Figure 13939: Rein tension parameters[1] (Newton) with different ways of rein handling in relation to riders rein handling preference ($p<0.0001$, matching preferences are marked with arrows).

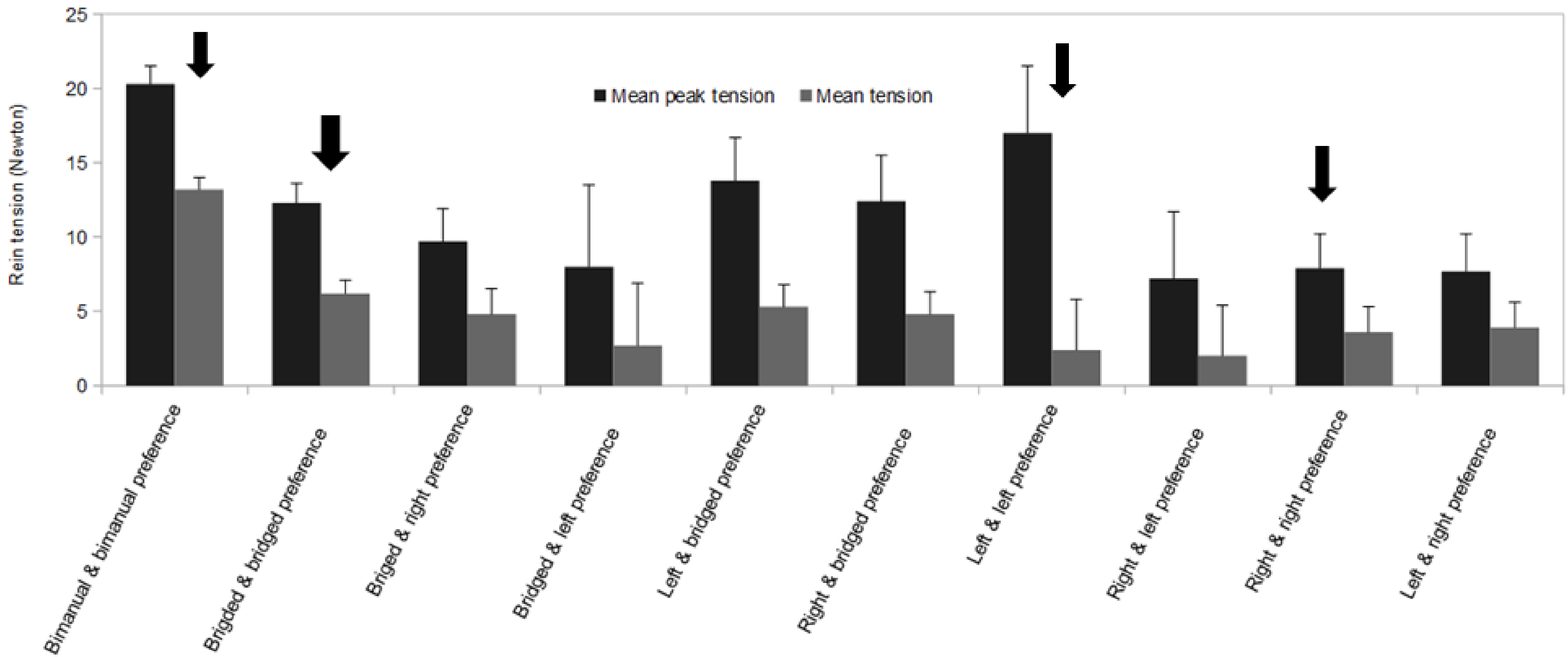


Figure 140: Rein tension parameters[1] (Newton) with different ways of rein handling in relation to riders rein handling preference (p<0.0001, matching preferences are marked with arrows).

The reins as such and the direction of riding (clockwise vs. counter-clockwise) did not influence rein tension. No significant relation of mean peak tension and rein handling with or without regard to horse's laterality and the lateral displacement of the hindquarters could be detected (all p>0.05).

Mean rein tension was lower on the side the hindquarters were displaced to (Figure 141, p=0.0002). Mean rein tension was higher in horses with their hindquarters displaced to the left (Figure 141, p=0.0002). However, little difference of mean tension (i.e. mean tension of left-handed rein handling – mean tension of right-handed rein handling) between left- and right-handed rein contact overall (Figure 142, p<0.0001) occurred.

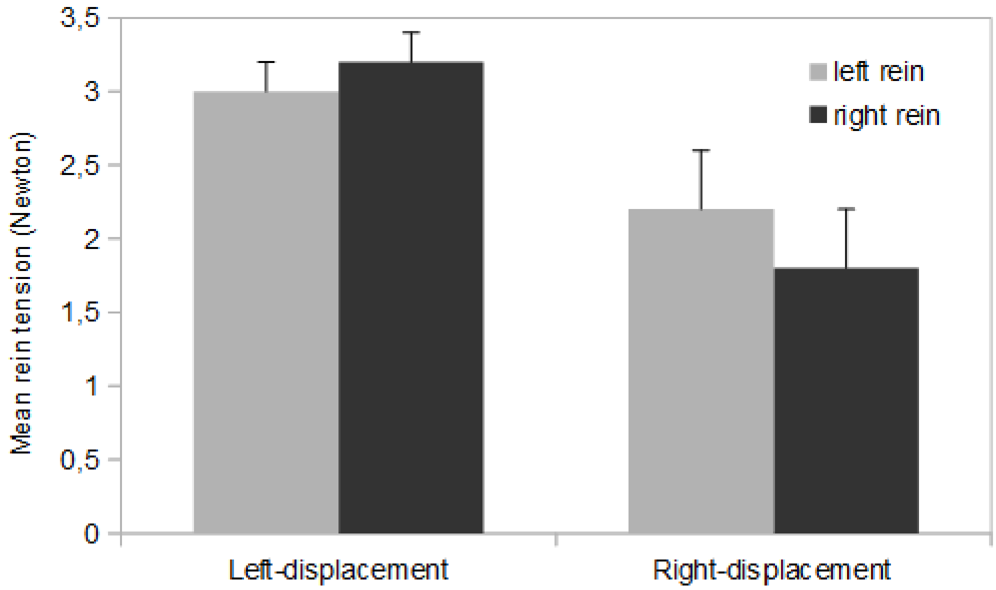


Figure 141: Mean rein tension[1] (N) of the left versus the right rein with one-handed rein handling in relation to the lateral displacement of the horse's hindquarters (left- versus right-displacement, p=0.0002)

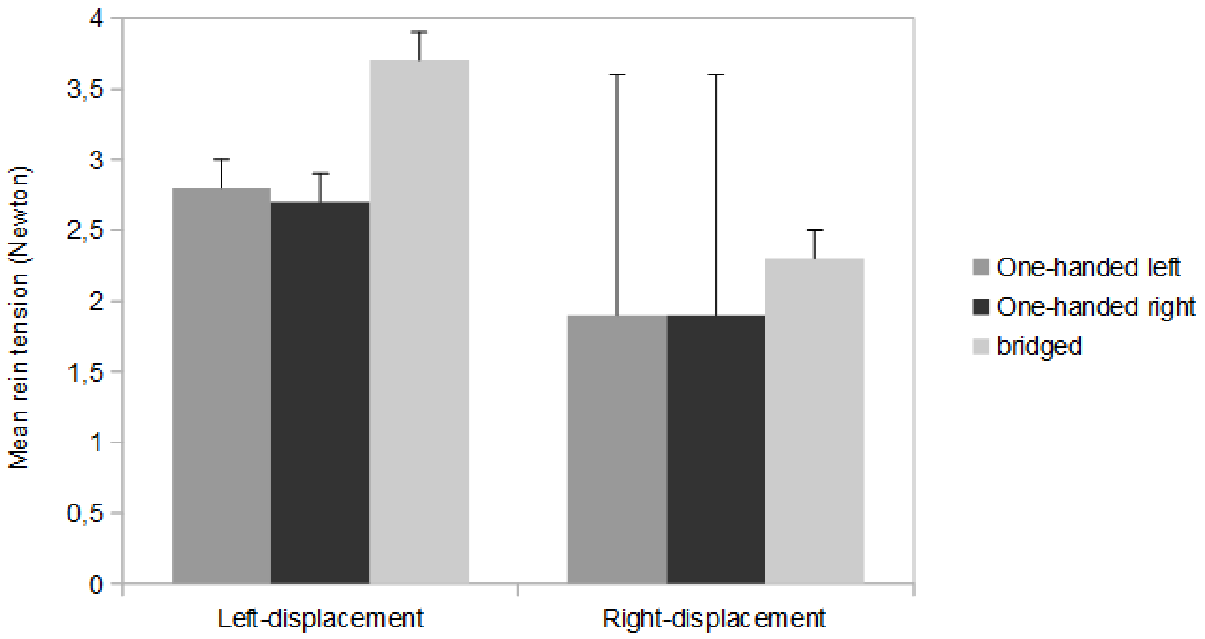


Figure 142: Mean rein tension[1] (N) of different ways of rein handling in relation to the lateral displacement of the horse's hindquarters (5 riders with 11 horses; left- (n=9) versus right-displacement (n=2), $p<0.0001$)

7.6.2 Discussion

7.6.2.1 Rein tension parameters in relation to the type of equipment used for communication

and

7.6.2.2 Rein tension parameters in relation to different riding styles

Equipment such as bits and bridles are means of communication based on the application of pressure to the horse's mouth and head used in all riding styles (Miesner et al. 2000, Holm 2008). The distribution of pressure varies according to different types of bits and bridles in conventional European riding (Preuschoft *et al.* 1995, 1999a), however rein tension data lack direct comparison of different riding styles. Rein tension values with curb bits (Western rides only) were lower compared to rides with snaffle bits (conventional European riding and Western riding combined). Curb bits increase pressure in the horse's mouth through levers, thus reducing the magnitude of rein tension that might be necessary to receive the desired reaction from the horse (Preuschoft 1990b, Preuschoft *et al.* 1999a & c). Rein tension in Western riding is lower as a logical consequence to riding horses with a very loose rein in a riding style based on short, discontinuous signals as a mean of communication (Holm 2008, Schmid 2014). Converted mean rein tension with curb bits and snaffle bits was equally high. Converted peak tension, however, was lower with curb bits (including curb chains) in Western riding as opposed to snaffle bits in both riding styles. Regarding the fact that rein tension values were higher with conventional European riding in general, the difference of rein tension values between curb bits versus snaffle bits in conventional European riding only is expected to be even larger. The common assumption that Western riding results in lower rein tension overall because riders use high peak tension to communicate instead of keeping constant rein contact seems to be confuted. The impression that curb bits might reduce horse-rider communication to minimum signals with less peak tensions in Western riding, if handled correctly (Wienrich 2011), seems to be more likely. However, the converted rein tension values for curb bits do not include the amount of pressure transferred to the curb chain. Still, communication might be more precise and gentle with Western riding and curb bits.

7.6.2.3 Rein tension parameters in relation to different combinations of bits and bridles used in both riding styles

Against the common aim to reduce pressure to the horse's mouth with the use of bitless bridles, rein tension and converted pressure expected on the bridge of the nose were higher than with the single-jointed snaffle bits. In previous studies no difference of rein tension between bitted and bitless combinations were documented (Warren-Smith *et al.* 2007, Bye et al. 2017), except for a Sidepull that, likely due to the smaller contact area, resulted in lower rein tension as voluntarily applied by the horses (Kubiak et al. 2017). However, increased pressure compared to actual rein tension has been reported for the bitless LG bridle before (Herrmann 2011). Rein tension can be applied utilizing lever action via the rings to some extent with this type of bridle, however, in the present study rein tension was applied directly to the rings without using lever forces. Accounting for results showing that the bridge of the nose is sensitive enough to be damaged by tight nosebands (Crago et al. 2017), the use of bridles with correctly fitted bits instead of bitless bridles might improve horse welfare.

However, the assumption that using no cavesson might be beneficial does not seem to be true either. The lowest amount of rein tension in both riding styles was recorded in rides with a noseband that still allowed the horse to open its mouth to some extent (i.e. cavesson in Western riding and grackle noseband in conventional European riding). A possible reason for this result might be that horses without cavessons were able to fully open their mouths, thus trying to reduce rein contact. However, even in an opened mouth, the magnitude of rein tension remains the same. Still, the horse's behaviour might lead to the rider applying more tension to receive the intended reaction. Furthermore, other riders might have specifically chosen a bridle that prevents the horse from opening its jaw intending to solve difficulties of communication with their horse. However, they prohibit their horse from opening the jaws in the fruitless attempt to reduce the painful pressure of the bit. Thus the rider's attempts to communicate via rein signals led to even higher rein tension and the impression of e.g. "very unharmonious" rides (See 7.5). The hypothesis that rein tension is higher in combinations of bits with bridles prohibiting jaw opening (Kapitzke 2001) seems to be verified to some extent. The deplorable fact that riders prevent their horse from chewing the bit and masking problems in horse-rider communication with tightened nosebands have been reported before (Kienapfel & Preuschoft 2010, Doherty et al. 2016).

Rein tension varied between the different types of bits and bridles, especially compared between mean and peak rein tension and converted rein tension values in conventional European riding, again suggesting that the recorded minima must be quite high (compare 7.3). Differentiating between the different bits used in Western riding, it appears that especially fixed curb bits enable the rider to apply low mean pressure (converted mean tension) and moderate pressure peaks (converted peak tension), whereas jointed curb bits lead to higher mean pressure applied to the horse's mouth. These bits combine the effects of snaffle bits with the lever action of fixed curb bits and therefore, cannot be used as precisely as fixed curb bits. Correction bits are usually used when riders experience difficulties in communication via rein signals. The snaffle with shanks comes with different lengths of levers, which might also explain the larger amount of mean tension applied.

7.6.2.4 Rein tension parameters in relation to the type of equipment used for communication with regard to different ways of rein handling

Symmetry of left and right rein tension is a proprioceptive task that appears be more difficult to achieve if both hands are required to coordinate. Therefore, bimanual rein contact and bridged reins were less stable and less symmetric than one-handed rein contact. With bridging the reins stability is increased compared to holding one rein in each hand indicating that the movement of the rider is transferred to both reins at the same time. In contrast, with bimanual rein contact the movement of the rider's body is transferred to each rein individually, thus also leading to a larger time shift of left and right rein tension peaks. Even though the rider's seat appeared to be independent from his/her hands, the rider’s movement might still be slightly asymmetric e.g. due to a rotation of the shoulders or hips (Symes & Ellis 2009, Alexander et al. 2015).

7.6.2.5 Rein tension parameters in relation to different ways of rein handling in conventional European riding and Western riding with regard to laterality

One-handed rein contact (right-handed riders only) with the non-dominant left hand led to larger quantitative asymmetry and higher mean tension overall in the right rein compared to the left, possibly because the right reins might have been held slightly longer. Furthermore, with one-handed rein handling, the tension of the inside rein is transferred to the bit directly, whereas the tension on the outside rein is deflected by the horse’s neck (Preuschoft, personal communication). The left hand seems to be held not as close to the median plane of the horse as the right hand, thus leading to asymmetric rein tension and less quantitative symmetry. This assumption is supported by the fact, that horses with a left displacement of their hindquarters were ridden with slightly higher rein tension left-handed, whereas the same magnitude of rein tension was applied to horses with their hindquarters displaced to the right with either hand. Rein tension of the side opposite to their lateral displacement was slightly higher.

Larger temporal asymmetry and less stability were found when the reins were held with the dominant right hand, suggesting that coordination might be better with the non-dominant hand. Riders with a preference of rein handling with their dominant, right hand showed more symmetric rein tension with higher mean and peak tension when using their preferred right hand. Peaks in riders preferring the non-dominant, left hand however, were twice as high with their preferred left hand whereas their non-preferred, dominant, right hand was associated with higher mean tension. Higher peaks with left-handed rein contact might be caused by the position of the hand relative to the median plane of the horse. Similar results of higher tension in the right rein have been documented with bimanual rein contact. It seems that the left hand might be advantaged when it comes to taking up a light contact overall. Holding the reins and communicating through the maintenance of a light and steady contact to the horse’s mouth is a matter of proprioception and practice. Research has shown an advantage of non-dominant hands for proprioceptive tasks (Han et al. 2013), which could explain why the non-dominant hand in right-handed riders kept a more stable and symmetric contact. Improved performance in unimanual compared to bimanual tasks has also been documented by other research (Han et al. 2013). In right-handed subjects, that are equally strong with both hands or with their non-dominant left hand, the perception and symmetry of grip force is better than for those with most strength in their dominant, right hand (Adamo et al. 2012).

Assuming that this might have been the case in those participants preferring their non-dominant left hand for one-handed rein contact, it might explain the difference in symmetry of rein tension that was observed.

Similar to bimanual contact, rein tension was higher in left-lateral horses but lowest in horses without reported laterality. Rein tension was lower when the hand holding the reins matched the horse’s laterality (right hand & right-lateral horse; left hand & left-lateral horse). However, except for horses without reported laterality and left-lateral horses during right-handed rein handling, rein tension was higher in the rein of the horse’s preferred side. It seems that human handedness might interact with horse’s laterality with one-handed rein contact as well, only with much less rein tension involved. Even with one-handed rein contact and a loose connection riders appear to prevent their horse from drifting with the non-preferred shoulder and avoiding the rein of the preferred side. Still, it might be an advantage for riders to train their proprioception and keeping a light and steady contact through bridging their reins and holding the reins in one hand. Riders who are strong with their dominant hand might profit from training the grip force and perception of their non-dominant hand, especially if they ride horses with mismatching directions of laterality. In contrast to the results for horse’s without laterality overall, it seems that the horses of this smaller sample used for recording one-handed rein tension might actually have been less lateralized than their conspecifics with a reported side preference. However, these assumptions need to be investigated in a larger sample of horse-rider-combinations also including left-handed riders.

7.6.3 Conclusion

7.6.3.1 Rein tension in relation to different bits and bridles

If handled correctly, fixed curb bits used in Western riding might reduce horse-rider communication to minimum signals with less peak tensions. The use of bridles with correctly fitted bits and nosebands instead of bitless bridles might improve horse welfare. Bridles with nosebands allowing the horses to open their mouths to some extent and chew the bit seem to be beneficial for a light and stable rein contact. Bridles prohibiting jaw opening have the potential to negatively affect horse welfare through increased rein tension and mask problems in horse-rider communication.

7.6.3.2 Rein tension in relation to different ways of rein handling

Bridging the reins increased stability and symmetry compared to holding the reins bimanually (i.e. one rein in each hand). One-handed rein contact showed improved symmetry and stability, revealing an advantage of the non-dominant left hand, especially in riders with a left-preference. Even with one-handed rein contact horse’s laterality seemed to affect the symmetry of rein tension. Matching the rider’s hand with the horse’s laterality as well as riding horse’s without reported laterality increased symmetry with one-handed rein contact. Riding with bridged reins or one-handed may improve rider’s proprioception of rein contact and symmetry and improve coordintation with their non-dominant hand.

8. Main Discussion

Factors influencing the degree and direction of horse's laterality, as well as the influence of laterality on the communication between horse and rider, have not yet been satisfactorily investigated. The reins are one of the main means of communication between horses and riders and asymmetric rein tension may lead to negative impacts of the horse's balance, horse-rider communication and training. Therefore, this study aimed to investigate several questions regarding the influence of human handedness and horse's laterality e.g. on horse-rider-communication, rein tension, sport success and risk of musculoskeletal injury.

8.1 Research question 1: Is there agreement between laterality tests used in horses?

and in particular:

8.2 Research questions 2: Do laterality test results obtained on the ground relate to laterality during riding?

The majority of warmbloods and Thoroughbreds did not show an eye preference. Horses showing any biased reaction mostly preferred their left eye, regardless of the breed and sample (Table 23). Sensory and motor laterality were only related in warmbloods, but this relationship may have to be validated in a larger sample of horses showing sensory laterality (Table 24). Especially, with sensory and motor laterality, results of previous research varied, too. Relationships between parameters of the two different domains could not be proven in all samples (Larose et al. 2006, De Boyer Des Roches *et al.* 2008, Carey & Hutchinson 2013). Strong motor laterality does not seem to increase sensory laterality (Carey & Hutchinson 2013).

The associated significance levels of the advanced foreleg during grazing remained, increased or decreased between the samples of the present study, but never changed direction. The results therefore match those of previous studies applying this method (McGreevy & Rogers 2005, McGreevy & Thomson 2006, Warren-Smith & McGreevy 2010, Austin & Rogers 2012). However, the majority of horses showed no leg preference (Table 23). A relation of laterality during riding seems to exist only to the rider's assessment of their horse's laterality, but not to rein tension and results were limited to left-lateral horses only (Table 24). This agrees with results of Wells & Blache (2008) reporting leg preference in horses that did not show laterality on a circle with or without a rider.

The assessment of leg preference during grazing is rather time consuming, however, during a leg preference test most horses did not show a significant preference (z-value >+/-1.95) either (Table 23). The preference test agreed with the rider's assessment of the horse's laterality before for two horses (Kuhnke et al. 2010). In a large sample of various breeds however, no relation to any method determining laterality during riding was found (Table 24). However, many horses in this sample were Western horses that seemed to be less lateralized in general. A relation of leg preference might only exist in horses that appear strongly lateralized.

Even though no direction of mane was most common overall in any sample, a relation to horse's laterality based on the assessment of their riders was found for right-lateral horses with the survey sample only (Table 24). However, there is a potential that riders might have been mistaken and the overall direction of laterality during riding in this sample remained unclear, too. In other research a relation of the direction of the mane to laterality during riding circles could not be documented in Quarter Horses (Whishaw & Kolb 2017). Therefore, it seems advisable to examine a possible relation of the direction of mane to laterality during riding based on the rider's assessment as well as on rein tension in a large sample of horses that appear strongly lateralized.

The direction of facial hair whorls did not agree with the results of any other test method in any sample (Table 23). Even though a relation of facial hair whorls with the rider's assessment of horse's laterality agreed in some studies (Elworthy 2004, Murphy & Arkins 2008, Shivley et al. 2016), there is further research that could not document similar results (Pywell 2005). It seems that body characteristics which are present in every individual might be useful indicators in some, but not all individuals.

In the riding literature, horses are most commonly described as having their hindquarters displaced to the right, which is supposed to be related to their side preference during riding (De la Guérinère 1733, Steinbrecht 1901, Miesner *et al.* 2000, Müseler 1933, Podhajski 1967). The lateral displacement of the hindquarters from the median plane has been investigated in foals and young horses while standing (Lerbs et al. 2014) or trotting in circles (Lucidi et al. 2013). Results of the present study were obtained from behind while standing or walking and agreed with the observations reported in the riding literature for the larger samples (Klimke 1985, Miesner *et al.* 2000, Müseler 1933, Table 23). In the smaller samples of young Thoroughbreds, warmbloods and Western breeds, laterality based on the lateral displacement of the hindquarters was randomly distributed. Most of the Thoroughbreds were closely related which might have biased the results, as offspring from left-lateral parents might have been overrepresented. Furthermore, sample sizes might have been too small to receive reliable results that allow conclusions at the population basis.

Hindquarters that deviate to the right occurred mainly in horses described as right-lateral, but also in a small number of left-lateral horses and vice versa (Table 24). However, horses with mismatching results might have been ambidextrous or preferred different sides depending on the task. Furthermore, laterality patterns of rein tension differed slightly between both directions of lateral displacement, especially for left-displaced horses and with one-handed rein handling (Table 24). Therefore, the lateral displacement of the hindquarters seems to influence rein tension symmetry to some extent. However, results appear more reliable in left-lateral horses.

According to the rider's assessment of their horse's preferred side for dressage tasks and turns, a side bias was present in the majority of horses of all samples (Table 23). Even though the overall direction of laterality varied between the samples, most riders reliably predicted their horse's side preferences during riding. Human handedness and the horses' laterality as assessed by their riders both had an influence on rein tension and delivered results similar to those previously reported (Kuhnke et al. 2010, Table 23). Horse's laterality seemed to be related to the magnitude and symmetry of rein tension, which seems to be the reason why results assessed with both methods mostly agreed (Table 23).

Repeatability and agreement of the direction of lateral displacement of the hindquarters when assessed on track and during video analysis was generally good for the same individuals (Table 23). However, only during video analysis, horses assessed racing in different directions showed inconsistent lateral displacement between directions or within specific races. Since horses are likely to switch to their non-preferred canter lead when they are fatigued (Williams & Norris 2007) and racing Thoroughbreds are pushed to their maximum performance during races as part of the competition, inconsistent lateral displacement might occur as an attempt to change loading and use the muscles differently in order to keep up speed. On the other hand however, results obtained while standing or walking might not be suitable for the identification of ambidextrous horses with regard to this parameter.

The preferred lead of race horses has been previously reported as a method to determine horse's laterality (Deuel & Lawrence 1987, Williams & Norris 2007). Race horses most commonly prefer the same limb for push off at the starting gate and one lead for their racing performance. However, differences according to the direction of preference can be found between racing Thoroughbreds and Quarter Horses (Deuel & Lawrence 1987, Williams & Norris 2007). The majority of Thoroughbred race horses seemed to prefer the outside lead overall, regardless of the direction of the racetrack (Table 23). The opposite has been reported before however, it remains unclear whether data were collected at the start or finish of the race (Barrey 2001, Biewener et al. 1983, Deuel & Lawrence 1987, Davies1996). The majority of horses assessed as right-lateral or left-lateral based on video analysis chose the lead according to the direction their hindquarters were displaced to, thus mainly performing in the inside lead in one direction and in the outside lead in the other direction (Table 24). Ambidextrous horses were mostly inconsistent or showed left-displacement of their hindquarters in a left lead in clockwise and right-displacement in a right lead in counter-clockwise races, thus preferring the outside lead regardless of the direction (Table 24). This furthermore indicates that ambidexterity seems to exist in horses which might be missed if results are obtained from evaluations in one direction only.

Table 23: Overview of the applied laterality test methods with regard to their relations and the different sample populations. (*Mixed model analysis of mean rein tension accounting for horse*rider as random effects and gait, rein*direction*task, laterality*handedness as fixed effects.)

Method	**Variable**	**Sample**	**Results**	**Level of significance (chi²)**	**Further research**
Advanced foreleg during grazing	number of advanced forelegs	67 Warmbloods (Chapter 5, sample A)	Most horses without preference. Significance levels remained, decreased or increased but never changed direction.	$p<0.0001$	Larger sample of horses showing leg preference advisable
30sec. vs. 60 sec. Scan sampling	Z-value +/- 1.95 = significant	61 Thoroughbreds (Chapter 5, Sample E)	The majority of horses showed „no preference“.	$p<0.0001$	
Advanced foreleg during eating from a bucket	number of advanced forelegs	12 Warmbloods (Chapter 5, part of sample A)	none	$p>0.05$	
(limb preference test)	Z-value +/- 1.95 = significant	88 Warmbloods, Quarter Horses and other breeds (Chapter 7)	none	$p>0.05$	
Visual laterality (Novel object test)	preferred eye (left, right, none)	67 Warmbloods (Chapter 5, sample A)	none	$p>0.05$	Larger sample of horses showing visual laterality advisable
Eye preference		61 Thoroughbreds (Chapter 5, sample E)	Left (one object only)	$p<0.0001$	
Lateral displacement of the hindquarters	displacement to the left or right	4408 Warmbloods & riding ponies (Chapter 5, samples A&B)	right	$p<0.0001$	Repeatability within individual horses and between observers Developmental factors that influence this laterality
in relation to the median plane while standing		67 Thoroughbreds (Chapter 5, sample C)	Mostly right; ambidexterity observed	$p<0.0001$	
		88 Warmbloods, Quarter Horses and	none	$p>0.05$	

		other breeds (Chapter 7)			
		61 Thoroughbreds (Chapter 5, sample E)	none	p>0.05	
Degree of the lateral displacement (Angle of deviation of the spine from the perpendicular through the withers)	degree of lateral displacement	12 Warmbloods (Chapter 5, part of sample A)	none	p>0.05	Method might need to be adapted and tested on a larger sample
Direction of facial hair whorls (trichoglyphs)	clockwise, counter-clockwise, radial, mismatching double whorls	67 Warmbloods (Chapter 5, sample A)	none	p>0.05	
		61 Thoroughbreds (Chapter 5, sample E)			
Rider's assessment (preferred side for dressage tasks)	Left-preference, right-preference	1286 horses of various breeds (Chapter 4)	Majority either left- or right-lateral depending on sample; no direction most common overall	p<0.0001	
		21 Warmbloods (Chapter 5, part of sample A)	The majority of horses were assessed as right-lateral.	p=0.021	
		88 Warmbloods, Quarter Horses and other breeds (Chapter 7)	The majority of horses (total and Quarter Horses separately) were assessed as right-lateral.	p<0.0001	

Direction of mane	left, right, bilateral	1286 horses of various breeds (Chapter 4)	no direction most common overall	p>0.05	
		67 Warmbloods (Chapter 5, sample A)	none	p>0.05	
		61 Thoroughbreds (Chapter 5, sample E)	right	p<0.0001	
		88 Warmbloods, Quarter Horses and other breeds (Chapter 7)	none	p>0.05	
Preferred lead during flat racing	left, right in relation to the direction of track	1950 Thoroughbreds (Chapter 5, sample D)	Mostly outside lead	p<0.0001	Relation to leg preference during grazing since numbers were too small
Lateral displacement of the hindquarters from the median plane during flat racing (video analysis)	displacement to the left or right or inconsistent displacement	1950 Thoroughbreds (Chapter 5, sample D)	Mostly right; ambidexterity observed	p=0.002 – p<0.0001	
		67 Thoroughbreds (Chapter 5, sample C)	Mostly right; ambidexterity observed	p<0.0001	
Rein tension symmetry	rein tension (N) in relation to the laterality of horses and riders and the direction of track	12 horse-rider pairs (Chapter 5, part of sample A)	Higher mean tension was applied with the dominant (right) hand and to left-lateral horses. The magnitude and stability of mean rein tension varied in relation to the direction of riding and the horse's preferred side.	Rider: p=0.044* Horse: p=0.02* Stability: p<0.0001*	
		106 horse-rider pairs (Chapter7)		P<0.0001*	

Table 24: Overview of the relation between the results of the applied laterality test methods in the different sample populations. (Mixed model analysis of mean rein tension accounting for horse*rider as random effects and gait, rein*direction*task, laterality*handedness as fixed effects; Methods to determine horse's laterality during riding are bolded.)

Method 1	**Method 2**	**Sample**	**Results**	**Level of significance (chi²)**	**Further research**
Advanced foreleg during grazing 60 sec. Scan sampling	Visual laterality	61 Thoroughbreds (Chapter 5, sample E)	Left eye preferred only in horses with left leg preference or no preference	Left leg: p=0.005 No preference: p=0.009	Relation to motor laterality with a larger sample of horses showing visual laterality
Advanced foreleg during grazing 60 sec. Scan sampling	**Rider's assessment**	21 Warmbloods (Chapter 5, part of sample A)	Most horses showed no preference. Some right-lateral horses tended to prefer either their left or right foreleg. Left-lateral horses showed a tendency to prefer the left foreleg only	p= 0.018	Relation of the advanced foreleg during grazing and eating from a bucket, the rider's assessment and rein tension with a larger sample of horses showing a distinct leg preference
Lateral displacement of the hindquarters in relation to the median plane while standing	**Rider's assessment**	21 Warmbloods (Chapter 5, part of sample A)	Results agreed for most horses. Only horses with their hindquarters displaced to the right were assessed as left-lateral.	P=0.003	Examine agreement of results in a larger sample of horses with distinct motor laterality and compare with rein tension symmetry in order to identify mechanisms of interaction
		88 Warmbloods, Quarter Horses and other breeds (Chapter 7)	Results are weakly correlated	p=0.001	
	Rein tension	12 Warmbloods (Chapter 5, part of sample A)	Rein tension tended to be higher in horses with a left-displacement	p=0.077	

		88 Warmbloods, Quarter Horses and other breeds (Chapter 7)	Influenced the magnitude and symmetry of rein tension and the rider's assessment of their own rein contact	P<0.0001 – p=0.04	
	Lateral displacement of the hindquarters during video analysis	67 Thoroughbreds (Chapter 5, sample C)	79% agreement overall; 81.5% agreement for horses determined as right-lateral and 69.3% for left-lateral horses (Method1) in clockwise races	p=0.0001	
		4408 Warmbloods & riding ponies (Chapter 5, samples A&B)	No significant difference concerning the distribution of left-vs.right-lateral horses in both samples	p>0.05	
Direction of mane	**Rider's assessment**	1286 horses of various breeds (Chapter 4)	Agreed with preferred side for riding in right-lateral horses	p<0.0001	Evaluate and compare to rein tension with a larger sample of horses with distinct laterality during riding
Preferred lead during flat racing	Lateral displacement of the hindquarters from the median plane during flat racing (video analysis)	1950 Thoroughbreds (Chapter 5, sample D)	The majority of horses were right-lateral or ambidextrous based on results from races in both directions. The preferred lead and lateral displacement were identical, in left- and right-lateral horses (Preference of inside lead in one and outside lead in the other direction). Ambidextrous horses displaced their hindquarters according to the racing direction and preferred the outside lead in either direction.	all p<0.0001	
Rein tension symmetry	**Rider's assessment**	12 horse-rider pairs (Chapter 5, part of sample A)	Rein tension symmetry agreed mostly with the direction of laterality assessed by the riders	p=0.019	
		106 horse-rider pairs (Chapter7)		P<0.0001*	

8.3 Research question 3: What is the most common direction of motor laterality in the populations of warmbloods, ponies, American Quarter Horses and Thoroughbreds?

Motor laterality in horses has to be divided into several different aspects. Since equitation or flat racing is the main purpose to breed and keep horses, only the test methods that are related to laterality during riding i.e. the lateral displacement of the hindquarters and the rider's assessment of their preferred side seem to be of further interest (Table 25).

Besides the method of observation, breed seems to be a decisive factor for laterality. In Thoroughbreds, Standardbred trotters and warmblood breeds lateralized behaviour was documented at the population basis with a variety of test methods (McGreevy & Rogers 2005, McGreevy & Thomson 2006, Murphy & Arkins 2008, Lucidi et al. 2013). In Quarter Horses in contrast, methods investigating motor laterality on the ground (Siniscalchi et al. 2014, McGreevy & Thomson 2006) or during riding (Whishaw 2015, Whishaw & Kolb 2017), showed that side differences could be observed for some individuals, however laterality was absent in the population. Similar results were observed in the present study, as well as in other species such as great apes (Christel 1993). Western breeds appeared less lateralized during riding based on measurements of rein tension, however, for most individuals preferences have been reported by their riders. Investigating the lateral displacement of the hindquarters from the median plane revealed that a lateral displacement to either side was present in every individual, regardless of the breed. In warmbloods a right-bias was observed, regardless of the sample size. Similar observations have repeatedly been documented since long time (de la Guérinère 1733, Steinbrecht 1901, Müseler 1933, Klimke 1985, Loch 2000, Miesner *et al.* 2000, Hinnemann & van Baalen 2004). Therefore it seems that concerning this aspect, warmbloods and ponies are right-lateralized at the population basis. Regarding the rider's assessment of their horse's side preference, a higher number of right-lateral horses were observed in the smaller samples too. With a sample size that might be large enough to conclude to an overall direction of laterality at the population basis, however, no direction could be determined with certainty. Since information about horse's laterality was obtained from two different questions in a survey (chapter 4) and each direction of laterality was stated slightly more often, it seems that a most common direction of laterality during riding does not exist at the population basis in warmbloods and ponies either.

In racing Thoroughbreds, the majority of horses in the present study seem to be right-lateral according to the lateral displacement of their hindquarters which agrees with previous research using similar methods (Williams & Norris 2007). However, when examining the lateral displacement of the hindquarters in relation to the preferred lead and considering both racetrack directions, ambidexterity can be observed in a large number of horses.

The distribution of laterality in different populations seems to be strongly related to the method applied. In contrast to the human population with about 11% left-handed and ambidextrous individuals (Annett 1978, Dragovic *et al.* 2008, Volkmann *et al.* 1998, McKeever 2004), it seems that horses are not that strongly lateralized at the population basis when it comes to laterality during riding. Regarding the lateral deviation of the hindquarters however, it seems that right-lateral horses have been (Klimke 1985, Miesner *et al.* 2000, Müseler 1933) and are still more common. However, only the rider's assessment was directly related to rein tension symmetry and the lateral displacement of the hindquarters seemed to influence rein tension patterns more subtle than commonly expected (Müseler 1933, Klimke 1985, Miesner *et al.* 2000). Furthermore, some riders reported either divergent preferences for different tasks or no side preference which, however, did not result in symmetric rein tension at all. Similarly, great variability of lateralized behaviours for the same task has been observed in great apes and humans between species and even within the same individual (Christel 1993). Therefore, a most common direction of laterality during riding might not even exist, whether at the population basis or within individual horses.

Table 25: An overview of the most common direction of different aspects of motor laterality with a relation to laterality during riding and their heritabilities in different breeds.

Laterality method	Sample population	Most common direction	Level of significance (chi²)	Heritability (h^2)
Lateral displacement of the hindquarters from the median plane	67 Warmbloods (Chapter 5, sample A)	Right-lateral	P<0.0001	not estimated
	3973 Warmbloods & 368 riding ponies (Chapter 5, sample B)	Right-lateral	P<0.0001	Laterality (warmbloods): 0.51
	67 Thoroughbreds (Chapter 5, sample C)	Mostly right; ambidexterity observed	p<0.0001	not estimated
	1950 Thoroughbreds (Chapter 5, sample D)	Mostly right; ambidexterity observed	p=0.002 – p<0.0001	Laterality:0.19 Placings: 0.72 Wins: 0.66
	61 Thoroughbreds (Chapter 5, sample E)	none	p>0.05	not estimated
	88 Warmbloods, Quarter Horses and other breeds (Chapter 7)	none	p>0.05	not estimated
Rider's assessment (preferred side for dressage tasks)	1286 horses of various breeds (Chapter 4)	Majority either left- or right-lateral depending on sample; no direction most common overall	p<0.0001	-
	21 Warmbloods (Chapter 5, part of sample A)	Right-lateral	p=0.021	-
	88 Warmbloods, Quarter Horses and other breeds (Chapter 7)	Right-lateral	p<0.0001	-

8.4 Research questions 4: Is the lateral displacement of the hindquarters a valid indicator for horse's motor laterality and if so, what is the heritability in warmbloods and Thoroughbreds?

The direction of the lateral displacement of the hindquarters varied between individuals, however, it did not influence mean rein tension. Still, it was the only parameter of those assessed on the ground that agreed with laterality during riding for most individuals with a displacement to either side. In contrast to common assumptions in the riding literature (De la Guérinère 1733, Steinbrecht 1901, Miesner *et al.* 2000, Müseler 1933, Podhajski 1967, Klimke 1985), the lateral displacement of the hindquarters and the rider's assessment of the horse's preferred side are not directly related. Neither does a relation of trigger points to the lateral displacement of the hindquarters or any other laterality test method exist. Still, the rider's assessment of their own rein contact varied between horses with their hindquarters displaced to the left or right. The lateral displacement of the hindquarters seems to influence the asymmetry patterns of horse-rider communication in a more subtle way e.g. when it comes to the magnitude, as well as quantitative and temporal symmetry of rein tension in bimanual and one-handed rein contact.

Results of horse's laterality based on their rider's assessment and the lateral displacement of their hindquarters matched for the majority of the sample, but not for all horses. Possible reasons might be that the rider's own handedness masked the horse's true side preference or ambidexterity. Also horses that were perceived as performing equally well might have been affected by difficulties of horse-rider communication based on the rider's handedness. Regarding the fact that truly symmetric and well-balanced horses are scarce (Steinbrecht 1901, Klimke 1985, Murphy & Arkins 2008), these horses might have potentially shown inconsistent lateral displacement and would thus have been identified as ambidextrous, had they been assessed when moving in both directions. However, the warmblood samples were only observed while standing or walking away from the observer on a straight line. The Thoroughbred samples in contrast lack the rider's assessment of the horse's laterality in order to compare results for horses considered to be ambidextrous. In general, the lateral displacement of the hindquarters is a body characteristic that is not absent even in ambidextrous horses. Therefore the assessment during movement in both directions appears necessary for the identification of ambidextrous horses. Using the lateral displacement of the hindquarters as an indicator for laterality during riding that is assessed in both directions might deliver results that are independent from the rider's influence.

Both, warmbloods and Thoroughbreds were assessed in situ and during video analysis. Results between samples revealed good agreement of results for the same individuals. Using video analysis, Thoroughbreds could be examined in both directions under the same conditions, thus providing the first method to observe ambidexterity in horses. The majority of races taking place in Germany are held in a clockwise direction, which might lead to horses being more adapted to and trained for racing in this direction as opposed to racing counter-clockwise. The observed larger number of right-lateral and ambidextrous individuals in a population bred for performance mainly in a clockwise direction indicates that these traits might be beneficial for performance. Phenotypic correlation between laterality and number of wins and placings was low and the lateral displacement of the hindquarters was not related between parents and their offspring on a phenotypic basis. Furthermore, parameters of success did not directly relate to the lateral displacement of the hindquarters or the preferred lead, however, genetic correlations were high in Thoroughbreds only (Tables 25 & 26). Selection of other related traits on a phenotypic level might have taken place, thus changing the structure of the population towards right-laterality or ambidexterity. A high genetic correlation suggests that laterality might be useful as an indicator for genetic merit for racing success and, that horses with a right-displacement might be genetically more prone to obtain a larger number of wins and placings. However, when interpreting the results, the relatively low sample size for estimation of genetic parameters needs to be kept in mind, which might explain the high heritabilities for placings and wins.

The visual lateral displacement of the hindquarters showed a side bias to the right at the population basis in warmbloods and ponies too, however, since horses were evaluated while standing or walking in one direction only, ambidexterity remained unnoticed. As observed in other species (Hopkins et al. 2011, Tabiowo & Forrester 2013, McManus 2002, Vallortigara 2006), both directions of laterality exist in horse populations, even though one direction of laterality is most frequent at the population basis. Similar to other studies that revealed the majority of their rather small samples being either left- or right-lateral according to the different methods applied, e.g. leg preference (McGreevy & Rogers 2005, McGreevy & Thomson 2006, Murphy et al. 2005, Murphy & Arkins 2008), some breeds among the overall population of warmbloods showed a lateral displacement to the left or right at the basis of their breed's population. Regarding the different incidence of left-laterality in Oldenburgs bred for show jumping compared to those bred for dressage it seems that the lateral displacement of the hindquarters is genetically related to certain performance traits in warmbloods and ponies, too. Furthermore, a left-displacement of the hindquarters was directly related to the competition level in warmbloods, indicating that this trait might benefit performance especially in dressage (Table 26). Since similar relations of the lateral displacement of the hindquarters to variables of success have been observed in racing Thoroughbreds, it appears that through phenotypic selection of certain performance traits (e.g. number of wins, show jumping index or to some extent horses' coat colours) the incidence of laterality in the population could be modified towards one direction. Even though heritability for laterality in warmbloods was high on the observed scale no results could be obtained for variables of sport success. Still, if the lateral displacement of the hindquarters proofs to be a reliable estimate, it would indicate that selection against laterality could be successful.

In humans several genetic models have been suggested to explain and predict the inheritance of left-handedness (Annett 1978, McManus 1985, Dragovic *et al.* 2008, McKeever 2004, Ocklenburg et al. 2017). Still, the mechanism behind the genetics of laterality remains unknown in humans as well as in animals and lateralized behaviours might be diverse, even within the same individual for identical tasks (Christel 1993).

Table 26: An overview of the laterality during riding, its heritability and its relation to variables of sport in warmbloods, ponies and Thoroughbreds

Laterality test method	**Sample population**	**Direction of laterality**	**Sport success**	**Level of significance**	**Heritability (h^2)**
Lateral displacement of the hindquarters	3973 Warmbloods & 368 riding ponies (Chapter 5, sample B)	Right-lateral	More common at level M and S	p=0.039	-warmbloods: Laterality: h^2=0.51
		Left-lateral	More common at international and Grand Prix level	p=0.039	
Lateral displacement of the hindquarters	1950 Thoroughbreds (Chapter 5, sample D)	Right-lateral	Achieved single wins and placings most often	P<0.0001	Laterality: 0.19 placings: h^2=0.72 wins: h^2=0.66
		Left-lateral	Remained unplaced most often	P<0.0001	laterality & number of wins: rg=0.82±0.19
		Ambidextrous	Achieved maximum number of wins	P<0.0001	laterality & number of placings: rg=0.70±0.16
Preferred lead during flat racing	1950 Thoroughbreds (Chapter 5, sample D)	Outside lead	More successful in clockwise races	P<0.0001	not estimated
		Inside lead	More successful in counter-clockwise races	P=0.022	
		Ambidextrous	More successful overall	P=0.022/<0.0001	
Rider's assessment (preferred side for dressage tasks) and rein tension symmetry	88 Warmbloods, Quarter Horses and other breeds (Chapter 7)	Right-lateral	No relation	p>0.05	not estimated
		Left-lateral	No relation	p>0.05	
		No laterality	No relation	p>0.05	
Rider's assessment (preferred side for dressage tasks)	1286 horses of various breeds (Chapter 4)	Matching directions in horse-rider combinations	Success was mainly influenced by human handedness; left-handed and ambidextrous riders were more successfull	P<0.0001	not estimated

8.5 Research question 5: Does motor laterality and race track direction affect performance in racing Thoroughbreds?

Variables of body symmetry are related to risk of injury (Ramzan & Palmer 2011, Anderson et al. 1999) as well as racing success (Smith et al. 2006, Leleu et al. 2005). In racing Thoroughbreds the preferred lead mostly agreed with the lateral displacement of their hindquarters during races in both directions. In left-lateral and right-lateral horses the preferred lead agreed with the direction of laterality based on the lateral displacement of their hindquarters in situ too. It seems that matching patterns of asymmetry between the lateral displacement of horse's hindquarters and their lead preference might improve performance. In contrast to previous reports (Barrey 2001, Biewener *et al.* 1983, Deuel & Lawrence 1987, Davies1996), the majority of Thoroughbred race horses seemed to prefer the outside lead overall, regardless of the direction of the racetrack. However, the amount of data and whether data were collected at the start or finish of the race remains unclear. Performance in the outside lead could mean that horses have already changed their lead due to fatigue before the finish line (Williams & Norris 2007). However, using the outside lead seems to provide an advantage for their performance. The preferred lead shows slightly different movement patterns compared to the non preferred lead. In their preferred lead, horses kept a constant stride frequency with an increase of stride length and overall speed (Deuel & Lawrence 1987) as well as positive effects from respiratory-locomotory coupling (Williams & Norris 2007), which might be a decisive advantage during racing. Even though no direct influence of the direction of laterality on the parameters of success was found, the lead in relation to the direction of racetrack seems to be related to racing success. Horses preferring the outside lead in either direction showed the highest number of wins and placings. In clockwise races the majority of horses without a specific preference were more successful than horses preferring either lead. In counter-clockwise races in contrast, the majority of horses preferring the left (inside) lead performed more successfully. However, ambidextrous and right-lateral horses were more successful overall. Right-lateral horses seem to be superior in clockwise races, since they perform better with the preferred inside (right) lead and benefit from the non-preferred outside (left) lead. In contrast, left-lateral horses seem to perform better with their left lead only, thus being more successful in counter-clockwise races. Still, since the majority of races are clockwise, right-lateral horses might be better trained in using the outside lead, thus reducing the advantage of left-lateral horses in counter-clockwise races. Ambidextrous horses, even though being closer to left-lateral than right-lateral horses, appear to be little lateralized and able to adapt to any direction. Preferring the outside lead regardless of the racetrack, they are able to perform more successfully than left-lateral horses. Laterality as an indicator of performance in both directions as well as the outside lead during races in either direction was related to racing success. In a population bred for and selected according to race performance, a shift towards a higher percentage of right-lateral and especially ambidextrous horses seems to have taken place. In contrast to previous findings, horses performing in the outside lead during approach of the finish line in either direction showed increased success, possibly because the outside lead enables them to pass the track's bends at a faster speed.

8.6 Research question 6: Does a relationship between motor laterality and shortened or stiff muscles exist?

A relationship between laterality and shortened or stiff muscles on horses' preferred sides (i.e. the one their hindquarters are displaced to), restricting them to bend to the opposite, non-preferred side, has been hypothesized for long time (de la Guérinère 1733, Steinbrecht 1901, Hinnemann & van Baalen 2004, Klimke 1985, Loch 2000, Miesner *et al.* 2000, Müseler 1933). However, trigger point reactions as an indicator for muscle tension, were neither directly related to horse's laterality as assessed by their riders, nor the lateral displacement of their hindquarters or to the side to which difficulties bending were reported by the riders. Even though the present results reject this common hypothesis, horse's muscle state might still influence the lateral displacement of the hindquarters and the rider's impression of their horse's side preference in a more subtle way. Muscles involved in lateral flexion (Budras & Röck 2017, Kienapfel et al. 2017) contributed to the sum of trigger point reactions of both sides with different proportions, indicating that asymmetries of these muscles may still influence the lateral displacement of the hindquarters. Furthermore, horses with rein contact that was perceived as "instable" or "very instable" also showed asymmetric trigger point reactions, suggesting an impact of muscular tension on horse-rider communication e.g. due to asymmetric muscle strength and motor control (Bowen et al. 2017, Scott & Swenson 2009).

Asymmetric muscles seem to be directly related to the horse's posture too. Variables of body symmetry such as tail carriage are influenced by the symmetry rather than the magnitude of trigger point reactions. Even though the muscles moving the horse's tail were not included in the sample of tested trigger points, the exact cause of horse's carrying their tail to one side might not be these muscles as such. Tension and asymmetries of muscle chains as a result of osteopathic lesions have been reported for humans before (Wallden 2011) and might be another possible explanation. Since the muscle chains of the large muscle groups of the neck, abdomen and hindquarters enable the "collection" of the horse, which includes the horse going on the bit (Preuschoft 1976, Preuschoft et al. 1994a), a balanced muscle state seems to be essential for horse's performance and health. In fact, the muscle groups responsible for protraction and retraction of the limbs were correlated with the sum of trigger point reactions. Especially the muscles moving the shoulder and the hip joint, stabilizing the spine and enabling lateral flexion (Budras & Röck 2000, Kienapfel et al. 2017) contributed most to the sum of trigger point reactions on both body sides and were most strongly correlated with asymmetric trigger point reactions indicating that quality of movement might influence muscular health and vice versa. In fact, muscle asymmetries were related to sacro-iliac pain and poor performance in other research (Dyson & Murray 2003).

According to the theory behind trigger point massage, trigger points are the areas where the most tension occurs in uptight muscles (Meagher 1985, Teslau 2006). They develop a taut band, i.e. a bundle of contracted, hard muscle fibres with ischemia, hypoxia, cell damage and inflammatory mediators, along with local and referred pain and a local twitch response (Hong & Simons 1998, Gerwin 2008). Sensitive muscle trigger points and pain have a negative impact on muscle strength and performance as well as on motor control (Bowen et al. 2017, Scott & Swenson 2009, Teslau 2006). Structural asymmetry as well as tensed and asymmetric muscle chains, lead to compensative changes in posture and increased loading of certain structures and body parts while others are loaded to a lesser extent than usual (Dyson & Murray 2003, Wallden 2011). This has been associated with an increased risk of injury to those structures in humans (Pugh & Bolin 2004, Al-Eisa et al. 2006, Cawley et al. 2015) and horses (Dyson *et al.* 2003, Pearce *et al.* 2005, Stashak 1995, Tomlinson *et al.* 2003). In fact, horse injuries were related to the sum of trigger point reactions of the right side. Especially with bilateral injuries the sum of trigger point reactions of the right side was higher than with an injury to either side alone. Since especially mean peak tension was higher in the right rein in all horse-rider-combinations, a larger sum of trigger point reaction might be the result of high rein tension. Regarding muscle state as a reported factor influencing horse's health and especially lameness (Dyson & Murray 2003), testing trigger point reactions might be a measure to detect and treat possible issues and prevent injuries.

Horse's muscle state did not differ according to rider's handedness, equipment, riding style and different attributes of horse-rider communication, indicating that even though a good muscular state could be affected by a large variety of influencing factors, the muscular system might also have the ability to compensate negative influence to some extent.

8.7 Research question 7: How do horse's laterality and human handedness affect rein tension in different riding styles and disciplines?

Asymmetries in rein tension have been discovered before (Clayton et al. 2003, Stahlecker 2007, Warren-Smith et al. 2007) and are most likely influenced by both human handedness and horse's laterality (Kuhnke et al. 2010). Previous research found that riders mainly influenced the amount of minimum and mean rein tension, whereas the horses seemed to determine the range and maximum rein tension applied (Eisersiö et al. 2015, Egenvall et al. 2015b). Stability of rein tension in the present study seemed to be solely determined by the rider. The mean difference of left and right rein tension and thus quantitative asymmetry was larger with gait transitions and faster gaits suggesting a relation of symmetry with speed. Time shift between the peaks of the left and right rein was ten times higher in canter and seven times higher in walk compared to sitting or rising trot. Temporal asymmetry might be influenced by the horse's head and neck movement and footfall pattern as such and the associated forces acting on the rider (Preuschoft *et al*. 1999a, b & c; Clayton *et al.* 2005, Preuschoft 2011). Less time shift would have been expected in walk than trot. However, tension peaks occur at hind limb stance in walk as well as during the stance phase of the inside forelimb/outside hind limb at canter (Clayton *et al*. 2005, Egenvall et al. 2015a), whereas in both sitting and rising trot, spikes are recorded during the suspension phase (Egenvall et al. 2015a). Furthermore, rising trot seems to enhance horse-rider coordination (Wolframm et al. 2013) and provides more stability to the rider (Peham *et al.* 2009). Therefore, symmetry and the movement pattern of the gait as such might be more important than speed. It seems that symmetry is influenced by several variables and at least two different levels of symmetry (i.e. quantitative and temporal symmetry) exist.

A significant proportion of the variance of mean standard deviation of rein tension as an indicator of stability was explained by the rider. Also, temporal asymmetry was greater in right-handed than left-handed and ambidextrous participants, thus indicating that the rider, but not the horse or horse-rider-combinations influence the stability and temporal symmetry of rein tension. Left-handed humans show advantages such as shorter reaction times and improved skill of their non-dominant hand (Steenhuis & Bryden 1999, Rousson et al. 2009), as well as superior proprioception in both arms (Schmidt et al. 2013). They perceive grip force more accurately, thus being able to perform superiorly in bimanual tasks (Judge & Stirling 2003) and more symmetrically overall (Adamo et al. 2012). The strength of handedness also seems to influence time perception especially with ambidextrous individuals differing from those with stronger handedness (Westfall et al. 2010). These attributes might explain the advantage of left-handed and ambidextrous riders in the present study for trying to keep a soft and stable contact to the horses' mouth. In contrast, right-handed individuals showed asymmetric perception and grip force in previous research, when their right hand was generally stronger than their left (Adamo et al. 2012), which seemed to be true for the majority of right-handed riders in the present sample.

The magnitude of rein tension was not influenced by human handedness alone. The total variance of mean rein tension in the present study was equally influenced by the horse and the rider. The magnitude of rein tension differed significantly between the directions of laterality. Therefore, quantitative asymmetry might be related to different directions of laterality in horse-rider-combinations, in contrast to temporal symmetry. As documented previously (Kuhnke et al. 2010) higher rein tension was applied to left-lateral horses compared to right-lateral horses or horses without reported laterality. Right-handed riders applied lower mean and peak tension to horses with matching (right-) laterality than to left-lateral horses and horses without reported laterality (Figure 143). In contrast, left-handed riders applied higher mean and peak tension to left-lateral compared to other horses (Figure 143). Ambidextrous riders seemed to be comparable to right-handed individuals for mean and to left-handed individuals for mean peak tension (Figure 143). However, results have to be regarded carefully, since only two ambidextrous riders participated and only rode right-lateral horses.

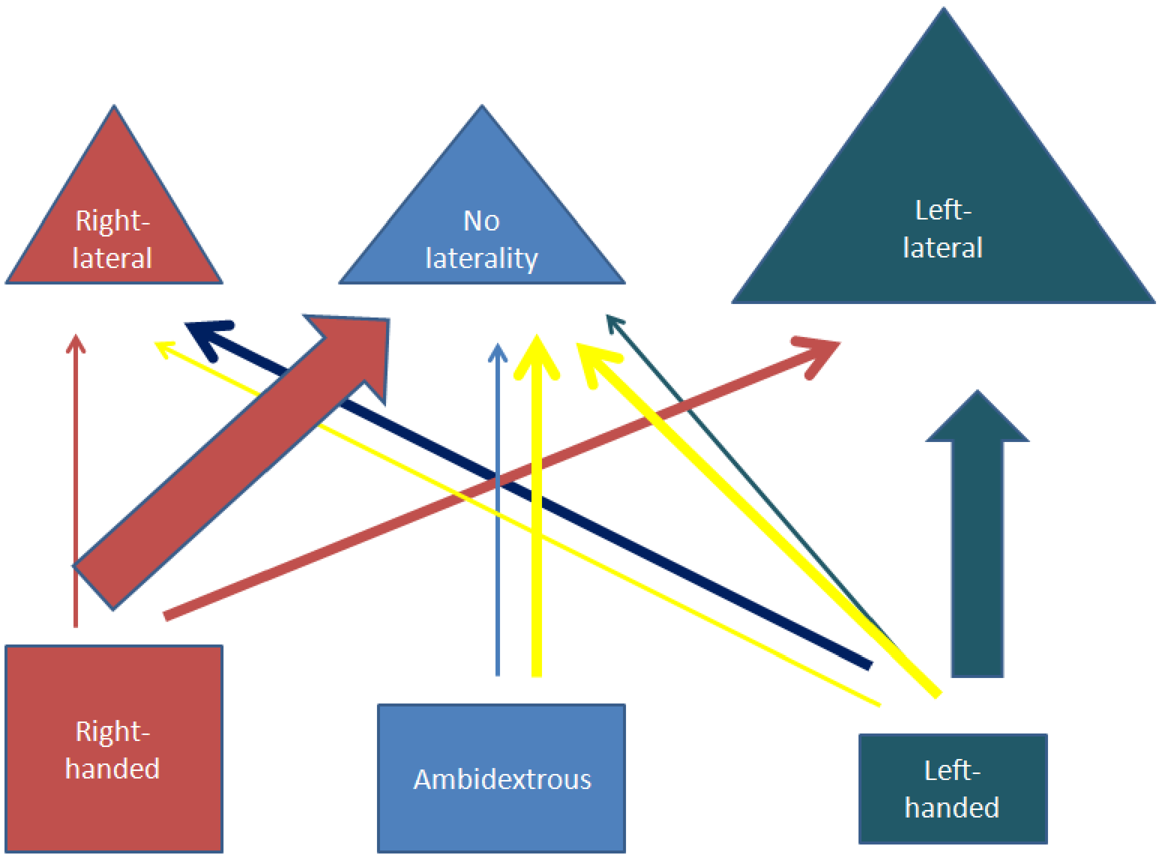


Figure 143: Schematic comparison of mean and peak rein tension overall between the different directions of horse's laterality and human handedness in horse-rider combinations (Boxes represent riders and triangles represent horses in horse-rider combinations). The size of the boxes resembles the magnitude of mean and peak rein tension within laterality and handedness, respectively. The size of the arrows indicates the proportion of mean and peak tension (red: mean and peak tension in right-handed riders, blue: mean tension of ambidextrous riders, turquoise: mean tension of left-handed riders, yellow: peak tension of left-handed and ambidextrous riders, mean tension p=0.04, mean peak tension p=0.03).

In the present study, riders applied higher peak tension to the right rein on straight lines, regardless of the direction. Except for straight lines counter-clockwise, when higher peak tension was applied to the outside (right) rein, rein tension was asymmetric and stronger on the inside rein on circles counter-clockwise (left rein) and on circles and straight lines clockwise (right rein). Stronger mean tension regardless of the direction was recorded in the inside rein, too (Figure 144). Attributes such as muscle strength and grip force of individuals have repeatedly been documented to be larger in the dominant hand (Steele 2000, Klum et al. 2012) in female and right-handed individuals for a variety of tasks, but also when holding the reins (Hobbs et al. 2014). This applied to the majority of riders in the present study and suggested a possible relation to human handedness. It has previously been argued that the non-dominant (left) hand in right-handed riders is weaker and therefore produces stiff and tensed rein signals as opposed to the soft and flexible rein signals given with the dominant (right) hand (Wyche 2004). The present results however, reject this hypothesis. It seems that the “weaker” left hand is able to act more sensitive, whereas the dominant (right) hand produces stronger and less flexible rein tension patterns, which has also been observed previously (Stahlecker 2007, Kuhnke et al. 2010).

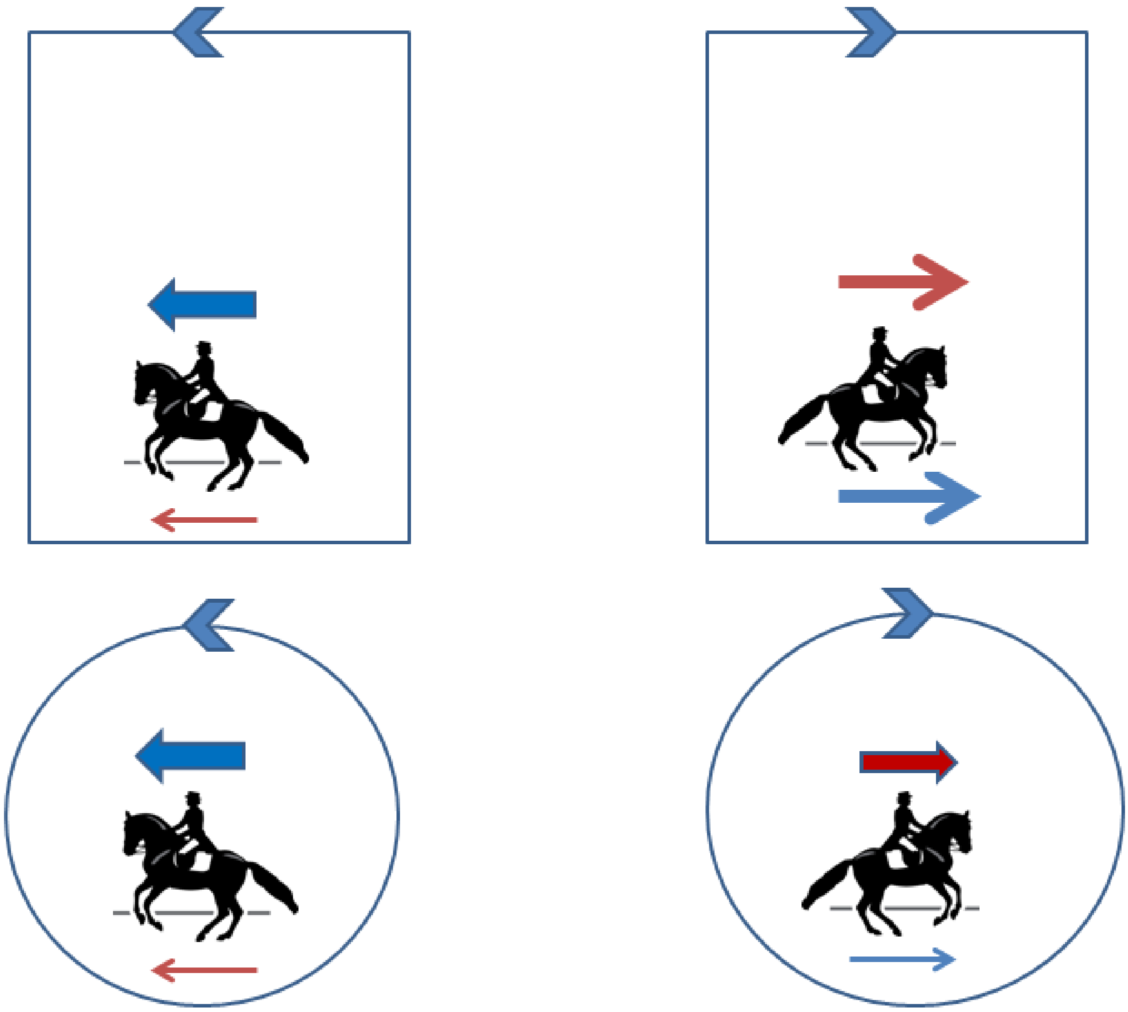


Figure 144: Schematic comparison of mean rein tension on circles and straight lines in clockwise (left side) and counter-clockwise (right side) directions. The size of the arrows indicate the proportion of mean tension (blue: right rein, red: left rein, p=0.0003)

Rein tension asymmetry was stronger on a circle especially when it comes to the stability of rein contact revealing higher standard deviation in the inside rein, regardless of the direction. According to the riding literature, the outside rein is supposed to control the impulsion from the inside hind limb as well as the horse’s speed (Auty 2003). It supports the horse’s balance (Auty 2003) and determines the position and size of the circle (Podhajski 1967). The inside rein however, is supposed to control the position of the horse’s head and neck (Podhajski 1967). It indicates, accepts, controls and maintains the bend created by seat and leg signals (Auty 2003, Podhajski 1967). However, the use of the inside rein in either direction might be caused by the longer stance phase of horse’s inside limbs of on a circle and the relation of rein tension with the horse’s movement (Falaturi 1998, Chateau et al. 2013) and might therefore be unavoidable. Another impact factor might be that riders are unable to use the arena’s walls as a boundary and orientation (Miesner et al. 2000, Kapitzke 2001) and are more likely to use their inside rein to cover up difficulties in communication with their horse via seat and leg signals. In up to 93% of horse-rider pairs, pelvic asymmetry has been reported (Browne & Cunliffe 2014). Riders tilting their pelvis to one side transfer more weight to the opposite side of their horse’s back (Guire et al. 2016, Gunst et al. 2019) thus giving unintended signals to their horse. Asymmetries of one body part often lead to asymmetries in another body part through muscle chains (Wallden et al. 2011). Laterality is suspected to cause asymmetry of the shoulder region with the non-dominant shoulder being higher and possibly leading to pelvic tilt and medial rotational instability of the dominant leg (Wallden et al. 2011). In riders rotating their shoulder, more weight is transferred to the side of the rotation (Gunst et al. 2019). If a right-handed rider is higher in his left shoulder and shows pelvic tilt to the right as a result, the horse’s left side of the back is loaded with more weight due to the asymmetry of both, the left shoulder and right pelvis (Guire et al. 2016, Gunst et al. 2019, Wallden 2011). In order to create more even pressure and improve their balance or simply to address their horse’s reactions, riders might try to rotate their dominant (right) shoulder increasing rein tension in the process.

Depending on the direction of the circle and the horse’s laterality, the horse’s preference might animate the rider to “correct” the horse with stronger rein tension signals of the inside rein. The mechanism behind higher rein tension with difficulties in the direction of the horse’s non-preferred side might be its tendency to drift towards the inside. It seems to “ignore” the riders leg signals and creates the impression of being flexed towards the opposite side (Klimke 1985, Müseler 1933), thus animating the rider to use the inside rein in order to support the inside leg signals with rein signals. Horses that are difficult to ride in both directions might be unbalanced and not supple for the rider’s signals at all (Klimke 1985). In contrast, horses that perform equally “well” in both directions might also be ridden with higher rein tension because they either perform actually equally “poor” in both directions or the rider might cover the horse’s difficulties with strong rein contact and an altered head and neck position (Kienapfel 2011, Kienapfel & Preuschoft 2016). This situation might be the reason for the impression that most horses perform easier in one direction than the other. However, the theories and demands of the riding literature have been established based on the subjective experiences and impressions of the old riding masters (e.g. De la Guérinère 1733). The demand to ride with stronger contact on the outside rein could also be a compensatory mechanism for the interaction of the horse's side preference and the rider's own asymmetries. Stronger tensions on the inside rein however, might be more natural according to the horse's movement patterns.

However, many riders have difficulties in correctly assessing their own rein contact (Stahlecker 2007, Clayton et al. 2013, Hawson et al 2014). The rider's perception of rein tension is subjective (Weber 1978, Stahlecker 2007) and often varies between left and right hands (Weber 1978) as well as between different riders (Randle et al. 2011, Hawson et al. 2014). Since the material of the reins (Randle et al. 2011) and the horse (Stahlecker 2007, Clayton et al. 2013, Hawson et al 2014) can be excluded as influencing factor, the reason might be the applied grip force as a result of human handedness (Flanagan 1996, Flanagan & Wing 1997, Weber 1978). The stability of rein contact seems to be directly related to the magnitude of rein tension and may deliver more reliable results than the rider's assessment of their own rein contact. Furthermore, quantitative asymmetry was larger in performances perceived as asymmetric with all directions of horse's laterality and seems to be a better indicator for the assessment of asymmetry than mean tension alone. The present results might explain and further support the fact that the rider's assessment of the horse's side preference showed a significant relation to rein tension symmetry. Even though stability of rein tension is determined by the rider, horse's laterality seems to influence the basic situation the rider has to deal with.

8.8 Research question 8: Which influence could the matching of horse –rider-laterality have on communication, training, risk of injury and sport results?

Even though laterality and its effects on health and performance have been studied intensively in humans (McManus 2002, Raymond & Pontier 2004, Economist 2004, Auerbach & Ruff 2006, Clotfelter 2008), it has hardly been regarded in relation to equestrian sports. However, previous research with right-handed riders only, indicated an advantage according to the magnitude, symmetry and stability of rein tension with matching directions of laterality in horse-rider-combinations (Kuhnke et al. 2010). However, rein tension seemed to be increased with left-laterality in horses and riders, especially in the combination of left-handed riders on left-lateral horses. The present study, therefore, seems to support these results only for a combination of right-laterality in both riders and horses. Regarding rein tension variables overall based on the direction of horse's laterality, contra-lateral combinations produced lower rein tension. These results might mirror the findings based on the survey, indicating that the handedness of the rider might be more important to success and safety than horse's laterality. In young horses symmetry of trunk movement seems to improve after several weeks of training (Nissen et al. 2016b) and symmetry does not differ between elite and medium performers in Thoroughbreds or Standardbred trotters (Leleu et al. 2005). Therefore it seems that asymmetry is no advantage for horses during equitation, even though many horses are asymmetric by nature e.g. due to pelvic asymmetries present as early as at birth (Lucidi et al. 2013). In humans however, more demanding tasks require action of additional brain regions (Weissman & Compton 2003). Dividing tasks between both hands and thus the different brain hemispheres speeds up processing. The advantage of the dominant hand is greater, the more difficult the type of movement is (Weissman & Compton 2003). Therefore, bimanual coordination of e.g. a soft and equal rein contact when each hand has to react to a slightly different situation created by the horse, seems to be more difficult than to simply hold on to an object.

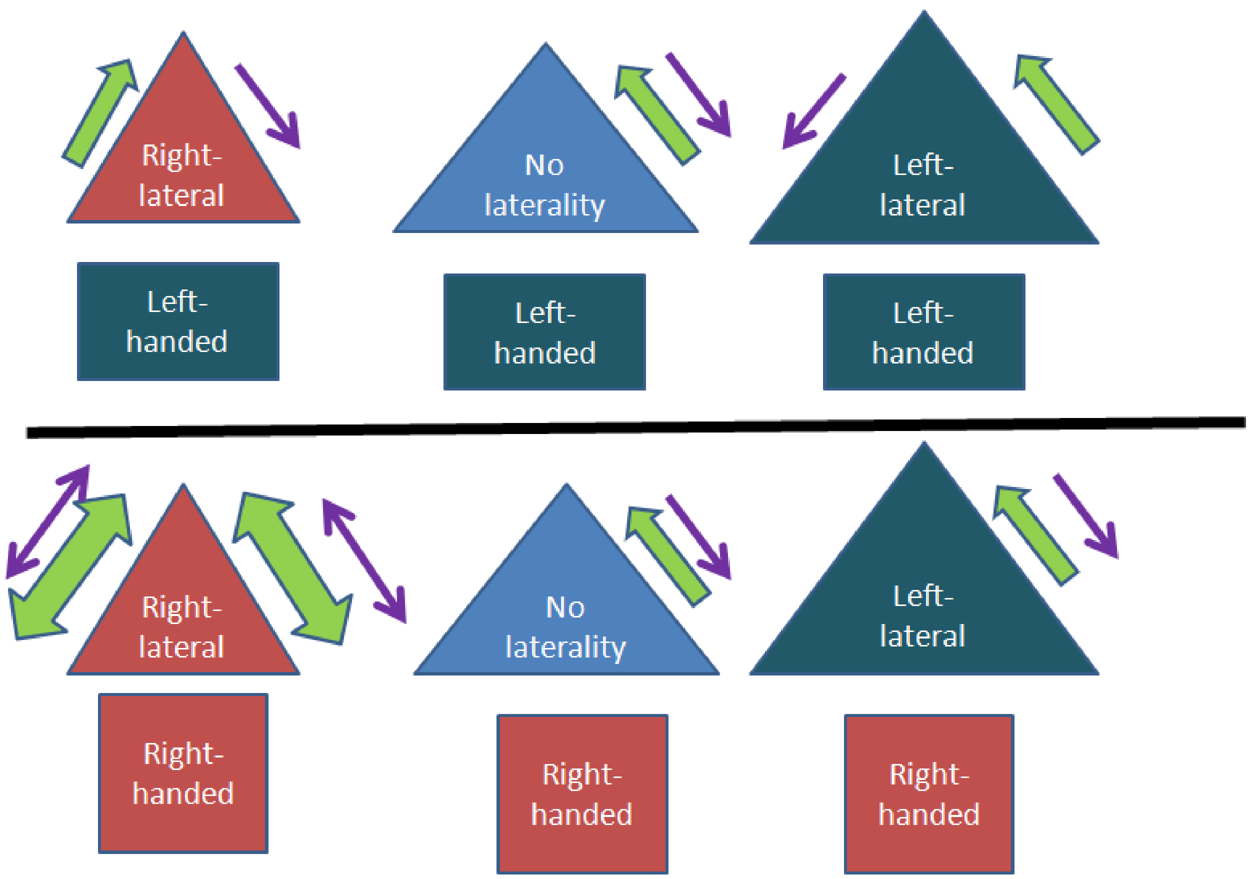


Figure 145: Schematic overview of the magnitude (green arrows indicate the rein with higher mean tension (p=0.003) and peak tension (p=0.04)) and stability (purple arrows indicate the rein with higher mean standard deviation (p=0.01)) of left and right rein tension in 106 horse-rider combinations (Boxes resemble riders and triangles resemble horses in horse-rider combinations). Double-arrows resemble equal rein tension values. Arrows on the left or right side resemble the left and right rein, respectively.

When it comes to the direction of laterality and handedness in horse-rider-combinations, rein tension was higher in the dominant hand and less stable in the dominant hand on the horse's non-preferred side with right-handed riders (Figure 145). Regarding the riding theories, a left-lateral horse would tend to avoid contact with the left rein and lean on the right rein overall (Klimke 1985, Müseler 1933). The horse actively increases rein tension on the side of the rider's dominant (right) hand. With their dominant hand, right-handed riders are also more likely to apply higher tension and which prevents that their non-dominant (left) hand creates symmetric tension while trying to prevent the horse from avoiding contact. Since a relation of the magnitude and stability of tension has been shown in right-handed riders of a smaller sample, too (chapter 5), contact in the right rein is less stable (Figure 146).

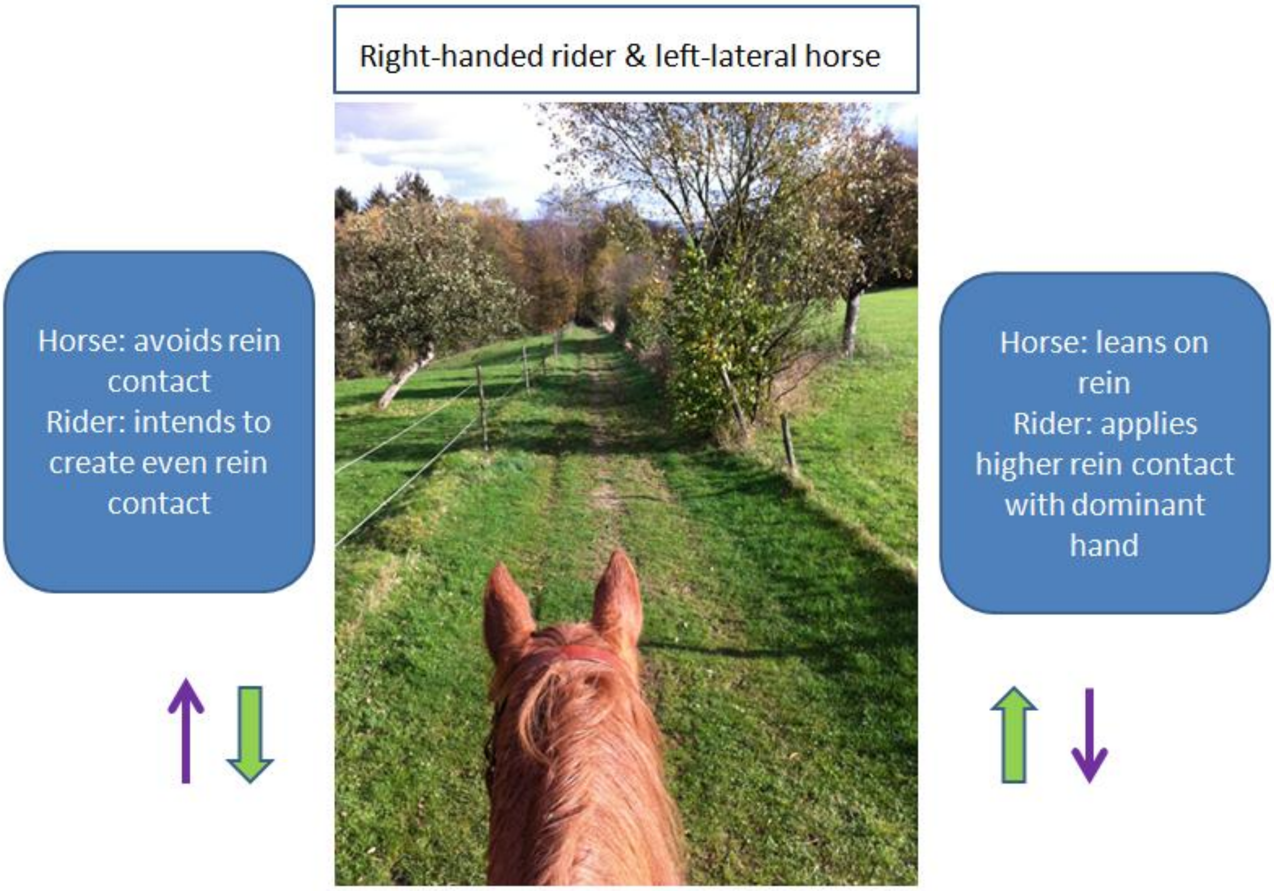


Figure 146: Schematic overview of the magnitude (mean rein tension, green arrow, p=0.003) and stability (mean standard deviation, purple arrow, p=0.01) of rein tension during the interaction of right-handedness and left-laterality in a horse-rider combination. Double arrows indicate equal rein tension values. The pair of arrows on the left indicate the left rein. The pair of arrows on the right indicate the right rein.

In contrast, almost symmetric rein tension according to mean tension and mean standard deviation were found in right-handed riders on right-lateral horses. Right-lateral horses would tend to avoid contact with the right rein and lean on the left rein overall (Klimke 1985, Müseler 1933). Since right-handed riders, however, seem to be able to maintain contact with their dominant (right) hand, they prevent the right-lateral horses from leaning on the left rein as much which creates the impression of symmetric and more stable rein tension (Figure 147).

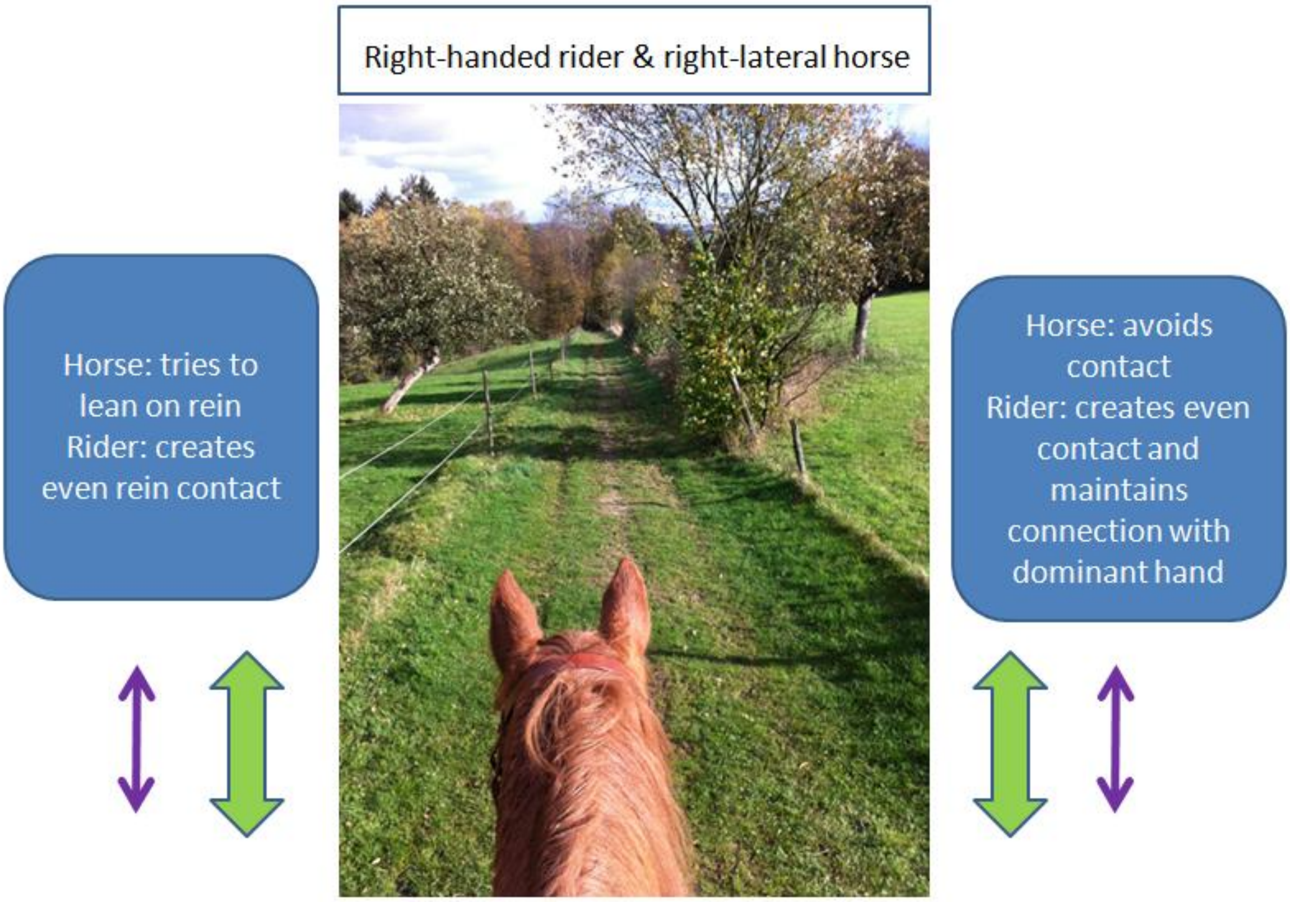


Figure 147: Schematic overview of the magnitude (mean rein tension, green arrow, p=0.003) and stability (mean standard deviation, purple arrow, p=0.01) of rein tension during the interaction of right-handedness and right-laterality in a horse-rider combination. Double arrows indicate equal rein tension values. The pair of arrows on the left indicate the left rein. The pair of arrows on the right indicate the right rein.

Rein tension in left-handed riders was higher on the horse's non-preferred side due to the horse leaning more on that rein and less stable on the horse's preferred side where it tries to avoid rein contact with all combinations (Figures 145, 148 & 149, Klimke 1985, Müseler 1933).

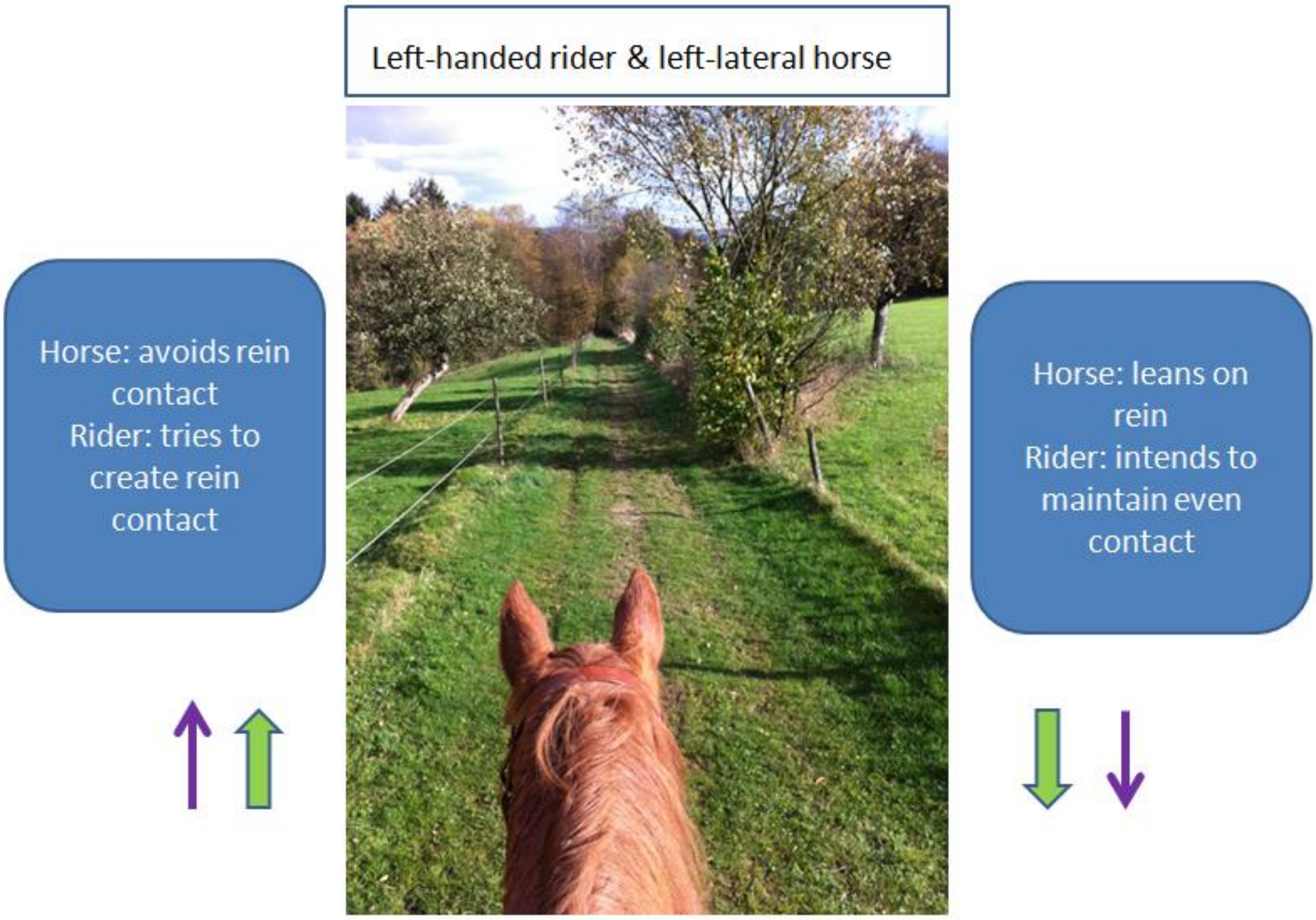


Figure 148: Schematic overview of the magnitude (mean rein tension, green arrow, p=0.003) and stability (mean standard deviation, purple arrow, p=0.01) of rein tension during the interaction of left-handedness and left-laterality in a horse-rider combination. Double arrows indicate equal rein tension values. The pair of arrows on the left indicate the left rein. The pair of arrows on the right indicate the right rein.

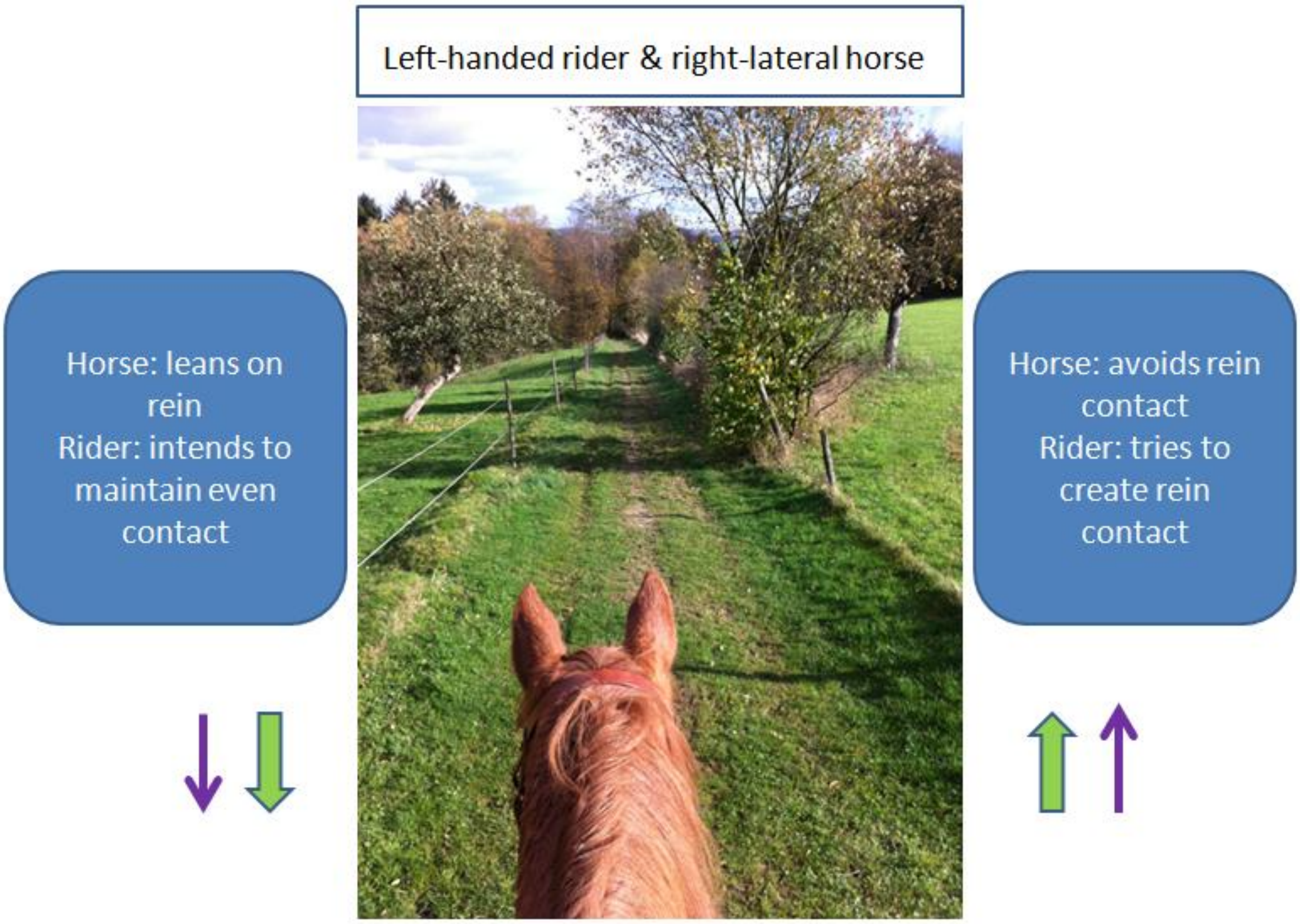


Figure 149: Schematic overview of the magnitude (mean rein tension, green arrow, p=0.003) and stability (mean standard deviation, purple arrow, p=0.01) of rein tension during the interaction of left-handedness and right-laterality in a horse-rider combination. Double arrows indicate equal rein tension values. The pair of arrows on the left indicate the left rein. The pair of arrows on the right indicate the right rein.

These results once again indicate that the rider determines the stability of rein tension, which is based on the situation created by horse's laterality. Right-handed riders seem to depend upon their dominant hand while trying to compensate their horse's laterality, suggesting a strong influence of human handedness on rein tension. Left-handed riders in contrast seem to be independent of their dominant hand thus supporting the theory of left-handed individuals being less lateralized (Goble & Brown 2008, Michałowski & Króliczak 2015, Rousson et al. 2009). In contrast to the right-handed sample which contained a broad number of any riding level, left-handed riders in the present study were riding either at basic or advanced level. Therefore it seems that left-handedness rather than experience alone might indeed enable the rider to act more independently of their own handedness when attempting to "correct" their horse's laterality patterns and improve their balance. Superior performance of left-handers during complex bimanual tasks has been documented before (Judge &

Stirling 2003, Adamo et al. 2012). They perceived grip force more accurately and were able to perform more symmetrically (Adamo et al. 2012). Right-handers in contrast, showed asymmetric perception and grip force possibly because their attention is biased toward their right hand during bimanual coordination (Buckingham and Carey 2009, Peters 1981, Adamo et al. 2012). They seem to move their right hand faster and more readily than their left (Buckingham et al. 2011). Bilateral training of tasks is argued to potentially modify the performance of non-dominant limbs (Teixeira *et al.* 2003). Practicing a task means its performance becomes less difficult and the advantage of the dominant limb decreases (Weissman & Compton 2003). In fact, right-handed individuals showed asymmetric performance when their right hand was generally stronger than their left. With equal general strength or the left hand being stronger, asymmetry decreased (Adamo et al. 2012).

Similar to bimanual contact, rein tension was higher in left-lateral horses and lowest in horses without reported laterality with one-handed rein handling. Rein tension was lower when the hand holding the reins matched the horse's laterality (right hand with right-lateral horse and left hand with left-lateral horse). However, except for horses without reported laterality and left-lateral horses during right-handed rein handling, rein tension was higher in the rein of the horse's preferred side (Figures 150 & 151). It seems that human handedness might interact with horse's laterality with one-handed rein contact as well, only with much less rein tension involved. The lower rein tension values (approximately 2-3 Newton with a left-right difference of up to one Newton) are most likely due the riding style producing less mean tension in general and the reins being held in one hand. Even with one-handed rein contact and a loose connection riders appear to prevent their horse from drifting with the non-preferred shoulder and avoiding the rein of the preferred side. However, only when using their non-dominant left hand riders were able to react to their horse's non-dominant side without their own handedness interfering with rein tension.

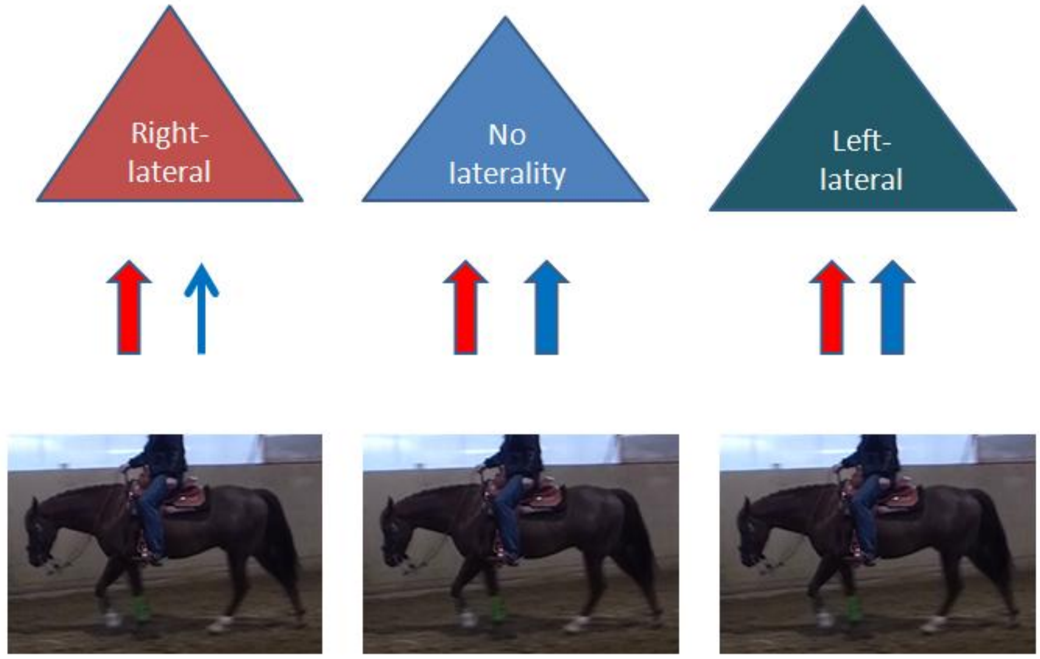


Figure 150: Schematic overview of the magnitude (size of arrows indicates the proportion of mean rein tension) of left (red arrow) and right (blue arrow) rein tension during one-handed rein handling of right-handed riders with the dominant (right) hand and horses with different laterality (p<0.0001).

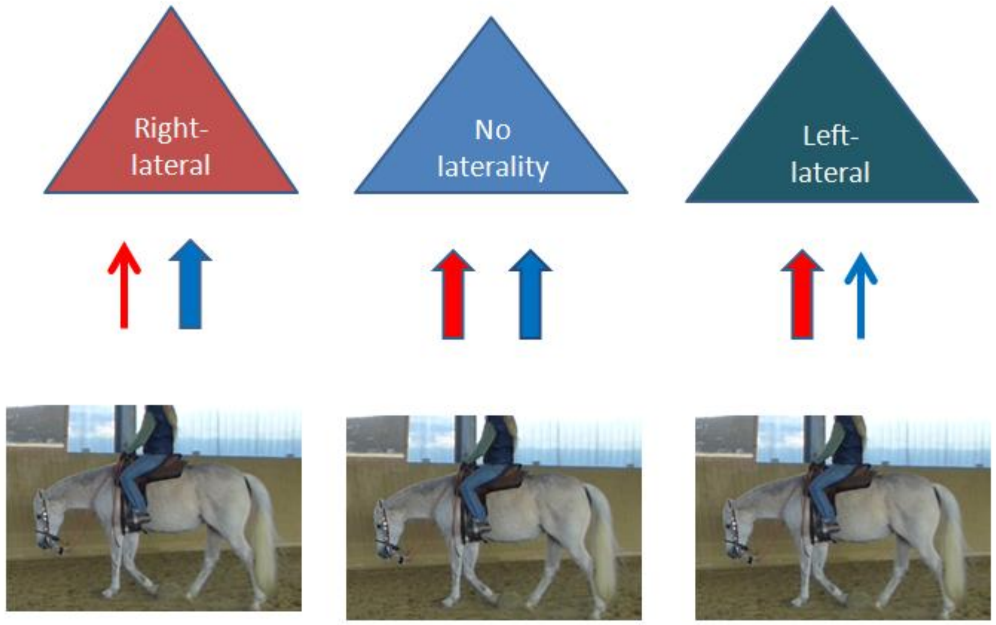


Figure 151: Schematic overview of the magnitude (size of arrows indicates the proportion of mean rein tension) of left (red arrow) and right (blue arrow) rein tension during one-handed rein handling of right-handed riders with the non-dominant (left) hand and horses with different laterality (p<0.0001).

Mean peak tension was higher in the right than the left rein for all horse-rider combinations. A potential explanation for this is the strength of the dominant hand in right-handed riders (Steele 2000, Hobbs et al. 2014, Klum et al. 2012). Even though left-handed subjects seem to perform more symmetrically when it comes to grip force (Adamo et al. 2012), they use their non-dominant hand more intensively than right-handed subjects (Steenhuis & Bryden 1999, Rousson et al. 2009). Therefore, one possible explanation for stronger tension of the right rein in left-handed riders could be overcompensation with their non-dominant right hand when riding right-lateral horses which avoid contact to the right rein. Horses without laterality showed higher mean tension and less stability, especially in the right rein with all riders. In addition, rein contact of these horses was assessed incorrectly. Riders perceived a rather high rein tension as "light" or "medium" whereas the lightest contact was described as "strong". This further indicates that these horses might not be truly balanced in both directions, even though no laterality has been perceived by their riders. However, horses with "very harmonious" or "very unharmonious" rides showed stronger trigger point reactions on the left than "unharmonious" or "tensed" rides indicating that the rider's perception of "harmony" might have been more focused on rein tension than on the suppleness of the horse and that rein contact rather than muscle state might be a more suitable variable to assess horse-rider communication. Furthermore muscular balance seems to support a stable connection between the horse's mouth and the rider's hands and thus improves horse-rider communication.

Results of the survey indicated that similar to other sports (Clotfelter 2008, McManus 2002, Raymond & Pontier 2004), left-handed and ambidextrous humans might be more successful and compete at higher level than right-handed individuals. With the rein tension sample however, this hypothesis could not be supported since indicators of sport success, such as the number of wins and placings and the competition level, were not significantly related to handedness, laterality, specific horse-rider-combinations or rein tension as such. Significant differences in rein tension between combinations competing at national vs. international level and leisure riders seem to be more influenced by riding style, accounting for the fact that the majority of horse-rider combinations competing especially on international level were Western riders, whereas most conventional European riders of this sample did not compete at all.

Rider handedness has been regarded as a possible influencing factor for asymmetries in rein tension leading to an increased risk of micro-trauma and repetitive strain especially of the shoulder region. (Pugh & Bolin 2004). Information based on the survey leads to the assumption that risk of musculoskeletal injury in the human hands, arms and shoulder region and the horse's locomotory system might be related to laterality. The dominant hand might be at high risk in right-handed riders, whereas left-handed riders might be more prone to injure their non-dominant hand, however a relation of these results with rein tension could not be documented with the much smaller sample of horses and riders available for rein tension measurements. The risk of musculoskeletal injury in horses and riders was not related to laterality and handedness nor did injuries influence rein tension directly. However, human handedness and the direction of laterality in horse-rider-combinations did seem to influence rein tension in relation to injuries especially in horses. Mean rein tension was higher when horse injuries were recorded on the side of the rider's non-dominant side, whereas rider injuries seemed to be related to rider handedness and matching directions of laterality in horse-rider combinations. Additionally, horse injuries were related to the sum of trigger point reactions of the right side where the highest mean peak tension was in all horse-rider-combinations. These results indicate that an interaction of rein tension, laterality and the muscular system might exist.

8.9 Research question 9: Which other factors might influence rein tension, symmetry and performance?

Additional sports are commonly discussed and recommended among riders for a balanced training and improved health and performance. In the present sample, the majority of participants were active in additional sports that aim to improve overall strength and stamina instead of coordination. This could be a possible explanation for the relation of sports activity with a larger spread of rein tension.

Riders who were unfamiliar with the horse ridden during the test session applied lower mean tension more symmetrically compared to riders participating with horses they ride on a regular basis, supporting results of previous research (Kuhnke et al. 2010). Unfamiliar tack e.g. saddles are known to influence performance even on a model horse (Biau & Debrils 2016), but also psychological reasons might be an explanation.

Rein tension in conventional European riding with snaffle bits or bitless bridles was higher and less stable throughout all gaits, transitions and manoeuvres compared to Western riding. The reason lies most obviously in the different aims and techniques of the two riding styles (Miesner *et al.* 2000, Müseler 1933, Podhajski 1967, Holm 2008, Schmid 2014). However, horses bred for Western riding and especially American Quarter Horses revealed lower, more stable and symmetric rein tension compared to warmbloods or other breeds too, regardless of the riding style. American Quarter Horses seem to be less lateralized at the population basis (Whishaw 2015, Whishaw & Kolb 2017). However, since rein tension values seem to be related to speed and the horse's pattern of movement

(Preuschoft 1999a, b & c), the different breeding aims and their resulting difference in the horse's pattern of movement might explain the differences between the horse breeds.

The distribution of pressure varies according to different types of bits and bridles (Preuschoft *et al.* 1995, 1999a). In the present study, rein tension values with curb bits (measured in Western rides only) were lower compared to conventional European or Western rides with snaffle bits and bitless bridles. Curb bits increase pressure in the horse's mouth through levers, thus reducing the magnitude of rein tension that might be necessary to receive the desired reaction from the horse (Preuschoft 1990b, Preuschoft *et al.* 1999a & c). The impression that curb bits might reduce horse-rider communication to minimum signals with less peak tensions in Western riding, if handled correctly (Wienrich 2011), might be possible. However, the effect of the curb chains that was used by some, but not all riders was not specifically considered in the present study. The use of bitless bridles aims to reduce pressure to the horse's mouth. In previous studies no difference of rein tension between bitted and bitless combinations were documented (Warren-Smith *et al.* 2007, Bye et al. 2017, Kubiak et al. 2017), except for the bitless LG bridle as used in this sample (Herrmann 2011). In the present study, rein tension and converted pressure expected on the bridge of the nose were higher than with single-jointed snaffle bits. Accounting for results showing that the bridge of the nose is sensitive enough to be damaged by tight nosebands (Crago et al. 2017), the use of bridles with correctly fitted bits and nosebands instead of bitless bridles might improve horse welfare. Rein tension was higher in combinations of bits with bridles prohibiting jaw opening. Especially with tightened nosebands, bridles that restrict jaw opening and thus prevent the horse from chewing the bit, might negatively affect horse welfare and mask problems in horse-rider communication (Kienapfel & Preuschoft 2010, Doherty et al. 2016).

Bimanual rein contact and bridged reins were less stable and less symmetric than one-handed rein contact. However, in addition to the effects of the riding style, bridged reins seem to improve stability (lower mean standard deviation) and symmetry (smaller time shift) of rein tension, possibly because the gravitational forces acting on the rider are transferred from both hands to each rein. Larger temporal asymmetry and less stability were found when the reins were held with the dominant right hand (right-handed riders only), suggesting that coordination might be better with the non-dominant hand in one-handed rein handling (Figure 152).

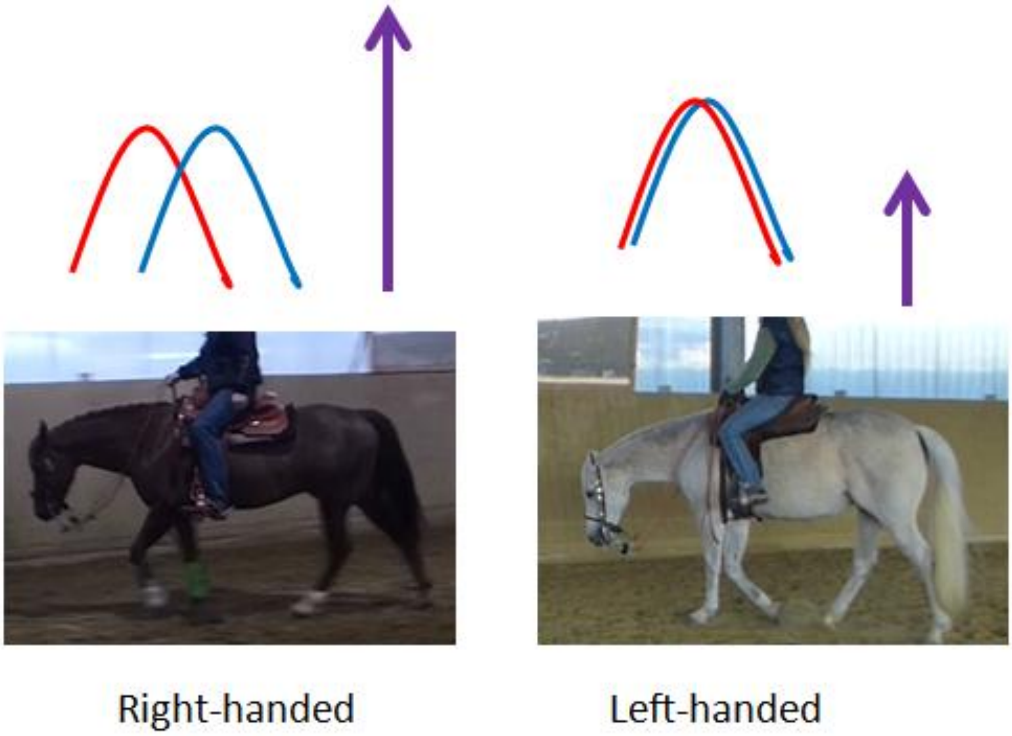


Figure 152: The temporal symmetry (distance in time between the peaks of the red (left rein) and blue (right rein) lines, p=0.001) and stability (mean standard deviation=purple arrows, p<0.0001) of right-handed versus left-handed rein handling.

One-handed rein contact (right-handed riders only) with the non-dominant left hand led to larger quantitative asymmetry and higher mean tension overall in the right rein compared to the left possibly because the right reins might have been held slightly longer. The left hand seems to be held not as close to the median plane of the horse as the right hand, thus leading to asymmetric rein tension and less quantitative symmetry. This assumption is supported by the fact, that horses with a left displacement of their hindquarters were ridden with slightly higher rein tension left-handed, whereas the same magnitude of rein tension was applied to horses with their hindquarters displaced to the right with either hand. Rein tension of the side opposite to their lateral displacement was slightly higher (Figure 153). With horses being bend in one direction through their body e.g. due to their hindquarters being slightly displaced laterally, rein tension of the inside rein is applied directly whereas rein tension of the outside rein is being deflected by the horse’s neck (Preuschoft (personal communication)) which could explain the present findings of uneven rein contact even during one-handed rein contact.

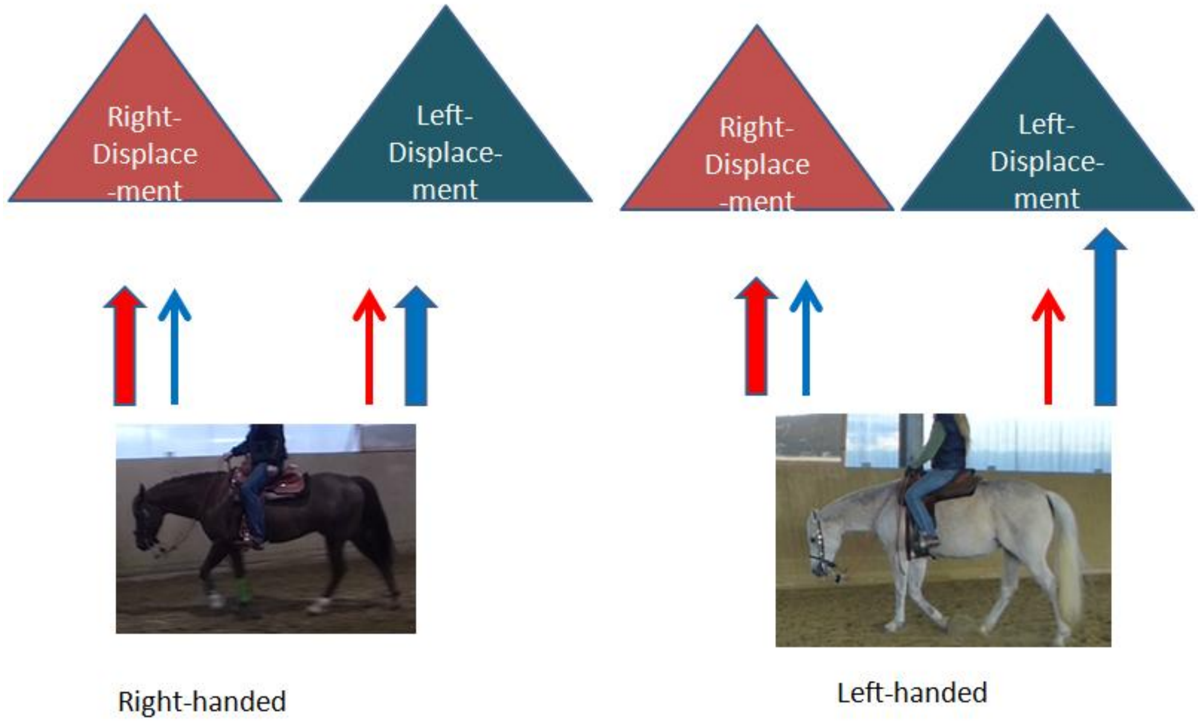


Figure 153: The magnitude of mean rein tension (p=0.0002) in the left (red arrow) and right (blue arrow) rein of horses with their hindquarters displaced to the left or right ridden either left-handed or right-handed. Rein tension was higher in the rein opposite to the hindquarters' displacement. Left-displaced hindquarters and left-handed rein handling produced larger asymmetry due to higher mean tension in the right rein.

Riders with a preference of rein handling with their dominant, right hand showed more symmetric rein tension with higher mean and peak tension when using their preferred right hand (Figure 154). Peaks in riders preferring the non-dominant, left hand however, were twice as high with their preferred left hand whereas their non-preferred, dominant, right hand was associated with higher mean tension and less stability (Figure 155).

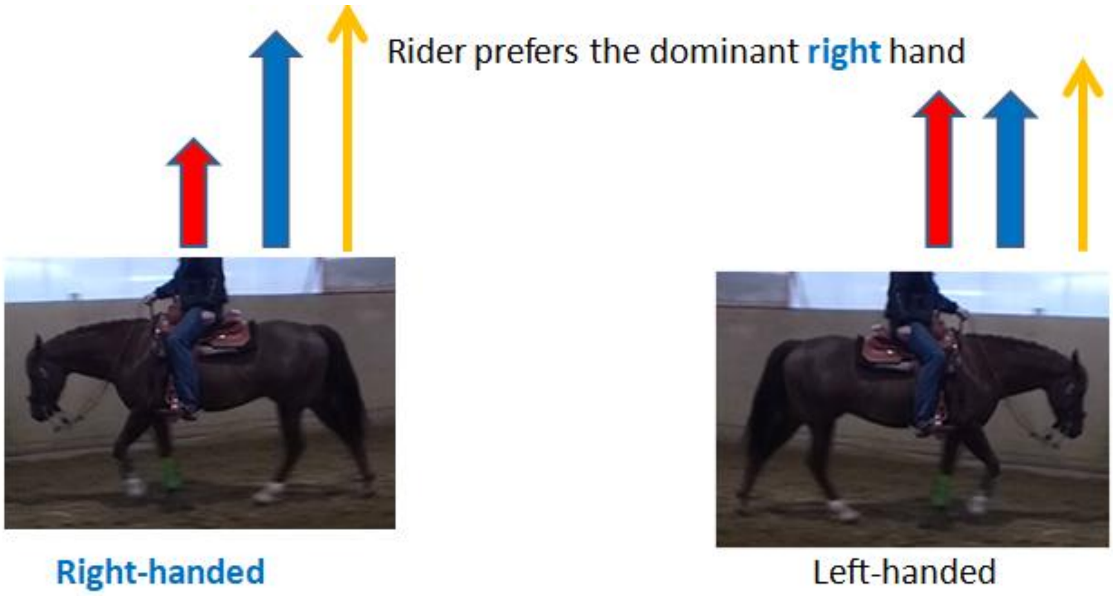


Figure 154: A schematic overview of the symmetry between left (red arrow) and right (blue arrow) rein tension and mean peak tension (orange arrow) in right-handed riders preferring to hold the reins with their right hand (all p<0.0001)

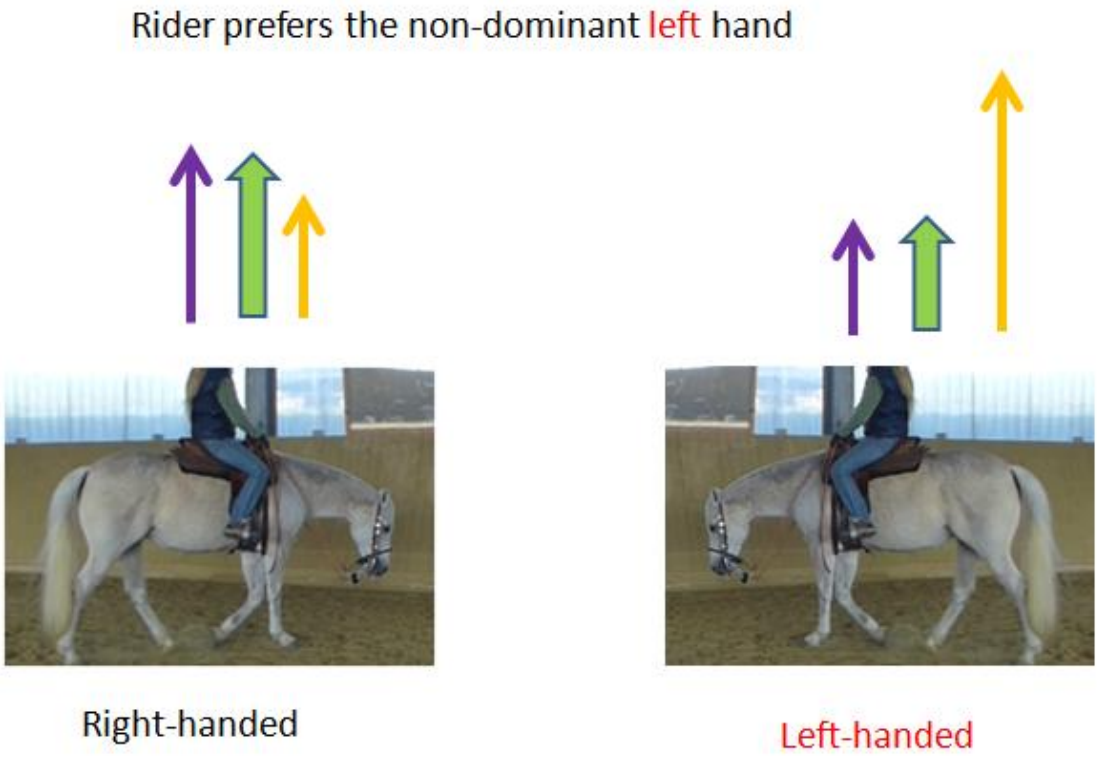


Figure 155: A schematic overview of the magnitude (mean tension overall =green arrow) and stability (mean standard deviation overall= purple arrow) of rein tension as well as mean peak tension (orange arrow) in right-handed riders preferring to hold the reins with their left hand (all p<0.0001)

Higher peaks with left-handed rein contact might be caused by the position of the hand relative to the median plane of the horse. Similar results of higher tension in the right rein have been documented with bimanual rein contact. It seems that the left hand might be advantaged when it comes to taking up a light contact overall. Holding the reins and communicating through the maintenance of a light and steady contact to the horse's mouth is a matter of proprioception and practice. Research has shown an advantage of non-dominant hands for proprioceptive tasks, which could explain why the non-dominant (left) hand in right-handed riders kept a more stable and symmetric contact (Han et al. 2013).

Improved performance in one-handed compared to bimanual tasks has also been documented by other research (Han et al. 2013). In right-handed subjects, that are equally strong with both hands or with their non-dominant left hand, the perception and symmetry of grip force is better than for those with most strength in their dominant, right hand (Adamo et al. 2012). Assuming that this might have been the case in those participants preferring their non-dominant left hand for one-handed rein contact, it might be another possible explanation for the difference in symmetry of rein tension that was observed. It might be an advantage for riders to train their proprioception and keeping a light and steady contact through bridging their reins and holding the reins in one hand. Riders who are strong with their dominant hand might profit from training the grip force and perception of their non-dominant hand, especially if they ride horses with mismatching directions of laterality. In contrast to the results for horse's without laterality overall, it seems that the horses of this smaller sample used for recording one-handed rein tension might actually have been less lateralized than their conspecifics with a reported side preference. However, these assumptions need to be investigated on a larger sample of horse-rider-combinations including left-handed riders.

9. Conclusion

9.1 Is there agreement between laterality tests used in horses?

and in particular:

9.2 Do laterality test results obtained on the ground relate to laterality during riding?

Laterality seems to be manifested in different ways, even within the area of motor laterality. These ways are not necessarily related to each other. Consequently tests based on sensory laterality, are not useful to conclude on motor laterality. Laterality test results obtained on the ground, such as leg preferences do not predict laterality during riding. It seems that the sole assessment of body characteristics which are present in every individual, such as the lateral displacement of the hindquarters, the direction of mane or facial hair whorls, might only be useful indicators for individuals with distinct laterality. The lateral displacement of the hindquarters can give a hint on the direction of laterality during riding in most horses. However, the assumed impact on the horse's performance during riding which is perceived as a side preference has never been investigated. Furthermore, ambidexterity might be missed if the method is applied while standing or walking in one direction only. Therefore, horses need to be assessed in both directions and the preferred lead during flat racing needs to be considered in Thoroughbreds too. Obtaining results on the lateral displacement of the hindquarters as well as the preferred lead from video analysis seems to be a reliable and reproducible method for large sample sizes. The rider's assessment of their horse's laterality seems to be the only method to predict laterality patterns of rein tension. The lateral displacement of the hindquarters and the rider's assessment of the horses' preferred side do not seem to be directly related. Nevertheless, the position of the hindquarters might contribute to the rider's perception of their horse's asymmetry and the symmetry of rein tension in a more subtle way as it has been assumed so far. However, the relation of these aspects of laterality need further research with larger samples showing distinct laterality patterns. The agreement between different aspects of laterality in horses seems to be limited to specific measures and outcomes. Attention should be paid to the desired information when selecting methods for assessment of laterality.

9.3 What is the most common direction of motor laterality in the populations of warmbloods, ponies, American Quarter Horses and Thoroughbreds?

A right-bias is the most common direction based on the body characteristic "the lateral displacement of the hindquarters" in warmbloods, ponies and Thoroughbreds, but not in Quarter Horses. A most common direction of motor laterality during riding or flat racing does not seem to exist at the population basis for horses in general. Western breeds appear less lateralized, both individually and at the population basis. Ambidexterity exists in Thoroughbreds. Therefore, even though a right-bias might be most common at the population basis for one aspect of motor laterality, evaluation of this one aspect alone is insufficient to receive a reliable result. Ambidexterity might exist in warmbloods and ponies too. However, further research is needed to develop methods of identification. Since there appear to be many factors influencing horse-rider communication and symmetry, it seems that laterality during riding cannot be precisely defined yet.

9.4 Is the lateral displacement of the hindquarters a valid indicator for horse's motor laterality and if so, what is the heritability in warmbloods, ponies and Thoroughbreds?

The rider's assessment of their horse's laterality was the only method that could be confirmed by rein tension measurements. Therefore, in order to identify horse's direction of laterality during riding, it seems to be the method of choice. The lateral displacement of the hindquarters does not conclude on laterality during riding for all horses. It influences rein tension symmetry less than expected and might contribute to the rider's perception of the horse's asymmetry in a more subtle way as it has been assumed so far. A relation of trigger points to the lateral displacement of the hindquarters does not exist. Against the common assumption of most riding literature, it does not seem to be the main reason for horse's laterality during riding.

Still, the lateral displacement of the hindquarters seems to be a valid indicator for horse's motor laterality that allows the identification of ambidextrous individuals e.g. during flat racing. Obtaining results on the lateral displacement of the hindquarters as well as the preferred lead from video analysis seems to be a valid, reliable and repeatable method for large sample sizes. Being a body characteristic that is free from the interference of the rider's handedness, it might have the potential to objectively identify ambidextrous horses in the riding horse population as well. Using a more objective method might improve the identification of laterality during riding and enable a correct prediction even in juvenile individuals, thus supporting the identification of suitable horse-rider combinations, improving the effectiveness of training and communication especially for ambidextrous horses and enabling riders and trainers to distinguish between ambidexterity and “equally poor” performance.

Similar to humans, left-laterality and ambidexterity appears to provide an advantage for sport success. The lateral displacement of the hindquarters seems to be genetically related to performance traits such as the number of wins, the show jumping index or less frequent coat colours. Therefore, laterality based on this assessment might be a useful indicator for genetic merit of these traits. Even though laterality does not seem to be influenced by parental behaviour, the phenotypic selection of certain performance traits has the potential to modify the incidence of laterality in the population towards the desired direction.

Future analyses should further investigate the influence of the lateral displacement of the hindquarters on rein tension and the rider’s impression of their horse’s suppler side for riding tasks. Laterality and the relationships to sport success should be further investigated at the genetic level as well as different trait definitions and assumptions of genetic architecture such as, for example, considering laterality as a binary trait (e.g., ambidextrous vs. either right or left lateral).

9.5 Does motor laterality and race track direction affect performance in racing Thoroughbreds?

Matching laterality patterns of horse’s hindquarters and their lead seem to improve performance during flat racing. The lead in relation to the direction of racetrack seems to be the decisive factor for racing success as horses approaching the finish line in the outside lead regardless of the direction of racetrack were more successful overall. With the majority of races being held clockwise, ambidextrous and right-lateral horses perform superiorly. Therefore, laterality seems to be a useful indicator to predict performance in both directions.

9.6 Does a relationship between motor laterality and shortened or stiff muscles exist?

Muscle state might actually influence the lateral displacement of the hindquarters and the rider’s impression of their horse’s side preference as well as horse-rider communication. Especially the muscles moving the shoulder and the hip joint, stabilizing the spine and enabling lateral flexion contributed most to the sum of trigger point reactions on both body sides and asymmetric trigger point reactions. Therefore, quality of movement might influence muscular health and vice versa. Muscular balance rather than the absence of tension and sensitive trigger points seems to be important for symmetry. Tail carriage could be a useful indicator of muscular balance. Testing trigger point reactions might be a measure to detect and treat possible issues and prevent injuries. However, also the magnitude and symmetry of rein tension has the potential to impact muscular balance. Therefore, riders should train to apply rein tension as light and equally as possible and frequently control their perception e.g. with the use of a rein tension device.

9.7 How do horse's laterality and human handedness affect rein tension in different riding styles and disciplines?

Rein symmetry is influenced by several variables. At least two different levels of symmetry (i.e. quantitative and temporal symmetry) exist, which are related to speed and the horse's footfall patterns. Stability and temporal symmetry of rein tension are determined by the rider alone. Quantitative asymmetry however, is related to different directions of laterality in horse-rider-combinations. Therefore, horse's laterality provides the situation riders have to react to. Riders appeared to act more sensitively with their non-dominant hand and use their dominant hand with more force and less flexibility. Furthermore, rider's assessment of their own rein contact did not agree with rein tension data for all assessed variables. Therefore, the stability and quantitative asymmetry of rein contact may deliver more reliable results than the rider's assessment of their own rein contact or the evaluation of mean rein tension alone. Horses perceived as performing "equally well" were asymmetric too and riders potentially covered their horse's difficulties with strong rein contact. As mentioned above, the use of a rein tension device to control perception of their own rein tension might help riders to improve communication with their horse.

Stronger tensions on the inside rein might be more natural according to the horse's movement patterns. Therefore, the demand to ride with stronger contact on the outside rein could also be a compensatory mechanism. However, rider's trying to abide by this rule might create even more asymmetry and limit effective communication.

9.8 Which influence could the matching of horse –rider-laterality have on communication, training, risk of injury and sport results?

Higher rein tension was related to left-laterality in horses and riders. Right-handed riders applied lower mean and peak tension to horses with matching (right-) laterality. Right-handed riders depend upon their dominant hand while trying to compensate their horse's laterality, whereas left-handed riders react to their horse's non-dominant side and appear to be less lateralized. Therefore, the handedness of the rider might be more important to success and safety than horse's laterality. In theory, training of the non-dominant hand might enable riders to react more independent from their own hand preference. Furthermore frequently riding different horses may improve rider's proprioception as well as the stability and symmetry of their rein tension patterns.

With one-handed rein handling using their non-dominant left hand, riders were able to react to their horse's non-dominant side without their own handedness interfering with rein tension. Therefore, alternating between bimanual and one-handed rein handling, especially of the non-dominant hand might improve proprioception and horse-rider communication.

Muscular balance seems to support a stability of rein tension and enhance horse-rider communication. Still rider's assessment of their own rein contact rather than their perception of their horse's muscle state might be a more suitable variable to assess horse-rider communication.

Further research with larger samples of horses and riders with previous injuries is needed to identify influencing factors in horse-rider-communication affecting risk of musculoskeletal injury other than rein tension. Additionally, since rider handedness seems to be the most important factor affecting rein tension, training especially right-handed riders to act more independently of their dominant hand might be an effective measure to improve horse-rider communication and reduce injuries in both horses and riders to some extent. Regularly testing the horse's muscular system for asymmetric or severe trigger point reactions might deliver further improvements.

9.9 Which other factors might influence rein tension, symmetry and performance?

Improving strength of the non-dominant hand could have the potential to improve horse-rider communication by reducing the influence of the dominant hand. Especially riders who are strong with their dominant hand or usually ride horses with mismatching directions of laterality might profit from this training. However, additional sport activities should be chosen which enhance coordination and improve the riders' specific weaknesses.

Even though the effect will most likely decrease during the process of familiarization, riding different (unfamiliar) horses on a regular basis might help riders to improve their perception of rein tension symmetry. Considering that horses bred for flat gaits with little impulsion enabled the rider to communicate with low and symmetrical rein tension, warmblood associations might have to deliberate their breeding aims as to whether expressive gaits with a lot of impulsion might at some point counteract horse-rider communication and performance.

Rein tension values varied between different types of bits and bridles. Even though a combination of bits with bridles prohibiting jaw opening might mask difficulties in horse-rider communication, other combinations of equipment might improve communication and enable a soft and steady contact. Therefore, riders should be encouraged to try different combinations of tack in order to find the optimal equipment for their specific horse. Furthermore, the use of different tack e.g. a flash noseband versus no cavesson might help riders to control and improve their rein tension patterns and communication. There seems to be an advantage of the non-dominant hand with one-handed rein handling. Bridging the reins and holding the reins in one hand might have the potential to improve riders' proprioception and train them to keep a light and steady contact, however rein handling should frequently be changed.

10. Summary

The aim of the present study was to investigate whether laterality test results obtained on the ground relate to laterality during riding. It intended to identify the most common direction of laterality in warmbloods, ponies, Thoroughbreds and Quarter Horses and its heritability. The present study investigated the influence of human handedness and horse's laterality on rein tension and aimed to identify their influence on the horse's muscular system, variables of sport success and the incidence of injuries in horses and riders. The present study contained an online-survey with 686 riders and 1286 horses as well as the comparison of twelve different methods to investigate horse's laterality on the ground and during riding between five groups of horses (sample A: 67 warmbloods, sample B: 4408 warmbloods and ponies, sample C: 67 Thoroughbreds, sample D: 1950 Thoroughbreds and sample E: 61 closely related Thoroughbreds) and rein tension measurements with a group of 88 warmbloods, Quarter Horses and mixed breeds (41 right-lateral, 35 left-lateral and 12 without reported laterality) with 65 riders (49 right-handed, 14 left-handed and 2 ambidextrous) in 110 rides (51 in conventional European riding and 59 in Western riding). Rein tension was analysed using Excel and linear mixed models in SPSS. The relation of different laterality test methods among each other was investigated using cross-tabulations, chi²-tests, phi and Cramer's V, as well as Pearson-correlations. Heritability was determined using uni- and bivariate linear animal models in DMU6.

Laterality seems to be manifested in different ways, which are not related to each other nor influence laterality during riding. Therefore, laterality test results obtained on the ground did not agree with laterality during riding. Only the rider's assessment of their horse's laterality and the lateral displacement of the horse' hindquarters allowed conclusions on laterality during riding. In most populations the majority of horses had their hindquarters displaced to the right. Based on the rider's assessment of their horse side preference for dressage tasks, no overall direction of laterality could be documented in any population. Heritability of the lateral displacement of the hindquarters was high in warmbloods (h^2=0.51) and low to moderate level in Thoroughbreds (h^2=0.19). In Thoroughbreds ambidextrous individuals could be identified with the investigation of both their lateral displacement of their hindquarters and their preferred lead with regard to both racetrack directions. Right-lateral and ambidextrous horses were more successful overall. Genetic correlations between laterality and variables of success were high in Thoroughbreds (wins: rg=0.82±0.19, placings: rg=0.70±0.16). In dressage and show jumping there seems to be an advantage for both left-lateral and ambidextrous riders as well as left-lateral horses. They performed more successfully and reached higher riding levels. A direct relation of the lateral displacement of the hindquarters to sensitive muscle trigger points could not be documented. However, a relation of trigger points to

one-sided tail carriage, stability of rein tension and injuries in horses seems to exist. In addition to the stability of rein tension, two aspects of symmetry (quantitative symmetry between left and right rein tension and temporal symmetry of left and right rein tension peaks) were identified that are influenced mainly by human handedness. Less rein tension was applied with a more stable and symmetric contact in Western riding compared to conventional European riding.

Horse’s laterality mainly influenced the magnitude of rein tension as well as the symmetry of the inside versus the outside rein. Right-handed riders depended upon their dominant hand while trying to compensate their horse’s laterality and produced more symmetric rein tension with right-lateral horses. In contrast, left-handed riders reacted to their horse’s non-dominant side, regardless of the horse’s direction of laterality. Additional influencing factors on rein tension were the riding style, horse breeds and rein handling, the equipment used for communication, additional sports and the familiarity with the horses.

The lateral displacement of the hindquarters allows the identification of ambidextrous horses, if assessed in both directions. Laterality might be a useful indicator for genetic predisposition of successful performance and should be regarded as a binary trait. Left-laterality seems to be related to sport success in horses and riders. The horse’s muscular system influences rein tension and horse’s health and should therefore be considered in future research. Left-handed riders appear to be less lateralized. Especially right-handed riders might benefit from strengthening their left hands and improving their proprioception and coordination with frequently riding different horses and changing between different techniques of rein handling. Riders should control their rein tension on a regular basis and verify their own assessments.

11. Zusammenfassung

Das Ziel der vorliegenden Studie war es, die Übereinstimmung der am Boden erfassten Lateralität von Pferden mit ihrer Lateralität während des Reitens zu vergleichen. Es sollten die häufigste Lateralitätsrichtung in den Populationen der Warmblüter, Reitponies, Vollblüter und Quarter Horses ermittelt und ihre Heritabilitäten festgestellt werden. Der Einfluss der Händigkeit des Reiters und der Lateralität des Pferdes auf die Zügelspannung wurde untersucht mit dem Ziel, mögliche Einflüsse auf den Muskelzustand, die Sportleistung und Verletzungshäufigkeit zu identifizieren. Dazu dienten eine Online-Umfrage mit 686 Reitern und 1286 Pferden, der Vergleich von 12 verschiedenen Methoden zur Feststellung der Lateralität am Boden und während des Reitens an fünf Pferdegruppen (Stichprobe A: 67 Warmblüter, Stichprobe B: 4408 Warmblüter und Reitponies, Stichprobe C: 67 Vollblüter, Stichprobe D: 1950 Vollblüter und Stichprobe E: 61 eng verwandte Vollbüter) und die Messung der Zügelspannung mit einer Gruppe von 88 Warmblütern, Quarter Horses und weiterer Rassen (41 Rechtslaterale, 35 Linkslaterale und 12 ohne festzustellende Lateralität) mit 65 Reitern (49 Rechtshänder, 14 Linkshänder und 2 Beidhändige) in 110 Ritten (51 im konventionellen, Europäischen Reitstil und 59 im Western Reitstil). Mit Excel, sowie SPSS wurden die Zügelspannung mittels gemischtem Modell und die Zusammenhänge der einzelnen Methoden mit Kreuztabellen, chi²-Tests, phi und Cramer's V, sowie Pearson-Korrelationen untersucht. Die Heritabilitäten wurden mit uni- und bivariatem, linearem Tiermodell mittels DMU6 erstellt.

Die Lateralität eines Indiviuums scheint auf verschiedene Arten manifestiert zu sein, die untereinander nicht in Relation stehen und nicht zwangsläufig die Lateralität während des Reitens beeinflussen. Die Lateralitätstests am Boden stimmten daher nicht mit der Lateralität während des Reitens überein. Einzig die Einschätzung des Reiters, sowie die natürliche Schiefe der Hinterhand ließen Rückschlüsse zu. In den meisten Populationen war eine natürliche Schiefe der Hinterhand nach rechts zu beobachten. Bezogen auf die Lateralität während des Reitens konnte keine bevorzugte Seite deutlich häufiger festgestellt werden. Bei den Warmblütern war die Erblichkeit der natürlichen Schiefe der Hinterhand hoch (h^2=0.51), bei den Vollblütern jedoch niedrig bis moderat (h^2=0.19). In der Population der Vollblüter konnten mittels der natürlichen Schiefe und des bevorzugten Renngalopps beidseitig veranlagte Pferde identifiziert werden. Rechtslaterale und beidseitig veranlagte Pferde waren insgesamt erfolgreicher. Die genetische Korrelation zwischen der Lateralität und den Rennerfolgen war bei den Vollblütern hoch (Siege: r_g=0.82±0.19, Plätze: r_g=0.70±0.16). Im Dressur- und Springsport schien die Links- und Beidhändigkeit der Reiter, sowie die Linkslateralität der Pferde ein Vorteil für Sporterfolge und das Erreichen höherer Reitklassen zu sein. Ein direkter Zusammenhang der natürlichen Schiefe mit Reaktionen der Muskeltriggerpunkte konnte nicht festgestellt werden, dennoch scheint es einen Zusammenhang mit schief getragenen

Schweifen, der Stabilität der Zügelspannung, sowie Verletzungen der Pferde zu geben. Neben der Stabilität der Zügelspannung konnten zwei Aspekte der Symmetrie (die quantitative Differenz zwischen rechtem und linkem Zügel, sowie die zeitliche Übereinstimmung der Spannungsspitzen) identifiziert werden, die maßgeblich durch die Händigkeit des Reiters beeinflußt wurden. Die Zügelspannung im Westernreiten fiel deutlich geringer, symmetrischer und stabiler aus als im konventionellen Europäischen Reitstil.

Die Lateralität des Pferdes beeinflußte insbesondere die Stärke der Zügelspannung und die Symmetrie des äußeren und inneren Zügels. Rechtshänder waren dabei deutlich von ihrer dominanten rechten Hand abhändig und erreichten symmetrischere Spannungsmuster mit rechtslateralen Pferde. Linkshänder hingegen stellten sich in jede Richtung auf die jeweilige nicht-dominante Seite des Pferdes ein, unabhängig von dessen Lateralität. Neben dem Reitstil selbst, konnten die Rasse der Pferde, die Art der Zügelführung sowie das verwendete Equipment, eine zusätzliche Sportaktivität des Reiters, und die Vertrautheit des Reiters mit dem Pferd (Fremdreiter) als weitere Einflußfaktoren auf die Zügelspannung identifiziert werden.

Die natürliche Schiefe der Hinterhand ermöglicht die Identifizierung von beidseitig veranlagten Pferden, sofern diese in der Bewegung in beide Richtungen erfasst wird. Die Lateralität könnte als Indikator für die genetische Veranlagung erfolgreicher Sportleistungen dienen und sollte als binäres Merkmal erfasst werden. Linkslateralität scheint sportliche Erfolge sowohl bei Reitern als auch bei Pferden zu fördern. Der Muskelzustand des Pferdes beeinflusst die Zügelspannung und die Gesunderhaltung des Pferdes und sollte zukünftig vermehrt Beachtung finden. Die Händigkeit scheint bei Linkshändern weniger stark ausgeprägt zu sein. Insbesondere Rechtshänder könnten von der Stärkung ihrer linken Hand, sowie der möglichen Verbesserung der Propriozeption und Koordination durch das häufige Wechseln der Pferde und verschiedene Arten der Zügelführung profitieren. Reiter sollten ihre Zügelspannung regelmäßig kontrollieren und ihre eigene Einschätzung überprüfen.

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13. Appendix

13.1 Questionnaires

13.1.1 Questionnaires of Online Survey (Chapter 4)

Teil A Die Lateralität des Reiters

Bitte lesen Sie sich die folgenden Fragen aufmerksam durch und kreuzen Sie die zutreffende Antwort an. Mit den Fragen 1-8 erfolgt die Berechnung des Händigkeitsindex der Reiter. Sie erhalten Punkte im Bereich von -2 (immer links) bis +2 (immer rechts) für jede Antwort. Alle weiteren Fragen dienen dazu, weitere Faktoren für die Interaktion der Händigkeit zu identifizieren. Bitte antworten Sie umfassend und ehrlich.

1. **Mit welcher Hand werfen Sie einen Ball?**

☐immer links ☐meist links ☐beide☐meist rechts ☐immer rechts

2. **Welche Hand benutzen Sie um mit einem Hammer einen Nagel in ein Brett zu schlagen?**

☐immer links ☐meist links ☐beide☐meist rechts ☐immer rechts

3. **Mit welcher Hand benutzen Sie ein Messer um Brot zu schneiden?**

☐immer links ☐meist links ☐beide☐meist rechts ☐immer rechts

4. **Mit welcher Hand benutzen Sie einen Löffel?**

☐immer links ☐meist links ☐beide☐meist rechts ☐immer rechts

5. **In welcher Hand halten Sie beim Zähne putzen die Zahnbürste?**

☐immer links ☐meist links ☐beide☐meist rechts ☐immer rechts

6. **Mit welcher Hand benutzen Sie einen Kamm/eine Haarbürste?**

☐immer links ☐meist links ☐beide☐meist rechts ☐immer rechts

7. **Welche Hand benutzen Sie zum Schneiden mit einer Schere?**

☐immer links ☐meist links ☐beide☐meist rechts ☐immer rechts

8. **Welche Hand benutzen Sie um einen Schraubverschluss zu öffnen?**

☐immer links ☐meist links ☐beide ☐meist rechts ☐immer rechts

9. **Welche Hand benutzen Sie um ein Streichholz anzuzünden?**

☐immer links ☐meist links ☐beide ☐meist rechts ☐immer rechts

10. **Geschlecht:** ☐weiblich ☐männlich

11. **Bitte ordnen sie sich einer der folgenden Altersgruppen zu:**

☐ 10-14 ☐15-20 ☐21-30 ☐31-40 ☐41-50 ☐ 51-60 ☐61-65 ☐66-70 ☐>71

12. **Wie viele Jahre Reiterfahrung haben Sie?**

13. **Wie viele Stunden pro Woche reiten Sie?**

14. **Welche Disziplinen üben Sie aus?**

☐ Dressur ☐ Springen ☐ Vielseitigkeit ☐ Distanz ☐ Voltigieren ☐ Rennreiten ☐ Ausritt

☐ Western ☐ Gangpferdereiten

15. **Welche Disziplin bevorzugen Sie?**

16. **Auf welchem Niveau reiten Sie aktuell?**

17. **Reiten Sie hauptsächlich ein bestimmtes Pferd?**
    ☐ Ja ☐ Nein

18. **Reiten Sie hauptsächlich Schulpferde bzw. häufig wechselnde Pferde?**
    ☐ Ja ☐ Nein

19. **Reiten Sie überwiegend junge Pferde oder bereits weit ausgebildete Pferde?**

☐ Jungpferde ☐ weit ausgebildet

20. **Wie viele Pferde reiten Sie am Tag/in der Woche?**

21. **Nehmen Sie Reitunterricht? Wenn ja, in welchem Umfang?**

☐ Ja,

☐ Nein

22. **Nehmen Sie regelmäßig an Turnieren teil? Wenn ja, auf welchem Niveau und in welcher Disziplin?**

☐ Ja,

☐ Nein

23. **Üben Sie einen Bürojob aus oder eher einen handwerklichen Beruf? Wenn handwerklich, welcher?**

☐ Tätigkeit im Büro ☐ handwerklicher Beruf, nämlich

24. **Betreiben Sie sportliche oder handwerkliche Aktivitäten (außer Reiten) in Ihrer Freizeit? Wenn ja, welche und in welchem Umfang?**

☐ Ja,

☐ Nein

25. Hatten Sie innerhalb der letzten 12 Monate Verletzungen oder Erkrankungen im Schulter/Arm/Handbereich? Wenn ja, welche Seite war betroffen wie lange dauerten sie an?

☐ Ja,

☐ Nein

Teil B Die Lateralität des Pferdes

Der Händigkeitsindex der Pferde wird durch die Fragen 18 - 30 ermittelt. Es werden Punkte im Bereich von -1 (links) bis +1 (rechts) vergeben. Alle vorherigen Fragen dienen dazu, weitere Faktoren für die Interaktion der Händigkeit zu identifizieren. Bitte antworten Sie umfassend und ehrlich.

1. Wie viele Pferde besitzen/reiten Sie regelmäßig?

2. **Bitte geben Sie das Geschlecht des/der Pferde/s an:**

Pferd1 ☐Stute ☐Wallach ☐Hengst

Pferd2 ☐Stute ☐Wallach ☐Hengst

Pferd3 ☐Stute ☐Wallach ☐Hengst

Pferd4 ☐Stute ☐Wallach ☐Hengst

3. Alter des Pferdes:

Pferd1 Pferd2 Pferd3 Pferd4

4. Wie lange ist das Pferd schon unter dem Sattel?

Pferd1 Pferd2 Pferd3 Pferd4

5. Rasse/Zuchtgebiet des Pferdes:

Pferd1 Pferd2 Pferd3 Pferd4

6. Abstammung des Pferdes (Vater x Muttervater)

Pferd1 Pferd2

Pferd3 Pferd4

7. In welcher Disziplin wird das Pferd eingesetzt?

Pferd1 Pferd2

Pferd3 Pferd4

8. Welchen Ausbildungsstand hat das Pferd derzeit?

Pferd1 Pferd2

Pferd3 Pferd4

9. Wie oft und wie lange wird das Pferd pro Woche geritten?

Pferd1 Pferd2

Pferd3 Pferd4

10. Wie oft und wie lange wird das Pferd pro Woche longiert?

Pferd1 Pferd2

Pferd3 Pferd4

11. Von wie vielen Reitern wird das Pferd regelmäßig geritten?

Pferd1 Pferd2 Pferd3 Pferd4

12. Wird mit dem Pferd Reitunterricht genommen?

Pferd1 Pferd2 Pferd3 Pferd4

13. Mit welchem Gebiss wird das Pferd regelmäßig geritten?

Pferd1 Pferd2

Pferd3 Pferd4

14. Wie oft erhält das Pferd Weidegang und wie lange?

Pferd1 Pferd2

Pferd3 Pferd4

15. War das Pferd innerhalb der letzten 12 Monate auf Turnieren siegreich? Wenn ja, wie oft und in welcher Klasse?

Pferd1 Pferd2

Pferd3 Pferd4

16. Ist das Pferd innerhalb der letzten 12 Monate auf Turnieren platziert worden? Wenn ja, wie oft und in welcher Klasse?

Pferd1 Pferd2

Pferd3 Pferd4

17. Konnte das Pferd innerhalb der letzten 12 Monate verletzungsbedingt länger als 3 Wochen nicht trainiert werden? Wenn ja, wie oft und wie lange liegt der letzte Fall zurück?

Pferd1 Pferd2

Pferd3 Pferd4

18. Auf welcher Hand ist das Pferd durchlässiger?

Pferd1: ☐ links ☐ beide ☐ rechts Pferd2: ☐ links ☐ beide ☐ rechts

Pferd3: ☐ links ☐ beide ☐ rechts Pferd4: ☐ links ☐ beide ☐ rechts

19. Auf welcher Hand zeigt das Pferd einen besseren Raumgriff und Schwung?

Pferd1: ☐ links ☐ beide ☐ rechts Pferd2: ☐ links ☐ beide ☐ rechts

Pferd3: ☐ links ☐ beide ☐ rechts Pferd4: ☐ links ☐ beide ☐ rechts

20. Auf welcher Hand galoppiert das Pferd bevorzugt?

Pferd1: ☐ links ☐ beide ☐ rechts Pferd2: ☐ links ☐ beide ☐ rechts

Pferd3: ☐ links ☐ beide ☐ rechts Pferd4: ☐ links ☐ beide ☐ rechts

21. Auf welcher Hand gelingen Dressurlektionen (z.B. Seitengänge, Tempowechsel) leichter?

Pferd1: ☐ links ☐ beide ☐ rechts Pferd2: ☐ links ☐ beide ☐ rechts

Pferd3: ☐ links ☐ beide ☐ rechts Pferd4: ☐ links ☐ beide ☐ rechts

22. Auf welcher Hand springt das Pferd bevorzugt?

Pferd1: ☐ links ☐ beide ☐ rechts Pferd2: ☐ links ☐ beide ☐ rechts

Pferd3: ☐ links ☐ beide ☐ rechts Pferd4: ☐ links ☐ beide ☐ rechts

23. In welche Richtung gelingen Wendungen leichter?

Pferd1: ☐ links ☐ beide ☐ rechts Pferd2: ☐ links ☐ beide ☐ rechts

Pferd3: ☐ links ☐ beide ☐ rechts Pferd4: ☐ links ☐ beide ☐ rechts

24. In welcher Richtung zeigt das Pferd die Tendenz den Zirkel zu vergößern?

Pferd1: ☐ links ☐ beide ☐ rechts Pferd2: ☐ links ☐ beide ☐ rechts

Pferd3: ☐ links ☐ beide ☐ rechts Pferd4: ☐ links ☐ beide ☐ rechts

25. In welcher Richtung zeigt das Pferd die Tendenz den Zirkel zu verkleinern?

Pferd1: ☐ links ☐ beide ☐ rechts Pferd2: ☐ links ☐ beide ☐ rechts

Pferd3: ☐ links ☐ beide ☐ rechts Pferd4: ☐ links ☐ beide ☐ rechts

26. Auf welcher Seite nimmt das Pferd Schenkelhilfen besser an?

Pferd1: ☐ links ☐ beide ☐ rechts Pferd2: ☐ links ☐ beide ☐ rechts

Pferd3: ☐ links ☐ beide ☐ rechts Pferd4: ☐ links ☐ beide ☐ rechts

27. Auf welcher Seite hält das Pferd den Zügelkontakt gleichmäßiger?

Pferd1: ☐ links ☐ beide ☐ rechts Pferd2: ☐ links ☐ beide ☐ rechts

Pferd3: ☐ links ☐ beide ☐ rechts Pferd4: ☐ links ☐ beide ☐ rechts

28. Entlastet das Pferd ein Hinterbein häufiger? Wenn ja, welches?

Pferd1: ☐ links ☐ beide ☐ rechts Pferd2: ☐ links ☐ beide ☐ rechts

Pferd3: ☐ links ☐ beide ☐ rechts Pferd4: ☐ links ☐ beide ☐ rechts

29. Wälzt sich das Pferd bevorzugt auf einer Seite? Wenn ja, welche?

Pferd1: ☐ links ☐ beide ☐ rechts Pferd2: ☐ links ☐ beide ☐ rechts

Pferd3: ☐ links ☐ beide ☐ rechts Pferd4: ☐ links ☐ beide ☐ rechts

30. Liegt das Pferd bevorzugt auf einer Seite? Wenn ja, welche?

Pferd1: ☐ links ☐ beide ☐ rechts Pferd2: ☐ links ☐ beide ☐ rechts

Pferd3: ☐ links ☐ beide ☐ rechts Pferd4: ☐ links ☐ beide ☐ rechts

Die Umfrage erfolgt anonym. In einem weiteren Abschnitt der Studie wird die Zügelspannung bei ausgewählten Reiter-Pferd-Paaren im Schritt, Trab und Galopp gemessen. Vorab wird ein kurzer Händigkeitstest (bevorzugtes Standbein beim Fressen) mit dem Pferd durchgeführt und die Symmetrie der Muskulatur dokumentiert. Die Messungen finden am Standort des jeweiligen Pferdes statt. Wenn Sie bereit sind, auch an diesem Abschnitt der Studie teilzunehmen, geben Sie bitte Ihre Kontaktdaten, sowie die Anzahl und den Standort des/der Pferde/s an.

Vielen Dank für Ihre Teilnahme!

13.1.2 Questionnaires for horses and riders (Chapter 7)

Name:

Geschlecht: weiblich / männlich Alter:

Reiterfahrung:.................. Jahre Ausbildungsstand:

Reitstunden pro Woche: Disziplin:

Händigkeit: Rechtshänder / Linkshänder / Beidhändig

Turnierreiter: ja / nein

Anzahl Siege/Platzierungen und Niveau

Verletzungen im Arm/Schulterbereich: ja / nein

Wenn ja, welche Seite und wie lange liegt die Verletzung zurück:

Ausgleichssport: ja / nein

Wenn ja, was und in welchem Umfang/Woche

Ermittlung des Händigkeitsindex:

1. Mit welcher Hand werfen Sie einen Ball?

immer links meist links beide meist rechts immer rechts

2. Welche Hand benutzen Sie um mit einem Hammer einen Nagel in ein Brett zu schlagen?

immer links meist links beide meist rechts immer rechts

3. Mit welcher Hand benutzen Sie ein Messer um Brot zu schneiden?

immer links meist links beide meist rechts immer rechts

4. Mit welcher Hand benutzen Sie einen Löffel?

immer links meist links beide meist rechts immer rechts

5. In welcher Hand halten Sie beim Zähne putzen die Zahnbürste?

immer links meist links beide meist rechts immer rechts

6. Mit welcher Hand benutzen Sie einen Kamm/eine Haarbürste?

immer links meist links beide meist rechts immer rechts

7. Welche Hand benutzen Sie zum Schneiden mit einer Schere?

immer links meist links beide meist rechts immer rechts

8. Welche Hand benutzen Sie um ein Streichholz anzuzünden?

immer links meist links beide meist rechts immer rechts

9. Mit welcher Hand drehen Sie einen Schraubverschluss auf?

immer links meist links beide meist rechts immer rechts

10. Welche Hand benutzen Sie zum Schreiben?

immer links meist links beide meist rechts immer rechts

Händigkeitsindex:

Pferd: Alter:

Geschlecht: Rasse:

Disziplin: Ausbildungsstand:

Reitstunden pro Woche: Anzahl Reiter:

Gebiss:

Turnierpferd: ja / nein

Anzahl Siege/Platzierungen und Niveau

Verletzungen: ja / nein

Wenn ja, welche Seite und wie lange liegt die Verletzung zurück:

In Dressurlektionen läuft das Pferd: links besser / rechts besser / auf beiden Seiten gleich gut

Bitte beschreiben Sie den Testritt. War der Ritt harmonisch? Wann / auf welcher Seite traten Probleme auf? Wie empfanden Sie den Zügelkontakt während des Ritts?

13.1.3 Overview of the muscle trigger points tested in the sample

1. M. rectus capitis lateralis
2. M. brachiocephalicus
3. M. multifidus cervicis
4. M. trapezius & M. rhomboideus (front part of the withers)
5. M. trapezius & M. rhomboideus (middle part of the withers)
6. M. trapezius & M. rhomboideus (hind part of the withers)
7. M. supraspinatus
8. M. infraspinatus
9. M. serratur ventralis thoracis
10. M. triceps brachii (upper part)
11. M. triceps brachii (lower part)
12. M. pectoralis ascendens
13. M. longissimus dorsi
14. M. longissimus costarum
15. Junction of M. longissimus and Mm. glutei
16. M. biceps femoris
17. M. biceps femoris (area of subdivision)
18. M. gastrocnemius
19. M. semitendinosus
20. M. semimembranosus
21. M. tensor fasciae latae
22. M. iliacus
23. M. gluteus medius and accessories

24. M. obliquus externus abdominis (origin)

25. M. obliquus externus abdominis (attachment site)

K1 M. masseter

K2 M. masseter

K3 M. masseter

13.2 List of tables

13.3 List of figures

13.4 List of abbreviations

e.g.	for example
i.e.	that is
SD	standard deviation

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Eidesstatliche Erklärung

„Ich erkläre: Ich habe die vorgelegte Dissertation selbstständig, ohne unerlaubte fremde Hilfe und nur mit den Hilfen angefertigt, die ich in der Dissertation angegeben habe. Alle Textstellen, die ich wörtlich oder sinngemäß aus veröffentlichten oder nicht veröffentlichten Schriften entnommen sind, und alle Angaben, die auf mündlichen Auskünften beruhen, sind als solche kenntlich gemacht. Bei den von mir durchgeführten und in der Dissertation erwähnten Untersuchungen habe ich die Grundsätze guter wissenschaftlicher Praxis wie sie in der „Satzung der Justus-Liebig-Universität Gießen zur Sicherung guter wissenschaftlicher Praxis“ niedergelegt sind, eingehalten.“