University of Veterinary Medicine Hannover

Genetic analyses of movement
traits in German warmblood horses

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Ann-Christin Becker
Wilhelmshaven

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Academic supervision: Prof. Dr. Dr. habil. Ottmar Distl
Institut für Tierzucht und Vererbungsforschung
Bünteweg 17p
30559 Hannover

1. Referee: Prof. Dr. Dr. habil. Ottmar Distl
2. Referee: Prof. Dr. Wilfried Brade

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To my father
Parts of this thesis have been accepted or submitted for publication in the following journals:

1. Livestock Science
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3. Animal
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Chapter 1
Chapter 1 (Introduction)

1 Introduction

Modern warmblood breeding aims at producing riding horses which are highly competitive in sport. Movement and its improvement are therefore in the focus of the breeding programs. Regardless of the discipline of riding sport, from recreational riding to dressage or show jumping on an international level, correct gaits and balanced movements belong to the most important basic qualities. Accordingly, gait quality has considerable impact on the value of a horse, and scoring of movement traits is an integral part of the evaluation of foals, broodmares and stallions relevantly influencing breeding and selection decisions.

Particularly dressage horses have been selected for good movements for a long time, resulting in modern warmblood horses which move with much more expression and elasticity than their ancestors. However, horses with certain unfavorable movement characteristics are still seen in the regular breeding events, so the question arose whether the current evaluation system is sufficient for reducing this condition. Therefore, in this thesis data provided by the Oldenburg breeding societies were used to analyze routinely assessed performance traits and the opportunities of introducing new movement traits for more specific improvement of gaits. Subjective scores for gaits during free movement and gaits under rider were chosen for the genetic analyses of the currently used movement traits, and the new movement traits were defined on the basis of detailed movement evaluation of foals and mares. Separate analyses of the already defined and the new movement traits were followed by extensive correlation analyses which also included conformation traits. The aims of this study were to learn more about the distribution and genetic background of unfavorable movement characteristics and to give advice how to interpret them in the context of future breeding for sport performance.

Overview of chapter contents

The content of the thesis is presented in single papers according to § 8 Abs. 3 of the Rules of Graduation of the University of Veterinary Medicine Hannover.

Because signs considered indicative of impaired balance were most important among the unfavorable movement characteristics seen in the warmblood horses,
Chapter 1 (Introduction)

literature on incoordination conditions was reviewed to get an overview over the broad spectrum of possible etiopathologies (Chapter 2). The estimation of genetic parameters for free movement and movement under rider using scores from mare performance tests of the Oldenburg Warmblood is presented in Chapter 3. The use of detailed movement evaluations of foals and mares of the Oldenburg horse breeding societies for defining and analyzing new movement traits serving as measures of impaired balance is described in Chapter 4. Chapter 5 contains the correlation analyses between the new detailed movement traits and routinely assessed conformation and performance traits from studbook inspections and mare performance tests. Chapter 6 comprises the general discussion and conclusions from the results given in chapters 2-5. Chapter 7 is the English summary of this thesis, and Chapter 8 is the comprehensive German summary which takes the overall research context into consideration.
Chapter 2
Chapter 2 (Review on movement disorders in the horse)

Review

Movement disorders and impaired coordination in the horse

A.-C. Becker¹, K. F. Stock¹ ², O. Distl¹

¹ Institute for Animal Breeding and Genetics, University of Veterinary Medicine Hannover (Foundation), Buenteweg 17p, D-30559 Hannover, Germany
² Vereinigte Informationssysteme Tierhaltung w.V., Heideweg 1, D-27283 Verden, Germany
Summary

Deviations from balanced and coordinated movement occur in horses as in many other species, with considerable variation in the severity of clinical signs. Although the term ataxia does not imply severe clinical manifestation, it is mainly used for the clearly affected horses. In the riding horse, even slight movement disorders may interfere with maximum performance capacity, giving reason to review the current knowledge on equine incoordination in general. After a brief overview over the disease terminology, etiological factors are mentioned with their presumed relevance and mode of action. According to literature, the age at which indications of imbalance are seen may be suggestive of the underlying pathologies, with developmental orthopedic disease (DOD) being probably responsible for most cases of incoordination in the young horse. In the adult horse, osteoarthrosis has been identified as a relevant causative factor. Familial disposition of equine incoordination has been long discussed, but knowledge on the role of genetics is still sparse. Clinically, movement disorders of different etiology are usually indistinguishable, interfering with specific trait definition for genetic analyses. Implications for future studies on movement disorders and impaired coordination in young and adult horses are described.

Keywords: Equine incoordination; Spinal ataxia; Gait disturbances; Genetic studies
Chapter 2 (Review on movement disorders in the horse)

**Introduction**

Movement disorders and signs of incoordination are unspecific symptoms which are seen in many species. They occur in the course of various disorders, and there is considerable variation in severity and duration of the clinical signs. The noticeable problems range from very slight and intermittent deviation from normal motion sequence to distinct lack of coordination. Because of the often slight and unspecific clinical signs, it was surmised that the role of diseases interfering with balanced movement in the horse may have been underestimated (Van Biervliet, 2007).

Central nervous structures are responsible for the regulation of all motor activity, with cerebellum and spinal cord being most important. Accordingly, distinction can be drawn between cerebellar ataxia and spinal ataxia. The highly complex function of the nervous system with its connections to all parts of the body implies vulnerability. Trauma of the spinal cord was mentioned as possible cause of gait disturbances as early as in 1861 (Youatt, 1861, cited by Fraser and Palmer, 1967). In the 20th century, affections of the spinal cord were studied more closely, and changes of the cervical vertebrae were identified as possible primary lesions (Dimock and Errington, 1939). Research mainly addressed etiological factors affecting stability and function of the cervical vertebral column on the one hand and therapeutic approaches on the other hand. However, the diverse etiology of movement disorders and incoordination interfered with the development of general therapeutic concepts. Furthermore, reversibility of impaired nervous function may be questionable, so that the importance of prophylactic measures increases. Because affection rates of impaired coordination were reported to differ considerably between families, relevant involvement of genes
was surmised. This review will give an overview about the current knowledge on movement disorders and incoordination in the horse, referring to the hereditary aspects of primary diseases.

**Terminology**

In the literature, different terms can be found for disorders coming along with disturbed motion pattern. Nomenclature is either symptomatic (descriptive) or etiological (specific). The descriptive term 'Wobbles', which was later changed to 'Wobbler syndrome', was introduced as summary phrase for the set of clinical signs observed in incoordinated horses suffering from spinal ataxia (Dimock and Errington, 1939). Wobblers may be affected by infectious or non-infectious diseases, but share the inability to move in balance.

Subsequently, the Wobbler syndrome was addressed in several studies which basically confirmed the initial findings (Rooney, 1962; Pohlenz and Schulz, 1966; Mechlenburg, 1967; Dahme and Schebitz, 1970; Mayhew, 1978). Refinement of diagnostics later allowed identifying compression of the spinal cord, primarily in the cervical part, as the most frequent cause of incoordination in the horse. Within the context of developmental orthopedic diseases (DOD), cervical vertebral malformation (CVM) was described in the 1990s (Stewart et al., 1991). To highlight the clinically relevant affection of the nerval structures, the disease was referred to as cervical stenotic myelopathy (CSM; Moore et al., 1994). Variation in clinical manifestation was accounted for by distinction between constant or static stenosis (cervical static stenosis, CSS) and recurrent or dynamic stenosis (cervical dynamic stenosis, CDS; Moore et al. 1994).
However, deformations of cervical vertebrae may also represent secondary changes, and their occurrence is not confined to the young and growing horse (Van Biervliet, 2007). With diagnostic focus on the cervical vertebral spine it may not be possible to identify the underlying disease, implying reference to symptomatic nomenclature.

The general term ataxia which resembles a symptom rather than a disease basically stands for any deviation from coordinated and balanced movement. However, it is uncommon to use this term in cases with only subtle indications of impaired coordination. Accordingly, horses with have been diagnosed as atactic usually show rather obvious clinical signs.

**Etiology**

Given the heterogeneity of impaired coordination in the horse, over the years a large variety of etiological factors has been discussed. Current knowledge about the most important factors will be summarized in the following.

**Nutrition and growth**

As the skeletal and nerval development is dependent on the appropriate supply with several nutrients, dietary aspects were early suggested as important factors in the whole DOD complex.

The coincidence of overfeeding and DOD has often been reported and discussed (Hoppe, 1984; Jeffcott, 1991). However, differences may exist between the diseases belonging to the DOD complex. For osteochondrosis, some authors surmised a general association between body weight and the proportion of horses affected with
osteochondrosis dissecans (Pagan and Jackson, 1996). Others found differences between joints with effects of body weight being possibly more relevant for the hock joints than for the fetlock joints (Wilke, 2003). Among the horses presented with noticeably impaired coordination there was an overrepresentation of big and fast grown individuals (Mayhew, 1978; Nixon, 1982; Mayhew, 1989).

Overfeeding of the growing horse with energy and protein may exert detrimental effects in different ways. Fast gain of weight and above-average body weight at a young age increase the stress exerted on the maturing skeleton. Maturation processes may be disturbed by the high loading, and imbalance between strength of the skeleton and weight to be carried may persist (Thompson, 1987). Effects of inappropriate diet composition may be intensified in situations where growth is maximized through excessive energy supply. Even slight absolute or relative deficiencies of nutrients may then become clinically relevant.

In connection with skeletal development, calcium and phosphorus are long known to be important. Deficiencies, excesses and inappropriate ratios of these two minerals can lead to persistent weakness of bones and joints (Savage et al., 1993). Copper is essential for the development of cartilage and nerve tissue, implying possible relevance for equine incoordination. Neurological symptoms have early been compared between sheep and horse (Olafson, 1942), and possible responsibility of copper in both species has been discussed. However, conflicting results were obtained with regard to effects of copper on cartilage and bone in foals (Knight et al., 1985; Knight et al., 1990; Hurtig et al., 1990; Davies, 1998; Pearce, 1998; Coenen et al., 2003; Vervuert et al., 2003). Surmised influences of vitamin A, possibly in combination with an inappropriate calcium to phosphorus ratio, on the
development of impaired coordination could not be verified in early studies (Bardwell, 1961). A lack of vitamin E is a possible cause of neurological symptoms across species and age groups. In the adult horse hypovitaminosis E was made responsible for degenerations of motor neurons in the spinal cord (McGorum and Mayhew, 2006; Mohammed, 2007). Horses affected by equine degenerative myeloencephalopathy (EDM) first show signs of incoordination and clumsiness, which deteriorates to outright ataxia (Kane, 2009).

**Age and use**

CVM has long been considered as a disease of the young horse (Levine et al., 2010). However, several studies addressing the influence of age on the prevalence of CVM did not support this assumption. The results indicated that the pathogenesis of CVM may be different in young and adult horses, but incoordination because of malformation of cervical vertebrae may also develop in older age (Levine et al., 2010). In the young horse, the majority of cases may be caused by DOD, whereas in the adult horse the importance of degenerative changes increases (Van Biervliet, 2007). Osteoarthritic enlargement of articular processes may be clinically inapparent in many horses, but responsible for clearly impaired coordination in others (Levine et al., 2010).

The use of horses was suggested to have an effect on CVM development in the adult horse. Prolonged cervical stress in intensively used riding horses may be interpreted as repeated vertebral microtrauma. Sport horses may therefore be on a higher risk to develop CVM than horses used for pleasure riding or breeding. In a
recent study which included 270 horses with signs of incoordination no significant differences were found between different types of use (Levine et al., 2010).

**Trauma**

Any trauma exerted on the neural structures involved in regulation of motor activity can lead to movement disorders. Accidents with fractures or luxations of single or multiple vertebrae are likely to affect motor neurons in the spinal cord. However, in many cases it may be difficult to state on the primary cause of incoordination. Slight signs of imbalance may have been present, but not recognized before the accident. Horses with coordination problems are stumbling more frequently and have a higher risk of falling. Accidents of such horses which lead to obvious clinical signs are consequences rather than causes of movement disorders.

Hematomas extending into the vertebral canal can cause clinical signs resembling those of vertebral fractures or luxations. However, with resolution of the hematoma functional recovery will set in rather quickly.

**Disturbed blood supply**

Vascular occlusion may not only secondary to for example traumatic compression of the spinal cord, but also occur primarily. Local cut-off or significant reduction of blood supply will result in asymmetric gait deficits or incoordination. Typical clinical signs for ischemic myelopathy are intermittent limping or incoordinated movement of limbs. In many cases, the neurological signs are transitional, and the ischemic lesions may heal after revascularization (Al-Mefty et al., 1993).

**Infectious diseases**
Because of the complex interconnections of nervous structures, any infection affecting the nervous system can result in movement or coordination disorders. Equine Herpes Virus (EHV) is well known as a cause of respiratory diseases or aborts. However, EHV-1 and less often EHV-4 may also evoke myeloencephalitis in horses of different ages, even in vaccinated ones (Blunden, 1992). The clinical signs vary widely, depending on which section of the spinal cord, the brain or the nerves have been affected. In the majority of cases an early sign of EHV myeloencephalitis is ataxia of the hind limbs. To clinically differentiate ataxia caused by EHV infection from CVM, case histories are to be considered. Horses that have been infected by a Herpesvirus usually show high fever and respiratory symptoms ten to fourteen days before they develop ataxia. Furthermore, the neurological symptoms of central nervous EHV may quickly improve, often within two to four days, whereas CVM related symptoms remain stationary or deteriorate.

Other virus infections which may involve impaired coordination in the horse include the neurotropic Rabies virus and the West Nile Virus. Western and Eastern Equine Encephalitis or Myeloencephalitis are caused by infections with closely related RNA viruses. Both have been primarily diagnosed in the USA and in Canada, but with international equine trading and traveling the risk of outbreaks in northern Europe may increase. Manifest infection with West Nile Virus may cause neurological symptoms in horses such as staggering or incoordinated gaits (Nielsen et al., 2008). However, infections are frequently asymptomatic, with an apparent-to-inapparent ratio of as high as 1:17 in 2005 (Nielsen et al., 2008).
Infection with Borrelia burgdorferi may cause clinically apparent Lyme disease in horses. A broad spectrum of possible manifestations has been discussed rather controversially, including impaired coordination (Schönert et al., 2008).

Equine protozoal myeloencephalitis is caused by species of Sarcocystis or Toxoplasmosis in the brain and/or spinal cord. Clinical signs vary depending on the location and extent of lesions, but ataxia is frequently seen in infected horses (Clark et al. 1981). A very similar clinical picture may be observed in horses with nematode infection of the central nervous system, a disease called nematodiasis (Pohlenz, 1965).

**Neoplastic changes**

Neoplasm can occur in almost every part of the organism, including those with regulatory elements of motor function. Neoplasias of the nerve tissue itself directly interfere with regular nerve function and may cause movement disorders. In addition, neoplasias of tissues surrounding nerval structures can lead to neurological symptoms through compression effects. The central nervous system is protected by firm bone, implying rigid space limitation. Accordingly, any tumor growth within the bony compartments is likely to cause functionally relevant compression of nerve structures. Because of its quantitative importance, one type of neoplasias will be mentioned explicitly.

Melanomas frequently develop in grey horses, with the root of the tail representing one of the main locations. The risk of melanomas generally increases with age, but the number or size of externally visible tumors does not always reflect the total burden. Melanomas will lead to ataxic signs as soon as they emerge in the vertebral
canal and compress the spinal cord (Schott et al., 1990). Acute and progressive neurological dysfunction may then be observed even in absence of any cutaneous melanomas (Traver et al., 1977).

**Hormonal balance**

Endocrine factors influence the development and maturation of cartilage and bone (Glade, 1986). DOD is characterized by a disturbance of the conversion of cartilage to compact bone, so imbalances of hormones involved in cartilage and bone metabolism are among the possible causes of DOD. Thyroid hormones T3 and T4 exert their influence on skeletal development through their effects on blood supply (Glade et al., 1984), whereas the growth hormone directly stimulates the activity and proliferation of chondrocytes (Savage et al., 1993). Parathyroid hormone and calcitonin are antagonists which together with vitamin D control the blood calcium and phosphorus concentrations. Imbalances in these minerals interfere with regular osteoblastic and osteoclastic activity, and the effects of disturbed bone metabolism may include movement disorders.

In many studies signs of CVM were more often seen in male than in female horses (Reed et al., 1985; Van Biervliet, 2007; Levine et al., 2007). Although the definite reason for these sex differences is still unknown, sexual hormones may be directly or indirectly involved. Estrogen and testosteron both influence bone metabolism, and for humans it has been described that the shape of vertebrae differs significantly between the genders (Grados et al., 1999). Sex-dependent behavior patterns have been described for the horse (Levine et al., 2007). Accordingly, rougher play of colts when compared to fillies may put them on a higher risk of spinal injuries.
Furthermore, recovery after affections of nerval structures may be better in females than in males according to their progesterone levels. For the rat is has been shown that progesterone increased the expression of neuroprotective factors and progesterone treatment improved the outcome after acute spinal cord injuries (Thomas et al., 1999; Labombarda et al., 2010).

**Intoxication**

Substances with neurotoxic potential may be responsible for impaired coordination in single horses or groups of horses. For example, acute selenium poisoning can lead to amyosthenia with the clinical picture of ataxia (Step et al., 1991). The plant horse-tail (*Equisetum spp.*)) contains an antagonist of vitamin A absorption. Intoxication symptoms therefore resemble those of hypovitaminosis A with degenerative structural changes in the brain and spinal cord and consecutively disturbed motor activity.

**Clinical signs**

Clinical signs of incoordination vary wide from slightly imbalanced movement or irregular tension and rigidity in the hind limbs over weakness and reluctance to carry weight to clearly atactic movement, spasticity or even paresis (Van Biervliet, 2007). After for example accidents or infections, severe symptoms of ataxia may become visible quickly. However, in many cases the clinical picture develops slowly, with first signs of imbalance being barely apparent and presumably often unrecognized. Table 1 gives an overview over the symptoms mentioned in literature which are considered to be indicative of incoordination in the horse.
Clinical signs alone do not allow etiological diagnoses. Use of refined diagnostics has shown that lesions of the cervical spinal cord lesions may be the most important causes of impaired coordination in the horses. Clinically obvious irregularities of gaits are in such cases primarily related to either dysfunction of the upper motor neuron (UMN) or general proprioceptive (GP) tracts. However, close connections and functional dependencies of UMN and GP cause symptoms resulting from both UMN and GP dysfunction. Generally, extent and severity of movement disorders depends on the location of neural lesions. Therefore, in some cases all four limbs can be affected, which appears rarely and mainly in severe cases, or only the hind or front limbs. Gait deficits are often symmetric, but may also be asymmetric. Asymmetry of movement disorders is not indicative of any specific etiology and is independent of age (Levine et al., 2010). In many cases, first clinical signs of impaired coordination are seen in the hind limbs which is due to the superficial location and accordingly higher trauma exposure of respective motorneurons in the spinal cord.

**Heritability and mode of inheritance**

Genetic disposition of equine incoordination has been considered since the very beginning (Dimock and Errington, 1939; Dimock, 1950). In 1950, Dimock interpreted his study results as proofs for the hereditary nature of the Wobbler disease and suggested a recessive inheritance. This suggestion was in agreement with previous literature (Weischer 1944), but was questioned subsequently (Jones et al., 1954).

Decades later, the question of heredity of DOD was addressed by a breeding experiment (Wagner et al., 1985). The results justified using the summary term DOD for Wobbler disease and osteochondrosis, but did not allow clear conclusions
regarding the former: Mating of two Wobblers did not increase the proportion of wobblers among their offspring. However, their risk of developing osteochondrosis was significantly elevated (Wagner et al., 1985).

Differences between breeds regarding the dispositions of movement disorders have been long discussed and may indicate relevant genetic influences. Several investigators found Thoroughbreds to be overrepresented among the horses with incoordinated movement (Falco et al., 1976; Mayhew et al., 1978). However, when interpreting information on affection rates per breed, the sources of information must be taken into account. Most studies on equine incoordination are based on case material of certain clinics, and it cannot be assumed that breed representation is representative. When a large equine hospital is located in a region where for example Thoroughbred breeding is very common, it may be expected that Thoroughbreds will also make up the largest part of incoordination cases (Gordis, 2004).

Until today conclusive information on the role genetics for incoordination in the horse is missing. The heterogeneous etiology of movement disorders makes trait definition difficult, and the information on the prevalences of the primary diseases is still very sparse. Most literature refers to clinical data unsuitable for population genetic analyses. Neurological patients or all patients of an equine hospital do not represent random samples of the horse population, and determined incidence rates are likely not to reflect the overall situation. To reliably estimate genetic parameters, screening data will be the ideal source of phenotype information. However, trait definition has to be considered thoroughly, keeping the balance between maximum specificity of information and feasibility of broad data collection.
Chapter 2 (Review on movement disorders in the horse)

**Implications for further studies**

It has been postulated that distinction between the causes of spinal cord compression may be necessary to appropriately interpret collected data on incoordination (Van Biervliet, 2007). Statements on prognosis and therapeutic options for the individual horse will require knowledge on the specific etiopathology, implying the use of refined diagnostics. However, less detailed information may be used to get an impression of the role and quantitative importance of movement disorders and incoordination in a horse population. Performing elaborate examinations like cervical spine radiography, magnetic resonance tomography or computed tomography in hundreds or thousands of horses is unrealistic, but would be necessary to distinguish etiologically.

According to the available study results it may be legitimate to assume predominance of one etiology each in young and adult horses: Incoordination may in the young horse primarily relate to DOD and in the adult horse to osteoarthrotic changes. Most of the sporadic causes of incoordination can be excluded by refined diagnostics, for example toxicological screening of the blood. Clinical appearance may then be used to assess the disease status with respect to incoordination in distinct age groups. Simplified data collection should be feasible in large numbers of horses, resulting in datasets large enough for population genetic analyses. Ideally, collection of incoordination data could be combined with routine inspections of young and adult horses. In this connection it must be taken into account that horses with obvious ataxia are unlikely to be presented at the regular inspection dates and cases of very slight impairment of coordination may be undetected when only the clearly indicative signs of ataxia (see Table 1) are considered. The set of clinical signs to be
recorded may therefore include additional characteristics of movement pattern. Because of the importance of neck and tail for balanced movement, documentation of posture and tension of neck and tail during movement may provide valuable information. Genetic parameters may then be estimated separately for signs of imbalance in young and adult horses to account for probably different etiologies and pre-selection effects in the two age groups.

**Conflict of interest statement**

None of the authors of this paper has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.
Chapter 2 (Review on movement disorders in the horse)

References


Chapter 2 (Review on movement disorders in the horse)


Chapter 2 (Review on movement disorders in the horse)


### Table 1 Clinical symptoms of incoordination (ataxia) in the horse according to literature.

<table>
<thead>
<tr>
<th>Clinical symptom</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incoordinated movement of hind limbs</td>
<td>Dimock and Errington, 1939; Dimock, 1950; Schebitz and Schulz, 1965; Fraser and Palmer, 1967; Dahme and Schebitz, 1970; De Lahunta et al., 1983; Levine et al., 2010</td>
</tr>
<tr>
<td>Weakness and / or reduced propulsive activity of the hind legs</td>
<td>Reed, 1985; Schütte, 2005; Biervliet 2007</td>
</tr>
<tr>
<td>Incoordinated movement of front limbs</td>
<td>Dimock, 1950; Biervliet, 2007; Levine et al., 2010</td>
</tr>
<tr>
<td>Asymmetric gait deficits</td>
<td>Fraser and Palmer, 1967; Biervliet, 2007; Levine et al., 2010</td>
</tr>
<tr>
<td>Dysmetria</td>
<td>Dahme and Schebitz, 1970; De Lahunta, 1983; Reed, 1985</td>
</tr>
<tr>
<td>Cervical hyperesthesia and / or pain response to flexion of the neck</td>
<td>Dimock and Errington, 1939; Fraser and Palmer, 1967; Mayhew et al., 1978; De Lahunta, 1983; Schütte, 2005; Levine et al., 2010</td>
</tr>
<tr>
<td>Spasticity</td>
<td>Mayhew, 1978; De Lahunta, 1983; Reed, 1985; Biervliet, 2007</td>
</tr>
<tr>
<td>Paresis</td>
<td>Mayhew, 1978; Biervliet, 2007</td>
</tr>
<tr>
<td>Varying stride length</td>
<td>Reed, 1985; Biervliet, 2007</td>
</tr>
<tr>
<td>Dragging of the hooves</td>
<td>Schebitz and Schulz, 1965; Dahme and Schebitz, 1970; Böhm, 1975; Reed, 1985; Biervliet, 2007</td>
</tr>
<tr>
<td>Outward or inward swaying of the lower limbs</td>
<td>Dahme and Schebitz, 1970; Biervliet, 2007</td>
</tr>
<tr>
<td>Balance problems when exercised on small circles</td>
<td>Ruppanner, 1972; Reed, 1985; Biervliet, 2007</td>
</tr>
<tr>
<td>Affinity to fall</td>
<td>Dahme and Schebitz, 1970; Böhm, 1975; Mayhew, 1978; Schütte, 2005</td>
</tr>
<tr>
<td>Pace irregularity</td>
<td>Böhm, 1975; Reed, 1985</td>
</tr>
</tbody>
</table>
Chapter 3
Genetic correlations between free movement and movement under rider in performance tests of German Warmblood horses

A.-C. Becker¹, K.F. Stock¹,², O. Distl¹

¹ Institute for Animal Breeding and Genetics, University of Veterinary Medicine Hannover (Foundation), Buenteweg 17p, D-30559 Hannover, Germany
² Vereinigte Informationssysteme Tierhaltung w.V., Heideweg 1, D-27283 Verden, Germany

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Abstract

Performance information on 2758 mares that had completed mare performance tests (MPT) of the Oldenburg horse breeders' society in 2000–2008 was used for genetic analyses focusing on options to improve existing breeding programs through refined trait definition. Testing conditions were largely unchanged in the study period, with most data referring to MPT results of 3- or 4-year-olds. For all mares, scores on a scale from 1 to 10 were available for walk, trot, canter, rideability, and free jumping, with gait scores representing means from evaluation during free movement (F) and under rider (R). Distinct F and R gait scores were available for a subset of the mares with MPT in 2003–2008 and were used to investigate the effect of evaluation type on variance components. Genetic parameters were estimated with residual maximum likelihood (REML) in multivariate linear animal models. Heritability estimates for the MPT traits ranged from 0.19 (rideability) to 0.56 (free-jumping). For the gaits heritabilities were similar (canter) or higher (walk, trot) for F scores than for corresponding R scores. The correlations between F and R scores for the same gait were found to be closer additive genetically (rg=0.7–0.9) than phenotypically (rp=0.4–0.6), but indicated that F and R scores may not represent exchangeable measures of the same trait. Further correlation analyses revealed moderately to highly positive additive genetic correlations between gaits and rideability for both F and R scores, whereas additive genetic correlations between walk and canter and between trot and free jumping was relevantly dependent on evaluation type. Because selection of riding horses represents multiple-trait selection, better reflection of covariances between selection traits will help maximizing the overall breeding progress. According to our results, Warmblood breeding may therefore benefit from refinement of trait definition with clear distinction between gait evaluation during free movement and under rider.
Chapter 3 (Movement evaluations in mare performance tests)
Chapter 4
Genetic analyses of new movement traits using detailed evaluations of warmblood foals and mares

A.-C. Becker\textsuperscript{1}, K. F. Stock\textsuperscript{1,2}, O. Distl\textsuperscript{1}

\textsuperscript{1}Institute for Animal Breeding and Genetics, University of Veterinary Medicine Hannover, Hanover, Germany

\textsuperscript{2}Vereinigte Informationssysteme Tierhaltung w.V., Verden, Germany

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Chapter 4 (Genetic analyses of new movement traits)
Summary
Detailed movement evaluations of warmblood foals and mares were performed in connection with regular breeding events of the Oldenburg horse breeding societies in 2009 and 2010. Unfavorable movement characteristics considered indicative for impaired balance were noted by a special judge (SJ) and the regular judges of the breeding events (RJ) and served as the basis for definition of new movement traits. Detailed movement information on 3,374 foals and 2,844 mares showed that more severe findings like irregular motion pattern in hind legs or irregularity in general motion pattern occurred only sporadically (prevalences of 1-2%). Irregular tail tone or posture was documented for 4% of the foals and 5% of the mares, resulting in prevalences of the comprehensive trait indications of imbalance (IMB) of 6.2% (foals) and 5.5% (mares). Binary coding was used for all traits, and genetic parameters were estimated bivariately in linear animal models with residual maximum likelihood (REML). Comparative analyses between judges revealed that differences between trait definitions of SJ and RJ were larger in the mares than in the foals, but justified combined use of SJ and RJ information in both age groups. Heritability estimates for the movement traits ranged on the original scale from 0.02 to 0.26 in the foals and from 0.03 to 0.12 in the mares, with heritabilities for IMB on the underlying liability scale of 0.46 (foals) and 0.22 (mares). Comparative analyses between age groups indicated that common genetic factors may be responsible for findings of impaired balance in foals and mares. The results implied that horse breeding may benefit from using the early available information on the movement of foals obtained by detailed movement evaluations. New movement traits reflecting unfavorable movement characteristics may be suitable to select against indications of imbalance in juvenile and adult horses, although favorable combination of foal and mare data in future genetic evaluations may require refined recording of unfavorable movement characteristics in the adult horses.
Chapter 5
Correlations of unfavorable movement characteristics in warmblood foals and mares with routinely assessed conformation and performance traits

A.-C. Becker¹, K. F. Stock¹², O. Distl¹

¹Institute for Animal Breeding and Genetics, University of Veterinary Medicine Hannover, Hanover, Germany;
²Vereinigte Informationssysteme Tierhaltung w.V., Verden, Germany

Animal 7 (2013), 11-21
Chapter 5 (Correlation analyses of new movement traits)

Summary
New movement traits reflecting unfavorable movement characteristics were defined on the basis of detailed movement evaluations (DME) of warmblood foals and mares performed in connection with regular breeding events of the Oldenburg horse breeding societies in 2009 and 2010. DME information was available for 3,374 foals and 2,844 mares and used for correlation analyses with conformation information on 1,987 mares from studbook inspections (SBI) in 2009 and performance information on 2,758 mares from mare performance tests (MPT) in 2000-2008. Analyses of variance revealed few significant differences between scores for SBI and MPT traits in mares without and with indications of imbalance (IMB) in general or specific findings like irregular tail tone or posture (TTP). SBI scores for general impression and development were significantly lower and MPT scores for trot under rider tended to be higher in IMB-positive mares. Genetic parameters were estimated in linear animal models with residual maximum likelihood (REML). Additive genetic correlations and Pearson correlation coefficients between univariately predicted breeding values indicated unfavorable genetic correlations of IMB and TTP with dressage related conformation and performance traits. For SBI and MPT traits we found similarities between the correlation patterns for DME traits in foals and mares. The results implied that breeding of dressage horses may benefit from revision of current movement evaluation and consideration of specific movement characteristics.
Chapter 6
Chapter 6 (General discussion)

6 General discussion

In this thesis, different aspects of movement and its evaluation in the warmblood horse were addressed. The breeding aim of modern Warmblood breeding organizations is a capable and healthy horse, with an appealing conformation as well as expressive and correct gaits. Because gaits rank high among the breeding objectives of the warmblood breeding organizations (Koenen et al. 2004), including the Oldenburg breeding societies, movement evaluations are integral parts of breeding events. From foal evaluations over conformation evaluations, for example in connection with studbook inspections, to performance evaluations in field or station performance tests, walk and trot and sometimes also canter are judged by experienced representatives of the breeding societies. Starting with rather general evaluation at very young age in foals specificity of gait scoring increases in the juvenile and young adult horse. Several studies have shown that young horse performance tests are indicative for future success in sport (Ducro et al. 2007a, 2007b; Lührs-Behnke et al. 2006a; Thoren Hellsten et al. 2006; Viklund et al. 2010a, 2010b; Wallin et al. 2003), justifying the efforts of breeding organizations to organize distinct events for early and standardized testing. However, even in these tests the traditional evaluation systems use broad trait definitions and do not allow any inferences on certain movement characteristics. Furthermore, subjective scores on a 1-10 scale are used in all evaluation settings, and the insufficient use of the score scales is a problem that has been frequently discussed (Stock and Distl, 2006; Stock and Distl, 2007; Viklund et al., 2010). Specific movement characteristics are not documented systematically and therefore unavailable when selection decisions have to be made.

Only very few breeding organizations conduct Young Horse Tests for mares or stallions evaluating and scoring the gaits under two different evaluation conditions, during free movement (F) and under rider (R). Because of the standardized testing protocols and documentation of separate scores for the gaits without and with rider the data of the Mare Performance Test (MPT) conducted by the Oldenburg breeding societies were considered suitable for this study to analyze the rider's influence and investigate the correlations between free movement and movement under rider. Gait
evaluations without rider often refer to only walk and trot at hand, whereas MPT for the Oldenburg Warmblood considers all three gaits shown when the mares move loosely in the arena. F scores are accordingly characterized by the absence of any direct influence of the handler on the outcome of movement evaluation on the tested mares. Without question the effort of time is greater scoring horses free moving and under the rider, but the study results recommend the additional effort.

According to our results gait evaluation during free movement should allow better distinction between genetically favorable and unfavorable individuals than gait evaluation under the rider, particularly with regard to trot. Evaluation during free movement reflects the natural gait quality of the individual horse. Scores for walk, trot and canter showed clear differences between evaluation types with largest differences for trot, the gait which is known to be most influenced by the rider. Scores evaluated free showed less variation than the corresponding scores under rider. Heritabilities were higher for trot free than under rider, whereas \( h^2 \) for walk (F and R) and canter (F and R) were almost identical. In this study the F scores and R scores were closer correlated additive genetically than phenotypically. However, estimates of \( r_g = 0.7 \) to 0.9 clearly indicated that corresponding F and R scores do not resemble exchangeable measures of the same trait. For routine genetic evaluations across Warmblood breeds this has to be taken into account. Joint analyses of performance data based on overall gait scores without consideration of the evaluation type would create the loss of specificity or even bear the risk of biased results. Movements of a horse are directly influenced by the rider. A skillful rider certainly improves the movement qualities of a horse compared to a horse ridden by an inexperienced rider. Favorable movement under rider does not only reflect good abilities, but also a certain level of trust and cooperativeness. With increasing professionalism of horse training and riding sport, appropriate interpretation of gait scores may require taking the influence of the rider into account. This is currently done in the genetic evaluation for performance in sport, but not for performance test data.

Multivariate analyses revealed that R scores for the gaits were only moderately and not much closer correlated with rideability than the respective scores. Accordingly, rideability scores do obviously not reflect the better or worse ability of a
horse to move under rider. Because successful dressage horses have to be able to show their movement potential under rider, scoring of gaits under rider is and will be an integral part of performance tests. However, free movement may provide additional information that is relevant for breeding. Correlations between gaits and jumping depended on whether F scores or R scores were considered, and the same was surmised to be true for other traits, including certain movement characteristics.

The selection programs for German warmblood horses are currently based on subjective gait and conformation scores on a scale from 1 to 10, still the most common method of conformation and performance evaluation. Although slight differences in the trait definitions may exist between the breeding organizations, the standard set of traits evaluated has been unchanged in Germany for at least two decades. To better capture the variability in the population, splitting-up of the standard traits and descriptive scoring on linear scales have been recommended repeatedly, but have been introduced by very few horse breeding organizations yet: 1989 in the Royal Warmblood Studbook of the Netherlands (KWPN; Koenen et al. 1995), and 2003 in the studbook of the Belgian warmblood horse (BWP; Rustin et al. 2009). In this study new movement traits were defined on the basis of detailed movement evaluations (DME) traits, suitable to support rather than replace the routine evaluations of foals and mares, but nevertheless compatible with linear scoring.

Gait characteristics have moderate to highheritabilities and made remarkable breeding progress in the last decades possible (Viklund et al., 2010). However, improvement of certain gait characteristics indicative of gaits of high quality will probably require more specific trait definition (like stride length in trot, elasticity in trot) and replacement of the traditional subjective scale by an objective linear scale of scores. Although an objective scale should clearly allow more precise evaluation, benefits of linear scoring will only become visible and usable for selection, when the judges are trained to use the full scale (Koenen et al. 1995). Scores from sport performance are further considered for genetic evaluations, but preselection effects may influence the estimated breeding values for dressage or jumping performance. Horses, especially mares, intended for breeding purposes are not regularly seen in
riding sport. Additionally, sport scores are only available later in a horse's life, whereas foal data reduces the generation interval by providing early information. Therefore evaluation data from foals and broodmares appeared to be a suitable source of early and barely preselected information and was used in the context of this study.

Beside the advantage of getting information early, more than half of all foals born are presented at the foal shows. Currently the foal shows are primarily used to register the foals and to get some early impression of the progeny of young stallions. Therefore, large numbers of foals can easily be evaluated under rather standardized conditions. The foals are presented on their dam's side, so simultaneous evaluation of active broodmares may be an option as well. Furthermore, evaluations of active broodmares will make it possible to perform repeatability analyses of the new movement traits. Suontama et al. (2011) showed for Finnhorse and Standardbred trotters that subjectively scored conformation traits are moderately heritable in foals ($h^2=0.1-0.5$) and mares ($h^2=0.1-0.8$). Further they found additive genetic correlations of 0.6-1.0 between analogous foal and mare traits, implying usability of foal data for breeding purposes. Given the additive genetic correlations we found for unfavorable movement characteristics we came to the same conclusion. Horse breeding may benefit from using detailed movement evaluations obtained in foals as an early source of information on movement.

Despite existing selection programs and the general breeding progress minor findings indicating incoordination or impaired balance of different severity were found in 6.2% of the foals and 5.5% of the mares, respectively presented at foal shows and studbook inspections of the Oldenburg breeding societies. Relevant influence of genetic factors on the distributions of imbalance signs could be determined for both age groups. In the literature, signs corresponding to disorders in hind legs or in the general motion pattern are considered indicative of impaired balance and coordination of horses of different ages (Van Biervliet, 2007). These more severe findings of imbalance were less often documented than changes in the posture or tone of the tail. However, horses affected by more severe findings were often seen in combination with at least one other indication of imbalance, particularly findings in the
tail, and genetic correlation between findings in the tail and more severe findings are significantly positive. Neck and tail are considered most important for balancing the horse’s body during movement (Moore, 2010). Abnormal positions of the neck or head were hardly seen in the foals and mares, but findings in the tail were seen in almost every 20th horse. Analyzing variances for mares with detailed movement evaluations and studbook inspection (SBI) records and mares with MPT records revealed positive genetic correlations between dressage related characteristics and unfavorable movements. Selection for favorable movements based on the currently used trait scores and without consideration of specific movement information may thus lead to an increase of unfavorable movement characteristics. Absence of significant differences between the SBI trait correctness of gaits and indications of imbalance and the tendency to even higher scoring of imbalance-positive mares in MPT trait trot under rider indicated that the current definitions of gait traits do not cope with all movement characteristics seen in the presented mares. Furthermore, significantly positive correlations between breeding values (BV) for IMB and TTP on the one hand and dressage-related SBI and MPT traits on the other hand. The results of this study may be interpreted as a hint towards some limit of balancing capacities which may have been reached in dressage horse breeding. Because of the fundamental role of the equine back for locomotion, any structural and functional changes in the back are likely to affect the general motion pattern of the horse, including its coordination abilities (Van Weeren et al., 2010). Conformational characteristics favorable for a dressage horse, like a rectangle frame (facilitating swinging of the back) with a relatively short neck (facilitating elevation), may in connection with the aptitude to move with much expression overstrain the mechanisms of coordination. Selection of dressage horses for better scores in SBI and MPT and without consideration of DME information will therefore bear the risk of increasing prevalences of indications of imbalance in future generations.

According to the results of the study, selection against unfavorable movement characteristics is possible in the warmblood horse. Heritabilities of 0.40-0.46 in the foals and 0.18-0.21 in the mares indicate the relevance of genetic factors for the development of unfavorable movement characteristics in both age groups and imply
that information from detailed movement evaluations may be used for breeding purposes. Positive genetic correlations between the different indications of imbalance in foals and mares will facilitate their simultaneous reduction.

Given the positive genetic correlations we found between dressage and unfavorable movement characteristics, extension of detailed movement evaluations is recommended to enable considering unfavorable movement characteristics when making breeding decisions. Warmblood riding horses showing indications of imbalance during free movement may not necessarily perform worse under rider than unaffected horses at young age. However, long-term effects of these conditions in warmblood riding horses are unknown so far. Detailed movement evaluations of foals and mares will provide a suitable basis for further correlation analyses between unfavorable movement characteristics and performance on different levels and in different disciplines of sport.

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Chapter 7
Chapter 7 (Summary)

7 Summary

Genetic analyses of movement traits in German warmblood horses

Ann-Christin Becker

The breeding goals of warmblood horses today focus on the performance in riding sport and quality of gaits has considerable impact on the value of a horse. Regardless of the intended use of the horse, correct gaits and balanced movement belong to the most important and basic qualities of a riding horse. Findings indicating incoordination or impaired balance were rarely, but regularly seen in horses of different ages in the context of breeding events of the Oldenburg breeding societies. The standard evaluation and selection procedures which are based on subjective scorings of rather generally defined traits were obviously not suitable to eliminate certain unfavorable movement characteristics. Knowledge on prevalences and distributions was needed to answer the question of the possible role of genetic factors. Detailed movement evaluations of foals and mares were used to define and analyze new movement traits, which may serve as measures of impaired balance. Furthermore investigations were undertaken analyzing the correlations between the new assessed movement traits and the standard conformation and performance traits routinely assessed during studbook inspections and mare performance tests in the field.

Performance information on 2,758 mares, mostly 3-4 years-olds that had completed mare performance tests (MPT) was used for genetic analyses focusing on options to improve existing breeding programs through refined trait definition. For all mares, scores on a scale from 1 to 10 were available for walk, trot, canter, rideability, and free jumping, with gait scores representing means from evaluation during free movement (F) and under rider (R). Distinct F and R gait scores were used to investigate the effect of evaluation type on variance components. Genetic parameters were estimated with residual maximum likelihood (REML) in multivariate linear animal models. Heritability
estimates for the MPT traits ranged from 0.19 (rideability) to 0.57 (free-jumping). For the gaits heritabilities were similar (canter) or higher (walk, trot) for F scores than for corresponding R scores. The correlations between F and R scores for the same gait were found to be closer additive genetically \( r_g = 0.7-0.9 \) than phenotypically \( r_p = 0.4-0.6 \), but may indicate F and R scores may not represent exchangeable measures of the same trait. Further correlation analyses revealed moderately to highly positive additive genetic correlations between gaits and rideability for both F and R scores, whereas additive genetic correlations between walk and canter and between trot and free jumping was relevantly dependent on evaluation type. Because selection of riding horses represents multiple-trait selection, better reflection of covariances between selection traits will help maximizing the overall breeding progress. According to our results, Warmblood breeding may therefore benefit from refinement of trait definition with clear distinction between gait evaluation during free movement and under rider.

For defining new movement traits detailed movement evaluations of 3,374 warmblood foals and 2,844 mares were further performed in connection with regular breeding events of the Oldenburg horse breeding societies in 2009 and 2010. Unfavorable movement characteristics considered indicative for impaired balance were noted by a special judge (SJ) and the regular judges of the breeding events (RJ) and served as the basis for definition of new movement traits. Detailed movement information showed that more severe findings like irregular motion pattern in hind legs (HM) or irregularity in general motion pattern (GM) occurred only sporadically (prevalences of 1-2%). Irregular tail tone or posture (TTP) was documented for 4% of the foals and 5% of the mares, resulting in prevalences of the comprehensive trait indications of imbalance (IMB) of 6.2% (foals) and 5.5% (mares). Binary coding was used for all traits, and genetic parameters were estimated bivariately in linear animal models with residual maximum likelihood (REML). Comparative analyses between judges revealed that differences between trait definitions of SJ and RJ were larger in the mares than in the foals, but justified combined use of SJ and RJ information in both age groups. Heritability estimates for the movement traits ranged on the original scale from 0.02 to 0.26 in the
foals and from 0.03 to 0.12 in the mares, with heritabilities for IMB on the underlying liability scale of 0.46 (foals) and 0.22 (mares). Comparative analyses between age groups indicated that common genetic factors may be responsible for findings of impaired balance in foals and mares.

Information on the new movement traits reflecting unfavorable movement characteristics for 3,374 foals and 2,844 mares was used for correlation analyses with conformation information on 1,987 mares from studbook inspections (SBI) in 2009 and performance information on 2,758 mares from mare performance tests (MPT) in 2000-2008. Analyses of variance revealed few significant differences between scores for SBI and MPT traits in mares without and with indications of imbalance (IMB) in general or specific findings like irregular tail tone or posture (TTP). SBI scores for general impression and development were significantly lower and MPT scores for trot under rider tended to be higher in IMB-positive mares. Genetic parameters were estimated in linear animal models with residual maximum likelihood (REML). Additive genetic correlations and Pearson correlation coefficients between univariately predicted breeding values indicated unfavorable genetic correlations of IMB and TTP with dressage related conformation and performance traits. For SBI and MPT traits we found similarities between the correlation patterns for DME traits in foals and mares. The results implied that breeding of dressage horses may benefit from revision of current movement evaluation and consideration of specific movement characteristics.
Chapter 8
8 Zusammenfassung

Genetische Analyse von Bewegungsmerkmalen beim Deutschen Warmblut

Ann-Christin Becker


Im Rahmen der Zuchtveranstaltungen des Verbandes der Züchter des Oldenburger Pferdes e.V. (OL) und des Springpferdezuchtverbandes Oldenburg International e.V. (OS) wurden Hinweise auf Koordinations- und Balancestörungen bei vereinzelten Pferden selten, aber recht regelmäßig gesehen. Die im Rahmen dieser Veranstaltungen routinemäßig erfassten Merkmale, die unter anderem die Grundlage für Zuchtentscheidung und Selektion darstellen, sind offenbar in Anzahl oder Detailliertheit nicht ausreichend, diese unerwünschten Bewegungsmerkmale zu erfassen und züchterisch zu berücksichtigen. Um sich diesem Problem und der Thematik zu nähern war es erst einmal nötig Informationen über Prävalenzen und Verteilungen dieser

Informationen zu Ergebnissen der Stutenleistungsprüfungen lagen für 2758 Stuten vor. Die Mehrheit dieser Stuten war zum Zeitpunkt der Stutenleistungsprüfung zwischen 3 und 4 Jahren alt. Diese Daten wurden für genetische Analysen genutzt, welche sich auf Möglichkeiten die bestehenden Zuchtprogramme auf Grundlage der verfeinerten Merkmalsdefinitionen zu verbessern konzentrierte. Die Grundgangarten Schritt, Trab, Galopp sowie Rittigkeit und Freispringen wurden auf einer Skala von 1 bis 10 beurteilt. Die Grundgangarten wurden zunächst jeweils frei (F) und unter dem Reiter (R) vorgestellt und beurteilt, die Wertnote ergab sich dann aus dem Mittelwert der beiden Einzelnoten. Die Einzelnoten der Grundgangarten (jeweils F oder R) wurden genutzt um die Effekte der Art der Vorstellung des Pferdes auf die Varianzkomponenten zu ermitteln. Die genetischen Parameter wurden mittels REML (residual maximum likelihood) im multivariaten linearen Tiermodell geschätzt. Die Heritabilitäten der Stutenleistungsprüfungsmerkmale befanden sich im Bereich 0.19 für das Merkmal Rittigkeit bis 0.57 für das Merkmal Freispringen. Die Heritabilitäten der Grundgangarten waren ähnlich für die Gangart Galopp und sogar höher für die F Merkmale Schritt und Trab im Vergleich zu den R Merkmalen. Die Korrelationen zwischen den F und R
Wertnoten für die jeweilige selbe Gangart war additiv-genetisch näher \((r_g = 0.7-0.9)\) als phänotypisch \((r_p = 0.4-0.6)\), möglicherweise darauf hinweisend, dass die F und R Noten nicht ein austauschbares Maß für dasselbe Merkmal darstellen. Weitere Korrelationsanalysen ergaben moderate bis hohe additiv-genetische Korrelationen zwischen den Grundgangarten (F sowie R) und dem Merkmal Rittigkeit, wohingegen additiv-genetische Korrelationen zwischen Schritt und Galopp und zwischen Trab und Freispringen abhängig vom Beurteilungstyp waren. Da die Selektion zur Züchtung eines Reitpferdes auf mehreren Merkmalen basiert, wird eine vollständigere Reflektion der Kovarianzen zwischen Selektionsmerkmalen den generellen Zuchtfortschritt maximieren. Den Ergebnissen der Studie nach zu urteilen, würde die Warmblutpferdezucht von einer Verfeinerung der Definition der beurteilten Merkmale mit einer klaren Trennung zwischen der Beurteilung frei und der Beurteilung unter dem Reiter profitieren.

(REML) geschätzt. Vergleichende Analysen zwischen den Beurteilern (SJ oder RJ) ergaben, dass Unterschiede zwischen den Merkmalsdefinitionen von SJ und RJ in den Stuten größer als in den Fohlen war, rechtfertigten aber dennoch eine kombinierte Nutzung der SJ sowie RJ Informationen in beiden Altersgruppen. Die Schätzungen der Heritabilitäten für die Gangmerkmale lagen auf der originären Skala zwischen 0.02 und 0.26 bei den Fohlen und zwischen 0.03 und 0.12 bei den Stuten, die Heritabilität für IMB auf der zugrunde liegenden Skala lag bei 0.46 (Fohlen) und 0.22 (Stuten).


Bewegungsauffälligkeiten ergaben, dass Stuten, die von schwereren Anzeichen von Imbalance betroffen waren niedrigere Schätzwerte (Least Square Means, LSM) in allen SBI Merkmalen aufwiesen als die nicht Auffälligen. Stuten die TTP oder IMB Merkmale zeigten, hatten ebenso niedrige LSM der SBI Merkmale, mit Ausnahme der Merkmale Kopf, Hals und Sattellage. Allerdings waren die Unterschiede in vielen Fällen nicht signifikant, besonders nicht für IMB und TTP. Die LSM der MPT Ergebnissen der Stuten betroffen von TTP und IMB ergaben kaum Unterschiede zu den nicht betroffenen Stuten, in nur 3 von 8 MPT Merkmalen hatten die Unauffälligen größere LSM als die Auffälligen. Genetische Analysen der MPT Merkmale ergaben niedrige bis moderate Schätzungen der Heritabilität für die SBI Merkmale und moderate Heritabilitäten für Rittigkeit, Gangmerkmale und Freispringen. Die Heritabilitäten für SBI und MPT Merkmale geschätzt in univariater sowie bivariater Analyse mit Merkmalen der detaillierten Bewegungsbeurteilungen (DME) waren sehr ähnlich. Die additiv-genetischen Korrelationen zwischen SBI und MPT lagen meistens zwischen -0.1 und 0.9, waren in vielen Fällen aber mit hohen Standardfehlern behaftet. Anzeichen für negative genetische Korrelationen mit IMB und TTP in Fohlen und Stuten wurden ausschließlich für das MPT Merkmal Freispringen gefunden. Die phänotypischen Korrelationen der detaillierten Bewegungsbeurteilungsmerkmale mit SBI und MPT Merkmalen waren niedrig. Der Pearson Korrelationskoefﬁzient zwischen univariat bestimmten Zuchtwerten für DME, SBI und MT Merkmale ergab konsistente Ergebnisse zwischen den Fohlendaten (-0.24 bis 0.26) und den Stutendaten (-0.41 bis 0.43). Signifikant positive Zuchtwertkorrelationen mit $r > 0.3$ mit IMB und MPT ergaben sich für Schwung und Elastizität, Schritt frei, Schritt unter dem Reiter, Trab frei, Trab unter dem Reiter und Rittigkeit. In Hinblick auf die gefundenen positiven genetischen Korrelationen zwischen Dressur-assoziierten Merkmalen und Bewegungsauffälligkeiten wird die Erweiterung der Standardbeurteilungsmerkmale um die DME empfohlen. Diese unerwünschten Merkmale können so differenziert betrachtet und in zukünftigen Zuchttentscheidungen berücksichtigt werden. Die Ergebnisse zeigten auch, dass junge Reitpferde, die Anzeichen von Bewegungsauffälligkeiten in der freien Bewegung
Chapter 9
Chapter 9 (List of publications)

9 List of publications

Journal articles


Oral presentations


Ann-Christin Becker, Kathrin Friederike Stock, Ottmar Distl (2010) Usability of detailed information on movement characteristics of mares and foals for breeding purposes in the German Warmblood horse. 61th Annual meeting of the EAAP, 23 to 27 August 2010 in Heraklion, Greece

Ann-Christin Becker, Kathrin Friederike Stock, Ottmar Distl (2011) Genetic Analysis of movement traits in German Warmblood horses. 62th Annual meeting of the EAAP, 29th of August to 2nd of September in Stavanger, Norway
Chapter 10
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