# Orthopaedic Health, Conformation and Longevity in Riding Horses

*- a genetic and phenotypic study*

Lina Jönsson
*Faculty of Veterinary Medicine and Animal Science*
*Department of Animal Breeding and Genetics*
*Uppsala*

Doctoral Thesis
Swedish University of Agricultural Sciences
Uppsala 2013

Acta Universitatis agriculturae Sueciae
2013:59

*Illustrations incl. cover picture: Staffan Philipsson*

ISSN 1652-6880
ISBN (Print version) 978-91-576-7856-0
ISBN (Electronic version) 978-91-576-7856-7

Print: SLU Service/Repro, Uppsala 2013

Orthopaedic Health, Conformation and Longevity in Riding Horses
*– a genetic and phenotypic study*


## Abstract

Soundness and longevity of the riding horse play a central role for animal welfare, sport performance and horse owner economy. Routine registration of health traits in horses is rare. Thus, knowledge of genetic variation in health of horses and long term effects on longevity is scarce. The major aims of this thesis were to estimate prevalence and heritability of orthopaedic health findings, and genetic and phenotypic relationships between orthopaedic health, conformation and longevity in the Swedish warmblood horse. The included studies I-IV were based on standardised documentation of health and conformation at the Riding Horse Quality Test (RHQT) of 8238 tested 4-5-year-old horses, participating during 1983-2005. Longevity was measured as number of years in competition (NYC), and lifetime performance results from official competitions (LPERF) during 1983-2012. Results show that conformation significantly influences health status of the horse, and that both health and conformation of the young horse influence future longevity and success in competition, both phenotypically and genetically. Longevity was generally better in horses with good young horse health regarding palpatory orthopaedic health, locomotion, hooves and assessed overall orthopaedic health. Effusions were the most common clinical health finding, whereas severe acute findings were relatively rare. Horses with flexion test reactions had significantly lower chances of competing later in life compared to horses without reactions. Regarding conformation, intermediate sized horses with high scores for type and head-neck-body conformation, light front and correct movements in trot at hand were found most important. Also, the assessed talent of a young horse was influenced by the health and conformation, both for dressage and jumping. Good health was genetically correlated with better longevity at a level of 0.3, with similar correlations between high conformation scores and longevity. Heritabilities of palpatory orthopaedic health and hooves were estimated at 0.10-0.14, and between 0.20-0.36 for overall conformation traits, except for limbs at 0.06. Considerable genetic variation of conformation and to some extent of health, and generally favourable associations between health, conformation, longevity and performance, suggest possibilities to improve health traits if considered in breeding.



*Keywords:* Orthopaedic health, conformation, limb deviations, longevity, genetic evaluation, correlations, horse breeding, heritability



*Author's address:* Lina Jönsson, SLU, Department of Animal Breeding and Genetics, P.O. Box 7023, SE-750 07 Uppsala, Sweden
*E-mail:* Lina.Jonsson@slu.se

# Contents

# List of Publications

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

I Jönsson, L., Roepstorff, L., Egenvall, A., Näsholm, A., Dalin, G. and Philipsson, J. (2013) Prevalence of clinical findings at examinations of young Swedish warmblood riding horses. *Acta Vet Scand.* 55:34, doi:10.1186/1751-0147-55-34.

II Jönsson, L., Näsholm, A., Roepstorff, L., Egenvall, A., Dalin, G. and Philipsson, J. (2013) Genetic analysis of clinical findings at health examinations of young Swedish warmblood riding horses. *Acta Vet Scand.* 55:22, doi:10.1186/1751-0147-55-22

III Jönsson, L., Näsholm, A., Roepstorff, L., Egenvall, A., Dalin, G. and Philipsson, J. Conformation traits and their genetic and phenotypic associations with health status in young Swedish warmblood riding horses. Submitted

IV Jönsson, L., Egenvall, A., Roepstorff, L., Näsholm, A., Dalin, G. and Philipsson, J. Health status and conformation of young Swedish warmblood riding horses – associations to longevity and lifetime competition performance. Submitted

# Abbreviations

| | |
|---|---|
| BLUP | Best linear unbiased prediction |
| DWB | Danish Warmblood |
| EBV | Estimated breeding values |
| H1 | Overall score, health examination 1 (medical health and hooves) |
| H2 | Overall score, health examination 2 (orthopaedic) |
| HOOF | Hoof examination |
| KWPN | Studbook of warmblood riding horse in the Netherlands |
| LOCO | Locomotion examination |
| LPERF | Lifetime performance in competition |
| NYC | Number of years in competition |
| OC | Osteochondrosis |
| OCD | Osteochondrosis dissecans (osseous fragments) |
| PALP | Palpatory orthopaedic health |
| POF | Palmar/plantar osseous fragment in fetlock |
| RHQT | Riding horse quality test |
| SWB | Swedish Warmblood |

# 1 Introduction

Soundness and longevity of the riding horse play an important role in the use of the horse as it affects animal welfare, sport performance and horse owner economy. A high proportion of culled riding horses, 50-70%, are culled because of musculoskeletal lesions (Sloet van Oldruitenborgh-Oosterbaan *et al.*, 2010; Egenvall *et al.*, 2006b; Wallin *et al.*, 2000). The same applies for insurance claim statistics of veterinary care (Egenvall *et al.*, 2006a). Further, 60% of former auction horses in Germany have shown lameness causing a substantial interruption in training in the years following the auction (Stock & Distl, 2005; Clausen *et al.*, 1990). Potential horse buyers of today have become cautious regarding the health status of the horse, where health is considered the most important feature compared to talent or pedigree (Hennessy *et al.*, 2008). However, the number of large scale studies of overall population health in horses is very limited due to a worldwide lack of central documentation of health traits in horses. Thus, the scientifically based knowledge of prevalence and heritability of health traits in normal horse populations is limited, as well as the knowledge of how each lesion affects future longevity and the functionality of the horse. Thus, practice has merely been based on the collective experiences among practitioners and judges of horses, accompanied by a limited amount of scientific studies.

The lack of documentation of health traits also applies to most of the European warmblood breeding associations of today, in contrast to performance traits that are routinely documented. As a result, consideration of soundness in genetic evaluations is generally absent, despite inclusion in the stated breeding goal of several breeds (Koenen *et al.*, 2004). During 1973-2005, health status of the Swedish warmblood (SWB) has been documented in a standardised and large scale manner, during the Riding Horse Quality Test (RHQT) of 4-5-year-old horses. The vast majority of these health recordings have not been digitally available, and evaluation of heritability of health traits and correlations to conformation, talent and future longevity has not been possible. After recent digitisation, this information has now become available for analysis.

# 2 Background

A prerequisite for analyses of conformation, performance and health traits for their prevalence, heritability and functionality of the horse, is to have consistent data of standardised large scale routine registrations available. Such recordings have, as a world unique opportunity, been kept in many years for young horses that have participated in the RHQT in Sweden.

## 2.1 The Riding Horse Quality Test (RHQT)

In 1973 the RHQT was introduced in Sweden. One purpose with the test was to provide standardised young horse information on a broad range of traits that could be used in searching talents for the sport, and to get data for scientific purposes and for estimation of breeding values. Another purpose was to provide an opportunity for evaluation of the training status and health of the young horses, accompanied with advice for the continued training of the horse, as well as being a marketing opportunity (Darenius *et al.*, 1983). The test was conducted as a one day field test for 4-year-old riding horses of both genders and 5-year-old mares that had a foal the previous year. During 1973-2005 horses were examined at five independent stations for:

- Medical health and hooves (H1)
- Orthopaedic health (H2), including palpatory orthopaedic health (PALP) and locomotion including flexion tests (LOCO)
- Conformation including gaits at hand
- Talent for dressage including gaits under rider and rideability
- Talent for jumping under rider or free jumping

Overall scores of health, conformation and talent were given on a 1-10 scale. Data including these scores and identity of the horses have been digitally available since the start of the RHQT. Additionally, descriptive information of specific health traits

were recorded on a 0-3 scale (no, minor, moderate or severe) of clinical health findings, and specific conformation and talent traits were noted as present/absent. This information has not been available in digital format until the present studies were conducted. The events are arranged annually at about 20 locations throughout the country, and the test requires no prior qualifications other than being broken-in and trained appropriately for the age. As all participating horses are tested both for jumping and dressage talents, results provide an overall picture of the status of the population. Annually, about 20-30% of available 4-year-old SWBs has participated in the RHQT. Horses are expected to be fairly unselected regarding talent and health, although worst cases, especially of impaired health, will not show up. According to a survey among horse owners, the inclusion of a health control in the RHQT has been found the most valuable part of the test (Eliasson, 1997). With such an examination, owners obtain information about the health status of their horse by independent veterinarians, and the results of the examination are recognised at sales of horses. The assessments of talents for dressage and jumping add further value to the RHQT system of evaluating young horses for the sport.

The long-term consistency in large-scale recording of conformation and performance traits of the RHQT has over the years allowed extensive scientific studies, e.g. three PhD theses by Wallin (2001), Thorén Hellsten (2008) and Viklund (2010). Results have advised on the continuous development of judging regimes for performance testing of sport horse stallions in Sweden and for development of genetic evaluation and monitoring genetic trends of the SWB.

## 2.2 The SWB breeding goal

The stated breeding goal of the SWB is to produce *'A noble and correct horse with good longevity that by its temperament, rideability and good movements and/or jumping ability is internationally competitive'* (Swedish Warmblood Association, 2013a). Performance of riding horses has been the main selection criterion in recent decades of SWB breeding. It has mainly been based on young horse RHQT information, and lately also on competition results, where large improvements have been achieved (Viklund et al., 2011). Today, the general quality of produced horses, regarding talents for sport, is often high. Less emphasis has been given to the part of the goal regarding health and longevity, which according to market surveys may be today´s largest challenge in producing horses that are attractive on the market (Jönsson, 2006). In order to consider health status it is also important to evaluate possible associations between conformation of the horse and its health status and longevity. Thus, the present thesis has three areas of main focus: conformation, orthopaedic health and longevity, and their interrelationships.

## 2.3 Conformation

### 2.3.1 Role of conformation

Conformation of horses has traditionally been an important part of the breeding goal, where selection mainly has been based on anecdotal practical experience (Beeman, 1973; Wrangel, 1887). It was early suggested that the proportions and relative angles between parts of the equine conformation would be important for the usability of the horse. Also, it was suggested that a horse that was rectangular, thus slightly longer from chest to tail than the withers height, would be preferred.

Conformation may be assessed in different ways and the desired conformation may even differ between studbooks of the same breed or strains of sport horses. In most cases assessment scores are set for traits considered of major importance, e.g. type, limb conformation and movements when shown at hand. In addition to these scores, efforts for a harmonised implementation of linear descriptions of specific traits, on a continuous scale between two biological extremes, are currently made in a number of warmblood populations, including the SWB, as an Interstallion cooperation project (Interstallion, 2011). These linear descriptions include a large number of specific traits, similar to the regime used in the Dutch (KWPN) and Belgian Warmbloods for several years, as a complement to the assessment scores.

In Sweden systematic recording of conformation scores started with the introduction of RHQT in 1973 (Darenius *et al.*, 1983). Conformation of SWB horses at the RHQT is evaluated using five overall scores for type, head-neck-body, limb conformation, movements in walk at hand and in trot at hand. For each score, descriptive information of specific traits anticipated to be important is recorded as present/absent, as further described in Paper III. Type mainly includes descriptions of proportionality of the horses regarding height, length and heaviness/lightness. Head-neck-body generally concerns position and length of neck, shoulder, back and croup. Limb conformation concerns angles, joints and correctness of the development of limbs (see '*Limb deviations*' below). Movements in walk and trot at hand are assessed for the correctness and action of movements, described as e.g. winging, paddling, ground covering ability, free/stiff movements, rhythm and hindlimb activity. For an illustration of conformation nomenclature, see Figure 1.

In a study of the SWB (n=1815) a high total sum of the five overall conformation scores have represented horses with a significantly lower risk of future early culling (Wallin *et al.*, 2001). Further, long necks have been found associated to high scores for movements during the conformation examination, where high scores for movements in turn were favourably associated to the overall orthopaedic health (n=195) (Holmström & Philipsson, 1993). Also, a significant relationship between a steep slope of the shoulder and impaired orthopaedic health

status was found. In another study of SWBs (n=636), slightly sloping shoulders were more common in elite dressage and jumping horses, compared to general riding horses that had straighter shoulders (Holmström *et al.*, 1990). A long neck, a long slightly sloping shoulder and a sloping long croup have also been found significantly correlated to good dressage performance in the KWPN (Koenen *et al.*, 1995). In the same study well developed muscles of the neck and haunches, and a slightly sloping croup were significantly correlated to show jumping performance. No large differences in favourable conformation between the disciplines were found.

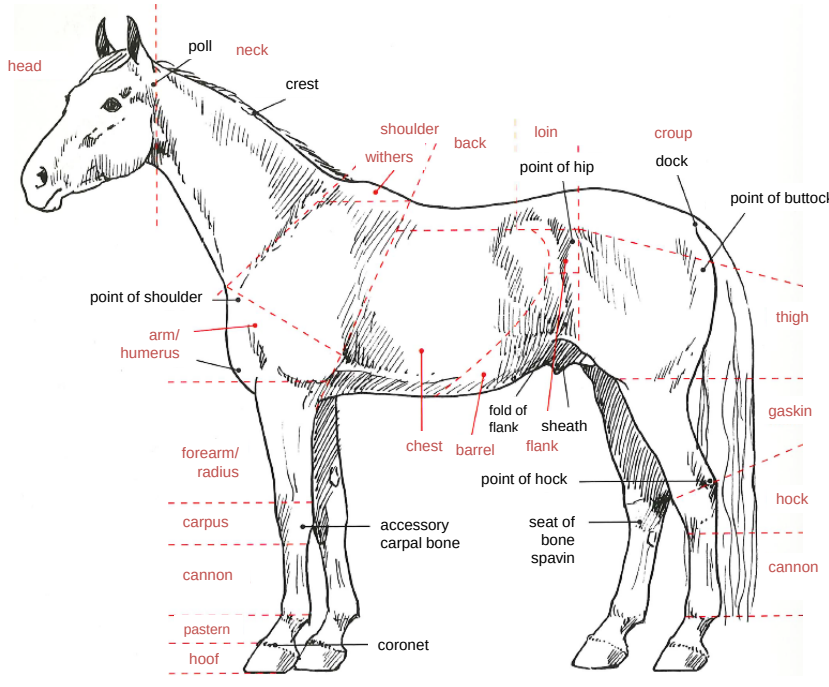



*Figure 1.* Overview of conformation nomenclature of the horse. Exact positions given in black and conformational areas given in red, between red lines.

Especially in dressage horses it has traditionally been considered important to have a good conformation for best quality of gaits, whereas conformation in show jumpers has not been considered as important. In the SWB the genetic correlation between conformation and success in dressage competitions has been estimated to 0.17-0.65, and regarding jumping performance to 0.22-0.24 (Viklund *et al.*, 2010). Similar results have been found in the KWPN population at 0.67 for conformation-dressage and 0.29 for conformation-jumping (Ducro *et al.*, 2007). This implies that conformation is more associated to dressage performance, but that it is also important for show jumpers.

*Limb conformation*

Traditional evaluations of conformation have put much emphasis on the correctness of the limbs (Wrangel, 1887). The reason is logical as the deviations from straight or "normal" angles are thought to put excessive strain on the joints (Denoix, 1999). During the examination of limb conformation, fore- and hindlimbs are examined from the side, front and the behind, standing still and during movement. The deviations that are recorded at the RHQT for fore- and hindlimbs are found in Figure 2 and 3, respectively. In forelimbs, the main focus is on deviations that are detected from the front, with focus on angles in, and spaces between forelimbs. According to practical experience paddling movements are often seen in horses with toed-in forelimb conformation or parallel displaced cannons, whereas winging is considered to relate to toed-out forelimb conformation (Magnusson, 2006). The difference in toed-out and outward rotated forelimbs is whether the deviation is seen only from the fetlock and down with a broken angle in the fetlock (toed-out), or if the whole limb is outward rotated (Magnusson, 2006).

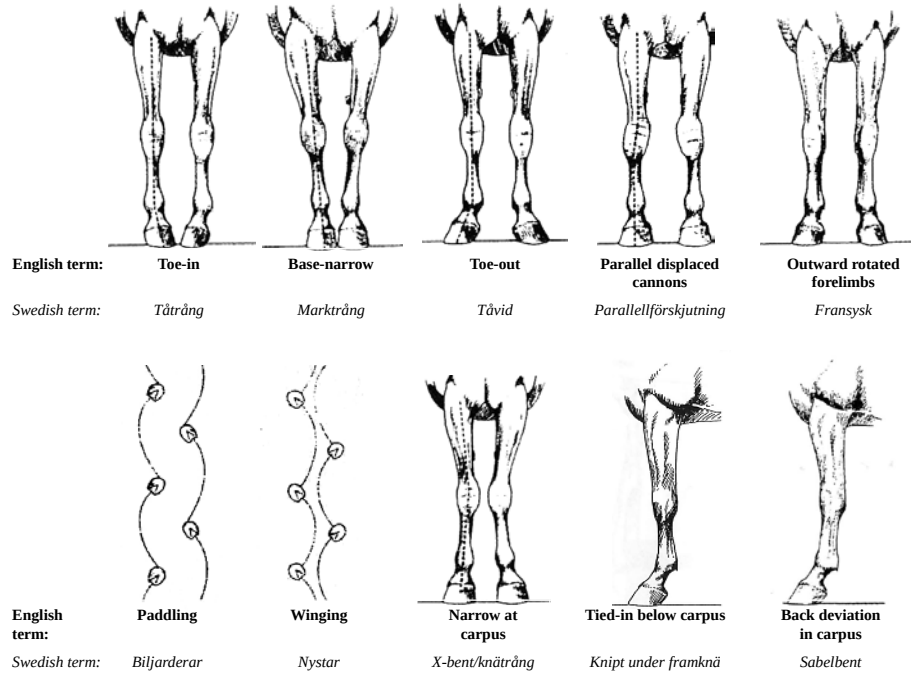



*Figure 2*. Limb deviations examined for in forelimbs, including deviations in movement patterns

In hindlimbs most examined deviations relates to hock conformation, evaluated from behind and from the side. From behind the width between the hocks is described, in addition to descriptions if the horse is base-narrow/wide, or toed-out. From the side, the hock is examined for hock angle and circumference of the cannon just below the hock. Earlier results have found a hock angle of 155.5-165.5$^0$ to be optimal for vertical impulse of upward and forward movements (Gnagey *et al.*, 2006), and a hock angle within the previous range, at 159$^0$, to be most common in elite horses (Holmström *et al.*, 1990). Both too large and too small hock angles are thought to be unfavourable. According to Magnusson *et al.* (1985b), Standardbred trotters with small hock angles are associated with significantly more effusions in the stifle and hock joints.

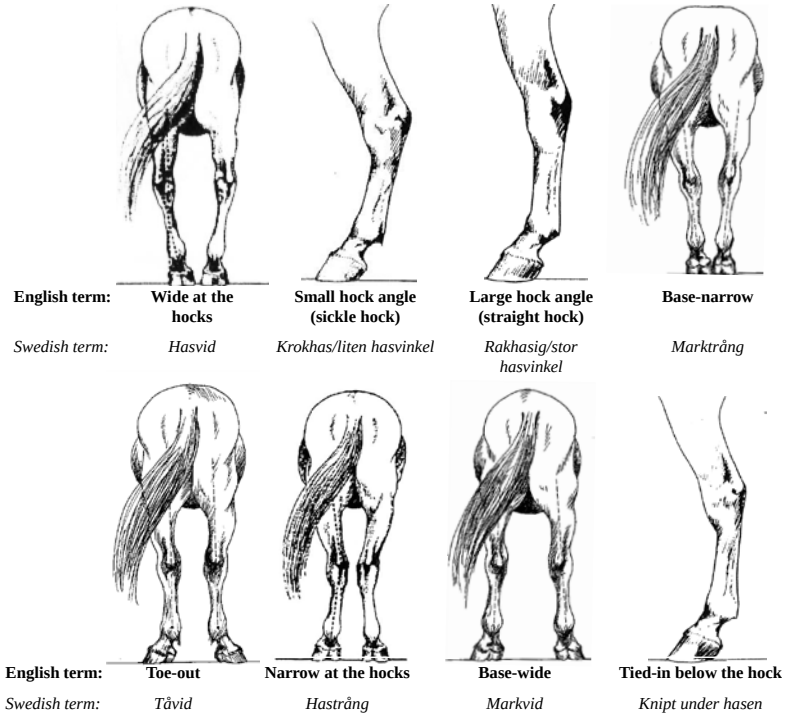



*Figure 3.* Limb deviations examined for in hindlimbs.

At the conformation examination, joints, pasterns and hooves are also evaluated for length, angle, size and shape as illustrated in Figure 4. For these characteristics horses are evaluated jointly for both fore- and hindlimbs at the RHQT evaluations. In addition to hoof characteristics illustrated in Figure 4, that are based on observations from a distance on soft ground surface, hooves are also examined more extensively during the RHQT health examinations. The importance of good hoof shape and size has been shown both for riding horses and trotters. In the KWPN population, uneven feet significantly shortened the career of elite show jumping horses (Ducro *et al.*, 2009b). For Standardbred trotters, normal sized hooves were favourable for a good orthopaedic health, whereas narrow hooves had a negative influence (Magnusson & Thafvelin, 1985b). Low heels have been suggested to give more injuries to the deep digital flexor tendon in a study of 179 horses (Holroyd *et al.*, 2012). Further, stiff pasterns (a large fetlock angle) in forelimbs of Standardbred trotters have been related to swelling of the superficial flexor tendon (Magnusson & Thafvelin, 1985b).

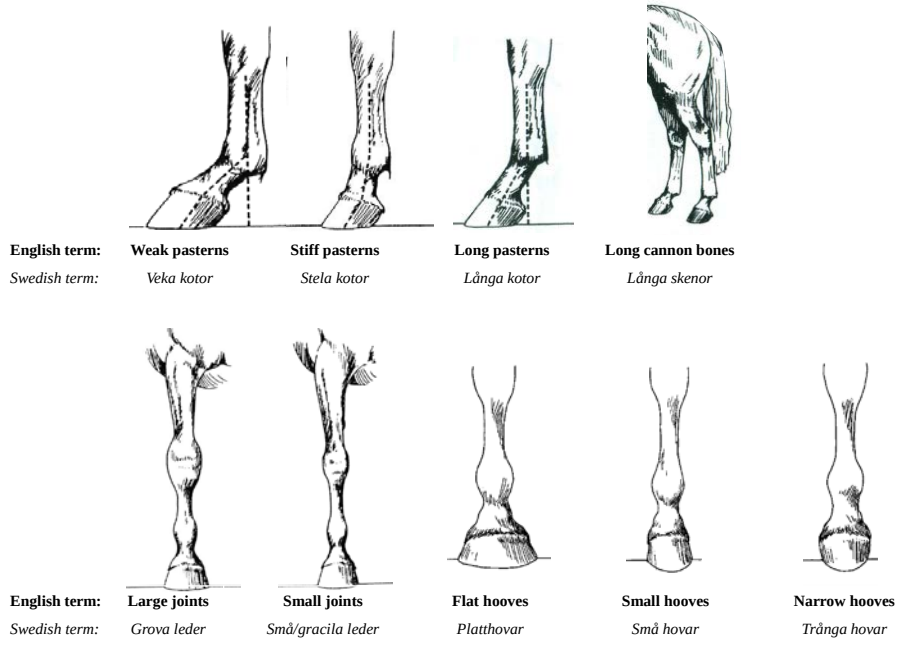



*Figure 4.* Deviations examined for in joints, pasterns and hooves.

Most limb deviations are thought to be negative for health and performance, with the possible exception of outward rotated limbs, which have been found to associate to better race performance in Standardbred trotters (Thafvelin & Magnusson, 1985). In SWBs a low overall score of limbs has been found to significantly increase the risk of early culling (Wallin *et al.*, 2001). However, no analysis of the underlying specific limb deviations causing culling was done in that study. Also in Thoroughbreds, limb deviations such as narrow forelimb conformation, long pasterns and offset knees have been associated to impaired health, although there are some discrepancies in results between studies (n=108/115) (Weller *et al.*, 2006; Anderson *et al.*, 2004). Thoroughbreds with limb deviations also have been found to race less as 2-year-olds compared to horses without limb deviations, but with no significant difference in lifetime performance (n=3916) (Love *et al.*, 2006).

*Size measures*

Withers height and cannon bone circumference just below carpus are measured and considered during the conformation evaluation. In the KWPN population, the tallest horses were found to be at highest risk of culling from basic jumping and dressage, when dividing horses into quartiles for withers height, but with no negative effects for the smallest horses (Ducro *et al.*, 2009b). In Standardbred trotters intermediate sized horses have been found most favourable for orthopaedic health (Magnusson & Thafvelin, 1985b).

### 2.3.2 Heritability and genetic evaluation

In order for a trait to be changed by selection, considerable genetic variation is advantageous. The heritability of overall scores for conformation in the SWB has previously been estimated to 0.24-0.41 for type, head-neck-body, walk at hand and trot at hand, and to 0.08 for limb conformation (Viklund *et al.*, 2008). Similar heritabilities have been found for conformation (except for limbs) in other warmblood populations at 0.35-0.45 in the Danish warmblood (DWB) (Thorén Hellsten *et al.*, 2009), 0.15-0.55 in German and Belgian warmbloods (Schöpke, 2011; Rustin *et al.*, 2009), and 0.12-0.30 in the KWPN population (Ducro *et al.*, 2009a; Koenen *et al.*, 1995). Regarding limbs, heritabilities have generally been found to be slightly higher in other populations than the SWB, at 0.20 in the DWB (Thorén Hellsten *et al.*, 2009), 0.22-0.35 in Hungarian and Belgian warmbloods (Posta *et al.*, 2009; Rustin *et al.*, 2009), 0.09-0.11 in the German Warmblood (Stock & Distl, 2006) and 0.14-0.23 in the KWPN (Ducro *et al.*, 2009a; Koenen *et al.*, 1995). These differences may depend on different recording regimes or different prevalences of limb deviations in different populations. Generally,

previous studies indicate considerable heritabilities of most conformation traits, with a possible exception for limbs.

Overall conformation scores are commonly included in the routine genetic evaluation of warmblood horses in Europe (Interstallion, 2011). The KWPN studbook also estimates breeding values for specific linearly scored descriptive conformation traits. Test trials for inclusion of linear scored traits in genetic evaluations are currently running, or will be executed in a few years, in several other studbooks.

The SWB population has a specific breeding goal for conformation where horses should be *"Noble, have long lines and long limbs, a noble head, well-positioned neck, well-developed withers, slightly sloping shoulders and croup, a strong back, correct extremities and good hoof wall quality, with a withers height of 162-170 cm"* (Swedish Warmblood Association, 2013a). An official estimated breeding value (EBV) is published for the combined information of type and head-neck-body. Also, separate EBVs are published for limb conformation and withers height, respectively, at the SWB breeding association website: www.blup.se (Swedish Warmblood Association, 2013b). Breeding values based on a Best Linear Unbiased Prediction (BLUP) animal model are published for stallions with at least 15 young horse tested offspring, and for mares with one tested offspring or with own test results. EBVs are also published for dressage and jumping traits. Thus, individual breeders decide how much emphasis they want to put on conformation traits vs. performance traits in their own selection of stallions and mares to be mated. A steady genetic improvement of type and increased withers height has been noted in the SWB population during the last 20 years, whereas improvements of limb conformation have been limited (Viklund *et al.*, 2011).

## 2.4 Orthopaedic health

Health problems and causes of culling of riding horses are commonly related to orthopaedic health, i.e. lesions in the skeletal system and associated muscles, joints and ligaments (Sloet van Oldruitenborgh-Oosterbaan *et al.*, 2010; Egenvall *et al.*, 2006b; Wallin *et al.*, 2000). A long training period is needed for each individual horse before entering competition. Horses are usually at least 10-12 years old, before they reach the highest level of competition, representing a long time period during which they have to stay sound. Thus, possibilities of predicting future soundness and longevity at a young age, would be advantageous for horse welfare as well as for horse owners and the horse industry.

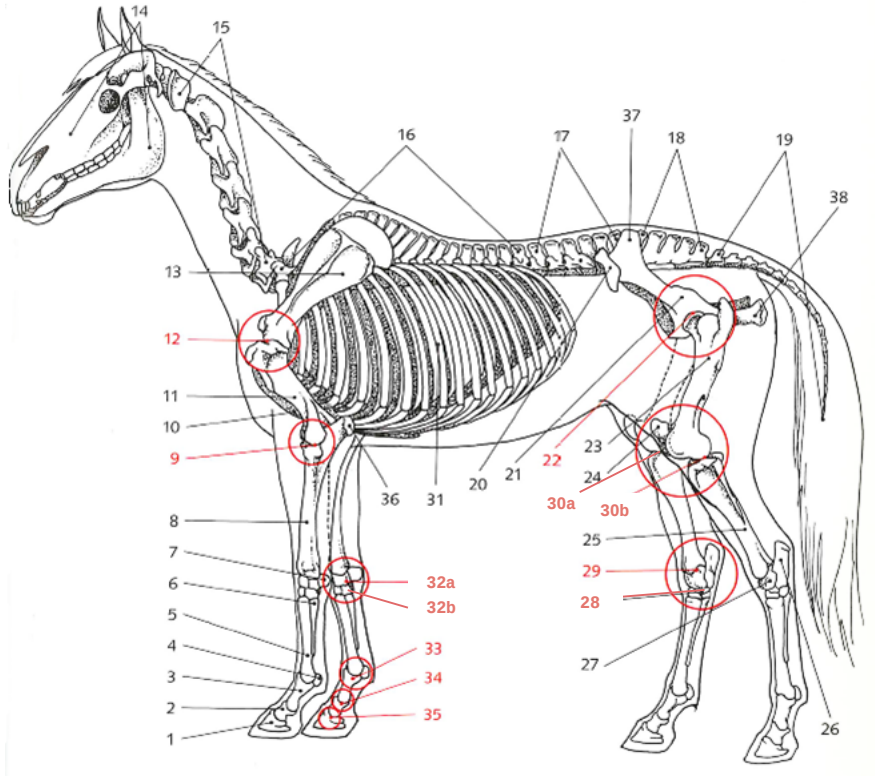
### 2.4.1 Method of examination

Routines for veterinary examinations of orthopaedic health commonly include palpation of the horse, i.e. manual search for deviations from normal variation in muscles, joints, skeleton and ligaments (Frykman *et al.*, 2012; Adams & Baxter, 2011). Commonly, also initial lameness examination and physical challenge of joints through flexion tests are used for detection of lameness. In some cases, radiographic examination of suspected joints or an overall screening of commonly affected joints is performed. For an illustration of the nomenclature of the skeletal system, see Figure 5.

At the RHQT, thorough examinations of palpatory orthopaedic health and locomotion, including flexion tests, have been performed. However, no radiographic examination has been included, due to costs and practical reasons, as many horses were tested each day.

*Palpatory examination*

Clinical findings from palpatory examinations may be categorised into five groups as defined in Table 1. The same findings may also be grouped according to systemic location as defined in Table 2.




1 distal phalanx
2 middle phalanx
3 proximal phalanx
4 proximal sesamoid bones
5 third metacarpal bone (cannon)
6 second/fourth metacarpal bones (splint)
7 accessory carpal bone
8 radius (and ulna)

9 elbow joint
10 sternum
11 humerus
12 shoulder joint
13 scapula
14 maxilla/mandible

15 cervical/neck vertebrae (n=7)
16 dorsal/thoracic vertebrae (n=18)
17 lumber/loin vertebrae (n=6)
18 sacral/croup vertebrae
19 coccygeal/tail vertebrae
20 point of hip
21 hip/pelvis
22 hip joint
23 femur
24 patella
25 tibia (and fibula)
26 calcaneus
27 talus
28 (tibiotarsal)/tarsometatarsal/centodistal joints (bone spavin area)
29 tarsocrural joint (hock)
30a femoropatellar joint (stifle)
30b femorotibial joint (stifle)
31 ribs (n=18 pairs)
32a antebrachiocarpal joint (upper part of carpus)
32b middle carpal/carpometacarpal joint (middle/lower part of carpus)
33 metacarpophalangeal joint (fetlock)
34 proximal interphalangeal joint (pastern joint)
35 distal interphalangeal joint (coffin joint)
36 elbow/olecranon
37 sacral tuber
38 point of buttock

*Figure 5*. Illustration of the skeletal system, with bone structures indicated in black and joints in red.

Table 1. *Definitions of categories of clinical findings*

| Clinical finding | Definition |
|---|---|
| Effusion | Swelling in a synovial structure caused by increased amount of synovial fluid |
| Heat | Finding of abnormally warm area at palpation |
| Soreness | Finding of abnormal reactivity/pain reaction at palpation |
| Swelling | Swelling other than effusion |
| Stiffness / atrophy | Reduced joint mobility / decreased muscle mass |

Table 2. *In the following four groups, presented specific structures are named in the RHQT protocol. Lesions in other locations are noted in free text and thus not included in the statistics*

| Systemic location | Definition |
|---|---|
| Joints | Shoulder and elbow joint, middle/lower carpus, upper part of carpus, fetlock, pastern and coffin joints, femoropatellar and femorotibial joints (stifle), point of the hock and tarsocrural joint (hock), carpal bursa, digital flexor tendon- and tarsal tendon sheaths |
| Muscles | Shoulder muscles, back muscles & spinous processes, croup/ hamstring-, and quadriceps muscles |
| Skeleton and hoof cartilages | Upper and lower part of cannon bones, proximal sesamoid bones, hoof cartilage, tarsometatarsal/centrodistal joint (bone spavin area), growth zones, periosteum |
| Tendons & suspensory ligaments | Superficial and deep digital flexor tendon sheaths, suspensory ligaments, plantar contour of the hock |

## *Assessment of locomotion*

### Unprovoked examination

The first part of a lameness examination is usually based on unprovoked movements shown at hand in walk and trot, where symmetry of locomotion is evaluated. By definition, lameness is a visual or auditory sign of asymmetric movements of specific body parts, to unload e.g. a sore limb (Adams & Baxter, 2011). This examination may be performed both on a straight line and while lunging on a circle, on hard and soft grounds (Frykman *et al.*, 2012; Adams & Baxter, 2011). At the RHQT the initial examination is limited to movements in walk and trot on a straight line on hard ground.

Examination with flexion test

An equine flexion test is a physical challenge of joints, most often followed by immediate trot for examination of movements on a straight line on hard ground (Adams & Baxter, 2011). It is performed to detect underlying or diffuse clinical signs of lameness that are not apparent during unprovoked movements. In principle, a flexion test can be performed for individual joints one at the time, or as a full limb flexion test with the time for flexing usually being 60 seconds. Applied force and time for the flexion test has been shown to significantly affect the produced reaction of an examined horse (Keg *et al.*, 1997). Thus, the validity of this test has been debated. The heritability of flexion test reactions has been estimated to 0.25 in a small study of 265 Standardbred trotters, where all horses were examined by the same veterinarian. However, the estimate had a large standard error (Dolvik & Gaustad, 1996). At the RHQT, a full limb flexion test has been employed for each fore- and hindlimb, during 30 seconds.

*Hoof examination*

At the RHQT, veterinary examinations of hoof characteristics are performed using 11 descriptive traits including: small, flat or asymmetrical hooves, mediolateral imbalance, poor hoof wall quality, hoof wall cracks, contracted or underrun heels, frog infection, frog atrophy and other hoof findings. Compared to the hoof examination during the conformation evaluation (Figure 4), this examination is based on close inspection on hard ground surface.

*Systematic evaluation of orthopaedic health in horse populations*

Due to a generally low knowledge of health trait incidences, prevalences, heritabilities and effects on longevity at population level, veterinary practice has merely been based on the collective experience among veterinarians, accompanied by smaller scientific studies and a limited amount of large scale studies. Magnusson and Thafvelin (1985a) evaluated the orthopaedic health status of 500 Standardbred trotters, where more lesions were found in the left side of the horse compared to the right, probably due to how races were performed, and mares had more lesions than males. They also found the most common lesions to be effusions in hindlimb digital flexor tendon sheaths and fetlocks, and in forelimb carpal, fetlock and coffin joints. Similar results have been found in Danish trotters (n=365) where injuries in joints and tendons were the most common causes for interrupted training (Vigre *et al.*, 2002). Other previous results have been based on insurance statistics, where fetlock lesions were found the most common cause of riding horse cullings, and where carpal, femoropatellar (stifle) and tarsocrural (hock) lesions were also common (Penell *et al.*, 2005). Animal hospital data is another source of health information, where for example the heritability of osteochondrosis

(OC/OCD) in the SWB has been estimated to 0.07-0.13 in hocks and fetlocks on the observed scale, corresponding to 0.32-0.37 on the underlying continuous scale (Jönsson *et al.*, 2011). Overall OC/OCD status has been found to reduce performance in show jumpers significantly (Ricard *et al.*, 2002), as have isolated OC findings in the stifle and the dorsal part of fetlocks (DOF) (Verwilghen *et al.*, 2013), although there are discrepancies in study results. Radiographic status, in particular for osseous fragments in fetlocks of German auction horses has been found associated to lower conformation scores of limbs and movements in walk, and to taller withers height (Stock & Distl, 2006).

The majority of health information from the RHQT has previously not been evaluated, except for the overall health scores. These scores were connected to future longevity in a survey based on 1815 horses, where low scores increased the risk of early culling (Wallin *et al.*, 2001).

### 2.4.2 Heritability and genetic evaluation

The heritability of overall orthopaedic health scores from the RHQT has previously been estimated to 0.06 (Wallin *et al.*, 2003). Heritabilities of radiographic findings e.g. OC have been studied, with quite diverse results depending on breed, included predilection sites and projections, but generally producing medium high heritabilities on the underlying quantitative scale (Jönsson *et al.*, 2011; van Grevenhof *et al.*, 2009b; Stock *et al.*, 2005). However, the knowledge of heritabilities of orthopaedic health traits recorded at palpatory veterinary examinations is generally limited. For hoof characteristics, heritabilities at 0.45 and 0.12-0.27 have been found in the Icelandic and the KWPN breeds, respectively (Albertsdóttir *et al.*, 2011; Ducro *et al.*, 2009a).

In the present routine genetic evaluation system of the SWB, no EBVs are estimated regarding health status, despite an inclusion of correctness and longevity in the stated breeding goal. Phenotypic health examinations have however been performed on RHQT tested young horses and on stallions at mandatory inspections before approval for breeding. These phenotypic examinations may have promoted owner awareness of health in individual horses, although no genetic evaluations have been applied. In 2012, the KWPN studbook in the Netherlands started to publish EBVs for OC as a first step of improving health in their population, based on the significance of this lesion on population health (van Grevenhof *et al.*, 2009a; 2009b). The KWPN studbook estimates that health lesions connected to OC alone stand for an economical loss of 10 million euros each year in their population of 12000 foals born/year (3-4 times more foals born/year than in the SWB)[1]. Their EBVs are based on radiographic examinations of 20 randomly selected yearling offspring of newly approved stallions. Efforts for improvements of health through

1. Personal communication, Ilse van Grevenhof, October 6th 2012, Ilse.vanGrevenhof@wur.nl

breeding are also aimed at in other European studbooks, but none of them have historical health registrations for their population to use in such evaluations, besides the SWB.

## 2.5 Longevity

According to a survey among Swedish riders, longevity in the sense of ability to cope with training and competition activity has been found the most important trait to focus on in breeding of riding horses (Jönsson, 2006). Similar results have been found among potential buyers on the horse market, in an Irish study (Hennessy *et al.*, 2008).

### 2.5.1 Measures of longevity

Longevity is originally defined as the time period that passes between birth and death of an animal, and may be a measurement of general soundness, as studied by Wallin *et al.* (2001; 2000). For the SWB, length of life in horses that had participated at the RHQT has been estimated to 14.7 years in males and 22.2 years in mares, with increased longevity in horses born at the end of the study period 1968-1982 (Wallin *et al.*, 2000).

However, longevity as defined in the breeding goal of SWB horses merely refers to functional longevity in competition, where the goal is to produce high performing and internationally competitive horses. As practiced today, a horse that is culled from competition activity may have an alternative use in breeding or as leisure riding horse, and euthanasia may not coincide with the culling from competition activity. Thus, it may be motivated to study number of years in competition (NYC), instead of actual length of life, to achieve improved functional longevity, as done by Braam *et al.* (2011) and Ricard and Blouin (2011). In the study of Braam *et al.* (2011), only horses with competition results were included, and the data were fourth root transformed, due to a skewed distribution. A similar approach of only including competition information of horses with competition results has been used in the official genetic evaluation of the SWB, except that log-transformation of competition data has been applied instead (Viklund *et al.*, 2010). In measurements of longevity in competition, males have been found superior compared to mares in basic dressage competitions and for competing in trotting (Ducro *et al.*, 2009b; Thafvelin & Magnusson, 1985), in contrast to the results of lifetime length (Wallin *et al.*, 2000).

Longevity in competition may however present difficulties in interpretation as the sports talent of the horse influences age at first start and length of competition life (Braam *et al.*, 2011). Further, it may be difficult to study possible differences between competition disciplines, as many horses participate in more than one

discipline, and should be credited for that. Also, causes for not competing in one discipline may be due to extensive activity in another discipline based on talent. Number of available competitions also differs between disciplines.

### 2.5.2 Heritability and genetic evaluation

The heritability of longevity in competition has been estimated to 0.10-0.20 (Braam *et al.*, 2011; Ricard & Blouin, 2011). Similar heritabilities regarding number of lifetime starts have been found in Standardbred trotters at 0.03-0.13 and 0.10, respectively (Saastamoinen & Ojala, 1991; Arnason *et al.*, 1982).

No routine genetic evaluation of longevity measured as NYC is performed for the SWB today. Prior studies have shown a considerable heritability for NYC in the population (Braam *et al.*, 2011), suggesting possibilities for improvements through breeding. In the present genetic evaluation, longevity in competition may be indirectly selected for as lifetime success in competition (LPERF) is included. Success is measured as the sum of upgrading points from placings, where a higher level of competition and a better placing gives the highest points. Assuming that a long and active career is needed for competing at highest level, longevity may thus partly be accounted for.

## 2.6 Main issues

A general lack of large scale routine health documentations connected to a unique identity of each horse in normal horse populations has limited the knowledge of prevalence and heritability of health traits. Consequently, records of conformation and longevity are rarely available in combination with health information. As a result, knowledge of associations between health, conformation and longevity is scarce, especially regarding specific clinical health findings and conformation characteristics. Further, few studies have been performed on associations between specific conformation characteristics and longevity in riding horses. The above mentioned limitations are valid worldwide, and have limited the possibilities to consider health and longevity in breeding programs of horses. The Swedish RHQT recording regime of health with simultaneous information of conformation and talent traits for performance, in addition to future competition results offers a unique opportunity to improve knowledge in these areas.

# 3 Aims of the thesis

The general aim of this thesis was to study factors that may be important when considering health in genetic evaluations, and whether there are possibilities to improve orthopaedic health and longevity in SWBs through breeding. In order to evaluate such possibilities relationships between conformation, orthopaedic health and longevity in competition as a sport horse have to be estimated, parallel to estimates of their heritability.

The more specific aims were to estimate:

- The prevalence of specific clinical findings and their individual importance for overall orthopaedic health status in 4-5-year-old riding horses
- Heritabilities of specific and overall health traits, and correlations between different health traits
- Heritabilities of overall and specific conformation traits, including limb deviations, and their genetic and phenotypic interrelationships, as well as their relationships to orthopaedic health
- Genetic and phenotypic relationships between health- and conformation as a 4-5-year-old horse on the one hand, and talent for performance, future longevity and success in competition on the other

The overall hypothesis of the thesis was that there are favourable associations between orthopaedic health, conformation and longevity in competition, and that these traits have a genetic variation that can be used in genetic evaluations for possible improvement of health and longevity.

# 4 Summary of performed studies

## 4.1 Material

The data used in Paper I-IV were based on information of health, conformation and assessed talents for dressage and show jumping, in 4-5-year-old horses. They were examined at the RHQT in years 1983-2005, except for 1985-1987 due to loss of data. Studied horses were followed through their competition careers for length and success in competition, based on documented competition results in years 1983-2012.

Data included both descriptive RHQT information of specific health and conformation traits, and assessed overall scores for health, conformation and talents for dressage and jumping at day of testing.

Specific health traits were included as 324 observations of palpatory orthopaedic health (PALP), 12 locomotion examination traits, including flexion tests (LOCO), and 11 hoof traits (HOOF), as found in protocols of the health examinations in Paper I. The overall orthopedic health score (H2) was also used, which was based on descriptive information of PALP and LOCO examinations.

For conformation, 14 descriptive traits of type, 25 traits of head-neck-body, 27 limb deviations and 11+12 specific traits of movements in walk and trot were evaluated, based on their description in the conformation protocol (Figure 6). The overall scores for each of the five areas of examination were also used. For further details see Paper 3.

Placings in regional and national competitions were used as information of competition activity. Number of years in competition (NYC) was chosen as a measure of functional longevity, as it relates well to the SWB breeding goal, and as it was previously found by Braam *et al.* (2011) to be an informative measure of functional longevity. Accumulated upgrading points after placings in competitions were also included as a measure of lifetime performance in competition (LPERF), as this information is included in the present genetic evaluation of SWBs. Further details of competition traits are found in Paper IV.

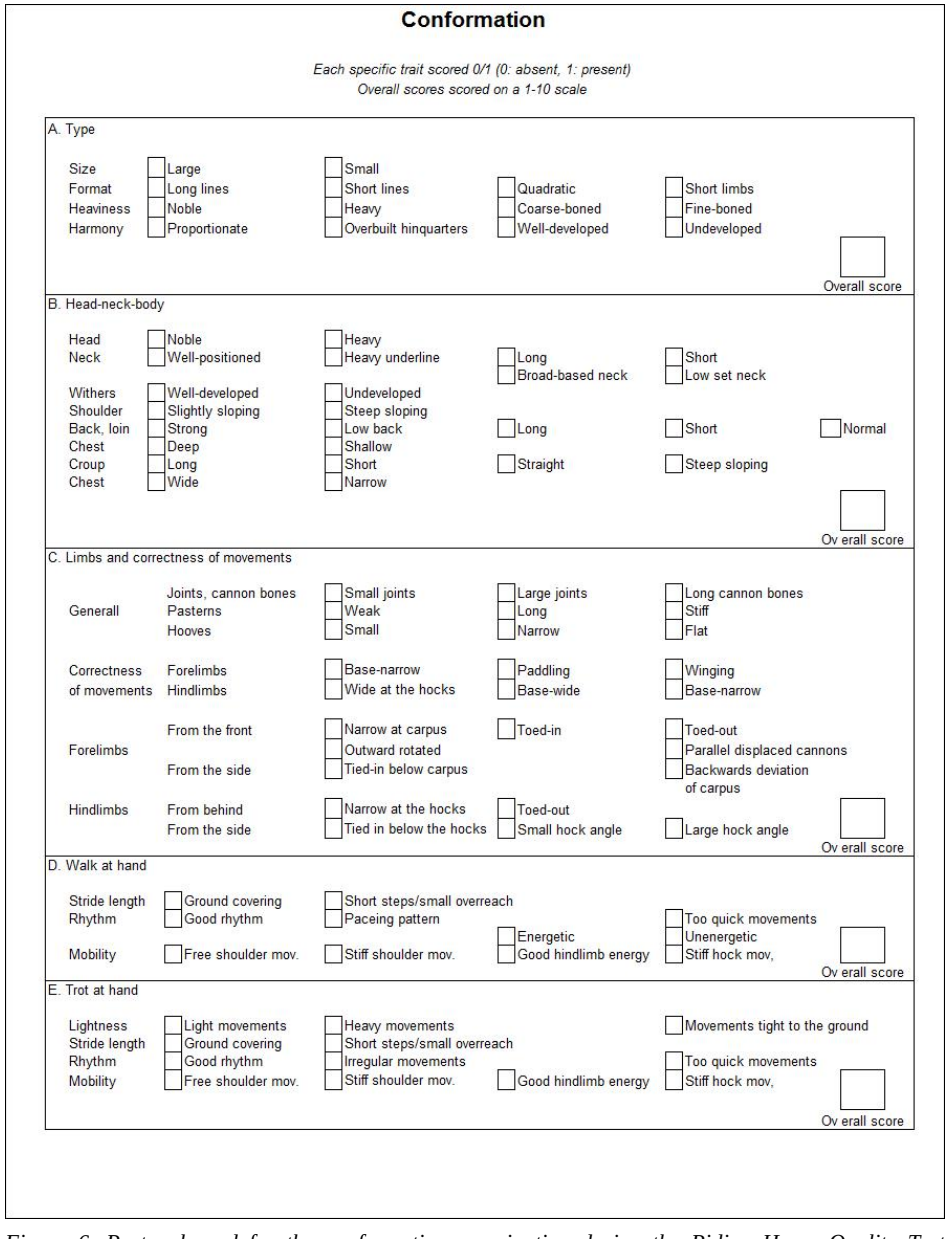



*Figure 6. Protocol used for the conformation examination during the Riding Horse Quality Test (RHQT). Translated from Swedish by the author.*

## 4.2 Methods

### 4.2.1 Digitisation and handling of data

The vast majority of health and conformation information, i.e. all descriptive information of specific traits, was originally only available on paper protocols and was not possible to evaluate. Each horse (n=9053) was evaluated using one protocol for each station of examination (n=5). Within the scope of this project, a program was developed where a scanned .tif image of each paper protocol was digitally interpreted using the neural network toolbox in Matlab® (Mathworks, 2010). The program was also designed to fetch previously stored RHQT information of each horse, from the existing database and display it in connection to each protocol image. Thus, automatic digitisation, followed by manual validation of RHQT information and horse identity was facilitated in an interactive environment. This generated data of 8281 horses with a complete health examination and a confirmed identity, out of which 8196 had conformation information, 8166 had information of talent for dressage, and 8144 for jumping. The gradual decrease of included horses with information from the different stations was a result of premature retirement from the test.

Descriptive information of specific health traits was initially analysed as recorded; in 4 severity classes. In analyses of effects of specific health traits on overall health, conformation and longevity, moderate and severe clinical findings were pooled due to low prevalence, and no difference was made between presence of uni- and bilateral findings. Clinical findings were also analysed as the sum of number and severity of clinical findings within 3 areas of examination, i.e. at the PALP, LOCO and HOOF examinations, respectively. For example one minor (1) and two moderate (2) clinical PALP findings resulted in a sum of 5 for PALP. Summed values included both bilateral findings. Corresponding summation of PALP findings was performed in 4 groups of systemic location (muscles, joints, tendons & ligaments, skeleton & hoof cartilage) and 5 groups of clinical signs (effusion, soreness, swelling, heat, stiffness/atrophy). Specific descriptive traits of conformation, and overall scores of health, conformation and talent were kept as recorded. Distributions of overall and summed health information were commonly skewed, but residuals were fairly normally distributed and were not markedly improved in extensive transformation trials. Thus, this information was kept untransformed. Both NYC and LPERF were heavily skewed because many horses have a low competition activity, whereas few horses have the absolute highest competition activity. Thus, NYC and LPERF were log-transformed ($\log(x+1)$), as this was shown to be most appropriate by Box-Cox transformation trials.

### 4.2.2 Phenotypic associations

Phenotypic effects were studied to estimate the importance of each trait. Effects of specific health and conformation traits on overall health and conformation scores, as well as on longevity, were analysed one at the time as class effects, to find what characteristics were of most positive and negative importance, respectively. Analyses were performed using General Linear models (GLM) in the statistical package SAS (SAS Insitute Inc, 2012). Also, summed health recordings and overall scores for health and conformation were related to performance at day of testing, NYC and LPERF in separate analyses. Further, analysis of all overall conformation and/or health trait effects on NYC/LPERF were analysed simultaneously in combined analyses. Additionally, the class effect of flexion test reactions on the presence of future start in competition was analysed using logistic regression in SAS.

All applied models with RHQT information as response variable included fixed effects of gender (male/female) and event, where event was a combination of location and date, also accounting for between examiner variation. Analyses with NYC or LPERF as response variables included the fixed effects of birth year, event and n offspring which was a constructed variable including both information of gender and the number of registered offspring in mares. In Paper I, also the effect of age on RHQT recorded health status was included. However, as this effect remained small and often non-significant in the following studies (Paper II-IV), it was consequently excluded.

### 4.2.3 Genetic analyses

Genetic analyses were performed for estimation of heritabilities and genetic correlations between health, conformation, talents for performance at day of testing, and NYC or LPERF, respectively. Results indicate which traits have the highest probabilities to be passed on to the next generation and affect longevity in produced offspring. Analyses were performed as mixed linear models in the DMU package (Madsen & Jensen, 2010). The same fixed effects as in phenotypic analyses were included (RHQT: gender and event; NYC/LPERF: birth year, event and n offspring) with the addition of a random animal effect in which the relationship matrix between studied horses, based on relatives 7 generations back, was included. Initial analyses commonly were univariate, whereas final results were based on bivariate or multivariate analyses. In cases of binary traits, heritability estimates were transformed according to Dempster and Lerner (1949), for estimation of the corresponding heritability on the underlying continuous scale.

## 4.3 Main findings

### 4.3.1 Clinical findings of health

At the health examinations, 74% of studied horses had at least one minor PALP finding, 42% had HOOF findings, and 21% had LOCO findings. However, only 24%, 3% and 5% had moderate or severe findings during these examinations (Paper I). As illustrated in Figure 7, 33% of horses *only* had PALP findings, whereas 24% had both PALP and HOOF findings, and 7% had findings in all 3 areas of examination (PALP, LOCO and HOOF). Almost all horses with LOCO findings also had PALP findings (17 out of 21% of all). Overall, 14% of examined horses were free from clinical findings in all 3 areas of examination. LOCO findings generally had the largest individual effects on overall orthopaedic health (H2). One fifth of the horses with LOCO findings had unprovoked lameness, whereas the remaining only showed lameness after the flexion tests. The overall score for orthopaedic health (H2) generally decreased with increased number and severity of findings within and between areas of examination.

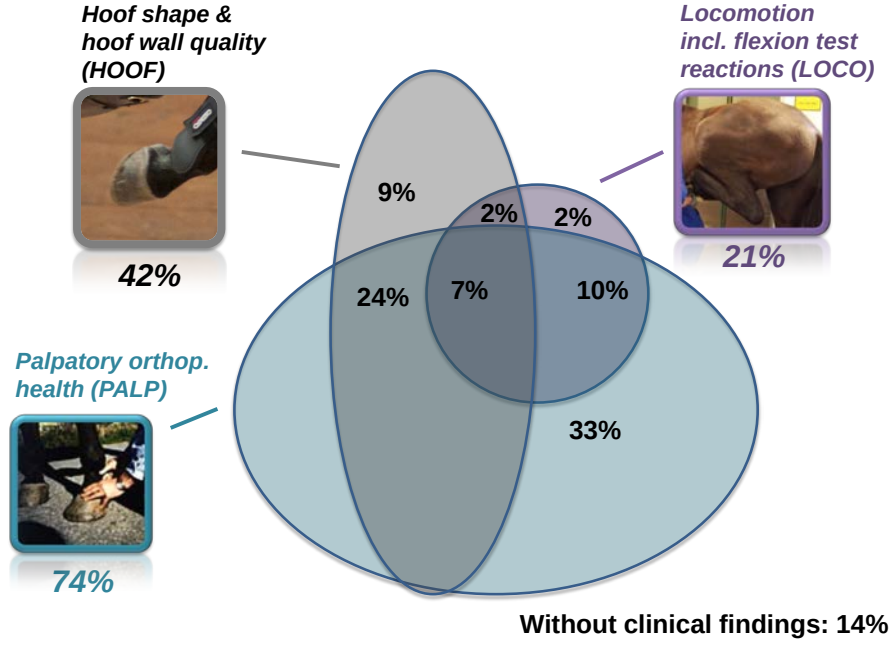



*Figure 7.* Proportion of examined horses with clinical findings in one or several of health examinations for PALP, HOOF and/or LOCO.

### 4.3.2 Heritability of health, conformation and longevity

According to Paper II, summed clinical findings of PALP were found to have a heritability of 0.12, which increased to 0.14 if only including clinical signs of effusions. Further, clinical findings of the HOOF examination showed a heritability of 0.10. Summed clinical findings from the LOCO examination, including flexion tests, and overall orthopaedic health (H2) were found to have lower heritabilities, at 0.04 and 0.06 respectively.

Overall conformation scores showed heritabilities between 0.20 and 0.36 with highest values for trot at hand, except for limbs at 0.06 (Paper III). High heritabilities were found for withers height and cannon bone circumference at 0.67 and 0.55, respectively. The highest heritabilities among the specific type traits were found for body size and a noble appearance at about 0.2 on the observed scale, corresponding to around 0.4-0.5 on the underlying quantitative scale. Among head-neck-body and limbs; neck position, toed-in forelimbs and small hock angles reached the highest heritabilities of 0.14-0.15 (0.20-0.48 on underlying scale). Most movement traits were in the range of 0.05-0.18 (about 0.10-0.30 on underlying scale) with the highest values for ground covering in walk and trot.

The heritabilities of NYC and LPERF were estimated to 0.20 and 0.24, respectively (Paper IV).

### 4.3.3 Associations between health, conformation and longevity

Results show that good 4-5-year-old health and favourable conformation, as it has been judged, are associated to each other (Paper III) and to better performance at day of testing, higher longevity and better lifetime performance in competition (Paper IV). Results of Paper III and IV showed the same or similar health and conformation characteristics to be most favourable. Most important conformation traits for a good health and longevity were high scores for type and head-neck-body conformation, and good movements in walk and trot at hand. Intermediate sized horses without major limb deviations were also favourable. Further, the 4 overall health traits were found important for longevity: overall orthopaedic health (H2), locomotion (LOCO), palpatory orthopaedic health (PALP) and hoof status (HOOF).

*Important conformation characteristics*

Among type and head-neck-body traits, the most important characteristics were found to be proportionate horses with a well-positioned neck and long lines, including croup and neck (Paper III and IV). Specific movement characteristics that were desirable in trot at hand during the conformation examination were also associated to improved health status and in some cases also to future longevity.

Thus, movements in trot were found important as a receipt on how all combined conformation and health traits interact and influence the overall functionality of the horse. Generally, movements should exhibit free shoulders, energetic, ground covering, with good rhythm and good hindlimb energy. Similar, but somewhat weaker associations were found for movements in walk.

Optimal withers height of horses was similar regarding both the 4-5-year-old health status (H2) and a successful competition career (NYC/LPERF) with most favourable heights in the range of 163-171 cm (Paper II and IV). The effect of size on 4-5-year-old overall orthopaedic health (H2) is illustrated in Figure 8. Generally, taller horses than what was found optimal for soundness and longevity were desired for highest talent scores for dressage, whereas size was less important for jumping talent (Paper IV). As demonstrated in Paper III, withers height has steadily increased during the studied years, whereas cannon bone circumference has changed only slightly.

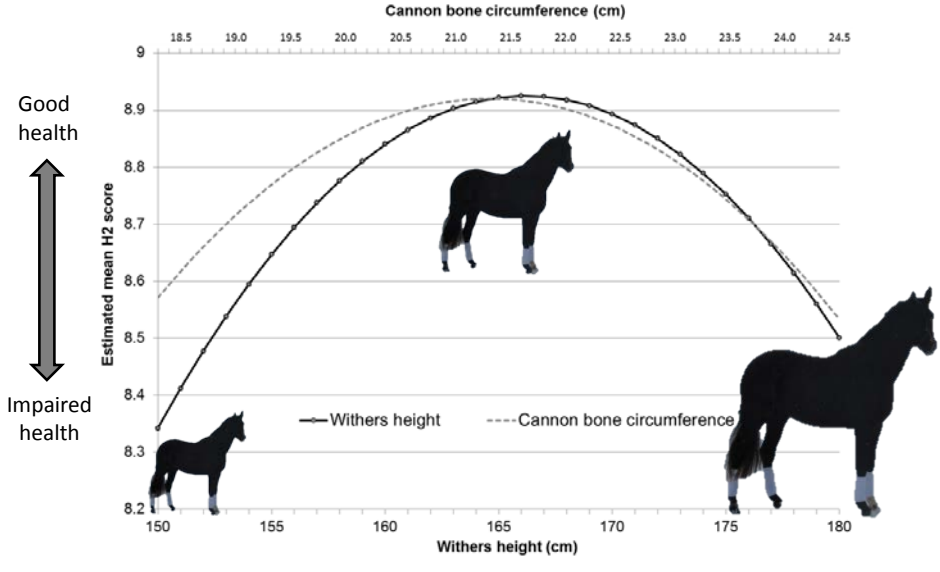



Figure 8. Relationship between withers height and cannon bone circumference and 4-5-year-old overall orthopaedic health (H2)

Several recorded limb deviations showed significant phenotypic effects on 4-5-year-old health, where stiff pasterns showed the largest unfavourable effects (Paper III). Both toed-in and toed-out forelimbs, and both small and large hock angles were also clearly associated with overall impaired PALP health, phenotypically. Some limb deviations also showed significant effects on effusions in specific locations on their own (Figure 9). Parallel displaced cannons were associated with significantly more effusions in carpus and forelimb digital flexor tendon sheaths. Toed-in forelimbs were associated to more effusions in fore- and hindlimb fetlocks, coffin-, stifle- and hock joints, and hindlimb digital flexor tendon sheaths. Small hock angles were associated to more effusion in hock- and stifle joints, and stiff pasterns to more effusions in hocks. Regarding influence on NYC, narrow at carpus and toed-in forelimbs had significant negative phenotypic effects (Paper IV, Table 8). Toed-out forelimbs had a positive effect on NYC, in contrast to its effect on PALP.

However, few limb deviations showed corresponding significant genetic correlations to health, due to generally low prevalences and low estimated heritability (Paper IV). Only parallel displaced cannons showed significant genetic associations to NYC and LPERF.

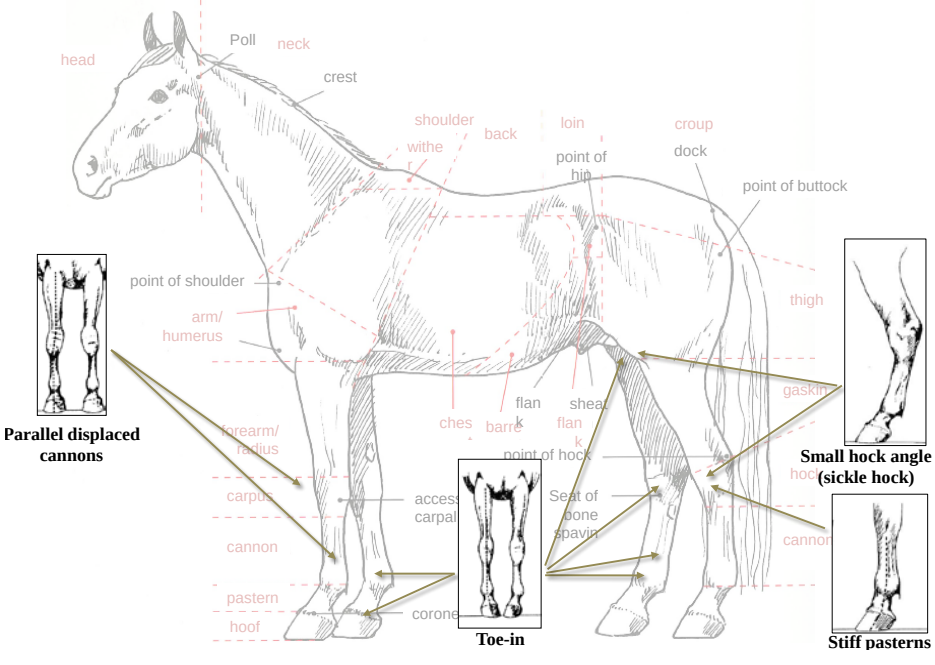



*Figure 9.* Limb deviations with significant phenotypic effects on specific findings of effusion.

Despite low heritabilities some limb deviations showed significant genetic correlations to each other (Figure 10, results from Paper III). Results support the theory of toed-in horses to have paddling movements, but only a non-significant positive correlation was found for parallel displaced cannons. Possibly, the previous assumption of parallel displaced cannons to be associated to paddling movements may be derived from its relationship to toed-in forelimb conformation. Results show that horses with larger cannon bone circumference more often have the above mentioned limb deviations compared to those with smaller cannon bone circumference. On the other hand, horses with a smaller cannon bone circumference more often had toed-out forelimbs, small joints and weak pasterns. Horses with large hock angles more often had weak pasterns, where presence of both deviations had larger negative effects on health than the sum of the two separate effects.

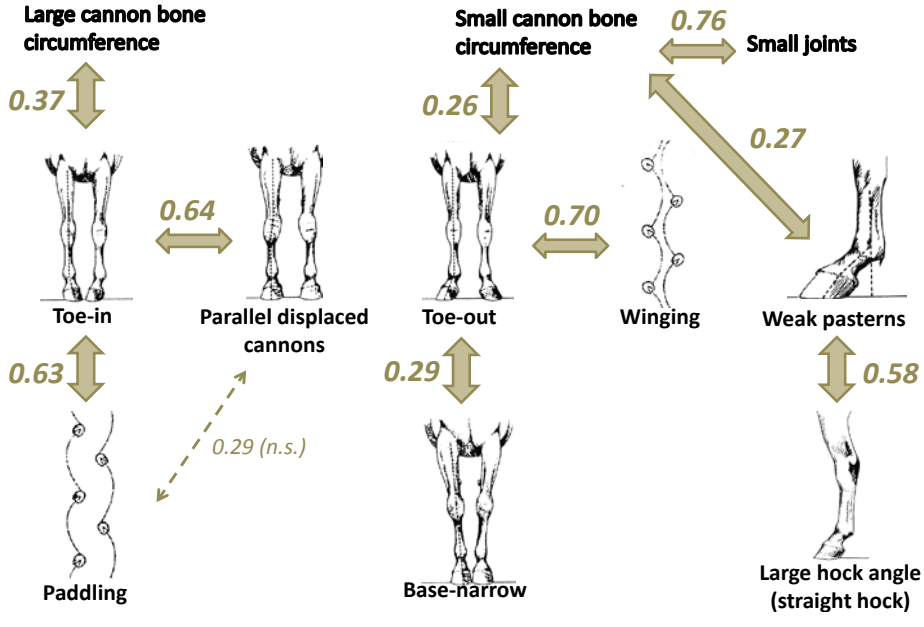



*Figure 10.* Genetic correlations between limb deviations. Massive arrows represent correlations significantly different from zero and the dotted arrow represents a non-significant correlation.

*Important health characteristics*

Generally, PALP findings of effusions, often had comparably small effects on health at day of testing (Paper I) but appeared to remain an issue for longer periods of time, with effects on longevity in competition (Paper IV). They also showed the largest heritability among health traits (Paper III). PALP findings of acute nature were rare, but if present had large effects on health status at day of testing (Paper I). These traits were often too rare to be included in analyses of effects on longevity, and if included, showed non-significant effects (Paper IV). Among clinical findings of HOOFs, poor hoof wall quality had a significant negative effect on longevity on its own (Paper IV), whereas hoof wall cracks were the most common HOOF finding (Paper I). Results further indicated that the summed overall HOOF status had a significant genetic variation (Paper II) and association to longevity (Paper IV).

Both LOCO and H2 status in 4-5-year-olds had significant phenotypic effects on longevity (Paper IV), but showed comparably low heritabilities (Paper II). Despite the low heritabilities, impaired LOCO and H2 status had significant genetic correlations to decreased longevity at a level of -0.3, similar to PALP and HOOF (Paper IV). The overall H2 score was an assessment based on PALP and LOCO information, where specific findings of both these examinations were important for the H2 score (Paper I).

*Role of conformation and health when considered together*

When overall conformation and health traits were studied jointly with each other, movements in trot at hand and type were the conformation traits found to contribute with most unique information for prediction of future longevity (Figure 11, based on results from Paper IV; Table 4, estimates/s.d. from multi-regression analysis). Head-neck-body was of high importance when analysed separately, but showed a non-significant effect when estimated simultaneously with other conformation traits, due to its strong correlation to type. Health examinations accounted for about 30-40 % of the total effect on future longevity that was due to results from both the conformation and health examinations (Figure 11).

If flexion test reaction information would not be available, the majority of information on LOCO and H2 would be lost, which together accounted for about half of the total effect of health on longevity (Figure 11).

Specific analyses of flexion test results revealed that horses with flexion test reactions had significantly lower chances of competing later in life (odds ratio: 0.59), compared to horses without flexion test reactions (odds ratio: 1), when analysed separately (Paper IV). Horses with moderate or severe flexion test reactions also generally had a 0.4 year shorter competition career than horses without flexion test reactions.

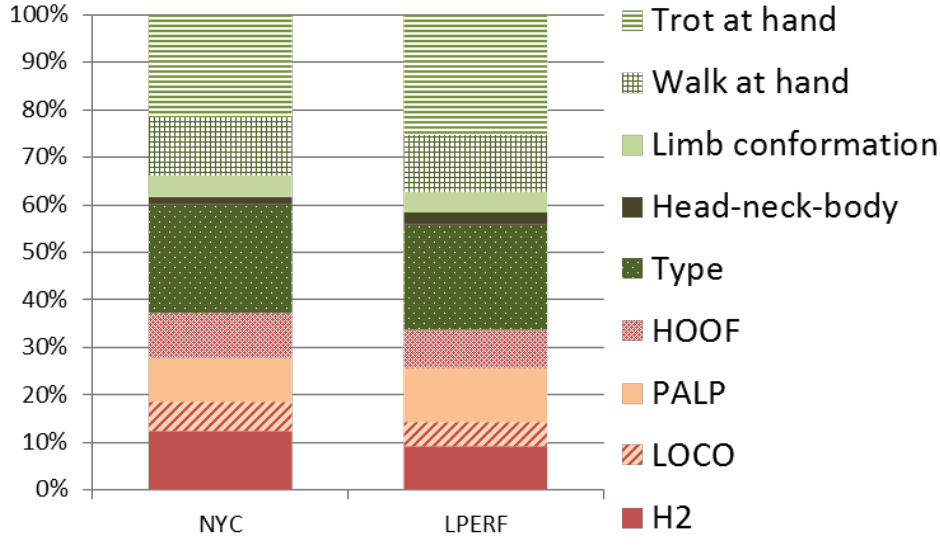



*Figure 11.* Effects of health evaluations (red/pink shades) and conformation examinations (green shades), when analysed together, on future longevity (NYC) and lifetime competition results (LPERF), respectively.

# 5 Additional results

## 5.1 Breeding values for orthopaedic health and hoof quality

Results of paper I-IV indicated that information of assessed overall orthopaedic health (H2), together with palpatory orthopaedic health (PALP) and results from the locomotion examination including flexion tests (LOCO), all contributed with important information of orthopaedic health status and longevity. Results suggested a combined EBV of these traits to be appropriate, as traits were correlated with each other and produced similar stallion rankings. Each of these traits showed unique effects on longevity of 0.08, 0.04 and 0.06 years per s.d. of change, for H2, LOCO and PALP, respectively (Paper IV, Table 4, Model 2c estimates/s.d). This corresponds to a relative value of the present sources of orthopaedic health information for longevity of 44% for H2, 22% for LOCO and 34% for PALP, which may be used as weights in a combined health index. If using indexes derived from a multi-trait BLUP animal model (as described in Paper II), which were transformed to a mean of 100 and a genetic standard deviation of 20, and weighted according to above mentioned factors for H2, LOCO and PALP, a combined index as shown in Table 3 was derived. Table 3 includes a top 20 ranking for orthopaedic health among stallions with at least 20 examined offspring, where highest EBVs represent best health status. The reliability of the combined EBV for orthopaedic health was on average 0.64 which corresponds to an accuracy ($r_{TI}$) of 0.80. This could be compared to individual reliabilities of 0.52, 0.43 and 0.59 for H2, LOCO and PALP, respectively.

The generally small differences in separate EBVs for H2, LOCO and PALP, and the small deviations from 1/3 in contribution of each trait may also warrant an even further simplified construction of the combined EBV, merely calculated as the mean EBV from the three traits.

Table 3. *The top 20 stallions regarding estimated breeding values (EBV) for combined orthopaedic health (including weighted information of H2, LOCO and PALP), among 133 stallions with at least 20 offspring examined for orthopaedic health. Indicated in* ***bold*** *if also included in the top 20 for hooves.*

| Combined EBV for orthopaedic health | | | |
|---|---|---|---|
| Stallion | EBV | s.e. | No of offspring |
| **Robin Z** | 135 | 9 | 184 |
| **Irco Mena** | 129 | 15 | 26 |
| Little Boy | 125 | 15 | 29 |
| **Landlord** | 124 | 12 | 77 |
| Urbino | 124 | 11 | 47 |
| Turban Rose | 123 | 14 | 45 |
| Trofé | 121 | 12 | 69 |
| Vivaldi | 119 | 13 | 46 |
| **Cardento** | 119 | 14 | 54 |
| Roderik | 119 | 15 | 33 |
| **Chapman (SWB)** | 118 | 11 | 111 |
| Neapel | 118 | 15 | 21 |
| Martini | 118 | 11 | 90 |
| **Irco Marco** | 117 | 12 | 61 |
| **Feliciano (SWB)** | 115 | 13 | 46 |
| Lester | 115 | 15 | 21 |
| Goldlöwe | 115 | 16 | 25 |
| **Krevad** | 115 | 12 | 56 |
| Flamingo | 114 | 12 | 35 |
| Labrador | 114 | 13 | 45 |

The corresponding stallion ranking for EBVs of hoof quality at the veterinary examination is found in Table 4. As found in Paper II the average reliability for HOOF status among stallions with at least 20 offspring was 0.58, which corresponds to an accuracy ($r_{TI}$) of 0.76. The two rankings (Table 3 vs. Table 4) were quite diverse from each other, which may be expected due to weak genetic correlations between orthopaedic health and hoof quality (Paper II). Out of the top 20 stallions, 8 individuals were included in the top for both HOOF and orthopaedic health (**bold**). The same structure was seen among the 20 bottom stallions (not shown in tables). Also, 5 of the top 20 stallions for one of the traits were at the same time among the bottom 20 for the other trait. This suggests that genetic evaluation of HOOF and orthopaedic health should be kept as separate evaluations.

Table 4. *The top 20 stallions regarding estimated breeding values (EBV) for good hoof status (HOOF), among 133 stallions with at least 20 offspring examined for hoof status. Indicated in **bold** if also included in the top 20 for hooves.*

| EBV for HOOF status | | | |
|---|---|---|---|
| Stallion | EBV | s.e. | No of offspring |
| **Landlord** | 136 | 12 | 77 |
| **Chapman (SWB)** | 132 | 10 | 111 |
| Utrillo | 130 | 10 | 23 |
| Electro | 130 | 11 | 81 |
| **Irco Marco** | 128 | 11 | 61 |
| Bordeaux | 126 | 12 | 39 |
| Maraton | 126 | 8 | 189 |
| Zorn | 123 | 15 | 21 |
| **Robin Z** | 121 | 9 | 184 |
| **Krevad** | 120 | 12 | 56 |
| Rastell | 119 | 13 | 49 |
| **Feliciano (SWB)** | 119 | 13 | 46 |
| **Irco Mena** | 117 | 14 | 26 |
| Cortus | 117 | 14 | 41 |
| **Cardento** | 117 | 13 | 54 |
| Briar (SWB) | 116 | 14 | 31 |
| Bayron (SWB) | 116 | 14 | 23 |
| Romano | 116 | 15 | 31 |
| Master (SWB) | 115 | 10 | 102 |
| Krocket | 114 | 14 | 26 |

# 6 General discussion

The presently studied material has provided a unique opportunity of estimating the relationships between health, conformation and longevity in riding horses. Results showed several favourable relationships between conformation, as assessed by experienced judges, and health. Both health and conformation contribute with information to predict future longevity and performance in competition, for both dressage and show jumping horses. Both too small and too tall horses were found negative for health, longevity and success in competition, where taller horses are preferred when selecting talents for dressage than what is optimal for future longevity.

Presently found heritabilities for conformation and to some extent for health, and favourable genetic correlations between health, conformation, longevity and performance, indicate possibilities to improve population health through breeding. To enable best possible improvements of health, breeding values for orthopaedic health and hooves, respectively, would have to be included in the genetic evaluation. A suggestion of how these evaluations preferably would be constructed is presented in this thesis.

## 6.1 Present results compared to earlier findings

Conformation has traditionally been an important selection criterion in horse breeding, where proportions and relative angles between parts of the body have been in focus (Wrangel, 1887). Both the present studies and results of Standardbred trotters have confirmed many of the traditionally suggested relationships between conformation and soundness (Magnusson & Thafvelin, 1985b). However, it was still somewhat surprising to see how highly associated the type/head-neck-body conformation of a horse is to its health status, and how well movements at hand on soft ground reveal correctness of conformation and serves as indicator of present and future soundness of the horse. On the other hand, limb deviations were not

found to influence future longevity as much as previously anticipated, as prevalence and severity of limb deviations apparently are low in the population. However, horses with limb deviations often exhibited associations to health disturbances.

By nature about 65% of the total body weight of the horse is distributed to the forelimbs (Hedge, 2004), which may become further unevenly loaded if the front part is heavy or low. Biomechanically, the role of head-neck position in training of horses for movements in trot, back movements, and load of front- and hindlimbs has also been demonstrated previously (van Weeren *et al.*, 2010; Wijnberg *et al.*, 2010; Rhodin *et al.*, 2009; Biau *et al.*, 2002). Further, long lines, in particular a long neck and croup were found important for health and future longevity. The importance of a relatively long neck on health and performance has also been demonstrated by Holmström and Philipsson (1993) and Koenen *et al*. (1995). The positive effect of slightly sloping shoulders on performance, found by Holmström *et al*. (1990) and Koenen *et al.* (1995) was phenotypically confirmed in the present study.

The previous results of Wallin *et al.* (2001) showing low limb scores to decrease longevity and a high sum of overall conformation scores to increase longevity was supported in the present studies. Present results further reveal that toed-in forelimbs and parallel displaced cannons may be relevant contributing factors of decreased longevity, whereas proportionate horses with good head-neck-body conformation and correct movements are the most relevant conformation traits for increased longevity.

Regarding health, results confirm earlier assumptions that effusions different in their effect on longevity depending on localisation. Present studies indicated that also mild effusions may affect longevity, in contrast to earlier assumptions. Effusions were also the category of clinical findings that had the highest heritability, thus representing the best opportunities for improvements through breeding. The negative effect found for several specific limb deviations of riding horses on orthopaedic health, i.e. effusions, in isolated locations (Figure 8) is in good accordance with results of Standardbred trotters (Magnusson & Thafvelin, 1985b). Those authors found parallel displaced cannons to be associated to effusions in the carpal joint, toed-in forelimbs to effusions in fetlock and coffin joints together with swellings of the metacarpal growth plates. Small hock angles were linked to more effusions in stifle and fetlock joints. Stiff pasterns were found to negatively affect the superficial flexor tendon in trotters, but were in the preset study associated to hock effusions in riding horses. According to previous literature the presence of splints may be increased in horses with parallel displaced cannons (Adams & Baxter, 2011). The present study only found slight differences in occurrence of splints between horses with and without parallel displaced cannons

(18% vs. 16%), and no differences were found among Standardbred trotters with and without parallel displaced cannons (Magnusson & Thafvelin, 1985b).

Impaired hoof wall quality and atrophied muscles, especially croup and hamstring muscles, were found associated to shorter future longevity, although they have a low focus in genetic evaluations and veterinary examinations of today. The importance of hoof size and shape for longevity in competition and health, respectively, have previously also been suggested by Ducro *et al.* (2009b) and Magnusson *et al*. (1985b), as have the importance of good muscling in haunches of Dutch show jumpers (Koenen *et al.*, 1995).

In the present studies males generally showed better health, longevity and performance in competitions compared to mares, even if number of registered offspring of mares were accounted for due to the large interruption of the competing career when producing a foal. The same results have been found in Standardbred trotters, however these studies did not correct for number of produced offspring (Magnusson & Thafvelin, 1985a; Thafvelin & Magnusson, 1985). Gender effects are also in accordance with studies of flexion test reactions where mares generally had more clinical findings (Busschers & van Weeren, 2001) and of longevity in competition among basic dressage horses in the Netherlands (Ducro *et al.*, 2009b). Possibly, mares may be less resistant to strains of training and/or more prone to show pain reactions than males. This is however, different from the results of Wallin *et al.* (2000), where mares had a significantly longer life span compared to males. Possibly, differences between length of life and length of the competition career may be due to the alternative use of mares in breeding, that postpone euthanasia to a larger extent compared to in males.

## 6.2 Novel results

The presently studied material has provided a unique opportunity of estimating the importance of several health and conformation traits on future longevity, documented in the same horses, in a large scale manner. Results showed significant genetic correlations to NYC/LPERF at levels of 0.26-0.36 for health and 0.14-0.30 for conformation. For health traits, this corresponds to 0.08-0.14 years shorter competition career for each minor clinical finding or unit of change in overall health score. An increase of one point in the overall conformation scores represents a 0.08-0.33 years longer competition career.

Results of simultaneous estimation of these traits provide knowledge of the separate importance of each area of examination when analysed in combination with other overall health and conformation traits. According to these analyses, type, walk at hand and trot at hand contributed with most unique information on future longevity among conformation scores. They represented an increase in

longevity of 0.25, 0.11 and 0.17 years, respectively and with genetic correlations to longevity of 0.14 to 0.24. For health, PALP, HOOF, LOCO and H2 all contributed with unique information of longevity in addition to conformation traits. Reduced health shortened the competition career with 0.02-0.07 years per unit of measured health, when analysed together with conformation information, where LOCO, H2 and PALP were strongly correlated. Reduced health in these traits all had significant genetic correlations to shorter longevity at a level of 0.3. Approximately half of the unique health information of longevity was influenced by the flexion test results. Horses with flexion test reactions had significantly lower odds ratios of participating in competitions later in life, 0.76 and 0.59 for minor and moderate/severe reactions, respectively, and the predicted decrease in longevity for horses with moderate/severe flexion test reactions was 0.4 years. If also considering all other veterinary information and conformation scores, the odds ratio changed to 0.83 and 0.71, respectively, whereas the predicted decrease in functional longevity was almost 0.3 years for moderate/severe reactions. This implied that flexion tests provide unique information for best prediction of future longevity.

## 6.3 Origin of association: Conformation - health - longevity

It may be speculated that the background of proportionate horses to favourably associated with soundness may relate to an evenness of loading of joints, ligaments and muscles. This evenness may for example apply to symmetry, 1: among connected joints e.g. stifle-hock-fetlock-pastern joint angles in hindlimbs, 2: between right and left side/limbs of the horse, 3: between fore- and hindparts of the horse, and 4: no rotation or inner/outer imbalance of the individual limb. Indications that deviating limb conformation directly influenced orthopaedic health were presented in Paper III/Figure 8 (p 25). This supports a theory that deviations from even loads of joints and surrounding tissues, presents unhealthy strains in that location and/or in other parts of the body, possibly due to compensatory loadings. Denoix (1999) has also suggested uneven loads of joints to produce large strains, in particular for the most distal parts of the limbs. The importance of an overall proportionate horse was found to be equally important also for future longevity and lifetime performance of the horse. Further, it has earlier been suggested by Becker *et al*. (2013) that proportionate horses are important for balanced movements. With this aspect it is also interesting to reflect on the theory that most riding horses have one side that is stronger (and less supple) than the other. In Standardbred trotters, the left side of the horse has been found more affected with orthopaedic health lesions than the right, thought to be due to always competing counter-clockwise on oval tracks (Magnusson & Thafvelin, 1985a). Possibly, riding horses may have

similar differences in prevalence of orthopaedic health lesions between the "strong" and the "weak" side, where the current training system practice of a high focus on straightness and equal training on both sides of the horse may be continuously emphasised (Swedish Equestrian Federation, 2003; Dyson, 2000).

Continuous measurements of withers height and cannon bone circumference revealed both traits to have an intermediate optimum for health and longevity. It is possible that the same phenomenon would be seen for other specific conformation characteristics if documented using a continuous linear scale. In cases of intermediate optimums there may be a risk of underestimation of correlations with health if using a continuous scale while not considering possible nonlinear relationships, as both extremes may be equally bad for health. In the present studies opposite extremes were analysed separately from each other, e.g. toed-in and toed-out forelimbs.

Paper IV showed that in addition to longevity, also talent scores for performance as a 4-5-year-old, including rideability, were significantly improved by a good conformation and health status of the horse. Possibly, a good health and conformation enables better prerequisites for correct work of the horse promoting a good rideability as perceived by the rider. Interestingly, some stallions with a reputation of passing questionable temperament to their offspring were also found in the lower end concerning orthopaedic health status of their offspring. Thus, one might speculate whether temperament issues in some cases may be associated with health status. Further studies are needed to evaluate this, and also to determine what specific talent characteristics are most important for the overall talent scores, and for health and longevity.

## 6.4 Value of RHQT health examinations of individual horses

The present results show that horse owners have obtained a valuable health evaluation of participating RHQT horses that was informative of future longevity. The unique combination of evaluating health, conformation and talent for two disciplines at the same day, at independent examinations, has provided a multi-perspective picture for prediction of future performance of each horse, where each examination provided important information. Based on the health examination results, owners get a professional opinion on future training and management strategies for best health, longevity and performance of each horse. It could further be valuable for horse owners to get a professional veterinary opinion if a conformation deviation has influenced the health status of the horse already at this young age. Thus, the RHQT recording system has proven to provide the horse owner with a valuable tool that informs on appropriate management of the horse to stay sound and perform according to shown talent. Furthermore, results of

individual horses collectively create a unique source of information at population level that can be used for genetic purposes and for monitoring time changes.

## 6.5 Consideration of soundness in practical breeding

Many environmental factors, e.g. rider and training regimes, influence the orthopaedic health of individual horses (Lönnell *et al.*, 2013). Strictly, only the part of a lesion caused by a genetic background can influence also the coming generations and thus a larger number of horses in the long run.

Heritabilities of health traits usually have been found to be low in several studied species. Also in the present study, heritabilities for health traits were generally low, whereas the additive genetic variation was 30-37% for PALP and HOOF, and 9% for LOCO, measured as additive genetic coefficients of variation (Paper II). Results are in accordance with those for functional traits in dairy cattle that despite low heritabilities at 0.01-0.14 (Buch *et al.*, 2011) have shown sizeable genetic variation *per se*. Thus, distinct improvements in these traits have been achieved through inclusion in the dairy cattle genetic evaluation, in spite of unfavourable genetic correlations with production (Philipsson, 2011; Philipsson & Lindhé, 2003). Contrasting to the case of functional traits in dairy cattle, presently studied health traits of horses were favourably correlated with the main breeding goal of performance, further increasing the likelihood of a successful breeding program for health traits. Due to favourable correlations between health, conformation, performance and longevity it may also be possible to use information of e.g. conformation traits, with higher heritabilities, as contributors of information for health status (Paper III and IV). However, it was clearly demonstrated in Paper IV that registered health information still contributes with unique information, not retrieved from the other examinations, suggesting that for optimal breeding programs health traits need to be specifically recorded and evaluated.

### 6.5.1 Practical implications

In the current breeding program of the SWB, young horse talent scores for performance and results in competition are the major focus. No EBVs for health are as yet included. According to simulation studies by Stock & Distl (2008) there are good possibilities to successfully select for health and conformation, together with improvements in performance. According to the present results, good health may also have a positive effect on performance. In Thoroughbreds the chances of starting in a race have been found significantly lower for horses with radiographic findings in fetlocks, especially in forelimbs (Meagher *et al.*, 2013). Today, EBVs for conformation are published for withers height and limbs, respectively, in

addition to a combined EBV for type and head-heck-body. The high relevance of head-neck-body and type on future longevity, and the high genetic correlation of 0.89 between these traits (Paper II) justify a continued combined EBV for them. The present results show that also information of correctness of movements, especially in trot, hoof status (HOOF) and orthopaedic health status are valuable to include in the genetic evaluation, where the latter may include information of PALP, LOCO and H2. If implementing a combined EBV for orthopaedic health with close to 1/3 of information relating to H2, LOCO and PALP, respectively, heritabilities suggest PALP to have the highest probabilities to change through breeding. Through the correlation between PALP and other health traits they may also be further positively influenced. In spite of the low heritability of H2 and LOCO they have been shown to contribute with valuable information for improved health.

If implementing a wider range of traits with published EBVs for each horse it is also important to inform and advise individual breeders on how to take these into consideration in combination with sport talent traits, for highest overall success in the offspring. Possibly total merit indexes could be implemented. However, as some traits e.g. HOOF and PALP, are weakly correlated, individual EBVs for each trait would preferably be published. Then, individual breeders can rank the importance between for example HOOF and PALP status when selecting stallions and mares to be mated.

Most characteristics in the SWB breeding goal for conformation are in accordance with characteristics that promotes good health and longevity. However, as the genetic material and thus the overall conformation in a population changes through selection, caution might need to be taken not to “over-shoot” the goal. The data suggests to avoid too noble horses, with too small joints, compared to their overall conformation. Small joints, small cannon bone circumference, toed-out horses, and weak pastern are characteristics that are found associated to each other and that usually are thought to be more common in Thoroughbreds. In a near future consideration also has to be taken not to continue promoting taller horses once the population reaches the optimal height for soundness (Paper III and IV). Possibly, the aim of a strong back in the breeding goal may be rephrased, where mainly the length has been found relevant in the present studies, where it should not be too short.

It may also be useful for each individual breeder to reflect on the mares that are selected for breeding. For practical reasons the best mares may be kept in active competition until a high age, instead of being used in breeding. Further, there is a risk of mares that cannot be used for riding due to health disturbances, injuries or questionable temperament, to enter breeding instead. At such a scenario, health disturbances that are influenced by a genetic predisposition may be transferred also

to the offspring. On the positive side, results of Paper IV showed that mares with 1-7 offspring generally had competed more than mares with no offspring. Thus, indicating that some selection for higher competing activity is applied also in mares.

The use of log-transformation of competition data was in accordance with the handling of competition results of Viklund *et al*. (2010), however different from the use of fourth root transformation of NYC in Braam *et al*. (2011). The discrepancy in most appropriate transformation of NYC between studies may be due to different horses included. In the study of Braam *et al*. (2011) and Viklund *et al.* (2010) all available horses in the pedigree database with competition results were included, but not horses without results. In the present study all horses with RHQT health information were included, where horses without competition records obtained a zero for competing activity. This was based on the present study results, that horses without competition recordings had significantly lower health, conformation and talent results at the RHQT. Thus an exclusion of these horses from analysis increases the risk of selection bias for these traits. This may be compared to an inclusion of start status in the genetic evaluation of Icelandic horses, which has been found to increase accuracy and decrease selection bias (Albertsdóttir *et al.*, 2011). Possibly, also the routine genetic evaluation of SWBs would gain in accuracy, if information of start status both in young horse tests and competitions were included.

### 6.5.2 International perspective

Health disturbances, which generally which generally have lower heritability than performance traits means that more examined offspring are necessary for reliable EBVs of health. When estimating EBVs for PALP and HOOF status, in stallions with at least 20 health examined offspring, a reliability of 58-59% was achieved (Paper II). For the combined EBV of orthopaedic health (H2, PALP and LOCO) a reliability of 0.64 was found (additional results). If international genetic evaluations would be implemented, as have been investigated by Thorén Hellsten *et al*. (2009; 2008), Ruhlmann *et al.* (2009) and Furre *et al*. (2013), health may be the trait that would gain the most, when the number of offspring per stallion increases. A prerequisite for international genetic evaluations of health is that similar health registrations are implemented also in other European studbooks.

The use of SNP-information (DNA markers) in genetic evaluations of horses, i.e. genomic selection, represents a future possibility for improved evaluations, similar to its breakthrough in cattle breeding (Hayes & Goddard, 2010; Meuwissen *et al.*, 2001). However, good phenotypes of traits that should be selected for will still be necessary for correct estimations of associations between a trait and analysed DNA-markers in the prediction equations. Initial genome wide

association studies are currently running in a limited number of European countries including Sweden (Mikko *et al.*, 2013; Orr *et al.*, 2012; Ricard *et al.*, 2012; Schröder *et al.*, 2012) and are being developed in some other countries. Available results generally suggest a large reference population, i.e. international collaboration, to be necessary for best success in this area.

### 6.5.3 Dressage horses and show jumpers

It is a common opinion that conformation is of less importance for show jumpers compared to dressage horses. Present results showed that conformation is of importance irrespective of discipline, although to a smaller extent in show jumpers compared to dressage horses (Paper IV), which is similar to the results of Ducro *et al.* (2007). This may imply that the role of conformation should not be neglected when breeding for show jumpers. Generally, the physical strains on show jumping horses are larger compared to dressage horses due to higher speeds and forces during performance. Thus, a conformation and health status that promotes even loading of bones, joints, muscles and ligaments is important. Regarding dressage horse breeding, a somewhat taller withers height has been strived for, compared to what is optimal for health and longevity. Further, for dressage horses one possibly has to distinguish between normally desired vs. extravagant conformation and movements, where there might be a risk in favouring the latter. As suggested by Becker *et al* (2013) selection for dressage horses with a more rectangular frame but at the same time a relatively short neck, tends to result in horses with more difficulties of maintaining balance. This, with the background of the present results, may be suspected to produce less sound horses, as proportionality, even loading and correct movements in good balance, were found important for the general health status.

In the present studies, talents for dressage and jumping were favourably correlated at 0.25 (s.e. 0.08), however the relationship may have decreased in later years due to more specialised breeding. For comparison, the correlations between gaits and jumping in the KPWN was only 0.02, and correlations between talent for jumping and competition results in dressage were negative in the range of -0.09 to -0.34 (Ducro *et al.*, 2007).

### 6.5.4 Flexion test reactions

The flexion test is a debated examination which horse owners hesitate to allow on their horses just before their performance test. It has also been criticised for a low level of standardisation of force and time when challenging the limbs (Keg *et al.*, 1997). Between years 2006 and 2010, flexion tests have unfortunately been excluded for cost reasons from the health examinations at the RHQT. Lameness evaluations of horses has also been criticised for its subjective character, leading to

difficulties among examining veterinarians on agreeing of presence and location of signs of lameness in a horse (Keegan *et al.*, 2010). The latter differences could however be decreased with the help of modern lameness location equipment (Adams & Baxter, 2011). In spite of all these arguments, Paper IV showed that the flexion test contributes with substantial information to predict future longevity that cannot be retrieved from the remaining health or conformation examinations. Horses with flexion test reactions had lower chances of competing later in life and also resulted in an average decrease in the competition career of 0.4 years. The flexion test had a large influence on the overall assessment of orthopaedic health status of examined horses and constituted a large part of the LOCO examination results. Out of studied horses 21% had flexion test reactions in at least one limb, where 13% had hindlimb reactions and 11% had forelimb reactions. In comparison, only 4% of examined horses showed any degree of clinical finding of initial locomotion including all limbs, and only 0.4% showed moderate or severe clinical findings. The heritabilities, on the other hand, were generally low at 0.04 for the entire LOCO examination, and at 0.03 for the maximum fore-/hindlimb flexion test reaction. Despite low heritabilities of LOCO and specific information of flexion test reactions, both traits showed significant medium high genetic correlations to future longevity of studied horses. Further, LOCO showed medium high correlations to limb conformation and trot at hand, and a high correlation to head-neck-body conformation.

## 6.6 Prerequisites for implementation of health in genetic evaluation

### 6.6.1 Phenotypic information of health

In 2011 the entire health examination was excluded from the RHQT in Sweden. An important prerequisite for implementing health and longevity into the routine genetic evaluations is to reintroduce routine health documentations of SWB horses in connection with the young horse tests of talents for performance. Preferably, also flexion tests would be included for optimal assessment of future longevity.

Today, 4-year-old horses belong to an age category that can participate both in activities arranged by the breeding association, and in regular competitions and special young horse championships. Thus, the number of RHQT tested horses has decreased in recent years. Simultaneously, participation in the 3-year-old test, arranged by the breeding association has increased.

Possibly health examinations of 3-year-old horses may be sufficient, if number of tested 4-year-old horses continues to decrease. A possible drawback of 3-year-old health examinations may be too little physical challenge in training to mimic typical strains on a riding horse. Thus, an evaluation of the use of such data would have to be performed before possible implementation. However, generally horses

are broken-in at a younger age today (2.5 years) compared to earlier, and horses are often well prepared for testing as 3-year-olds. This may imply a fair amount of exposure to training pressure already at this age. An advantage with 3-year-old documentation of health would possibly be less environmental influence of e.g. the rider on the presented health status.

### 6.6.2 Examiner influence

Similar to most subjective evaluations, health recordings were significantly influenced by examining veterinarians, which was corrected for in all analyses in Paper I-IV by including event as a fixed effect in the analyses. Such corrections are also necessary to perform if including health traits into the genetic evaluation. These corrections are not possible to apply in practical veterinary practice, e.g. pre-sale examinations. However, the results of this thesis may serve as a tool for further harmonisation among individual practicing veterinarians and for providing information on what clinical findings are most influential on future soundness and longevity, and thus should obtain most attention.

### 6.6.3 Alternative sources of information

For genetic evaluation purposes the studied large scale young horse health data in combination with assessment of conformation and talent is highly superior to other sources of health information. However, in order to increase the general knowledge of health traits, also other sources of health information may be utilized.

As health examinations have been successfully documented in young horses, possibly the same rigorous examinations may be documented in stallions prior to acceptance in breeding. However, some of these stallions may be older if approved on performance and have been exposed to higher environmental loads in training and competition which must be accounted for when evaluating such information.

In an ideal system, health examination results of all horses for example examined at animal hospitals should also be available for evaluation, with a unique identity connected to each recording i.e. the Universal Equine Life Number (UELN). Preferably each identity would be confirmed using the ID-chip of each horse. Similar suggestions of an increased practice of central documentation of health data have been presented by a Swedish governmental investigation, in order to overcome the limitations of evaluating health status in horse populations (SOU, 2006), as well as in scientific reviews (Egenvall *et al.*, 2011; Houe *et al.*, 2011). Such practice would demand all horses to be examined and documented for overall health in a more thorough manner than today, regardless of suspected health disturbance. A more thorough whole body examination practice is supported by the present results, as advantageous also for a correct diagnosis, as specific lesions influence each other, and some lesions may be secondary to others. In such a case a

higher public tolerance for minor clinical findings may be necessary, by owners and insurance companies, where evaluation of the significance of findings should be kept separate from the description of clinical findings. Further, it would be desirable with higher transparency of the health history of horses, in order for new owners to be able to make a more informed decision of which horses to use in breeding. A drawback of using animal hospital data from one single clinic is relatively few animals, which may be pre-selected for impaired health. However, if documentation from all clinics were to be included at a national level, and were combined with the pedigree database of available SWBs, as suggested by Jönsson *et al.* (2011), one could get an overview of horses with clinical findings, whereas those without records from clinics possibly could be classified as normally healthy individuals.

## 6.7 Methodology issues

### 6.7.1 Longevity in competition

In the present studies NYC was used as a measure of functional longevity. It should be remembered that this is not a pure longevity measurement, but is also influenced by the sport alent of the horse. Further, the measure was mainly based on information of placings in regional and national competitions. Thus, information of all starts in competitions was not included, due to lack of information, and horses competing internationally may have incomplete competition results. However, in order to reach international level horses would likely first have good results in national competitions. Information of rider, competition venue or which horses that participated in each competition may influence the results, but was not available in the used competition records. Even if available, rider and horse effects are usually heavily confounded as most riders only have one horse. Possibly, the large number of horses studied, may reduce the influence of rider on estimated effects of young horse traits e.g. health or conformation on longevity at population level.

The role of specific health and conformation traits for longevity in each competition discipline could unfortunately not be correctly estimated based on competition statistics, since causes for not competing in one discipline may be due to activity in another discipline. However, the role of conformation and health traits of 4-5-year-old horses for their talents in jumping and dressage, which was evaluated for all horses, was found valuable for estimating possible differences between disciplines. These estimates showed that conformation and health is important for horses of both disciplines, although conformation was found more important for dressage horses compared to jumpers.

### 6.7.2 Conformation traits

Specific conformation traits were described on a 0/1 scale, which may limit the refinement of the original observation of the trait. Large hock angles showed some inconsistent associations to health, between phenotypic and genetic estimates (Paper III). A possible explanation could be that most of these deviations are slight and thus quite near an optimum. A previous Swedish study defined a hock angle at 159° as large, whereas the same angle was defined as intermediate in an American study (Gnagey *et al.*, 2006; Holmström *et al.*, 1990). Similar discrepancies may be found also for other specific traits. Possibly, it would be preferable to describe these traits on a linear scale with more classes. Linear scoring systems are becoming more common in European warmblood breeds (Interstallion, 2011). A prerequisite is that the traits in question biologically have a quantitative linear background. Certain defects may however only be possible to record on a 0/1 scale.

### 6.7.3 Health traits

Previous results have found that the occurrence of health disturbances increases with age and in correspondence to the extent of training/riding of the horse (Ireland *et al.*, 2012; Bonnett & Egenvall, 2010), which should be remembered when comparing young horse data to other sources. Also, the worst cases regarding health may not participate at the RHQT. However, a large proportion of these worst cases are expected to be randomly occurring and of temporary acute nature. Wallin *et al*. (2001) previously found RHQT health information of 4-year-olds to significantly influence future longevity. Similar results have been found in insurance statistics, where costly veterinary care events were associated with more cullings in the 5 following years (Egenvall *et al.*, 2006a). With the aspect of using health data in genetic evaluations, young horse data may be advantageous due to smaller influence of rider/trainer effects, enabling better evaluations of the genetic predisposition for unsoundness.

### 6.7.4 Data analysis

Linear models where consistently used in the genetic analyses of this project. Thresholds models may have been more appropriate for specific categorical traits. However, in present studies relationships between several continuous and categorical traits were to be estimated simultaneously, thus linear models were highly preferable. However, heritabilities of binary recorded traits were transformed to the underlying continuous scale according to Dempster and Lerner (1949). A previous study of the categorically recorded trait osteochondrosis (OC) in the SWB population further found sire threshold models such as Gibbs sampling to produce unstable heritability estimates when sire offspring groups are small, as in the SWB (Jönsson *et al.*, 2011). In such cases there is a high risk of extreme

category problem (Misztal & Gianola, 1989), especially in traits with low prevalence. The study of OC also found linear and threshold estimates to produce heritability results on the same level. Survival analysis was not employed, due to the small part of studied horses that were affected by censoring (less than 0.2%), the remaining horses appeared to have finished their competition careers before 2012.

# 7 Conclusions

Papers I-IV showed that both orthopaedic health and conformation in 4-5-year-old horses contributed with unique information to predict future longevity in competition. The summed clinical findings and overall conformation assessments of the horse were generally most informative to predict functional longevity.

The studies more specifically concluded that:

- Clinical findings during movement examinations (LOCO), including flexion tests, had a large effect on assessed health status. Generally, non-acute findings of effusions were most common. They often showed a low estimated effect on overall health at day of testing, but were generally more associated with longevity than acute palpatory orthopaedic health (PALP) findings.
- Summed/overall health and conformation traits showed significant genetic correlations to NYC/LPERF at levels of 0.26-0.36 for health and 0.14-0.30 for conformation. For health traits, this corresponded to 0.08-0.14 years shorter competition career for each minor clinical finding or unit of change in overall health score. An increase of one point in the overall conformation scores represented a 0.08-0.33 years longer competition career.
- Significant but low heritabilities were present for health traits, where the sum of palpatory orthopaedic health (PALP) and of hooves (HOOF) showed highest heritabilities at 0.12 and 0.10 respectively. Orthopaedic health traits (PALP, LOCO and H2) were correlated to each other, whereas the genetic correlation between PALP and HOOF was low and non-significant.
- High overall conformation assessments often showed the highest relationships with good 4-5-year-old health status, but relationships were also seen between specific conformation traits and health. The majority of studied overall conformation traits, withers height and cannon bone circumference showed heritabilities in the range of 0.20-0.67 and favourable associations to one or several of the health traits H2, LOCO, PALP or HOOF. Best health status was

found for an intermediate-sized horse, with a well-positioned neck, a light front, and no major limb deviations. Correct movements at trot were important.

- Most important conformation traits for a high longevity were found to be high scores for type and movements at hand, particularly in trot. Regarding health status, the four summed/overall health examination results H2, LOCO, PALP and HOOF were all important for longevity and contributed with information not retrieved from the conformation examination.
- Flexion test results were found to contribute with unique information for prediction of future longevity that could not be retrieved from the conformation examination or the rest of the health examination. Moderate/severe flexion test reactions were associated with a 0.4 year shorter competition career than horses without such reactions.
- Found heritabilities for conformation and health, and the favourable genetic correlations between health, conformation, longevity and performance, indicated possibilities to improve population health through breeding. To enable possible improvements of health, breeding values for orthopaedic health and hooves, respectively, would have to be included in the genetic evaluation and selection practice. A suggestion of EBVs for health that may be employed is presented in the thesis.

# 8 Future research

A general lack of central documentation of health status in horses has resulted in a situation where knowledge of prevalence, importance and heritability of health traits generally has been scarce. Some of these questions may have been answered in this thesis, but this type of large and systematically recorded data set rather opens the doors to more questions, than providing the entire picture of the mechanisms of health traits. Below is a selection of future research topics that would add further value to our understanding of health traits and their importance in horses, especially from a breeding point of view.

- *Associations between osteochondrosis and PALP/LOCO findings*
  An interesting aspect would be to study how radiological findings such as osteochondrosis (OC) as studied by Jönsson *et al*. (2011) are associated to the results of this type of thorough and standardised clinical examinations, both regarding phenotypic effects and genetic correlations. Another interesting part of such a study would be to study the effects of OC on functional longevity.

- *Evaluation of specific talent traits for performance and health*
  Within the scope of this project, specific information on talent for performance in dressage and jumping, e.g. leg technique or use of back in jumping, were also digitised, but analyses of these traits were not possible to include in the present studies. In addition to the knowledge that presently has been retrieved for overall scores for talent, it would be interesting to evaluate genetic variation in specific descriptive talent traits, and study interrelationships and relationships to important conformation and health traits, and later success in competition.

- *Usefulness of genomic information*
  During the last years, genomic selection has been implemented in dairy cattle breeding and similar attempts are also seen in a few horse breeding associations.

It would be interesting to include health traits into that research field, to elucidate if genome information could contribute to a genetic evaluation for healthier and more durable horses, which requires good phenotypic recordings of health to be feasible.

- *Role of muscle atrophy on longevity*
  A somewhat surprisingly large effect of muscle atrophy was seen on NYC and LPERF, in particular for croup/hamstring muscles. As it is of low consideration today, the importance of this finding possibly has to be revised. Thus, more in depth studies of these types of findings would be interesting to perform.

- *Role of hoof quality on longevity*
  The overall sum of HOOF findings showed a heritability of 0.10 and significant correlations to NYC/LPERF, as did specific observations of hoof quality phenotypically. It would thus be interesting to continue study the role of the hoof for performance and longevity more in depth, as little consideration generally is given to this area today.

- *Temperament and health*
  Results showed that rideability and talents for sport are both affected by the health status of the horse. Some stallions with a reputation of producing offspring with bad temperament or rideability were also found to produce less healthy offspring. In the future it would be interesting to further study what associations may be present between temperament and rideability of the horse, and its health status.

- *Veterinary practice of reporting clinical findings*
  In the future it would also be interesting to further evaluate different regimes of health recordings among veterinarians or clinics, and relate them to future longevity of horses. Such comparisons between veterinarians could reveal what recording practices are the most accurate and informative for future studies, i.e. for defining thresholds of clinical findings before reporting as deviation from normal variation. This could be used as an aid in harmonisation of assessments between examiners at the RHQT, as well as for veterinary practice in the industry, e.g. for pre-sale examinations.

- *Effects of environmental factors as training, rider and feeding*
  For most of the above mentioned research topics it would be interesting also to evaluate the role of factors such as training intensity/strategy and feeding on

health status and longevity of riding horses, preferably in combination with information on genetic factors.

- *Compensatory lesions*
  It would be interesting to further study how a clinical finding in one location influence health status in other parts of the horse, what differences are seen e.g. regarding findings in fore- and hindlimb locations, respectively, and to evaluate what findings are causal or not when several clinical findings coincide. Also, possible differences in occurrence of clinical findings between the "strong" and the "weak" side of the horse would be interesting to study. It would also be interesting to elaborate under what circumstances a poor conformation produces poor health, and when on the contrary a poor health status may be causative for a lower conformation evaluation where, e.g. posture or movements may be influenced.

# 9 Samband mellan hälsa, exteriör och hållbarhet

## 9.1 Bakgrund

Ridhästars hälsa och hållbarhet är viktiga faktorer för bra tävlingsprestation, för den allmänna hästvälfärden, samt för enskilda hästägares ekonomi. Eftersom utbildningen av en ridhäst tar flera år, där tävlingshästar når den högsta nivån först vid ca 10-12 års ålder, sker stora tidsmässiga och ekonomiska investeringar för varje producerad häst. Därför är det viktigt att hästen kan hållas frisk under och efter utbildningsperioden. En stor del av de hästar som döms ut från ridhästverksamhet (50-70%) uppvisar någon typ av hälsostörning i rörelseapparaten (Sloet van Oldruitenborgh-Oosterbaan *et al.*, 2010; Egenvall *et al.*, 2006b; Wallin *et al.*, 2000). Detta har bidragit till att både för svenska och utländska ryttare som söker häst, är ett bra hälsotillstånd högst prioriterat, före t.ex. hästens talang eller härstamning (Hennessy *et al.*, 2008; Jönsson, 2006).

En strävan att producera korrekta, prestationsdugliga och hållbara ridhästar genom avel finns uttryckt i avelsmålet för den svenska varmblodiga hästen som lyder: *”En ädel, korrekt och hållbar varmblodshäst som genom sitt prestationsinriktade temperament, sin ridbarhet, goda rörelser och/eller hoppförmåga är konkurrenskraftig internationellt”* (Swedish Warmblood Association, 2013a). Kunskapen har tidigare varit väldigt begränsad kring förekomst av olika hälsostörningar, och vad de har för arvbarhet eller samband med andra egenskaper i avelsmålet som t.ex. exteriör eller prestation. Därför har man tidigare inte kunnat erbjuda avelsvärdering för hälsoegenskaper, så som man kunnat för prestationsegenskaper. Bristen på kunskap kring hälsoegenskaper gäller även internationellt, eftersom man inom hästnäringen inte har en tradition av att dokumentera hälsoundersökningar centralt på ett enhetligt sätt. I Sverige har man haft en standardiserad dokumentering av ridhästars hälsotillstånd som genomförts i samband med den s.k. kvalitetsbedömningen av 4-5 åriga ridhästar, och som är världsunik inom hästnäringen. Den sträcker sig över en tidsperiod på över 30 år, där hälsan hos varje kvalitetsbedömd häst dokumenterats på ett standardiserat sätt.

Denna unika hälsoregistrering har först nu, efter digitalisering av alla uppgifter och överföring till en databas, kunnat utvärderas fullt ut.

## 9.2 Sammanfattning av studierna

Studierna bygger på information från drygt 8000 kvalitetsbedömda 4-5 åriga hästar som undersökts under åren 1983-2005 för hälsotillstånd, exteriör och talang för hoppning och dressyr. Samma hästar följdes därefter upp genom tävlingsresultat under åren 1983-2012. Som mått på hållbarhet användes antalet aktiva tävlingsår. Därutöver användes livstidsprestation, beräknad som ackumulerade uppklassningspoäng i tävling.

Kvalitetsbedömningsmaterialet visade sig vara väl lämpat för att kunna belysa olika exteriöra och veterinärt registrerade egenskapers arvbarhet och samband med hästars hållbarhet i tävling. Resultaten visade att hästens hälsa som 4-5 åring hade signifikanta samband med hur hållbar hästen var i framtiden. Detta gällde både palpatoriskt hälsotillstånd (PALP), hältor före och/eller efter böjprov (LOCO), hovstatus (HOOF) och bedömningen av hästens sammantagna ortopediska hälsostatus (H2). Böjprovsreaktioner visade sig ha ett tydligt samband med hästens senare hållbarhet i tävling. Sambanden fanns både för uppvisad hälsa hos undersökta hästar där både genetiken och miljön spelar roll (fenotypiskt), och i fråga om genetiska samband, där bara den genetiska delen av ett hälsotillstånd utvärderas. Enbart den genetiska delen av hälsotillståndet kan föras vidare via avel. Högst arvbarhet hade palpatoriskt hälsotillstånd, t.ex. gallor och svullnader, samt hovarnas form och kvalitet med skattningar mellan 0.10-0.14, d.v.s. värden som är av samma storlek som för hållbarhetsegenskaper hos andra husdjursslag.

Ett gott hälsotillstånd visade sig också ha tydliga samband med en hög exteriör- och talangbedömning som 4-5 åring, med genetiska samband upp till 0.75 på en skala mellan 0 och 1 (-1). Bäst hälsa och hållbarhet hade medelstora hästar med god typ och huvud-hals-bål samt någorlunda korrekta rörelser i trav vid hand under exteriörbedömningen. Detaljbeskrivningar av hästarna visade att det för hälsa och hållbarhet framförallt var fördelaktigt med välproportionerliga och långlinjerade hästar med väl ansatt, relativt lång hals samt långt kors. Flera av detaljbeskrivningarna för hästens rörelser i trav tydde på att denna rörelsebedömning ger en bra bild av hästens sammantagna exteriöra förutsättningar för korrekt och därmed hälsosamt arbete.

Resultaten visade att en bra hälsa och exteriör är viktigt för alla hästar oavsett talang för dressyr eller hoppning, även om exteriören, och särskilt hästens rörelser i skritt och trav, har störst betydelse för blivande dressyrhästar. I avel för hopphästar bör man alltså med fördel också ta fortsatt hänsyn till hästens exteriör. I dressyrhästaveln bör man som väntat fortsätta att lägga stor vikt vid en bra typ och

korrekta goda rörelser. Man bör också ha i åtanke att höga betyg för gångarter i denna studie var kopplat till en högre mankhöjd än vad som är optimalt för hälsa och hållbarhet. Detta innebär att man inte bör premiera de allra största hästarna fullt så mycket inom dressyraveln, om man vill uppnå ett bra hälsotillstånd i populationen.

Resultaten tyder på att det går att förbättra ridhästpopulationens hälsa genom avel eftersom det finns en tydlig genetisk variation i hälso-, exteriör- och prestationsegenskaper samt i hållbarhet mätt som antal tävlingsår. Dessa egenskaper är lyckligtvis gynnsamt korrelerade med varandra. Hälsotillståndet har genom åren förbättrats marginellt, trots frånvaro av en avelsvärdering för hälsa, förmodligen som ett indirekt resultat av ett avelsarbete för bättre exteriör och livstidsprestationer, som är kopplade till hälsa. Men framsteget är litet och för att få en verklig effekt skulle man behöva skatta avelsvärden även för hovkvalitet och för ortopediskt hälsotillstånd. Det senare skulle med fördel innehålla information om eventuella hältor före och/eller efter böjprov (LOCO), palpatoriskt hälsotillstånd (PALP) och bedömt sammantaget ortopediskt hälsotillstånd (H2). I avhandlingen redovisas hur sådana avelsindex för hingstar kan se ut för ortopediskt hälsotillstånd och hovkvalitet.

## 9.3 Slutsatser

Det finns tydliga samband mellan en god exteriör och ett gott hälsotillstånd och talang för ridsportens discipliner. Både exteriör och hälsa registrerade vid kvalitetsbedömningen har visat sig bidra med viktig information om hästens framtida hållbarhet och prestation i tävling. Sambanden gäller både för dressyr och hopphästar. Både för stora och för små hästar är negativt för hälsotillstånd, hållbarhet och prestation i tävling. Det finns en risk att alltför stora hästar premieras inom dressyraveln jämfört med vad som är optimalt för ett gott hälsotillstånd och bra hållbarhet.

Betydande genetisk variation i exteriör samt även till viss del hälsa, tillsammans med gynnsamma genetiska korrelationer mellan hälsa, exteriör, hållbarhet och prestation, tyder på goda möjligheter att förbättra populationens hälsotillstånd genom avel. För att möjliggöra detta skulle man behöva ta större hänsyn till hälsoegenskaper i det praktiska avelsarbetet genom att skatta avelsvärden även för ortopedisk hälsa och för hovegenskaper. För att detta ska kunna ske behöver hälsobedömningen återinföras vid unghästbedömningarna.

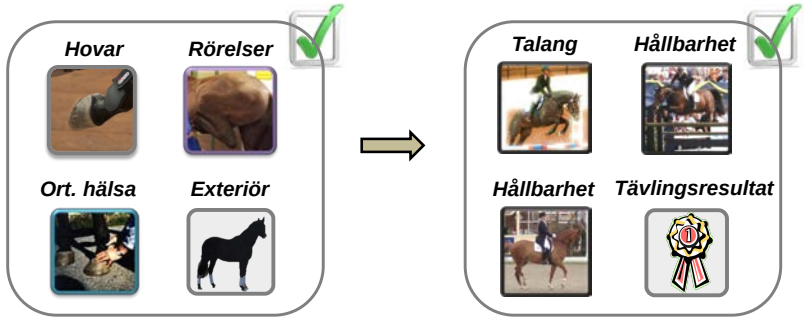



*Figure 12.* En god ortopedisk hälsa, bra hovar och bra exteriör främjar talangbedömningen vid samma dag samt hållbarhet och prestation i framtida tävling.

## 9.4 Framtida forskning

Vidare studier skulle behövas för att förstå:

- Hur hälsoresultaten från kvalitetsbedömningen relaterar till hästens röntgenstatus för t.ex. osteochondros.
- Hur specifika egenskaper i gångarter och hoppning är associerade till totalbetygen för respektive disciplin, samt till viktiga hälso- och exteriöregenskaper, hållbarhet och framgång i framtida tävling.
- Om information om hästens genom, via genetiska markörer, skulle kunna bidra till information i en avelsvärdering för bättre hälsa.
- Hur dokumentation om hovegenskaper samt atrofierade muskler bör uppmärksammas på ett bättre sätt, eftersom de visade större kopplingar till hästens hållbarhet än man tidigare antagit att de har.
- Om det kan finnas ett samband mellan dåligt temperament eller dålig ridbarhet och ett sämre hälsotillstånd hos hästar.
- Vilken nivå av noggrannhet veterinärer bör tillämpa när avvikelser från det ”normala” ska dokumenteras, för att registreringen ska ge bäst information om hästens framtida hållbarhet.
- Vilka effekter miljöfaktorer som träningsupplägg och utfodring har på framtida hållbarhet, gärna i kombination med information om genetiska förutsättningar.
- Vilka hälso- och exteriörmässiga anmärkningar som är ursprunglig orsak till problemen och vilka som istället har uppkommit till följd av de första p.g.a. till exempel kompensatorisk belastning.

# 10 References


Adams, O.R. & Baxter, G.M. (2011). *Adams and Stashak's lamness in horses, 6th edition*. Ames, Iowa: Wiley-Blackwell. pp 1-1272.

Albertsdóttir, E., Eriksson, S., Sigurdsson, Á. & Árnason, T. (2011). Genetic analysis of 'breeding field test status' in Icelandic horses. *J Anim Breed Genet* 129(2), 41-49.

Anderson, T., McIlwraith, C. & Douay, P. (2004). The role of conformation in musculoskeletal problems in the racing horse. *Equine Vet J* 36(7), 571-575.

Arnason, T., Darenius, A. & Philipsson, J. (1982). Genetic selection indicies for Swedish trotter broodmares. *Livest Prod Sci* 8(6), 557-565.

Becker, A.-C., Stock, K. & Distl, O. (2013). Correlations of unfavourable movement characteristics in warmblood foals and mares with routinely assessed conformation and performance traits. *Animal* 7(1), 11-21.

Beeman, G.M. Correlation of defects in conformation to pathology in the horse. In: *Proceedings of the 19th annual convention of the American Association of Equine Practitioners (AAEP)*, Atlanta, Georgia, Dec 1973. pp. 177-197.

Biau, S., Couve, O., Lemaire, S. & Barrey, E. (2002). The effect of reins on kinetic variables of locomotion. *Equine Vet J* Suppl. 34, 359-362.

Bonnett, B.N. & Egenvall, A. (2010). Age patterns of disease and death in insured Swedish dogs, cats and horses. *J Comp Path* 142, S33-S38.

Braam, Å., Näsholm, A., Roepstorff, L. & Philipsson, J. (2011). Genetic variation in durability of Swedish Warmblood horses using competition results. *Livest Sci* 142(1), 181-187.

Buch, L.H., Sörensen, M.K., Lassen, J., Berg, P., Jakobsen, J.H., Johansson, K. & Sörensen, A.C. (2011). Udder health and female fertility traits are favourably correlated and support each other in multi-trait evaluations. *J Anim Breed Genet* 128, 174-182.

Busschers, E. & van Weeren, P.R. (2001). Use of flexion test of the distal forelimb in the sound horse: repeatability and effect of age, gender, weight, height and fetlock joint range of motion. *J Vet Med Assoc* 48, 413-427.

Clausen, v.M., Preisinger, R. & Kalm, E. (1990). Analyse von Krankenheitsdaten in der Deutschen Warmblutzucht. *Züchtungskunde* 62(3), 167-178.

Darenius, A., Philipsson, J., Fredricson, I., Thafvelin, B., Bergsten, G., Rådberg, L. & Elowson-Anda, E. (1983). Kvalitetsbedömning av unga ridhästars hälsotillstånd, exteriör och ridegenskaper. *Svensk veterinärtidning* 35, suppl. 3, 42-48.

Dempster, E.R. & Lerner, I.M. (1949). Heritability of threshold characters. *Genetics* 35, 212-236.

Denoix, J. Functional anatomy of the Equine interphalangeal joints. In: *Proceedings of the Annual convention of the American Association for Equine Practitioners (AAEP)* 1999. pp. 174-177.

Dolvik, N.I. & Gaustad, G. (1996). Estimation of the heritability of lameness in standardbred trotters. *Vet Rec* 138, 540-542.

Ducro, B., Bovenhuis, H. & Back, W. (2009a). Heritability of foot conformation and its relation to sports performance in a Dutch Warmblood horse population. *Equine Vet J* 41, 139-143.

Ducro, B., Gorissen, B., van Eldik, P. & Back, W. (2009b). Influence of foot conformation on length of competitive life in a Dutch Warmblood population. *Equine Vet J* 41, 144-148.

Ducro, B., Koenen, E.P.C., Van Tartwijk, J.M.F.M. & Bovenhuis, H. (2007). Genetic relations of movements and free-jumping traits with dressage and show-jumping performance in competition of Dutch Warmblood horses. *Livest Sci* 107, 227-234.

Dyson, S.J. Lameness and poor performance in the sport horse: Dressage, show jumping and horse trials (eventing). In: *Proceedings of the annual convention of the American Association for Equine Practitioners (AAEP)* 2000. pp. 308-315.

Egenvall, A., Bonnett, B.N., Olson, P., Penell, J.C. & Emanuelson, U. (2006a). Association between costly veterinary-care events and 5-year survival of Swedish insured warmblooded riding horses. *Prev Vet Med* 77, 122-136.

Egenvall, A., Nødtvedt, N., Roepstorff, L. & Bonnett, B.N. (2011). Integrating databases for research on health and performance in small animals and horses in the Nordic countries. *Acta Vet Scand* 53(Suppl 1):S4, doi: 10.1186/1751-0147-53-S1-S4.

Egenvall, A., Penell, J.C., Bonnett, B.N., Olson, P. & Pringle, J. (2006b). Mortality of Swedish horses with complete life insurance between 1997 and 2000: variations with sex, age, breed and diagnosis. *Vet Rec* 158, 397-406.

Eliasson, C. (1997). Samband mellan resultat i kvalitetsbedömning och förberedelse av hästen samt med hästägarens ryttarerfarenhet [Correlation between Riding Horse Quality Test results and previous training of the horse and trainer experience]. *Master thesis no. 182, Department of Animal Breeding and Genetics. Swedish University of Agricultural Sciences*, 1-48.

Frykman, Å., Lagerquist, U., Roethlisberger Holm, K. & Winberg, F. (2012). *Besiktning av häst*. Stockholm: Sveriges Veterinärförbund och Hästsektionen inom Sveriges Veterinärmedicinska Sällskap. pp1-112.

Furre, S., Viklund, Å., Heringstad, B., Philipsson, J. & Vangen, O. (2013). Improvement in the national genetic evaluation of warmblood riding horses by including information from related studbooks. *Acta Agr Scand A–An*, 1-8.

Gnagey, L., Clayton, H.M. & Lanovaz, J.L. (2006). Effect of standing tarsal joint angle on joint kinematics and kinetics. *Equine Vet J* 38(7), 628-633.

Hayes, B. & Goddard, M. (2010). Genome-wide association and genomic selection in animal breeding. *Genome* 53(11), 876-83.

Hedge, J. (2004). *Horse conformation: structure soundness and performance*. Guilford, Connecticut: The Lyons Press. pp1-484.

Hennessy, K.D., Quinn, K.M. & Murphy, J. (2008). Producer or purchaser: Different expectations may lead to equine wastage and welfare concerns. *J Appl Anim Welf Sci* 11(3), 232-235.

Holmström, M., Magnusson, L.-E. & Philipsson, J. (1990). Variation in conformation of Swedish warmblood horses and conformational characteristics of elite sport horses. *Equine Vet J* 22(3), 186-193.

Holmström, M. & Philipsson, J. (1993). Relationships between conformation, performance and health in 4-year-old Swedish Warmblood Riding Horses. *Livest Prod Sci* 33, 293-312.

Holroyd, K., Dixon, J., Mair, T., Bolas, N., Bolt, D., David, F. & Weller, R. (2012). Variation in foot conformation in lame horses with different foot lesions. *The Vet J* doi: http://dx.doi.org/10.1016/j.tvjl.2012.07.012.

Houe, H., Egenvall, A., Virtala, A.-M., Olafsson, T. & Østerås, O. (2011). Databases in veterinary medicine - validation, harmonisation and application: introduction. *Acta Vet Scand* 53 (Suppl 1):S1, doi: 10.1186/1751-0147-53-S1-S1.

Interstallion. In: *Proceedings of Interstallion workshop on linear scoring in sport horses - experiences of current practice and potential developments*, Arlanda, Sweden, Dec 2011: Retrieved 13 Feb 2013, http://www.biw.kuleuven.be/genlog/livgen/chgs_is_Seminars.html.

Ireland, J.L., Clegg, P.D., McGowan, C.M., McKane, S.A., Chandler, K.J. & Pinchbeck, G.L. (2012). Disease prevalence in geriatric horses in the United Kindom: Veterinary clinical assessment of 200 cases. *Equine Vet J* 44(1), 101-106.

Jönsson, L. (2006). *Den svenska varmblodiga hästens avelsmål - en enkätundersökning och analys av genetiska trender [The Swedish warmblood breeding goal - a survey and analysis of genetic trends]*. Master thesis No. 285. Swedish University of Agricultural Sciences, Uppsala.

Jönsson, L., Dalin, G., Egenvall, A., Näsholm, A., Roepstorff, L. & Philipsson, J. (2011). Equine hospital data as a source for study of prevalence and heritability of osteochondrosis and palmar/plantar osseous fragments of Swedish Warmblood horses. *Equine Vet J* 43 (6), 695-700.

Keegan, K.G., Dent, E.V., Wilson, D.A., Janicek, J., Kramer, J., Lacarrubba, A., Walsh, D.M., Cassells, M.W., Esther, T.M., Schiltz, P., Frees, K.E., Wilhite, C.L., Clark, J.M., Pollitt, C.C., Shaw, R. & Norris, T. (2010). Repeatability of subjective evaluation of lameness in horses. *Equine Vet J* 42(2), 92-97.

Keg, P.R., van Weeren, P.R., Schamhardt, H.C. & Barneveld, A. (1997). Variations in the force applied to flexion tests of the distal limb of horses. *Vet Rec* 141, 435-438.

Koenen, E.P.C., Aldridge, L.I. & Philipsson, J. (2004). An overview of breeding objectives for warmblood sport horses. *Livest Prod Sci* 88, 77-84.

Koenen, E.P.C., van Veldhuizen, A.E. & Brascamp, E.W. (1995). Genetic parameters of linear scored conformation traits and their relation to dressage and show-jumping performance in the Dutch Warmblood Riding Horse population. *Livest Prod Sci* 43, 85-94.

Lönnell, A.C., Bröjer, J., Nostell, K., Hernlund, E., Roepstorff, L., Tranquille, C.A., Murray, R.C., Oomen, A., Van Weeren, R., Bitschnau, C., Montavon, S., Weishaupt, M.A. & Egenvall, A. (2013). Variation in training regimens in professional show jumping yards. *Equine Vet J* doi: 10.1111/evj.12126.

Love, S., Wyse, C., Stirk, A., Stear, M., Calver, P., Voute, L. & Mellor, D. (2006). Prevalence, heritability and significance of musculoskeletal conformational traits in Thouroughbred yearlings. *Equine Vet J* 38(7), 597-603.

Madsen, P. & Jensen, J. (2010). An User´s Guide to DMU. A package for analysing multivariate mixed models. Version 6, release 5. *Danish Institute of Agicultural Science, Department of Animal Breeding and Genetics, Research center Foulum, Tjele, Denmark*, 1-30.

Magnusson, L.-E. & Thafvelin, B. (1985a). *Studies on the conformation and related traits of Standardbred trotters. III The orthopedic health status of the Standardbred trotter at 4 years of age.* Diss. Skara: Doctoral thesis. Swedish University of Agricultural Sciences.

Magnusson, L.-E. & Thafvelin, B. (1985b). *Studies on the conformation and related traits of Standardbred trotters. IV. Relationships between the conformation and soundness of 4-year-old Standardbred trotters.* Diss. Skara: Doctoral thesis. Swedish University of Agricultural Sciences.

Magnusson, L. (2006). *Hästens exteriör, prestation och hållbarhet*. Malmö: Liber AB. pp 1-114.

Mathworks (2010). Version 7.11. Matlab users guide, retrieved 13th Dec 2012, http://www.mathworks.se/help/techdoc/matlab_product_page.html

Meagher, D., Bromberek, J., Meagher, D., Gardner, I., Puchalski, S. & Stover, S. (2013). Prevalence of abnormal radiographic findings in 2-year-old Thoroughbreds at in-training sales and associations with racing performance. *J Am Vet Med Assoc* 242(7), 969-976.

Meuwissen, T., Hayes, B. & Goddard, M. (2001). Prediction of total genetic value using genome-wide dense marker maps. *Genetics* 157, 1819-1829.

Mikko, S., Eriksson, S. & Viklund, Å. Genetic background to performance traits in Swedish Warmblood (SWB). In: *Proceedings of the 10th Dorothy Russell Havemeyer Foundation International Horse Genome Workshop*, Azores, Portugal, July 2013. p. 154.

Misztal, I. & Gianola, D. (1989). Computing aspects of a nonlinear method of sire evaluation for categorical data. *J Dairy Sci* 72, 1557-1568.

Orr, N., Hill, E., Gu, J., Govindarajan, P., Conroy, J., Van Grevenhof, E.M., Ducro, B., Van Arendonk, J.A.M., Knaap, J., Van Weeren, P.R., MacHugh, D., Ennis, S. & Brama, P. (2012). Genome-wide association study of osteochondrosis in the tarsocrural joint of Dutch Warmblood horses identifies susceptibility loci on chromosomes 3 and 10. *Anim Genet* DOI: 10.1111/age.12016.

Penell, J.C., Egenvall, A., Bonnett, B.N., Olson, P. & Pringle, J. (2005). Specific causes of morbidity among Swedish horses insured for veterinary care between 1997 and 2000. *Vet Rec* 157, 470-477.

Philipsson, J. (2011). Interbull developments, global genetic trends and role in the era of genomics. *Interbull bulletin* 44, I-XIII.

Philipsson, J. & Lindhé, B. (2003). Experiences of including reproduction and health traits in Scandinavian dairy cattle breeding programmes. *Livestock Production Science* 83(2–3), 99-112.

Posta, J., Komlosi, I. & Mihok, S. (2009). Breeding value estimation in the Hungarian sport horse population. *Vet J* 181, 19-23.

Rhodin, M., Goméz, A., Byström, A., Johnston, C., van Weeren, P.R., Roepstorff, L. & Weishaupt, M. (2009). The effect of different head and neck positions on the caudal back and hindlimb kinematics in the elite dressage horse at trot. *Equine Vet J* 41(3), 274-279.

Ricard, A. & Blouin, C. (2011). Genetic analysis of the longevity of French sport horses in jumping competition. *J Anim Sci* 89, 2988-2994.

Ricard, A., Danvy, S. & Legarra, A. (2012). Computation of deregressed proofs for genomic selection when own phenotypes exist with an application in French show-jumping horses. *J Anim Sci* doi: 10.2527/jas.2012-5256

Ricard, A., Valette, J. & Denoix, J. Heritability of juvenile osteo-articular lesions of sport horses in France. In: *Proceedings of the 7th World Congress on Genetics Applied to Livestock Production (WCGALP).* Montpelliére, France, August 2002. Session 05-08.

Ruhlmann, C., Janssens, S., Philipsson, J., Thorén-Hellsten, E., Crolly, H., Quinn, K., Manfredi, E. & Ricard, A. (2009). Genetic correlations between horse show jumping competition traits in five European countries. *Livestock Science* 122(2–3), 234-240.

Rustin, M., Janssens, S., Buys, N. & Gengler, N. (2009). Multi-trait animal model estimation of genetic paramenters for linear type and gait traits in the Belgian warmblood horse. *J Anim Breed Genet* 126, 378-386.

Saastamoinen, M.T. & Ojala, M.J. (1991). Estimates of genetic and phenotypic parameters for racing performance in young trotters. *Acta Agr Scand* 41(4), 427-436.

SAS Insitute Inc (2012). SAS Online doc 9.2, Cary, NC, SAS Institute Inc, retrieved 12th Dec, 2012, http://support.sas.com/documentation/

Schöpke, K. (2011). *Entwicklung einer Zuchtwertschätzung für das Deutsche Sportpferd.* Diss. Halla/Saale: Doctoral thesis. Martin-Luther-Universität Halle-Wittenberg.

Schröder, W., Klostermann, A., Stock, K.F. & Distl, O. (2012). A genome-wide association study for quantitative trait loci of show-jumping in Hanoverian warmblood horses. *Animal Genetics* 43(4), 392-400.

Sloet van Oldruitenborgh-Oosterbaan, M., Genzel, W. & van Weeren, P.R. (2010). A pilot study on factors influencing the career of Dutch sport horses. *Equine Vet J* 42 Suppl. 38, 28-32.

SOU (2006). *Statens offentliga utredningar (SOU 2006:13): Djurskydd vid hästavel. Delbetänkande om djurskydd i hästaveln.* Stockholm 2006

Stock, K. & Distl, O. (2006). Genetic correlations between conformation traits and radiographic findings in the limbs of German riding horses. *Genet Sel Evol* 38, 657-671.

Stock, K. & Distl, O. (2008). Multiple-trait selection for radiographic health of the limbs, conformation and performance in Warmlood riding horses. *Animal* 2(12), 1724-1732.

Stock, K.F. & Distl, O. (2005). Survey on the development of Hanoverian Warmblood horses selected for sale at auction in 1991 to 1998. *J Equine Vet Sci* 25(5), 210-223.

Stock, K.F., Hamann, H. & Distl, O. (2005). Estimation of genetic parameters for the prevalence of osseous fragments in limb joints of HanoverianWarmblood horses. *J Anim Breed Genet* 122, 271-280.

Swedish Equestrian Federation (2003). *Ridhandboken. 1, Grundutbildning för ryttare och häst.* Kolbäck: Svenska ridsportförbundet. pp1-224.

Swedish Warmblood Association (2013a). Breeding plan, retrieved 18th Jan, 2013, http://www.asvh.se/avel/avelsplan

Swedish Warmblood Association (2013b). Website of estimated breeding values (EBVs) for Swedish warmblood horses, retrieved 19th June, 2013, http://www.blup.se

Thafvelin, B. & Magnusson, L.-E. (1985). *Studies on the conformation and related traits of Standardbred trotters. V. Relationships between the conformation and performance of 4-year-old Standardbred trotters.* Diss. Skara:Doctoral thesis. Swedish University of Agricultural Sciences.

Thorén Hellsten, E. (2008). *International sport horse data for genetic evaluation.* Diss. Uppsala: Doctoral thesis No 2008:32. Swedish University of Agricultural Sciences.

Thorén Hellsten, E., Jorjani, H. & Philipsson, J. (2008). Connectedness among five European sport horse populations. *Livest Sci* 118:1, 147-156.

Thorén Hellsten, E., Jorjani, H. & Philipsson, J. (2009). Genetic correlations between similar traits in the Danish and Swedish Warmblood sport horse populations. *Livest Sci* 124(1), 15-20.

van Grevenhof, E.M., Ducro, B.J., van Weeren, P.R., van Tartwijk, J.M.F.M., van den Belt, A.J. & Bijma, P. (2009a). Prevalence of various radiographic manifestations of osteochondrosis and their correlations between and within joints in Dutch warmblood horses (KWPN). *Equine Vet J* 41(1), 11-16.

van Grevenhof, E.M., Schurink, A., Ducro, B.J., van Weeren, P.R., van Tartwijk, J.M.F.M., Bijma, P. & van Arendonk, J.A.M. (2009b). Genetic parameters of various manifestations of osteochondrosis and their correlations between and within joints in Dutch warmblood horses. *Journal of Animal Science* 87, 1906-1912.

van Weeren, P.R., McGowan, C.M. & Haussler, K.K. (2010). Science overview: Development of a structural and functional understanding of the equine back. *Equine Vet J* 42 Suppl. 38, 393-400.

Verwilghen, D., Janssens, S., Busoni, V., Pille, F., Johnston, C. & Serteyn, D. (2013). Do developmental orthopaedic disorders influence future jumping performances in Warmblood stallions? *Equine Vet J* Doi: 10.1111/evj.12027.

Vigre, H., Chriel, M., Hesselholt, M., Falk-Rønne, J. & Kjaer Ersbøll, A. (2002). Risk factors for the hazard of lameness in Danish Standardbred trotters. *Prev Vet Med* 56, 105-117.

Viklund, Å. (2010). *Genetic evaluation of Swedish warmblood horses.* Diss. Uppsala: Doctoral thesis No 2010:48. Swedish University of Agricultural Sciences.

Viklund, Å., Braam, Å., Näsholm, A., Strandberg, E. & Philipsson, J. (2010). Genetic variation in competition traits at different ages and time periods and correlations with traits at field tests of 4-year-old Swedish Warmblood horses. *Animal* 4(5), 682-691.

Viklund, Å., Näsholm, A., Strandberg, E. & Philipsson, J. (2011). Genetic trends for performance of Swedish Warmblood horses. *Livestock Science* 141(2), 113-122.

Viklund, Å., Thorén Hellsten, E., Näsholm, A., Strandberg, E. & Philipsson, J. (2008). Genetic parameters for traits evaluated at the field tests of 3- and 4-year-old Swedish Warmblood horses. *Animal* 2(12), 1832-1841.

Wallin, L. (2001). *Longevity and early prediction of performance in Swedish horses.* Diss. Uppsala: Doctoral thesis No 288. Swedish University of Agricultural Sciences.

Wallin, L., Strandberg, E. & Philipsson, J. (2001). Phenotypic relationship between test results of Swedish Warmblood horses as 4-year-olds and longevity. *Livest Prod Sci* 68, 97-105.

Wallin, L., Strandberg, E. & Philipsson, J. (2003). Genetic correlations between field test results of Swedish Warmblood Riding Horses as four-year-olds and lifetime performance results in dressage and show jumping. *Livest Prod Sci* 82, 61-71.

Wallin, L., Strandberg, E., Philipsson, J. & Dalin, G. (2000). Estimates of longevity and causes of culling and death in Swedish warmblood and coldblood horses. *Livest Prod Sci* 63, 275-289.

Weller, R., Pfau, T., Verheyen, K., May, S. & Wilson, A. (2006). The effect of conformation on orthopaedic health and performance in a cohort of National Hunt racehorses: preliminary results *Equine Vet J* 38(7), 622-627.

Wijnberg, I., Sleutjens, J., van der Kolk, J. & Back, W. (2010). Effect of head and neck position on outcome of quntitative neuromuscular diagnostic techniques in Warmblood riding horses directly following moderate exercise. *Equine Vet J* 42 Suppl. 38, 261-267.

Wrangel, C.G. (1887). *Handbok för hästvänner I*. Stockholm: Albert Bonniers Förlag. pp 1-1347.

# 11 Acknowledgements

The studies included in this thesis were performed at the Department of Animal Breeding and Genetics, Swedish University of Agricultural Sciences (SLU). The Swedish-Norwegian foundation for Equine Research is gratefully acknowledged for funding the project, as well as the Swedish Warmblood Association and the Swedish Equestrian Federation for providing studied data. Travel grants from the SLU funds for internationalisation of postgraduate studies made it possible for me to participate in conferences during my research education.

During my PhD education I have had the opportunity to get to know a lot of people that have been vital to my development professionally as well as personally – thank you for always being willing to help as I unexpectedly have popped into your office! There are a number of people I would like to thank a little extra:

Till min handledargrupp Jan Philipsson, Lars Roepstorff, Agneta Egenvall, Anna Näsholm och Göran Dalin, trots många handledare med många åtaganden har vi fått till ett **kanon**team där jag fått expert hjälp på alla områden, jag är så tacksam för allt ni gjort för mig!

Till min huvudhandledare Jan: du inspirerade mig att börja jobba med hälsodata på häst och jag har inte ångrat det en dag! Du är en av de som startade hälsoregistreringarna på ridhästar, som du så osjälviskt låtit mig använda. Utan dig hade inte projektet funnits! Du har gett mig verktygen att arbeta mer och mer självständigt som förberedelse till att snart kunna stå på egna ben och du har introducerat många viktiga arbetskontakter.

Till Agneta Egenvall för ditt stöd och support i de allra tuffaste stunderna av projektet! När det verkligen gäller är du där, oavsett hur svår din egen situation är. Tack också för nyttiga ifrågasättanden och nya synvinklar under projektets gång, det har gett ett stort värde för projektets utveckling!

Till Lars som varit nyckelperson till att Matlabprogrammeringen skulle fungera, utan dig hade det inte blivit någon digital tolkning av protokollen, då hade jag garanterat suttit och matat in rådata större delen av projektet! Samtidigt har jag lärt

mig massor om hur man arbetar i Matlab. Tack också för alla värdefulla infallvinklar från en klinikers perspektiv i processen att tolka resultaten.

Till Anna, tack för att du alltid funnits nära till hands att svara på stora som små frågor, och för hjälpen att praktiskt genomföra analyser som vi kommit fram till vid handledarmötena. Du har varit ett stor stöd i vardagen!

Till Göran, tack för att du är så givmild med din veterinärmedicinska kunskap och erfarenhet, och för den positiva energi du sprider. Du ska veta att alla dina positiva kommentarer kring projektet har värmt varje gång och hjälpt till att skapa ny energi för det fortsatta arbetet!

Till härliga, härliga hästgänget på Hgen: Åsa Viklund, Emma Thorén Hellsten, Elisabeth Olsson, Åsa Braam, Sofia Mikko, Sofia Folestam, Louise Lindberg och Susanne Eriksson, vi har varit ett vinnande koncept, och ni har alltid förgyllt arbetsdagarna. Ett speciellt tack till Åsa, utan dig hade jag inte vågat ta det stora klivet till hästägare – bästa beslutet någonsin! ☺

Alla härliga människor som varit doktorander på Hgen under min tid här, tack för stöttning, hjälp och inspiration!

Till alla i administrativa personalen som alltid hjälpt till under åren med stort och smått inte minst Dan, Harriet och Jörgen – ni är oumbärliga!

Till Carola min barndomsvän som alltid känns som igår att prata med oavsett hur länge sen det var vi senast sågs. Det var du som övertalade mig att börja rida tillsammans med dig. Även om inte hästar var något stort intresse för mig just då följde jag med för att prova på, sen den dagen var jag fast ☺

Till Malin Persson fd. Bengtsson, och Jan-Erik Bengtsson med familjer på Gränsgård, där intresset för tävlingshästar och avel föddes på riktigt. Tack för all värdefull kunskap och erfarenhet ni gett mig under åren!

Till Eva Rigmar-Cederberg och Görel Nyman för ert förtroende att träna era fina uppfödningar genom åren i Uppsala, och mina trogna tränare i Uppsala, Mats Samuelsson, Lotta Pettersson, Anette Johansson och Ann-Sofie Oscarsson som så många gånger hjälpt till att komma framåt i utvecklingen. Ni har alla hjälpt mig att utveckla min praktiska erfarenhet av hästar och träning.

Mina agronomtjejer, samt Nathalie Nordberg och Sara Gustafsson, vilka minnen vi har tillsammans från skol/studenttiden, tjejhelger, Arons hus-semestrar och mycket, mycket annat! Ni är bäst!

Till min mamma och pappa med familj, samt min släkt, speciellt morfar, som alltid stöttat mig i att flytta till Uppsala och därefter stanna kvar som doktorand, även om ni egentligen vill ha hem mig ☺ Ni är guld värda och jag skulle inte kunnat göra något av detta utan ert stöd! Ni har alltid stöttat och trott på mig och velat veta mer om vad jag gör. Och sist men inte minst till mina fyrbenta följeslagare Hvide, Izor och Kenzo som tålmodigt väntar på matte stressiga dagar och ger en energin åter på ett kick!