Physiological response to exercise in the Icelandic horse

Guðrún Jóhanna Stefánsdóttir
Faculty of Veterinary Medicine and Animal Science
Department of Animal Nutrition and Management
Uppsala

Doctoral Thesis
Swedish University of Agricultural Sciences
Uppsala 2015

Acta Universitatis agriculturae Sueciae
2015:84

Cover: Viti from Kagaðarhóli, a five-year-old stallion and his rider Gísli Gíslason, at a breeding show in Reykjavík 2012.

Photographer: Óðinn Örn Jóhannsson.

Photo processing: Þorkell Magnússon.

ISSN 1652-6880
ISBN (print version) 978-91-576-8366-3
ISBN (electronic version) 978-91-576-8367-0

Print: SLU Service/Repro, Uppsala 2015

Physiological response to exercise in the Icelandic horse.

Abstract

This thesis examined the exercise physiology of the Icelandic horse by: 1) studying physiological response in stallions and mares of different ages performing a true breed evaluation field test (BEFT); 2) comparing the effect of ridden tölt and trot at three speeds on physiological response; 3) evaluating physiological response to a simulated 100 m flying pace race; 4) measuring the effect of increasing body weight ratio (BWR) of rider to horse (20, 25, 30, and 35 %) on physiological response in an standardised incremental field exercise test at tölt at 5.4 m/s; and 5) determining the effect of rider on physiological response. In all studies, speed, distance, heart rate and breathing frequency were recorded and plasma lactate concentration, haematocrit and rectal temperature were measured before and after the exercise tests.

The main results of this thesis were that Icelandic horses performed high intensity exercise during the true gait tests (BEFT and pace race) and, depending on the weight of the rider, the horses at the medium speed tölt and trot (~5.5 m/s) typical of leisure horses also temporarily performed high intensity exercise. Anaerobic metabolism was crucial for performance at pace. Aerobic fitness was higher in stallions than in mares and age had a limited effect on the physiological response in BEFT, although 4-year-old horses had lower aerobic capacity than older age groups. Peak heart rate decreased with age. There were only minor differences in physiological response to tölt and trot in a group of experienced adult Icelandic horses. There was an effect of rider, with physiological response increasing with increased BWR of rider to horse. Trained and experienced Icelandic horses may exceed their lactate threshold at medium speed (~5.5 m/s) at BWR common for Icelandic horse-rider combinations. Post exercise plasma lactate concentrations were correlated with recovery heart rate. Thus by recording recovery heart rate, trainers of Icelandic horses can get an estimate of post exercise plasma lactate concentration, which reflects the extent of anaerobic metabolism and workload. Overall, the results suggest that training of aerobic and anaerobic metabolism is important for BEFT performance and that training of anaerobic metabolism is of critical importance for pace performance.

Keywords: Breed evaluation field test, exercise physiology, flying pace, gaits, heart rate, Icelandic horse, plasma lactate concentration, physiological response, tölt.

Author's address: Guðrún Jóhanna Stefánsdóttir, SLU, Department of Animal Nutrition and Management, P.O. Box 7024, 750 07 Uppsala, Sweden
E-mail: Gudrun.Stefansdottir@ slu.se

Dedication

To the Icelandic horse

“Hesturinn, skaparans meistaramynd, er mátturinn steyptur í hold og blóð”.
Úr ljóðinu Fákar eftir Einar Benediktsson

”The horse, the creator´s masterpiece, is energy cast in flesh and blood”
From the poem ‘Horses’ by Einar Benediktsson

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 G. J. Stefánsdóttir, S. Ragnarsson, V. Gunnarsson & A. Jansson (2014). Physiological response to a breed evaluation field test in Icelandic horses. *Animal* 8(3), 431-439.

II G. J. Stefánsdóttir, S. Ragnarsson, V. Gunnarsson, L. Roepstorff & A. Jansson (2015). A comparison of the physiological response to tölt and trot in the Icelandic horse. *Journal of Animal Science*, doi: 10.2527/jas2015-9141

III G. J. Stefánsdóttir, V. Gunnarsson, S. Ragnarsson & A. Jansson. Physiological response to a simulated 100 m flying pace race in Icelandic horses. Submitted.

IV G. J. Stefánsdóttir, V. Gunnarsson, L. Roepstorff, S. Ragnarsson & A. Jansson. The effect of a rider and added weight on physiological response in Icelandic horses. Submitted.

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

Abbreviations

AST	Aspartate amino transferase
BCS	Body condition score
BCS_{back}	Body condition score of the back of the horse
BEFT	Breed evaluation field test
bpm	Beats per minute
BW	Body weight
BWR	Body weight ratio of rider to horse
BWR_{20}	20% body weight ratio of rider to horse
BWR_{25}	25% body weight ratio of rider to horse
BWR_{30}	30% body weight ratio of rider to horse
BWR_{35}	35% body weight ratio of rider to horse
BWR_{20b}	Repeated 20% body weight ratio of rider to horse
CK	Creatine kinase
Hb	Haemoglobin
Hct	Haematocrit
HR	Heart rate
HR_2	Heart rate at plasma lactate concentration 2 mmol/l
HR_4	Heart rate at plasma lactate concentration 4 mmol/L
HR_{max}	Maximum heart rate
HR_{peak}	Peak heart rate
Lac	Plasma lactate concentration
min	Minute
RMSE	Root mean square error
RR	Respiratory rate
RT	Rectal temperature
s	Seconds
SD	Standard deviation
SE	Standard error
SF	Stride frequency

SL	Stride length
SPR	Simulated 100 m flying pace race
TPP	Total plasma protein
V_2	Estimated speed at plasma lactate concentration 2 mmol/L
V_4	Estimated speed at plasma lactate concentration 4 mmol/L
V_{140}	Estimated speed at heart rate 140 beats per min
V_{180}	Estimated speed at heart rate 180 beats per min
W_4	Estimated body weight ratio of rider (with saddle) to horse at plasma lactate concentration 4 mmol/L
yr	Years

Table 1. *Thesis at glance*

Paper	Description of exercise test	Distance and gaits	Speed[1] m/s	Duration	Horses /Riders	BWR%[2] (mean ± SD)	Heart rate, bpm (mean ± SD)	Plasma lactate concentration mmol/L at end of exercise or each phase of the exercise (mean ± SD)	Main conclusion
I	A breed evaluation field test (BEFT)	2.9 ± 0.4 km in all gaits	3.7-5.9 8.9-15.8	9:37 min:s	266 /69	27.5 ± 3.1	Average: 184 ± 13 Average peak: 224 ± 9	Average: 18.0 ± 6.5 Highest value: 34.4	Involved high intensity (anaerobic) exercise
II	A comparison of tölt and trot at three speeds	642 m per speed in tölt and in trot	3.2 4.1 5.5	3:20 min:s 2:36 min:s 1:57 min:s	8 /2	27.5 ± 4.4	Tölt: 132 ± 11 Trot: 131 ± 8 Tölt: 153 ± 11 Trot: 154 ± 10 Tölt: 180 ± 12 Trot: 186 ± 10	Tölt: 1.07 ± 0.22 Trot: 0.92 ± 0.19 Tölt: 1.48 ± 0.62 Trot: 1.27 ± 0.33 Tölt: 4.66 ± 2.05 Trot: 4.92 ± 1.67	Only minor differences between tölt and trot at the same speeds
III	A simulated 100 m flying pace race	2 × 100 m in flying pace	9-12.1	8.0 -11.0 s × 2	9 /2	28.1 ± 4.7	Pace run I: 206 ± 7 Pace run II: 204 ± 8	Pace run I: 11.9 ± 2.4 Pace run II: 18.8 ± 4.7	Anaerobic metabolism is crucial for flying pace performance
IV	An incremental exercise test with increased BWR of rider to horse.	642 m per BWR in tölt	5.4	5 × 1:59 min:s	8 /1	20 25 30 35 20	Mean HR during last min: 20%: 187 ± 10 25%: 191 ± 11 30%: 195 ± 12 35%: 199 ± 11 Rep20%: 189 ± 13	20%: 3.7 ± 0.96 25%: 4.2 ± 0.94 30%: 5.7 ± 1.09 35%: 8.0 ± 1.49 Rep20%: 5.9 ± 1.07	Increased physiological response to increased BWR; the test could be used to assess W_4.[3]

[1]Range mean and peak speed (Paper I), range mean speed (Paper III). [2]Body weight ratio of rider + saddle to horse. In Paper I, BWR was estimated based on the weight of the horse and rider, and a spot sample of saddles (mean: 8.7 kg). [3]BWR value where plasma lactate concentration is 4 mmol/L.

1 Background

1.1 Origin of the Icelandic horse and scope of breeding and sport

The Icelandic horse is the only horse breed in Iceland. It is a descendent of the horses which came with settlers in the period 874-930, mainly from Scandinavia but also from the British Isles (Adalsteinsson, 1981; Bjørnstad & Røed, 2001; Vilá *et al.*, 2001). Since then, it has been used primarily for riding but also as a pack horse and in agriculture. For the first centuries after settlement, the horse was essential for people to live in the country, as it was the only means of land transport of humans and goods. The importance of the horse in Icelandic society changed dramatically after mechanisation. Around 1950, a new chapter started in the Icelandic horse's history. Breeding became dedicated and since then horses have been selected based on a graded judging scale for both conformation and performance, where they show all their gaits while carrying a rider (Björnsson & Sveinsson, 2006). At the same time, its role has changed to being a leisure and sport horse for gait competitions, both in Iceland and abroad (Björnsson & Sveinsson, 2006). This means that the horses performing best in gaits with a rider have been selected in breeding for 65 years.

The Icelandic horse is widespread and, although Iceland is certified as the country of origin of the Icelandic horse (Ministry of Fisheries & Agriculture, 2011), there are breeding associations in 19 countries (FEIF, 2015a) and the breed can be found in more than 35 countries outside Iceland (Worldfengur, 2015). The breed evaluation system and the studbook, Worldfengur, are international and are accessible on the website of the International Federation of Icelandic Horse Associations (FEIF, 2002; Worldfengur, 2015). The number of Icelandic horses worldwide is ~250 000 (FEIF, 2015a), of which ~75 000 are registered in Iceland (Statistics Iceland, 2015). According to FEIF (2015a), there are around 500 clubs with approximately 60 000 members in the FEIF countries. In the past five years (2010-2014), 1700-2600 horses were fully judged in breeding shows per year and on average 670 (range 597-730) competition events were held per year in the FEIF countries (FEIF, 2015a).

1.2 Gaits of the Icelandic horse

The Icelandic horse is a naturally gaited riding horse (Andersson *et al*., 2012) and is appreciated for its gait abilities, particularly the tölt. Like all horses, the breed has walk, trot, canter and gallop, but the distinguishing gaits of the Icelandic horse are tölt and pace. Icelandic horses with tölt in addition to the three basic gaits are called four-gaited and those which also have pace are called five-gaited (Björnsson & Sveinsson, 2006). Tölt is a four-beat symmetrical gait with one or two legs always on the ground, *i.e*. without suspension. The footfall sequence is left hind, left front, right hind and right front. Flying pace is a symmetrical gait with suspension, where the two lateral legs move together and the gait is two-beated or slightly four-beated. The footfall sequence is left hind and left front together and then right hind and front together. Lateral gaits such as tölt (for which other names are also used) and pace can be found in other horse breeds apart from the Icelandic horse (Promerová *et al*., 2014).

1.3 Age of the Icelandic horse

The Icelandic horse is generally known for health and longevity, and it is not uncommon for individuals to reach 20-30 years of age (Björnsson & Sveinsson, 2006). The longevity and reasons for culling and death of 772 Icelandic horses born in 1980-1985 and 1990-1991 were analysed by Sigfusson (2003). At 18 years of age, 50% of these horses were still alive, which was considered a high proportion, especially as most of the horses culled were culled for low quality and not bad health.

1.4 Training of the Icelandic horse

The main focus when training the Icelandic horse is to improve the qualities of the gaits to perform well in the two categories of exercise tests for which the Icelandic horse is most commonly trained: 1) A breeding show, hereafter referred to as a breed evaluation field test (BEFT), which has the aim of evaluating breeding horses according to the breeding standard (FEIF, 2002) and 2) gait competitions. There are three main types of competitions for which structure and judgements are standardised (FEIF, 2015b): sport competitions, pace race competitions and "*gæðinga*" competitions, for which there are special rules (FEIF, 2012a). Some of the most common of these disciplines (exercise tests) are described in more detail in Table 4 (pp. 22-23). The qualities of the gaits which are emphasised during training are *e.g*. rhythm (beat, the regularity of the strides), leg action (height of the arc), lightness in movement (subjective impression), stride length (subjective, the longer the better), suppleness and also speed (high speed is of value in all gaits in BEFT and in most competition disciplines). However, compared with training of race horses, *e.g*. Standardbred and Thoroughbred, there is much less emphasis on speed and endurance. Anecdotal information indicates that very few trainers of Icelandic horses use stopwatch timing for speed measurements or heart rate recording during training, although there may be exceptions in a few cases among those who train for pace racing. However, in a recent survey on training of Icelandic pace racing horses (Jansson *et al*., 2014), none of the experienced trainers included documented heart rate response to exercise. Over time, the training of the Icelandic horse has thus been based on sense or feeling, *i.e*. subjective evaluation by the trainers of the progress in the quality of the gaits. The importance of aerobic and anaerobic capacity for performance of the Icelandic horse is still unknown, although it is logical to assume it is important and this thesis may provide some information. It means that the same basic principles of exercise physiology should apply to the Icelandic horse as to other horses, but with great emphasis on 'specificity' (Marlin & Nankervis, 2002) concerning the gaits. There has been increased popularity of gait competitions and increased participation in BEFT for Icelandic horses in the past decade (FEIF, 2015a). Furthermore, the demands on these horses to perform well in BEFT and gait competitions have been increasing, which can lead to injuries (Weishaupt *et al*., 2013; Björnsdóttir *et al*., 2014). There has been a debate concerning the intensity to which the Icelandic horse is exposed during BEFT and gait competitions and even in daily usage, for example in trekking. One reason is that the Icelandic horse is rather small (~140 cm at withers and 330-370 kg; Stefánsdóttir *et al*., 2014a) compared with *e.g*. Swedish and German Warmblood riding horses (~165 cm; Holmström, 1990; Stock & Distl, 2006). Moreover, the riders are often of adult body weight (BW). The mean BW in Iceland was reported 73 and 87 kg, respectively, for females and males (Þórsson *et al*., 2009, while the BW range for riders in BEFT was 59-112 kg (Stefánsdóttir *et al*., 2014a). There is also great demand for high speed, leg action and impression at the gaits (FEIF, 2002; FEIF, 2015b), which increases the workload. Welfare of the Icelandic horse is a highly ranked objective of the International Federation of Icelandic Horse

Associations (FEIF, 2015c), which states on its website that it aims ‘to put the welfare of the horse first in everything we do’. However, knowledge is lacking on the physiological response of the Icelandic horse to exercise and competitions.

1.5 Scientific knowledge on physiological response to exercise and training in the Icelandic horse

In order to estimate the current status of scientific knowledge on the physiological response to exercise and training in the Icelandic horse, two world-wide databases, Web of Science (from all databases) and Scopus, were searched on 5 May 2015 (Table 2). The search was first kept wide using the keywords “Icelandic horse AND exercise” or “Icelandic horse AND training”. That resulted in less than 30 publications (Table 2), of which most were not on exercise physiology but on other aspects, such as biomechanics, genetics, feeding, behaviour or health. The search was then narrowed by adding one more keyword: “physiological response”, “heart rate” or “lactate”. That resulted in a maximum of two publications for each of these keywords, one of which was Paper I in this thesis (Stefánsdóttir *et al*., 2014a). The other publication was by Gehlen *et al*. (2008) on the influence of subclinical findings on cardiac parameters in Icelandic horses. This bibliometric analysis confirmed the lack of scientific knowledge on physiological response to exercise and training in the Icelandic horse. It is an important animal welfare issue to generate such knowledge, so that training programmes and competition content can be adjusted to support the general welfare of the breed.

Table 2. *Number of publications from 1900 to present (5 May 2015) in Web of Science and from 1960 to present in Scopus relating to exercise and training of the Icelandic horse and its physiological response. Both databases accessed 5 May 2015*

Search for keywords:	**Web of Science**	**Scopus**
Icelandic horse AND exercise	16	3
Icelandic horse AND training	26	14
Icelandic horse AND exercise AND physiological response	1	1
Icelandic horse AND training AND physiological response	1	1
Icelandic horse AND exercise AND heart rate	2	2
Icelandic horse AND training AND heart rate	2	1
Icelandic horse AND exercise AND lactate	2	2
Icelandic horse AND training AND lactate	2	1

2 Introduction

2.1 Exercise performance and different competition disciplines

Exercise performance is about the ability of the body to convert chemical energy from nutrients into adenine triphosphate (ATP) and use it as mechanical energy in the muscles to move the body. This process requires cooperation by all organ systems of the body with the pulmonary, cardiovascular and muscular systems in the primary role of circulating and using oxygen. The ability of all the systems to support muscle metabolism affects fitness, or physical work capacity (McMiken, 1983). Energy as ATP is produced either with oxygen (aerobic pathways) or without oxygen (anaerobic pathways) in the muscles. The metabolic pathways producing energy in the form of ATP are of the utmost importance and, although at all exercise levels both aerobic and anaerobic pathways are active, one usually dominates depending mainly on the intensity and duration of the exercise (Gerard *et al*., 2014). Different horse disciplines have different energy demands and metabolism (aerobic or anaerobic), which are reflected in HR and plasma lactate concentration (Table 3). During low intensity exercise, most of the energy requirement is met by aerobic metabolism, *e.g.* during endurance riding (Marlin & Nankervis, 2002; Cottin *et al*., 2010) and dressage (Williams *et al*., 2009). Disciplines of high intensity require increased anaerobic metabolism, *e.g.* racing (Keenan, 1979; Valberg & Essén-Gustavsson, 1987; Ronéus *et al*., 1999; Mukai *et al*., 2007) and sports requiring bursts of activity, *e.g.* show-jumping (Art *et al*., 1990a; Lekeux *et al*., 1991) and polo (Ferraz *et al*., 2010). Four-beat gaited Brazilian horse breeds have been found to mainly perform aerobic exercise during field testing (Wanderley *et al*., 2010; Manso-Filho *et al*., 2012; Silva *et al*., 2014). However, Standardbred pacers during racing use similar metabolism to their trotting companions, *i.e.* considerable anaerobic metabolism (Evans *et al*., 2002), but still mostly aerobic (Marlin & Nankervis, 2002; Gerard *et al*., 2014).

For comparison, the execution, gaits and speed (described in words) and estimated distance covered in BEFT (FEIF, 2002), common sport disciplines, pace races and classes A and B in *gæðinga* competitions for the Icelandic horse are described in Table 4 (FEIF, 2012a; 2015b). No published studies on the physiological response to these disciplines were available prior to this thesis, but some physiological response parameters during indoor competition in (four-gait) V1, (five-gait) F1, (tölt) T1, 60 pace race and a round-up (similar to barrel race) were measured in a pilot study (Bjarnadóttir, 2010).

Table 3. *Comparison of peak heart rate (HR_{peak}), average HR (HR_{av}) and blood/plasma lactate concentration (Lactate)[1] after (immediately to 10 min) different horse sport disciplines and in a standardised field gait test (SFGT)*

Sport discipline:	**Distance, m**	**Duration,** min:s	**HR_{av}, bpm,** mean ± sd	**HR_{peak}, bpm,** mean ± SD/SE[2]	**Lactate, mmol/L** mean ± SD/SE[2]	**Lactate, mmol/L** range
Thoroughbred racing[3]	1600-1800	1:44-1:57		223 ± 11		
Thoroughbred racing[4]	1200	1:16		214 ± 2	22.5 ± 0.6	
Thoroughbred racing[5]	1000-2402	1:00-2:26				16.4-38.5
Thoroughbred racing[6]	1100	1:05-1:09			29.6 ± 4.7	
Standardbred, trotters, racing[7]	2140-2640	2:40-3:40			31.3 ± 5.5	15.0-42.7
Standardbred, pacers, racing[8]	1760				20.9 ± 4.1	
Standardbred, pacers, racing[8]	2160				20.8 ± 5.2	
Quarter horse[9]	274, 320, 366	0:17-0:23		211		~20-25.0
Three-day eventing, cross-country phase D[10]	6205, and > 30 jumps	11:20	171 ± 20		19.1 ± 4.2	
Jumping[11]	460	1:12		191 ± 4	9.4 ± 0.9	
Dressage, competition, median level[12]		5:22	107 ± 8	132 ± 10		
Polo horses (elite)[13] (training session)		7:00			18.7 ± 5.4	
Brazilian gaited horses (fit), SFGT[14]	6070	28:39	130 ± 3	174 ± 4		
Brazilian gaited horses (unfit) SFGT[14]	6310	27:58	166 ± 4	200 ± 3		
Brazilian gaited horses (fit) SFGT[15]	5760	30:00			2.6 ± 0.4	

[1]Plasma lactate concentration, except in [4]Mukai *et al*. (2007) and [15]Wanderley *et al*. (2010) where blood lactate concentration is reported

[2]Standard deviation (SD) except in [4]Mukai *et al*. (2007), [11]Art *et al*. (1990a) and [15]Wanderley *et al*. (2010), where standard error (SE) is reported, and in [9]Reynolds *et al*. (1993), where standard deviation or standard error is not presented.

[3]Krzywanek *et al*. (1970). [4]Mukai *et al*. (2007). [5]Snow *et al*. (1983a). [6]Keenan (1979). [7]Ronéus *et al*. (1999). [8]Evans *et al*. (2002). [9]Reynolds *et al*. (1993). [10]White *et al*. (1995). [11]Art *et al*. (1990a). [12]Williams *et al*. (2009). [13]Ferraz *et al*.(2010). [14]Manso Filho *et al*. (2012). [15]Wanderley *et al*. (2010).

Table 4. *Description of different exercise disciplines for Icelandic horses and estimated (not measured) distance*

Exercise test /exercise discipline	Track	Description of test/gaits and speed[1]	Estimated distance
Breed evaluation field test[2]	Straight 250-300 m	The horse is expected to show performance in all gaits. A minimum of six passes are made along the track and a maximum of 10 passes, where 200 m of the track are used for judging the gaits. The rider decides in what order the gaits are shown and for how long each gait is shown (each gait can be shown more than once). There are no criteria mentioned in the breeding standards for how long the gaits should be shown (FEIF, 2002) except for pace, where to get a full score for pace the sprint has to be at least 150-180 m (FEIF, 2002). See section 4.1.1. for further description.	~1200-3000 m
Sport disciplines[3]		**For each sport discipline, the items which have to be performed are numbered (1, 2 , etc.):**	
Tölt (T1)	Oval, 250 m	1) Slow tölt, one round, turn (change rein), 2) tölt with speed changes, with slow tölt on the curves and lengthen stride distinctly on the long sides, one round, 3) extended (fast) tölt, one round. The order should be as listed and in total 3 rounds.	~750-810 m
Four-gait (V1)	Oval, 250 m	1) Slow tölt, 2) slow to medium speed trot, 3) medium walk, 4) slow to medium speed canter, 5) extended (fast) tölt. At least one long side in all gaits except walk (half a long side) is needed to get score for each gait and speed. The rider decides the order in which the gaits are shown, but has in total 4.5 rounds to do so.	~1000-1215 m
Five-gait (F1)	Oval, 250 m	1) Slow to medium speed tölt, 2) slow to medium speed trot, 3) medium walk, 4) slow to medium speed canter, 5) racing pace. At least one round in tölt, trot and canter and half a round in walk. Each gait may be shown only once. Racing pace should be shown only on the long sides (both). The rider decides the order the gaits are shown in, but has in total 4.5 rounds to do so.	~1000-1215 m
Pace races[3]			
100 m pace	Straight, 200-250 m	100 m pace with a flying start. The gait before the start line and after the 100 m timed pace race is voluntary and decided by the rider and horse. Timed distance is 100 m (in pace).	~150-250 m, of which at least 100 m after starting line in flying pace at racing speed

Exercise test /exercise discipline	Track	Description of test/gaits and speed[1]	Estimated distance
150 m pace	Straight 200-250 m	150 m pace with standing start. The first ~49 m can be in any gait, but has to be in pace at the 50 m line and for 100 m and pace over the finishing line. Timed distance is 150 m (start and 100 m in pace).	150 m of which the last 100 m in flying pace at racing speed
250 m pace	Straight 200-250 m	250 m pace with a standing start. The first ~49 m can be in any gait, but has to be in pace at the 50 m line and for 200 m and over the finishing line. Timed distance is 250 m (start and 200 m in pace).	250 m of which the last 200 m in flying pace at racing speed
'*Gæðinga*'competition[4]		**For each class (A and B), the items which have to be performed are numbered (1, 2 , etc.):**	
B-class (four-gaited *gæðingar*)	Oval, 250-300 m	1) Walk, 2) slow tölt, 3) extended (fast) tölt, 4) trot, 5) gallop. Each gait (in each speed) should be shown on one long side and one long side is free choice to get full marks. The rider decides the order of the gaits, but has three rounds.	~750-960 m
A-class (five-gaited *gæðingar*)	Oval, 250-300 m and a straight track at least 175 m long	In this class pace is added (compared with class B) and shown on a straight track, which counts as one long side (0.5 round) of an oval track. There are three rounds (2.5 plus pace on the straight track of 175 m long). In addition, the same gaits as in B-class are shown except there is no demand for slow tölt and the tempo is free on tölt up to medium speed.	~750-960 m

[1]For all sport disciplines (T1, F1 and V1) and '*gæðinga*' competitions, only the preliminaries and not the finals are described. In the preliminaries, the rider and horse perform individually, but in the finals there are usually 5-6 horses on the track at the same time and a longer distance is ridden.

[2]FEIF (2002)

[3]FEIF (2015b)

[4]Bárðarson (2008) and FEIF (2012a)

2.2 Exercise testing in horses (treadmill and field)

For decades, exercise testing has been extensively used to estimate fitness (aerobic and anaerobic capacity) and responses to training and to analyse reasons for poor performance in both humans and horses (Couroucé-Malblanc & Hodgson, 2014; Franklin & Allen, 2014). Exercise testing can be performed on a treadmill or in the field (most often on track). In the early 1960s, Persson (1967) was the first to use a high-speed treadmill to study exercise physiology in horses. Performing the same exercise test protocol on a treadmill and in the field (track) alters the physiological response and may result in lower HR and blood lactate responses for horses tested on an uninclined treadmill compared with a track (Couroucé *et al.*, 1999). There are advantages and disadvantages of both types of exercise tests. The main advantages of treadmill exercise testing are standardisation of the environment, speed and duration of each step of the exercise test, making it highly repeatable, and providing possibilities for a wide range of physiological measurements because of easy access to equipment (*e.g.* an oxygen mask) and to horses at suitable times during and after exercise (Evans, 2008; Franklin & Allen, 2014). The advantages of field exercise tests are that they are generally more representative of the competition and training environment, including the rider (or driver) effects, can be incorporated into the daily training routine without much preparation and do not need facilities with an expensive treadmill (Evans, 2008; Couroucé-Malblanc & van Erck-Westergren, 2014; Munsters *et al.*, 2014). However, standardisation (*e.g.* environment, speed, surface of track) is more difficult and there are limits on the physiological measurements that can be performed (Evans, 2008; Franklin & Allen, 2014). Despite this, the methodology used in field exercise tests should be kept as consistent as possible, *e.g.* duration of warm-up, each step of the exercise test and recovery, timing of blood sampling, rider and track (Couroucé-Malblanc & van Erck-Westergren, 2014). It has been argued that field exercise testing has a greater advantage over treadmill exercise testing in the sport horse disciplines (dressage, jumping and three-day eventing) than in the racing horse disciplines (Sloet van Oldruitenborgh-Oosterbaan & Clayton, 1999; Hodgson & McGowan, 2014; Munsters *et al.*, 2014). Similarly, it is suggested that field exercise tests have advantages over treadmill exercise tests in the two main categories of exercise tests (gait competitions and a BEFT) most often performed by the Icelandic horse. In this thesis, field testing was used and the BEFT was performed on a straight track designed according to FEIF (2002) (Paper I). The other studies were performed on an oval gravel competition track accepted for *gæðinga* competitions (FEIF, 2012a) (Papers II and IV) and on a straight gravel track accepted for pace races (FEIF, 2012b; 2015b) (Paper III). This makes the results presented in the thesis relevant for practitioners.

2.3 Description of exercise intensity

The terms submaximal, maximal and supramaximal are commonly used to describe the intensity of exercise. Maximal refers to exercise (workload) at maximum oxygen uptake (VO_{2max}) and supramaximal to exercise at intensities above that (Gerard *et al.*, 2014). Submaximal is used for all intensities below maximal exercise intensity in human literature (Kenney *et al.*, 2012). In many studies on horses, maximum oxygen uptake is unknown and exercise intensity is therefore sometimes based on a pre-determined percentage of maximum HR (HR_{max}) (Eto *et al.*, 2004). Another alternative is to estimate whether exercise is performed below or above the lactate threshold, with submaximal referring to exercise intensity below the threshold of lactate accumulation (4 mmol/L) (Anna Jansson, personal communication). There is not a consistency in the literature on the use of these terms, and for example Yamano *et al.* (2006) referred to exercise from 60 to 100% VO_{2max} as a high intensity exercise.

2.4 Types of exercise protocols

Exercise test protocols used for horses come from human testing (Åstrand, 1952; Harris, 1958), but have been used for horses for a long time (Persson, 1967; Persson *et al.*, 1983). An incremental standardised exercise testing protocol commonly used in horses was described by Seeherman & Morris (1990). However, a high-speed, single-step exercise test has also been used, especially for sprint racehorses (Bayly *et al.*, 1987; Couroucé-Malblanc & Hodgson, 2014; Franklin & Allen, 2014). An incremental standardised exercise test usually consists of a warm-up and several exercise steps (often 1-3 min duration per step) at increasing speed, which may or may not be separated by a period of recovery (Couroucé-Malblanc & van Erck-Westergren, 2014). During human testing on a cycle ergometer, it is possible to increase resistance (Kenney *et al.*, 2012), and during horse testing it is possible to keep the speed and gait but add more weight on the horse (see Paper IV). In addition to the two types of exercise testing mentioned (incremental and single high speed) most commonly used for racing horses (Franklin & Allen, 2014), various types of exercise testing (some incremental) have been developed for riding horses, both indoors (Harris *et al.*, 2007; Powell *et al.*, 2008) and outdoors (Sloet van Oldruitenborgh-Oosterbaan *et al.*, 1987; Wanderley *et al.*, 2010; Manso Filho *et al.*, 2012). Recently, field exercise testing in Warmblood sport horses was reviewed (Munsters *et al.*, 2014). The remainder of this thesis focuses on exercise testing in the field.

2.5 Measurement of speed (workload) and physiological response during exercise testing

The most common parameters measured during field exercise testing are speed, heart rate (HR) and lactate concentration (Couroucé, 1999). Speed is used as a parameter to which to relate the physiological response, but is not itself a physiological response. Based on these three parameters (speed, HR and lactate), various fitness parameters (e.g. $V_{4,}$ $V_{2,}$ V_{180}, V_{140}, HR_4 and HR_2) can be calculated. Sofar measurements of oxygen consumption to evaluate aerobic capacity are mostly performed in the laboratory, *e.g.* using the open flow method (Franklin *et al.*, 2012), although portable respiratory gas analysers have been used in some recent field studies (Cottin *et al.*, 2010; Sides *et al.*, 2014). Many more parameters than speed and the physiological parameters HR and lactate concentration can be measured during exercise testing and these three and others measured in Papers I-IV are briefly discussed below.

2.5.1 Speed (workload)

During field exercise testing, a key issue is measurement and control of the speed (Courcoucé, 1999; Couroucé-Malblanc & Hodgson, 2014), since speed reflects workload (Sloet van Oldruitenborgh-Oosterbaan *et al.*, 1987). The simplest and traditional method of measuring speed is using stopwatch timing over a known distance, with clear markings on the track often used for assistance. However, this method does not provide information about acceleration and deceleration or peak speed reached. The global positioning system (GPS) technology offers the possibility to measure these parameters in addition to speed and distance. It can be used simultaneously with a HR monitor and has been used during exercise testing and training in racing horses (Gramkow & Evans, 2006; Kingston *et al.*, 2006; Vermeulen & Evans, 2006; Fonseca *et al.*, 2010) and gaited horses (Mansho-Filho *et al.*, 2012; Silva *et al.*, 2014), after having been tested with success in humans for tracking position and speed (Schutz & Chambaz, 1997; Schutz & Herren, 2000). GPS is still not applicable in indoor riding facilities (Munsters *et al.*, 2014) although Local Positioning Systems (LPS) can now do that (Lars Roepstorff, personal communication). The accuracy of the GPS speed and distance measurements depends on connections to satellites and the frequency of the radio signals between the GPS device on earth and the satellites (Maddison & Mhurchu, 2009). According to Munsters *et al*. (2014), speed can be measured reliably by both methods, provided they are used consistently. Based on the work in this thesis it is considered that the type of method (stopwatch or GPS) being most accurate to use, might depend on several factors as; the shape of the track (straight/oval), conditions (indoor, outdoor), the speed itself and distance covered.

2.5.2 Heart rate

Heart rate in horses at rest is 25 to 40 beats per minute (bpm) (Marsland, 1968). During exercise there is a linear relationship between HR and speed from ~120 bpm up to HR_{max} (Persson & Ullberg, 1974; Persson 1983). The HR_{max} of horses lies between 204 and 254 bpm (Krzywanek *et al*., 1970; Seeherman & Morris, 1990) and has been shown to decrease with age (Betros *et al*., 2002). Peak HR (HR_{peak}) is used to represent the highest HR reached during a particular exercise test or training session if it is not evident that it is the HR_{max} (Hodgson, 2014a). Heart rate can be used as an indirect measurement of oxygen consumption and energy expenditure during exercise (Coenen *et al*., 2011). There is a close relationship between HR and oxygen consumption (VO_2) in horses, with the equation (VO_2 in mL/kg BW/min = $0.002816 \times HR^{1.9955}$; $r^2 = 0.911$) reported by Coenen *et al*. (2011) and VO_2 in mL/kg BW/min = $0.833 \times HR - 54.7$ ($r^2 = 0.865$) by Eaton *et al*. (1995). Based on these equations, energy expenditure can be estimated by transforming oxygen into joules based on 20.1 kJ/L VO_2 (Coenen *et al*., 2011). The Eaton *et al*. equation has been suggested to give better estimates of oxygen utilisation at high HR and the Coenen *et al*. equation better estimates at lower HR (NRC, 2007). Commercial HR monitors have been used to measure HR during equine exercises for more than 30 years (Foreman & Rabin, 1983; Wilson *et al*., 1983; Evans & Rose, 1986), and in recent years most studies in equine exercise physiology have used HR monitors from Polar (Parker *et al*., 2010; Munsters *et al*., 2014). The gold standard for measurement of HR is the electrocardiogram (ECG) and that method has been used as a reference method when evaluating the accuracy of other methods (Evans & Rose, 1986; Parker *et al*., 2010). In Papers I-IV, a Polar HR Monitor (RS800CX, Polar Electro Oy, Kempele, Finland) was used.

2.5.3 Lactate concentration

The physiological response most commonly measured in blood or plasma during exercise tests in horses is lactate concentration (Hodgson & McGowan, 2014). Lactate is the end product of anaerobic glycolysis (McMiken, 1983) and is produced in working muscles at all exercise intensities, with increasing levels at higher intensities (Lindholm & Saltin, 1974; Judson *et al*., 1983; Harris *et al.*, 1991). Lactate is removed from muscles with active transport into blood (Pösö, 2002). The lactate concentration in blood/plasma reflects the intensity of the exercise to a certain extent (Harris *et al*., 1991) and the degree of training, as ‘an indirect indicator of cardiovascular and metabolic capacity’ (Couroucé-Malblanc & Hodgson, 2014). There is a point in exercise intensity often referred to as the anaerobic threshold, where the concentration of plasma lactate equals 4 mmol/L, and production of lactate is faster than the removal and lactate starts to accumulate (Persson, 1983). In horses, plasma lactate concentration is 0.3-1.0 mmol/L at rest (Keenan, 1979; Judson *et al*., 1983; Snow *et al*., 1983a; Bayly *et al.*, 2006), and commonly increases to 20-30 mmol/L after strenuous exercise such as racing (Keenan, 1979; Snow *et al.*, 1983a; Reynolds *et al*., 1993; Ronéus *et al.*, 1999; Evans *et al*., 2002; Mukai *et al*., 2007), and levels as high as ~40 mmol/L have been measured occasionally (Snow *et al.*, 1983a; Ronéus *et al*., 1999). Lactate is usually analysed in plasma and the concentration in plasma is about 20-50% higher than in blood (Pösö *et al*., 1995; Räsänen *et al*., 1995; Stefánsdóttir *et al*., 2012). Several types of hand-held analysers are available for analysing lactate in blood in humans (Medbø *et al*., 2000) and some of these have been used in field testing of horses (Wanderley *et al*., 2010; Stefánsdóttir *et al*., 2012). However, some of the analysers produced for humans may not be able to analyse the high lactate levels of horses (Stefánsdóttir *et al*., 2012). Common methods for measurement of blood/plasma lactate concentrations in the laboratory are the use of gas analysers (Munsters *et al*., 2014) and an enzymatic-spectrophotometric assay, which has been used for a long time (Brandt *et al*., 1980; Ludvigsen *et al*., 1983), and an enzymatic-spectrophotometric assay (see section 4.4.3) was used in Papers I-IV.

2.5.4 Haematocrit and haemoglobin

Haematocrit is the percentage of the total volume of blood that consists of red blood cells (Hodgson & Foreman, 2014). These red blood cells contain haemoglobin, a complex haem-containing protein, which transports oxygen from the lungs to muscles and tissues during exercise (Kingston, 2008; McGowan & Hodgson, 2014). There is a strong relationship between haematocrit and haemoglobin in serum in horses (Zobba *et al*., 2011), but measurement of haemoglobin is a more direct measure of the blood’s capacity to carry oxygen (McKenzie, 2014). The horse has an unique ability to mobilise a large number of red blood cells from the spleen into the bloodstream during exercise, thus increasing the oxygen transport capacity of the blood (Persson, 1967; Snow *et al*., 1983b; McKeever & Lehnard, 2014). The degree of excitement of the horse can have an effect and can cause splenic contraction and significant mobilisation of red blood cells (Snow *et al*., 1983b). An increase in haematocrit as a result of exercise can be due to a combination of splenic contraction and fluid shifts within the body (Keenan, 1979; Snow *et al*., 1983b). Both haematocrit (Persson, 1967; Ringmark *et al*., 2015) and haemoglobin (Persson, 1967; 1968) increase as a long-term response to training. Haematocrit also increases with age (Persson, 1967; Persson *et al*., 1996) and is higher in stallions than mares (Persson *et al*., 1996). Until maximum splenic contraction is reached, haematocrit level during exercise reflects the amount of red blood cells released from the spleen and the intensity of the exercise (Persson, 1967). Maximal haematocrit in Standardbred and Thoroughbred racehorses reaches 60-68% after high intensity exercise (Persson, 1983; Snow *et al*., 1983b; Evans *et al*., 1993). A limited or no relationship has been found between resting levels of haemoglobin or haematocrit and performance (Revington, 1983b; McGowan & Hodgson, 2014), mainly because red blood cells are unevenly distributed between the circulatory system and the spleen (Persson, 1983). Breed differences may exist in the values of haematocrit and haemoglobin (McKenzie, 2014; Kingston & Hinchcliff, 2014), but sometimes it is not clear whether the difference presented is related to the breed or training background (Prince *et al*., 2002; McGowan & Hodgson, 2014). Some haematological values for different horse breeds during and after different horse disciplines are presented in Table 5. Haematocrit can be determined from measurement of centrifuged microhaemtatocrit tubes, which is referred to as packed cell volume (PCV) or (spun) haematocrit (McKenzie, 2014).

Table 5. *Haematocrit (L/L) and haemoglobin (g/L) values (mean or mean ± SD) for different horse breeds at rest, during (peak values) and after different horse disciplines*

Discipline	**Breed**	**N**	**Haematocrit at rest**	**Haematocrit at end of exercise (60 sec to < 10 min)**	**Peak haematocrit**	**Haemoglobin at rest**	**Haemoglobin at end of exercise**
Trained for racing[1]	Thoroughbreds	65	0.42 ± 0.03			151 ± 10	
Trained for racing[2]	Standardbreds	174	0.39 ± 0.04			124 ± 19	
Trained for simulated racing[3]	Standardbreds	6	0.39 ± 0.01	0.60 ± 0.01			
Racing[4]	Thoroughbred	15	0.42 ± 0.05	0.60 ± 0.03		143 ± 15	206 ± 14
Racing[4]	Thoroughbred	18	0.43 ± 0.03	0.64 ± 0.02		159 ± 11	234 ± 9
Racing[5]	Quarterhorse	25	0.37	0.60			
Treadmill exercise to fatigue[6]	Thoroughbred	6	0.41	0.60	0.63		
Three-day eventing, phase D[7]	Various breeds	11	0.38 ± 0.02	0.62 ± 0.03			
Three-day eventing, phase D[7]	Various breeds	22	0.37 ± 0.03	0.58 ± 0.03			
Endurance (100 km)[8]	Arabian horse[a]	80/22/52	0.42	0.47	0.51	134	145
Polo[9]	Criollo × Thoroughbred and Thoroughbred	12	0.41	0.62		132	193
Four-gait exercise test (speed ~3.2 m/s, 30 min)[10]	Mangalarga Marchador	13	0.31	0.40			
Four-gait exercise test (speed ~3.0 m/s, 30 min)[11]	Mangalarga Marchador and Campolina	16 (8/8)	0.33	0.41			

[1]Revington (1983a). [2]Steel & Whitlock (1960). [3]Jansson & Dahlborn (1999). [4]Snow *et al*. (1983b). [5]Reynolds *et al*. (1993). [6]Bayly *et al*. (2006). [7]Andrews *et al*. (1995). [8]Teixeira-Neto *et al*. (2012), [9]Zobba *et al*. (2011). [10]Wanderley *et al*. (2010). [11]Silva *et al*. (2014).

[a]Eighty horses started the endurance ride, 52 reached peak haematocrit after 50 km and 22 completed 100 km.

2.5.5 Creatine kinase and aspartate amino transferase

The most common enzymes measured to indicate muscle damage are aspartate amino transferase (AST) and creatine kinase (CK) (McGowan & Hodgson, 2014). These enzymes may leak into blood due to alterations in cell membrane permeability or from ruptured muscle cells after strenuous (Snow *et al*., 1983a) or prolonged (Volfinger *et al.*, 1994) exercise. Creatine kinase has a shorter half life in blood than AST, and it has been suggested that sampling at least 24 h after exercise is suitable to differentiate between those animals showing a normal physiological response to exercise and those with an abnormal or pathological response (Harris & Snow, 1990). The laboratory resting reference value of enzyme activity for CK in horses ranges from 100 to 470 U/L and for AST from 185 to 375 U/L (MacLeay, 2010). As a response to a submaximal extercise test, there should not be more than a doubling of the resting CK activity 2-4 hours after exercise and it should have returned to baseline 24 h after exercise, and there should not be more than a 50% increase in AST activity (MacLeay, 2010). In Papers I and IV, an enzymatic method (spectrophotometer) was used to analyse CK and AST.

2.5.6 Total plasma protein

Total plasma protein (TPP) increases during exercise due to hydrostatic pressure (water is pushed out of the vessels to some extent) and that might be related to intensity. In addition, TPP is affected by dehydration, with a proportional increase in protein in plasma. Increased TPP has been shown to follow both submaximal and maximal exercise in horses (Judson *et al*., 1983; Hargreaves *et al*., 1999), which is normal and not a major problem for short-term exercise, but can be for longer-term exercise. In mature performance horses, the normal range for TPP is wide, 55-75 g/L (McGowan & Hodgson, 2014). The common way to measure TPP, both in laboratories and veterinary practices, is to use a optical refractometer (George & O'Neill, 2001).

2.5.7 Respiratory rate

Healthy horses breath through the nostrils, not the mouth (Heffron & Baker, 1979; Ainsworth & Cheetham, 2010) and normal respiratory rate (breathing frequency) at rest of the adult horse varies from 8 to 15 breaths/min (Ainsworth & Cheetham, 2010). During exercise, the rate increases linearly with speed from rest up to 6-8 m/s, but at a faster speed the increase is only slight (Butler *et al*., 1993; Ainsworth, 2014). Respiratory rate is coupled with stride frequency (1:1) in horses at canter and gallop (Attenburrow, 1982; Lafortuna *et al*., 1996) and may also be in trot (often non-1:1 pattern), but seldom in walk (Art *et al*., 1990b; Lafortuna *et al*., 1996; Boggs, 2002). The reason for coupling at canter and gallop is mechanical or energetic advantages (Boggs, 2002). In galloping horses, stride and respiratory frequencies of 120-148 breaths/min have been reported (Hörnicke *et al*., 1987; Franklin *et al*., 2012). Respiration (breathing) is important in cooling the body after exercise by dissipating heat as moisture (Hodgson *et al*., 1993; Hargreaves *et al*., 1999). Respiratory rate can be counted by listening to the breathing, feeling it by positioning a hand in front of the nostril or by watching movements of the nostril, chest or flank. Respiratory rate has also been counted by connecting the horse's breathing (through the nostril) to a capnograph analyser, which gives a visual display of every expiration (Morgan *et al*., 2002). In this thesis, respiratory rate was counted (listening to the chest) using a stethoscope (Paper I), by listening to it (Papers II-III) and by positioning a hand in front of the nostril (Paper IV).

2.5.8 Rectal temperature

The normal body temperature in adult horses is in the range 37.5-38.5 °C, with a diurnal variation of up to 1 °C (Hines, 2010). As a homeothermic animal, the horse tries to maintain (thermoregulate) its internal body temperature within a narrow range (37-40 °C), irrespective of environmental conditions (McCutcheon & Geor, 2008). However, the greatest challenge to the thermoregulatory system of the horse is usually exercise, where the conversion of chemical energy into mechanical energy (*e.g.* muscle work) is inefficient and approximately 75-80% of the energy is released as heat (Brody, 1945; Hodgson, 2014b). This metabolic heat production increases muscle and core body temperature of the horse despite mechanisms of heat loss, primarily by convection and evaporation (Marlin *et al*., 1996; McCutcheon & Geor, 2008), but also through increased skin blood flow (Carlson, 1983), respiration (Hodgson *et al*., 1993; Hargreaves *et al*., 1999) and, not least, sweating (Carlson, 1983; Hodgson *et al*., 1993; Morgan *et al*., 2002). Therefore the intensity and duration of exercise together with environmental conditions (temperature, humidity) are the main factors affecting how much the body temperature will rise (Hodgson *et al*., 1993; Marlin *et al*., 1996). Measurements of muscle, blood, skin and/or rectal temperature can reflect the intensity and duration of the exercise to some extent. In Papers I-IV rectal temperature was measured.

3 Aims of the thesis

The general aim of this thesis was to increase knowledge of the physiological response to exercise in the Icelandic horse during exercise conditions typical for this breed.

Specific aims were to:

- Study the physiological response in terms of heart rate, respiratory rate, haematocrit, rectal temperature and some plasma variables, in Icelandic stallions and mares of different ages performing the riding assessment in a breed evaluation field test (Paper I).
- Compare the effect of ridden tölt and trot at three speeds on the physiological response (heart rate, plasma lactate concentration, haematocrit, respiratory rate, rectal temperature) in Icelandic horses (Paper II).
- Evaluate the physiological response (heart rate, plasma lactate concentration, haematocrit, respiratory rate, rectal temperature) to a simulated 100 flying pace race in Icelandic horses (Paper III).
- Measure the effect of increasing body weight ratio of rider to horse on heart rate, plasma lactate concentration, respiratory rate, haematocrit, stride length and stride frequency in the Icelandic horse (Paper IV).
- Determine whether the rider has an effect on the physiological response in Icelandic horses (using Papers I-IV).
- Compare recovery patterns between different types of exercise sessions relevant for the Icelandic horse (using Papers I-IV).

The hypotheses tested were:

- The breed evaluation field test is a high intensity exercise and some physiological responses could be affected by sex and age (Paper I).

- Horses show higher heart rate, haematocrit and plasma lactate concentration in response to tölt compared with trot at the same speed (Paper II).
- A 100 m flying pace race is a high intensity exercise requiring anaerobic metabolism (Paper III).
- Horses show higher heart rate, plasma lactate concentration, haematocrit, respiratory rate, stride frequency and decreased stride length in response to increased weight load (Paper IV).
- There is an effect of rider on the physiological response in Icelandic horses.
- Recovery patterns differ between different types of exercise sessions relevant for the Icelandic horse

4 Materials and methods

All studies in this thesis were field exercise tests. The first study (Paper I) was a BEFT at Hella in southern Iceland and the three other studies (Papers II-IV) were experiments conducted at Hólar University College in north-west Iceland.

4.1 Design of studies and description of the field exercise tests

4.1.1 A breed evaluation field test (BEFT) (Paper I)

The data were collected in real conditions, in order to assess the physiological response to a BEFT (Paper I). The BEFT aims to evaluate Icelandic horses before they are used for breeding and consists of three parts: (1) Objective body measurements, (2) judging of conformational traits and (3) judging of riding abilities. Scores for conformation and riding abilities are weighed to give the final total score. Riding abilities include performance in walk, tölt, trot, flying pace (pace) and canter/gallop, as well as spirit and general impression, and account for 60% of the total score, while conformation counts for 40% (FEIF, 2002). In a BEFT, riding abilities of a horse are judged in two separate assessments. In the first and main assessment, the horse is expected to show all its gaits, although the rider decides how this is actually done in terms of order in which the gaits are shown and also decides how much the horse is urged forward in each gait. The horse is ridden alone on a straight field track (250-300 m long, 4-6 m wide) and 200 m of the track is used for judging and 50 m at each end to turn around. The horse has to be ridden along the track a minimum of six times and a maximum of 10 times, *i.e.* 3-5 passes in each direction (FEIF, 2002). The second assessment is voluntary and is carried out if the rider/trainer/owner would like to try to improve the scores from the first assessment. In this thesis, horses were only measured for physiological response in the first assessment. A horse must be at least 4 years old in the calendar year to be judged for riding abilities in a BEFT. Stallions and mares are shown in separate sex and age classes (4, 5, 6 and ≥7 years old) and geldings are shown in one group irrespective of age (FEIF, 2002), as very few are judged annually (Worldfengur, 2015). In total, 266 horses, only mares and stallions, were included in Paper I. According to the judging scale used in a BEFT, each trait is scored within the range 5.0-10.0, with 0.5 increments. A score of 5.0 is given if a gait is not shown and 10.0 is given for an excellent trait (FEIF, 2002). The judging scale is thoroughly described in the FEIF rules for Icelandic Horse Breeding (FEIF, 2002). Important factors which count in the score for each gait are *e.g.* rhythm, length of stride, suppleness, leg action, and speed capacity. Three internationally accepted judges generally work in a committee and give a joint score for each trait (FEIF, 2002). In Paper I six judges worked, three at a time. According to the rules of FEIF (2002), there was an obligatory shoe and health check (legs and mouth) immediately after a horse had finished the riding assessment and it lasted for 1-2 min. The inclusion criteria for including a horse in the study and then using the results from it were that the owner/trainer was willing to take part and that the horses had been judged for both conformation and riding abilities and had completed both those parts.

4.1.2 An incremental exercise test in tölt and trot at the same speeds (Paper II)

A cross-over design was used in Paper II, with eight horses, two treatments (incremental exercise test in tölt and trot) and two riders (Table 1 in Paper II). Each horse performed two tests per day (one gait with two riders, minimum 4.5 hours in between) and all treatments were performed on two separate days, with one day of rest in between. The exercise tests were performed outdoors on a 300 m oval gravel riding track accepted for *gæðinga* competitions (FEIF, 2012a). There were two horses on the track at the same time, one in trot and one in tölt, to help standardise the speed (Figure 1). The riders rode on the outer circumference of the track, which corresponded to a distance of 321 m. The exercise test was preceded by 10 min of warm-up, 5 min in walking and 5 min in tölt and trot in circles in both directions (clockwise and counterclockwise). The exercise test started within 1-3 min after end of warm-up and comprised an incremental exercise consisting of three 642 m phases; at ~3.0 m/s ($Speed_3$), ~4.0 m/s ($Speed_4$) and ~5.0 m/s ($Speed_5$). The time between phases was 1-2 min for taking blood samples. The horses were followed for 30 min recovery period. The horses were mounted (with rider and tack) during the warm-up, exercise test and ~10 min of the recovery period, but from then until 30 min of recovery, they carried only the riding tack.

Figure 1. Comparison of tölt and trot in Paper II. Two horses on the track at the same time, one in trot (bay) and one in tölt (chestnut).

4.1.3 A simulated 100 m flying pace race (Paper III)

A cross-over design was used in Paper III, with nine horses and two riders. On day one, five horses performed a simulated 100 m flying pace race (SPR) with rider 1 and the other four horses performed with rider 2. On day 5 the SPR was performed again, with the riders changed over. The exercise test was preceded by a 10 min warm-up, 5 min in walking and 5 min in tölt and trot in circles of different sizes in both directions (clockwise and counterclockwise). A true 100 m flying pace race is performed outdoors, individually on a straight track, and riders have two attempts with a few minutes of rest in between to get an approved (correct gait) pace run. The SPR was performed outdoors on a 400 m straight gravel riding track (Figure 2) and consisted of two runs, of which at least 100 m was in flying pace at full speed according to rules of FEIF (2012b). The horses were ridden (individually), in any gait the rider wished for the first 49 m (preparation period) but paced when crossing the 50 m line, *i.e*. "with flying start" (FEIF, 2012b) and then paced in racing speed for the timed 100 m (over the finishing line), and finally slowed down during 25 to 50 m (in total approximately 150-200 m run). The horses were walked for 5 min between the two pace runs. The horses were followed for 30 min recovery period. The horses were mounted (with rider and tack) during warm-up, exercise test and ~10 min of the recovery period, but from then until 30 min of recovery, they carried only the riding tack.

Two weeks before the start of the SPR, all horses participated in a true 100 m flying pace competition according to rules of FEIF (2012b) at Saudarkrokur in north-west Iceland. All of the horses except one had at least one registered time recording from a 100 m flying pace race and six had ≥ 3 recordings (Worldfengur, 2015).

Figure 2. Horse in flying pace in a simulated 100 m pace race in Paper III.

4.1.4 An incremental exercise test in tölt with increased weight of rider added as dead weight (lead) (Paper IV)

In Paper IV, eight horses and one rider were used and each horse performed an incremental exercise test once, outdoors on an oval gravel riding track. The incremental exercise test was preceded by a 10 min warm-up, 5 min in walking and 5 min in tölt on circles of different sizes in both directions (clockwise and counterclockwise). The exercise test started within 4:18 ± 1:24 min:s (mean ± SD) after the warm-up and consisted of five phases, each comprising 642 m in tölt at a speed of 5.4 ± 0.1 m/s (mean ± SD) (Figure 3), where the BWR of rider (plus saddle) to horse started at 20% (BWR_{20}), was increased to 25% (BWR_{25}), 30% (BWR_{30}) and 35% (BWR_{35}) and finally decreased to 20% (BWR_{20b}). Between phases, horses were stopped for 5:26 ± 1:13 min:s (mean ± SD) to add weight and for collection of a blood sample.

The horses were followed for 30 min recovery and a clinical examination was performed before and 24 and 48 h after the exercise test. The examination included palpation/examination of neck, back and legs and a whole limb flexion test (30 s) with a trot up on a concrete floor and walk and trot in a circle on soft ground.

Figure 3. Horse and rider performing at tölt in the weight carrying study in Paper IV. Some of the equipment on the horse and rider was for studying the symmetry in locomotion (sensors on legs and croup), the results for which are not included in this thesis.

4.2 Horses

In the BEFT, data were collected on 266 privately owned horses (86 stallions and 180 mares) (Paper I). The age of the horses ranged from 4 to 11 years, with the number of horses in the age classes 4, 5, 6 and ≥7 years and older being 37, 83, 74 and 72, respectively.

In the three experiments at Hólar University College, 25 school horses were used (14 geldings and 11 mares). The age was 15.1 ± 2.8 years (range 8-19 years). Seven of the horses used in Paper II were also used in Paper IV, but with two years between the experiments.

The BW of the horses ranged from 289 to 403 kg and the height at withers from 134 to 149 cm in Papers I-IV.

4.3 Riders, saddles and body weight ratio of rider to horse

In Paper I, 69 riders were involved and each rode 1-29 horses. Five riders rode ≥10 horses and 13 riders ≥5 horses, while 56 riders rode 1-4 horses. Rider BW was 83 ± 11 kg (range 59-112 kg, n = 67) and weight of saddle and blanket was 8.7 ± 1.0 kg (range 6.8-10.4 kg, n = 23). The ratio of rider BW (without saddle) to horse BW 24.9 ± 3.0 % (range 16.9-35.6%).

In both Papers II and III, two riders were involved and both rode all the horses. In Paper II, the BW of these two riders plus saddle was 87.5 and 119.0 kg, respectively, and in Paper III it was 87.0 and 119.0 kg, respectively. In Paper II, the ratio of rider BW plus saddle to horse BW was 23.3 ± 0.8% and 31.7 ± 1.1 %, respectively, while in Paper III it was 23.8 ± 1.3% and 32.4 ± 1.8 %, respectively.

In Paper IV, one rider with BW 65 kg and a saddle of 8.4 kg rode all horses, but the weight of the rider (plus saddle) was increased by adding dead weight (lead). The BWR of rider (plus saddle) to horse tested in Paper IV was 20%, 25%, 30% and 35%, with 20% repeated at the end of the exercise test. The saddle was specially adjusted, with three bags tightly fixed on the flaps on both sides to add up to 10 kg of lead on each side and extra heavy stirrups (4 kg each) when appropriate (Figure 4). In addition, weight was added using three saddle pads (1.3 kg, 2.2 kg and 13.8 kg) and the rider could carry added weight of up to 15 kg in a vest designed for divers (Figure 4).

Figure 4. The adjusted saddle (1) pocket on a saddle loaded with lead (2), "heavy" saddle pads (3), lead (4), "heavy" stirrups (5) and weight (lead in diver's vest) carried by the rider (6) in weight carrying study in Paper IV.

4.4 Measurements of speed, distance, stride frequency, stride length and physiological response

4.4.1 Speed, distance, stride frequency and stride length

In Papers I-IV, a GPS sensor (Polar G3, GPS sensor, Polar Electro, Kempele, Finland) was connected to the HR monitor to record speed and distance. According to the manufacturer, the accuracy of distance measurements is ± 2% and of speed measurements ± 2 km/h. These recordings were used as input together with the HR recordings to the software Polar Pro Trainer 5 Equine Edition (Polar Electro, Kempele, Finland). These measurements of speed and distance were used for the warm-up and the BEFT in Paper I, for the warm-up and estimation of total distance performed per horse in Papers II-III and for the warm-up in Paper IV.

All exercise tests (Papers I-IV) were recorded using a HD video camera (Sony HDR CX360VE, Tokyo, Japan). In Paper II the speed during the exercise tests was measured by observation of video recordings and the use of a stopwatch and compared with the speed measured by GPS. For the fastest speed (~5 m/s), the GPS values were lower than the stopwatch values ($P<0.01$), indicating that GPS lost accuracy in such conditions. Therefore the speed was estimated from the videos using a stopwatch for all calculations in Paper II and also during the two pace runs in Paper III. The speed of the horses during the exercise test in Paper IV was measured live, using stopwatch timing at the experimental place.

In Paper II the videos (in slow motion, 50 frames/s) were used to time and count number of strides per horse and to estimate stride frequency and stride length. In Paper IV the horses were filmed with a high speed camera (Casio EX-F1, using 300 frames/s) over 22 m distance on both straight sides of the oval track. For evaluation of stride frequency and stride length the last eight filmed strides of each horse for each phase were used if speed was consistent and strides and balance in the tölt were considered representative (see Paper IV). The film recordings were evaluated in Kinova software (version 0.8.15).

4.4.2 Heart rate recordings

Heart rate of the horses was recorded in Papers I-IV and heart rate of the rider in Paper IV, using a Polar HR Monitor (RS800CX, Polar Electro Oy, Kempele, Finland). The HR monitors were always set to record in 1 s mode. All HR recordings were input to the software Polar Pro Trainer 5 Equine Edition (Polar Electro, Kempele, Finland) for analysis.

In Paper I, HR was recorded during warm-up, the riding assessment and 5 min recovery. It was not possible to follow the horses over a longer recovery period for practical reasons. Only HR recordings where a minimum of 80% of the recording for the whole riding assessment was considered reliable were used, which resulted in 102 observations. On average, 6 ± 6 % (34 ± 34 s/horse) of the HR recordings from the 102 horses were excluded from analysis.

In Paper II, data on HR during the last 60 s of the warm-up, the three phases of the exercise test and the 5^{th}, 15^{th} and 30^{th} min of the recovery period were used for analysis. The HR recordings were occasionally of low quality or lacking (lost connectivity between electrodes and the skin), but all horses contributed data on mean heart rate for all three speeds at both gaits (except at trot at the highest speed, where data from one horse were lacking), with a minimum of 21 observations/speed.

In Paper III, HR was recorded during warm-up, the two pace runs (SPR) and the 30 min recovery period. The inclusion criterion for the results to be used in the analysis was that the horse paced at least 100 m continuously after the 50 m starting line according to the rules of FEIF (2012b). Of the 36 pace runs (9 horses × 2 runs × 2 riders) performed in the study, four runs had less than 100 m in flying pace after the horse had passed the 50 m starting line. Data on HR during these four pace runs were excluded from the analysis but all recovery HR data were used, except for one horse which showed weak symptoms of pain during recovery (at 10 min) after the SPR. Of 32 HR recordings during the successful pace runs, six recordings were corrected according to Marchant-Forde *et al*. (2004; error types 1 and 5) and six recordings were deemed unreliable and not used.

In Paper IV, HR data during the last 60 s of the warm-up, the five phases of the incremental exercise test and the 5^{th}, 15^{th} and 30^{th} min of the recovery period were used for analysis for the horse, and HR recordings from the same times during the exercise test for the rider. HR data on two horses for the whole exercise test and recovery were missing because of technical failure and for the rider for two whole exercise tests for two horses because of lost connectivity.

In Papers II and III, the HR at rest was the minimum HR recorded before exercise tests and in Paper IV the resting HR was taken late at night 2-4 days after the exercise tests and a period of low HR during 30 min was used.

4.4.3 Blood samples and analyses

In Papers I-IV, blood samples were collected from the jugular vein in chilled lithium heparinised tubes (9 mL per sample). In Paper I, two blood samples were collected by venepuncture, before the warm-up and the riding assessment and within 5 min after the horse left the track after performing the riding assessment. In Papers II-IV, horses were fitted with a catheter (2.0 × 105 mm, Intranule, Vygon Sweden AB, Skellefteå, Sweden) in the jugular vein under local anaesthesia (Xylocaine, 20 mg/mL, AstraZeneca, Södertälje, Sweden) at least one hour before starting the exercise tests in the morning and it was removed the same day after finishing the 30 min recovery period. Two more blood samples were taken by venepuncture after 1 and 2 days of recovery in Paper IV. In Paper II, eight blood samples were collected; at rest, at end of warm-up, at end of each phase of the exercise test (3.0, 4.0 and 5.0 m/s) and at end of 5, 15 and 30 min recovery. In Paper III, seven blood samples were collected; at rest, at end of warm-up, at end of pace runs I and II and at end of 5, 15 and 30 min recovery. In Paper IV, 12 blood samples were collected, at rest, at end of warm-up, at end of each phase of the exercise test (BWR_{20}, BWR_{25}, BWR_{30}, BWR_{35} and BWR_{20b}) and at end of 5, 15, 30 min, and 24 and 48 h recovery. The horses generally coped well with blood sampling. In Paper, I all 266 horses were blood sampled twice without problems. In Papers II-IV, all horses accepted the insertion of catheter and blood sampling except one horse in Paper III (showed fear reactions). Haematocrit was analysed in triplicate (Paper I) or duplicate (Paper II-IV) after centrifugation in microcapillary tubes and haemoglobin was analysed in Paper I. In all studies (Papers I-IV) plasma was separated by centrifugation and then stored at -18°C until analysis of plasma lactate concentration (Paper I-IV, for method see below), the muscle enzymes CK and AST (Papers I and IV, enzymatic method, spectrophotometer, Architect c4000, Abbott Park, IL, USA) and total plasma protein (Paper I, refractometer, Atago, Tokyo, Japan).

Plasma lactate concentration

In Papers I-IV, plasma lactate concentration was analysed using an enzymatic (L-lactate dehydrogenase and glutamate-pyruvate transaminase) and spectrophotometric method (Bohehringer Mannheim/R –Biopharm, Darmstadt, Germany). Plasma lactate concentration was analysed in all samples in Papers II-IV, but only in the second sample (after the riding assessment) in Paper I.

4.4.4 Respiratory rate

In Papers I-IV, respiratory rate of the horses was counted for at least 15 s. In Paper I it was done at rest before the warm-up, and within 5 min after the riding assessment. In Papers II and III it was done at rest before the warm-up, at end of the exercise test and at end of the 30 min recovery period. In Paper IV it was done at rest before warm-up, at end of warm-up, at end of each phase of the exercise test (BWR_{20}, BWR_{25}, BWR_{30}, BWR_{35} and BWR_{20b}) and at end of 5, 15 and 30 min recovery.

4.4.5 Rectal temperature

In Papers I-IV, rectal temperature of the horses was measured. In Paper I it was done before the warm-up, and within 5 min after the riding assessment. In Papers II-IV it was done at rest before warm-up, at end of the exercise test and at end of 30 min recovery.

4.5 Statistical analyses and calculations

The statistical analyses were performed by SAS (Statistical Analysis System package, Inst. Inc Cary, NC USA), using SAS 9.2 (Papers I and II) and SAS 9.4 (Papers III and IV), and are described thoroughly in the individual papers. In all papers, normal distribution of the data was verified with residual plots and some lactate data had to be log-transformed (Papers II-IV). ANOVA was used in all papers. In all papers, the Tukey test was used for comparisons and level of statistical significance was set to $P<0.05$ and a tendency to $P<0.1$. PROC CORR and PROC REG were used to estimate relationships between parameters (Papers I-IV).

In Paper I, four models and PROC GLM (models 1 and 2) and PROC MIXED (models 3 and 4) were used. The results were expressed as least squares mean ± root mean square error (RMSE) and as means ± SD, where stated.

In Paper II, two models and PROC MIXED (model 1 and 2) were used. The results were expressed as least squares mean ± standard error (SE) from model 1, unless otherwise stated.

In Paper III, one model and PROC MIXED were used. The results were expressed as least squares mean with their SE for comparison of the two pace runs, but for comparison of all seven samples (HR, Lac, Hct) and three samples (RR and RT) the results were expressed as mean ± SE.

In Paper IV, three models and PROC MIXED (models 1, 2 and 3) were used. Results from models 1 and 2 were expressed as least squares mean ± SE, but results from model 3 were expressed as mean ± SE.

The peak HR, peak plasma lactate concentration and peak haematocrit and recovery HR, recovery plasma lactate concentration and haematocrit in recovery were compared between Papers I-IV (where appropriate) using PROC GLM, with study as a fixed factor.

In Paper II, Microsoft Excel was used to calculate linear regressions between speed and HR (V_{140}, V_{180}) within individual horses, exponential regressions between HR and plasma lactate concentration within individual horses (HR_2), between speed and plasma lactate concentration within individual horses (V_2, V_4) and in Paper IV between body weight ratio of rider to horse and plasma lactate concentration within individual horses (W_4). In Paper II, all regressions within individual horses were calculated within a gait and a rider. The exponential equation between plasma lactate concentration and BWR of rider to horse was calculated using mean values (Paper IV).

5 Results

5.1 General

All horses in Papers I-IV were considered healthy and in functional condition by the owners/staff and had thin to fleshy BCS (2.25-4.00 in Paper I and 2.5-3.5 in Papers II-IV on a scale of 1.00 to 5.00 according to Stefánsdóttir & Björnsdóttir (2001)). Only horses deemed sound and ‘well fed’ (FEIF, 2002) were allowed to attend the riding assessment in the BEFT according to international rules (FEIF, 2002). In Paper III (pace race), one horse showed weak symptoms of pain (pawing, shaking head) during recovery (at ~10 min) after the second SPR and was treated accordingly (see Paper III). In Paper IV, all horses had no clinical remarks during palpation and at walk both before and one and two days after the test. All horses except one were also without clinical remarks at trot before and after the test and, although the one horse with clinical remark appeared “short-strided and earth-bound” in trot before the exercise test, it was estimated to be symmetrical (for further details see Paper IV).

5.2 A breed evaluation field test (BEFT) (Paper I)

5.2.1 Duration, distance and speed of the BEFT (Paper I)

The distance covered in the BEFT was 2.9 ± 0.4 km (range 1.8-3.8 km, n=248), the duration was 9:37 ± 1.22 min:s (range 5:07-15:32 min:s) and the average speed during the BEFT was 17.8 ± 1.4 km (range 13.2-21.3 km/h, n=248). Stallions covered a longer distance than mares during the BEFT (2.9 vs. 2.8 km, RMSE=0.3; $P<0.05$) and in the warm-up and BEFT (5.1 vs. 4.8 km, RMSE=0.8; $P<0.05$) and at a faster speed during the BEFT (18.0 vs. 17.4 km/h, RMSE=1.1; $P<0.001$). Horses with a score for pace (score ≥5.5) covered a longer distance (2.9 vs. 2.8 km, RMSE=0.3; $P<0.05$) and at a faster speed

(18.0 vs. 17.5 km/h; RMSE=1.1; P<0.01) than horses that received no score for pace. Compared with 5-, 6- and ≥7-year-olds, there was a tendency for 4-year-old horses to be ridden a shorter distance (2.7 vs. 2.8, 2.9 and 2.9 km, RMSE=0.3; P=0.06), for a shorter duration (9:12 vs. 9:35, 9:48 and 9:53 min:s; P=0.05) and at a lower peak velocity (40.7 vs. 42.5, 42.6 and 42.5 km/h, RMSE=3.3, P=0.07).

5.2.2 Physiological response to the BEFT (Paper I)

The HR during the BEFT was 184 ± 13 bpm (range 138-210 bpm, n=102), during 36% of BEFT it was ≥200 bpm, and peak HR during the BEFT was 224 ± 9 bpm (range 195-238 bpm, n=102). Mean HR as a proportion of peak HR during the BEFT was 82% (range 64-90%). Plasma lactate concentration after the BEFT was 18.0 ± 6.5 mmol/L (range 2.1-34.4 mmol/L, n=266) and 72% of the horses had Lac ≥15.0 mmol/L (range 15.2-34.4 mmol/L). RR, RT, Hct, Hb, CK, AST and TPP increased following the BEFT (P<0.001) (Table 6).

Table 6. *Physiological response in Icelandic horses (stallions and mares, mean age 5.9 ± 1.4 year, range 4-11 years) before warm-up and within 5 min after a breed evaluation field test (BEFT). All physiological parameters were significantly higher (P<0.001) after the BEFT than before*

	Before				After			
Physiological parameter	n	Mean ± SD	Min	Max	n	Mean ± SD	Min	Max
Respiratory rate, breaths/min	265	30 ± 11	12	76	266	101 ± 30	12	168
Rectal temperature, °C	265	37.8 ± 0.3	36.7	38.6	265	39.5 ± 0.5	38.0	41.1
Haematocrit, %	266	35 ± 4	25	50	266	45 ± 3	36	55
Haemoglobin, g/L	253	128 ± 16	95	197	266	164 ± 14	132	202
CK concentration, U/L	266	249 ± 181	105	1913	266	315 ± 247	103	2162
AST concentration, U/L	266	353 ± 98	158	894	266	382 ± 106	124	928
Total plasma protein, g/L	264	6.0 ± 0.4	4.9	7.4	250	6.4 ± 0.4	5.2	8.0

Effects of sex

Compared with mares, stallions had lower mean HR (178 vs. 189 bpm, RMSE=11; P<0.001) and minimum HR (115 vs. 125 bpm, RMSE=13; P<0.01) during the BEFT and lower recovery HR during the 5-min recovery (108 vs. 115 bpm, RMSE=9; P<0.01) and during the last minute of the 5-min recovery (90 vs. 96 bpm, RMSE=9; P<0.001). Stallions also had lower Lac after the BEFT than mares (13.1 vs. 18.6 mmol/L, RMSE=5.0; P<0.001), lower RT after the BEFT (39.4 vs. 39.6 °C, RMSE=0.5°C; P<0.05) and higher Hct (before: 39 vs. 34 %, RMSE=3%; P<0.001; after: 49 vs. 43 %, RMSE=2%; P<0.001), higher Hb (before: 140 vs. 122 g/L, RMSE=13 g/L; P<0.001; after:

176 vs. 157 g/L, RMSE=10 g/L; P<0.001) and TPP (before: 61 vs. 59 g/L, RMSE=4 g/L; P<0.001); after: 65 vs. 63 g/L, RMSE=4 g/L; P<0.001).

Effects of age

Four-year-old horses had higher RR than 5-, 6- and ≥7-year-old horses (117 vs. 102, 97, 96 breaths/min, RMSE=28; P<0.05) after the BEFT. The 4-year-old horses had lower Hct (45 vs. 46, 46 and 47 %, RMSE=2%, P<0.05) and Hb values (161 vs. 166, 168 and 170 g/L, RMSE=10 g/L; P<0.01) than 5-, 6- and ≥ 7 year-old horses after the BEFT. The 5-year-old horses had lower Hct (P<0.01) and Hb values (P<0.05) than the ≥7-year-old horses after the BEFT.

Effects of "flying" pace

Compared with horses that received no score for pace, horses with a score for pace had higher Lac (17.7 ± 0.6 vs. 14.0 ± 0.6 mmol/L, RMSE=5.0; P<0.001) and higher recovery HR during the 5-min recovery period (114 ± 1 vs. 109 ± 1, RMSE=9; P<0.01) and during the last minute of the 5-min recovery period (95 ± 1 vs. 91 ± 1; RMSE=9; P<0.01).

Effect of velocity, distance and BWR

The mean HR during the BEFT was affected by velocity (P<0.001) and increased by 4 bpm per km/h. The HR during the 5-min recovery period and HR during the last minute of that period were both affected by velocity (P<0.001) and both increased by 2 bpm per km/h. Velocity had an effect on Lac (P<0.001), with faster horses having higher values (1.3 mmol/L increase per km/h). The RR after the BEFT was affected by velocity (P<0.01) and increased by 5 breaths/min per km/h.

Rectal temperature after the BEFT was affected by distance and was 0.2°C higher per km covered in the BEFT.

The Lac after the BEFT increased (P<0.01) by 0.4 mmol/L for every 1% increase in BWR of rider to horse.

5.3 Physiological response to the gaits (Papers II and III)

5.3.1 Comparison of tölt and trot (Paper II)

There was no difference in HR between tölt and trot at any time point (P>0.05). The calculated parameters (V_2, V_4, HR_2, V_{140} and V_{180}) did not differ between tölt and trot (mean ± SD: 4.5 ± 0.3 m/s, 5.3 ± 0.3 m/s, 163 ± 12 bpm, 3.6 ± 0.6 m/s and 5.2 ± 0.4 m/s, respectively; P>0.05).

At the slowest speed tested (~3.0 m/s), haematocrit and plasma lacate concentration were higher (P<0.05) in tölt (40 ± 1 %, 1.1 ± 0.06 mmol/L) than in trot (39 ± 1 %, 0.9 ± 0.06), but at other time points haematocrit and plasma lactate concentration did not differ between tölt and trot ($P>0.05$). There was significantly prolonged recovery of haematocrit and breathing frequency following tölt and a tendency for prolonged recovery of plasma lactate concentration ($P=0.0675$). Moreover, the decrease in rectal temperature from the end of exercise and until 30-min recovery was lower after tölt than after trot (0.30 vs. 0.44°C; $P<0.05$).

Stride frequency was greater in tölt than in trot at all speeds ($P<0.001$), whereas stride length was greater in trot than in tölt at all speeds ($P<0.001$).

5.3.2 Flying pace (Paper III)

The speed of the 100 m pace runs was 10.4 ± 0.7 m/s (mean ± SD; range: 9.2 ± 12.1 m/s) and was not different between pace runs I and II ($P>0.05$). Heart rate was higher during pace run I than II (207 ± 3 vs. 205 ± 3 bpm; $P=0.02$) and peak HR ranged from 200 to 224 bpm (n = 8). Mean HR during the pace runs corresponded to 98% of individual peak HR. Plasma lactate concentration was higher after pace run II than I (18.5 ± 1.3 vs. 11.9 ± 0.7 mmol/L, $P<0.001$). Plasma lactate concentration peaked after 5 min recovery but this level was not different from that after pace run II and remained until 15 min recovery (mean ± SD: 19.2 ± 5.5, 18.8 ± 4.7 and 15.7 ± 5.8 mmol/L, respectively, $P>0.05$). Haematocrit was not different between pace runs I and II (44 ± 0.9 vs. 44 ± 0.8 %; $P=0.75$).

The previous best time according to Worldfengur (2015) in a 100 m flying pace competition of the horses participating in the study, in the period 2009 until after the pace competition in May 2012, was negatively correlated with plasma lactate concentration at the end of the SPR (Best time = 10.899 – 0.1159 × Lac; $r^2=0.34$; $P=0.047$).

There was a negative relationship between horse age and peak HR during the SPR ($HR_{peak} = 231.1 - 1.653 \times age$; $r^2=0.66$; $P=0.0147$) (Table 7), and between horse age and average HR during the pace runs ($HR = 229.18 - 1.8142 \times age$; $r^2=0.60$; $P<0.05$). There were also negative correlations (r=-0.53 to -0.79; $P<0.05$; Table 4 in Paper III) between age and recovery HR. There were positive correlations (r=0.58-0.80; $P<0.05$; Table 2 in Paper III) between plasma lactate concentration at different time points and recovery HR during the 5th, 15th, and 30th min and during the last 15 s of the 5th, 15th and 30th min.

5.4 Physiological response to rider (Papers I-IV)

5.4.1 Physiological response to a rider and additional weight (lead) (Paper IV)

Heart rate increased linearly with increasing BWR (lsmean ± SE: 187 ± 4, 191 ± 4, 195 ± 5 and 199 ± 4 bpm, respectively, P<0.05). HR during BWR_{20b} did not differ from BWR_{20} and BWR_{25}. HR increased by 7 bpm for each 10% increase in BWR in the range tested (P<0.01).

Plasma lactate concentration increased exponentially with increasing BWR from 20 to 35% (lsmean ± SE: 3.7 ± 0.3, 4.2 ± 0.3, 5.7 ± 0.4 and 8.0 ± 0.5 mmol/L, respectively, P<0.05; $Lac = 1.2221 \times e^{0.0524\times BWR}$; r^2=0.97). Plasma lactate concentration decreased after BWR_{20b} (5.9 ± 0.4 mmol/L) compared with BWR_{35} but was still higher than after BWR_{20} and BWR_{25} (P<0.01). The BWR where Lac reached 4 mmol/L (W_4) was 22.7 ± 4.3 % (range 17.0-27.5%).

Breathing frequency increased linearly with increasing BWR (lsmean ± SE: 54 ± 7, 69 ± 8, 88 ± 7 and 103 ± 9 breaths/min; P<0.05) and was not lower after BWR_{20b} (104 ± 7 breaths/min) than after BWR_{35} (P>0.05). Breathing frequency increased by 3 breaths/min for every 1% increase in BWR in the range tested (P<0.001). Haematocrit (%) was not affected by BWR (P>0.05) except it was lower after BWR_{20b} than after BWR_{35} (P<0.05).

There was a positive linear relationship between BWR and stride frequency (P<0.001) and a negative linear relationship between BWR and stride length (P<0.01). Stride frequency increased by 0.02 strides/s and stride length decreased by 4 cm per 10% increase in BWR in the range tested.

There was a positive correlation between back BCS and W_4 ($W_4 = 11.706 \times BCS_{back} - 29.11$; r^2=0.56). Furthermore, back BSC was negatively correlated with Lac after 15 min recovery (r=-0.91; P<0.01). There were negative correlations (r=-0.73 to -0.93; P<0.05) between haematocrit and BW, and between haematocrit and some body measurements (*e.g.* height at withers, at croup, cannon bone and carpus circumference).

5.4.2 Physiological response to rider (Papers I-III)

In Paper I, the random factor 'rider' accounted for 5 to 46% of the random variation in the models for distance, duration and speed, *i.e.* the variation that was not explained by the fixed factors (sex, age group and whether a horse was scored for pace or not). The highest variation (46%) was for peak speed during warm-up, and the second highest (30%) for total distance ridden in warm-up and BEFT. The random factor 'rider' also accounted for 0 to 18% of the random variation in the models for physiological response to the BEFT and for total score for riding abilities, *i.e.* the variation that was not described by the fixed factors (sex, age group, whether a horse was scored for pace or not, the average velocity of a horse in the BEFT as a continuous variable, the distance ridden in the BEFT as a continuous variable, and the BWR of rider to horse as a continuous variable). Plasma lactate concentration after the BEFT increased ($P<0.01$) by 0.4 mmol/L for every 1% increase in BWR of rider to horse and the rider accounted for 14% of the random variation in the model for plasma lactate concentration (model 4, Paper I).

There were clear effects of rider in Papers II and III. In Paper II, horses showed higher HR, plasma lactate concentration, breathing frequency and rectal temperature during exercise and recovery with the heavier rider ($P<0.05$; data not shown). In Paper III, there were no differences between the two riders in speed and HR of the horses during the two pace runs or in Hct immediately after the pace runs ($P>0.05$; comparison of two samples), but the heavier rider resulted in higher values for plasma lactate concentration, HR, haematocrit and rectal temperature when comparing all samples except at rest (six for HR, haematocrit and lactate and two for RT) ($P<0.05$; data not shown in Paper III).

5.5 Comparison of peak and recovery values between studies (Papers I-IV)

5.5.1 Peak values of HR, Hct and plasma lactate concentration (Papers I-IV)

Peak HR was only compared between Papers I, III and IV, as mean peak HR in Paper II (tölt vs. trot) was <190 bpm. Peak HR was significantly higher in Paper I (BEFT study) than in Paper III (pace race study) and Paper IV (weight carrying study) (mean ± SD: 224 ± 8 vs. 208 ± 7 and 203 ± 10, respectively; $P<0.001$). Peak HR was correlated with horse age (Table 7) in Papers I (BEFT study), III (pace race study) and IV (weight carrying study).

Peak plasma lactate concentration was higher in Papers I (BEFT study) and III (pace race study) than in Papers II (tölt vs. trot study) and IV (weight carrying study) (mean ± SD: 18.0 ± 6.5 and 19.8 ± 5.2 mmol/L vs. 5.0 ± 1.9 and 8.0 ± 1.5 mmol/L, respectively; $P<0.001$).

Table 7. *Regressions between peak heart rate (HR_{peak}) and horse age in Papers I, III and IV*

Paper/s	Regression	r^2	P-value
III	$HR_{peak} = 231.07 - 1.6531 \times age$	0.66	0.0147
I, III and IV	$HR_{peak} = 234.82 - 1.8287 \times age$	0.35	0.0001
I and III	$HR_{peak} = 234.82 - 1.7286 \times age$	0.22	0.0001
I	$HR_{peak} = 231.20 - 1.2062 \times age$	0.04	0.0359

Peak haematocrit (usually at end of exercise) was significantly higher in Papers I (BEFT study), III (pace race study) and IV (weight carrying study) than in Paper II (tölt vs. trot) (45, 44, 46 vs. 42 %, respectively; P<0.001).

5.5.2 Physiological parameters back to level at rest after 30 min recovery (Papers II-IV)

After 30 min recovery, Hct had recovered in all studies, but RT had not (Table 8). Heart rate had recovered in Paper IV (weight carrying study), but not in Paper II (tölt vs. trot) and Paper III (pace race) (Table 8). Respiratory rate had recovered after the weight carrying study (Paper IV) and after trot in the tölt vs. trot study (Paper II), but not after tölt in the tölt vs. trot study (Paper II) and not in the pace race study (Paper III) (Table 8).

Table 8. *Recovery after 30 min in Papers II-IV (r = recovered, n= not recovered). Recovery means that values are no longer different from values at rest*

Paper	HR[1]	Lac	Hct	RT	RR
II, tölt vs trot	n	r	r	n	r trot, n tölt
III, pace race	n	n	r	n	n
IV, weight carrying	r	n	r	n	r

[1]*HR=heart rate, Lac=plasma lactate concentration, Hct=haematocrit, RT=rectal temperature, RR=respiratory rate*

5.5.3 Recovery values of HR, plasma lactate and Hct (Papers I-IV)

The recovery HR during 5 min, the 5th min and the last 15 s of the 5th min was significantly higher (P<0.05; Figure 5) in Paper I (BEFT study) than in all other studies (Papers II-IV). The recovery HR during the 15th and 30th min was significantly higher (P<0.001) in Paper III (pace race study) than in Paper II (tölt vs. trot study), but not different from that in Paper IV (weight carrying study) (P>0.05) (Figure 6).

Plasma lactate concentration was significantly higher (P<0.001) at end of exercise in Papers I (BEFT study) and III (pace race study), and after 5-, 15- and 30-min recovery in Paper III than in Paper II (tölt vs. trot study) and IV (weight carrying study) (Figure 7).

Haematocrit at end of exercise was higher in Paper I (BEFT study) than Paper II (tölt vs. trot study) (P<0.001) (Figure 8). Haematocrit at end of 5- and 15- min recovery was higher in Papers III (pace race study) and IV (weight carrying study) (P>0.05) than in Paper II (tölt vs. trot study) but at end of 30-min recovery it was higher in Paper IV (weight carrying study) than Paper II (tölt vs. trot study) (P<0.05) (Figure 8).

There were correlations ($r \geq 0.7$; $P<0.05$) between plasma lactate concentration immediately post exercise and during recovery, and recovery HR 15 and 30 min post exercise (Table 9).

Table 9. *Regression (when $r \geq 0.70$; $P<0.05$) between plasma lactate concentration (y) and recovery HR (x) based on results in Papers II-IV*

Predictors (x)	Response (y)	Regression	r^2	n[1]
During 15th min	At end of exercise	Y= -25.322 + 0.5383 x	0.60	47
During 30th min	At end of exercise	Y= -18.852 + 0.5561 x	0.63	47
During last 15 s of 15th min	At end of exercise	Y= -24.539 + 0.5381 x	0.62	47
During last 15 s of 30th min	At end of exercise	Y= -17.951 + 0.5438 x	0.54	47
During 15th min	After 15 min recovery	Y= -28.403 + 0.5466 x	0.54	49
During 30th min	After 30 min recovery	Y= -20.315 + 0.5094 x	0.63	49
During last 15 s of 15th min	After 15 min recovery	Y= -28.221 + 0.556 x	0.58	49
During last 15 s of 30th min	After 30 min recovery	Y= -19.086 + 0.4897 x	0.52	49

[1]*Number of measurements*

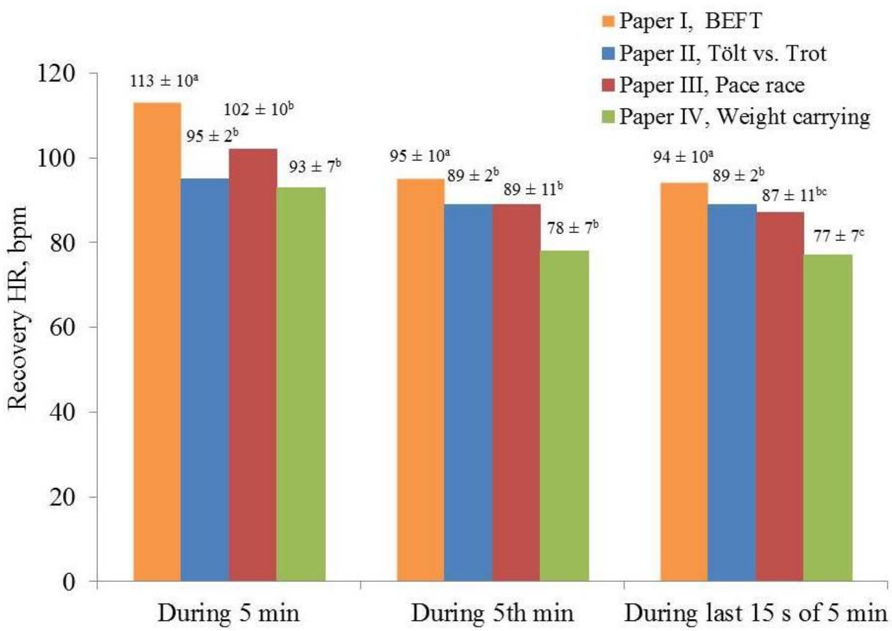

Figure 5. Heart rate (HR) (mean ± SD bpm) during 5 min recovery, during 5th min of recovery and during last 15 s of 5 min recovery in all studies (Papers I-IV). Bars within each time point with different superscripts differ ($P<0.05$).

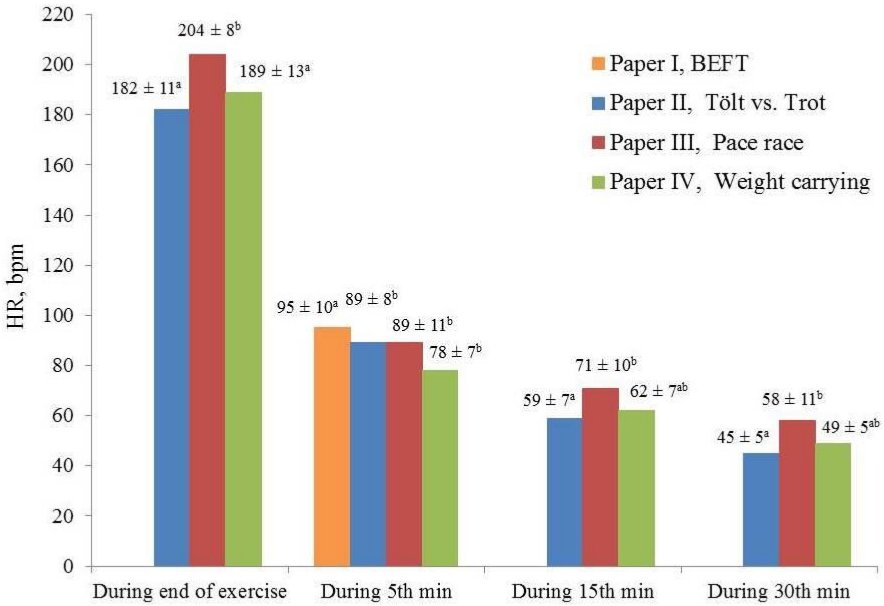

Figure 6. Heart rate (HR) (mean ± SD bpm) during end of exercise[1] and during 5th, 15th, and 30th min of recovery in Paper II-IV. Bars within each phase with different superscripts differ (P<0.05). [1]During last min at 5.0 m/s in tölt and trot study (Paper II), during the later pace run (Paper III) and during last min with repeated body weight ratio of 20% of rider to horse in the weight carrying study (Paper IV).

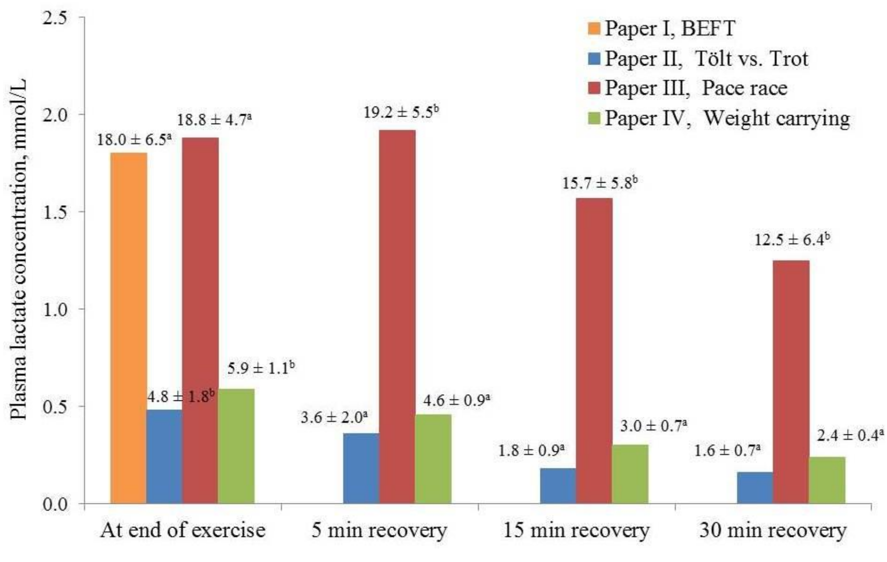

Figure 7. Plasma lactate concentration (mean ± SD mmol/L) at end of exercise in Papers I-IV and at end of 5-, 15-, and 30- min recovery in Papers II-IV. Bars within each phase with different superscripts differ (P<0.05)

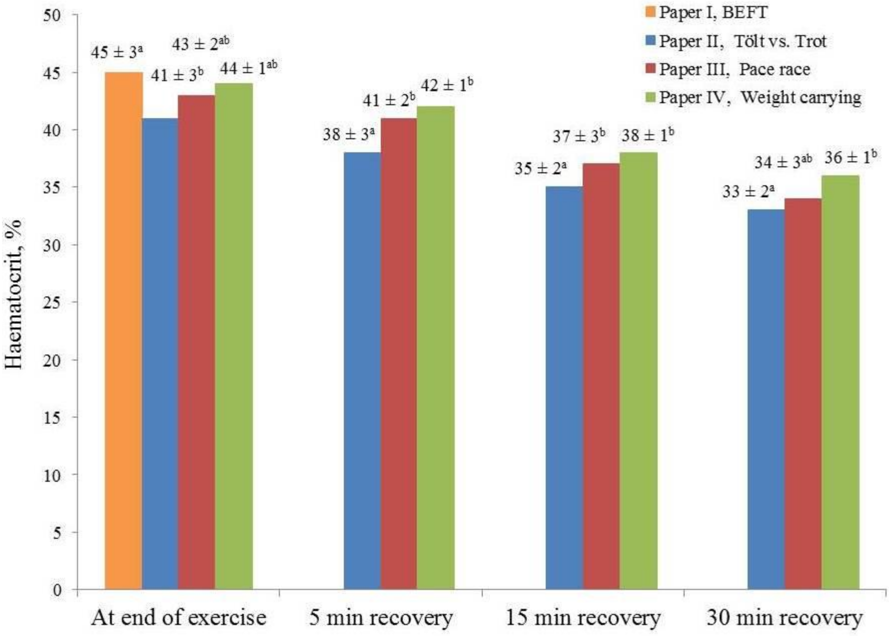

Figure 8. Haematocrit (means ± SD %) at end of exercise in Papers I-IV and at end of 5-, 15-, and 30- min recovery in Papers II-IV. Bars within each phase with different superscripts differ ($P<0.05$).

6 Discussion

6.1 General

The main findings in Papers I-IV were that Icelandic horses performed high intensity exercises during the true gait tests (BEFT in Paper I, pace race in Paper III). Moreover, depending on the weight of the rider, even horses at the medium speed tölt and trot (~5.5 m/s) typical of leisure horses temporarily performed high intensity exercise (tölt vs. trot in Paper II, weight carrying test in Paper IV). The physiological response (HR, plasma lactate concentration) to the true gait tests (Papers I and III) was comparable to that measured in high intensity horse disciplines such as racing (Krzywanek *et al*., 1970; Reynolds *et al*., 1993; Evans *et al*., 2002; Mukai *et al*., 2007), polo (Ferraz *et al*., 2010) and three-day eventing (White *et al*., 1995).

6.2 A breed evaluation field test

6.2.1 Metabolic demands of the BEFT

This thesis is the first work to measure physiological response in Icelandic horses performing a true BEFT. There is generally a limited amount of data in the literature on physiological response during true competitions in different horse disciplines (Table 3). The BEFT is not a competition but an official test to evaluate breeding horses. The outcome (score) can affect the marketing value of the horses (Albertsdóttir *et al*., 2011), as well as their success in breeding (particularly for stallions), which means that there is a lot at stake. The reasons for lack of data on true competitions in horse disciplines might be *e.g*. difficulties in getting the necessary participation by trainers or owners before, during and after competition and sampling (*e.g*. of blood) at critical points. This is understandable, as there is a lot of tension and action around competition. Therefore the great participation by trainers and owners in Paper I was remarkable. It provided the opportunity: 1) to evaluate the physiological response to BEFT and 2) to evaluate the effect of sex and age groups, with good accuracy. The reasons for this good participation were probably that: 1) the official advisory system in horse breeding recommended the research; 2) many trainers and owners were visited personally beforehand or contacted by phone, the research was explained and their cooperation was requested directly; and 3) a meeting was held beforehand with the staff working at the BEFT at Hella to explain the research and ask for cooperation. However, the main reason was most likely that trainers and owners are very open to increasing their knowledge on training the Icelandic horse and saw a chance to benefit from the results and improve their training strategies.

The results reflect the metabolic demands of the BEFT (Paper I). Such knowledge of metabolic demands is the first step when training for a discipline, in order to evaluate how much training should focus on aerobic *vs.* anaerobic capacity (Marlin & Nankervis, 2002). In the BEFT, high aerobic capacity was an advantage (Paper I), but anaerobic metabolism was also needed during extended (fast) gaits, *e.g.* at pace, as horses with a score for pace had significantly higher plasma lactate than horses with no score for pace (Paper I). In addition, horses in the BEFT with pace subjectively judged as 'fast' and 'sure' had significantly higher lactate concentration than when no comment was given ('fast': 23.6 ± 1.2 vs. 17.9 ± 0.5, $P<0.001$; 'sure': 20.2 ± 0.9 vs. 18.1 ± 0.6, $P<0.05$), indicating that successful pace is more anaerobic than less successful pace (Stefánsdóttir *et al.*, 2014b). Furthermore, the results in Paper III confirmed that anaerobic metabolism is crucial for good performance in pace. It is suggested that during the BEFT, anaerobic metabolism is probably also needed during gallop, extended (fast) gaits (tölt and trot) and the sharpest tempo alterations (accelerations). Speed at tölt and trot was commonly >5.5 m/s during the BEFT (unpublished results) and V_4 in tölt and trot was 5.3 m/s (Paper II). The results (Paper I) provide new information which might help trainers to better adjust their training programmes preparing horses for the BEFT. However, the qualities of the gaits (*e.g.* beat, long strides, suppleness, lightness in movements, high leg action and speed capacity) have previously been, and will most likely continue to be, a priority during training of the Icelandic horse. This is because the more technical the competition/exercise test is, the less emphasis is put on fitness and *vice versa* (Marlin & Nankervis, 2002). This also partly explains why research on the exercise physiology of Icelandic horse disciplines lies well behind that on many other horse sports which almost exclusively aim for speed, *e.g.* racing (Thoroughbred, Standardbred, Quarterhorse) and endurance (*e.g.* Arabian horse). However, the same basic training principles apply to all horses (increase stamina, speed and strength), in addition to 'training specificity' depending on sport/exercise test and individual horse (Marlin & Nankervis, 2002). It is challenging and demanding to prepare horses for the BEFT, as they are expected to perform in all gaits (relaxed walk to full speed gallop) within the same test, which lasts on average <10 min. Training for three-day eventing might to some extent be comparable, since the horse needs to be calm and focused for the dressage but physically fit for the cross-country event (Serrano *et al.*, 2002). Eventing horses were estimated to be undertrained (for the cross-country phase) and the conflicts facing trainers of eventing horses were discussed in a study by Serrano *et al.* (2002). Limited information was available on the training background of the horses in Paper I. However, there was great variability in the physiological response, which can be explained by: 1) different fitness levels (training background), 2) different natural ability to perform (genetics); and 3) different demands from the riders. According to the riders who scored each horse for preparation/training (scale 1 to 10, 1 = badly and 10 very well prepared), there was a wide range in the level of preparation, although most of the horses (62%) were estimated to be quite well prepared/trained (≥7) to attend the BEFT (Paper I). However, only one physiological parameter (minimum HR) was correlated ($r \geq 0.2$; $P<0.05$) with the riders' opinion, and correlations between rider opinion and scores were few and weak ($r<0.25$; $P<0.05$). That indicates that the riders' opinion was poorly reflected in the physiological response or the scores, which was unexpected and needs further study.

6.2.2 Indirect selection for strength and speed over decades

In the past 65 years (since mechanisation), a graded judging scale has been used to evaluate Icelandic breeding horses (Hugason, 1994). Horses are judged both for conformation and for riding abilities, with the latter currently representing 60% of the total score (FEIF, 2002). The general breeding standard emphasises strength, flexibility, light-bodied and muscular body (FEIF, 2002). This is logical, as increased lean body mass has been positively related to performance in horses of other breeds (Kearns *et al.*, 2002; Fonseca *et al.*, 2013). Icelandic horses have to undergo a physiologically strenuous exercise test while carrying a rider, to be evaluated for breeding (Paper I). Therefore it is suggested that indirectly, the Icelandic horse has probably been selected for strength and speed, both for conformation and riding abilities, during the last 65 years at least. This is supported by the genetic improvement (higher scores) of the horses performing the BEFT in the period 1994-2007 and the fact that horses are preselected into the BEFT, which implies that a horse is considered to be of higher than average quality if it attend the BEFT (Albertsdóttir *et al.*, 2011). It was found recently that broad chest, broad croup and uphill conformation (high withers, high front back) are important for riding abilities and more common in elite Icelandic riding horses (Kristjánsson, 2014).

6.2.3 Effect of sex (stallions and mares)

There was a clear effect of sex in response to the BEFT. Although stallions covered longer distances (warm-up plus BEFT) and performed at higher speed, they had lower HR and plasma lactate concentration (Paper I). Altogether, this indicates that aerobic fitness was higher in stallions than in mares, which is also supported by the higher Hct and Hb values. A higher Hct in Standardbred trotter stallions than in mares has been reported previously (Persson *et al*., 1996) and a higher Hb concentration has been found in stallions than mares of other breeds (Persson, 1967; Čebulj-Kadunc *et al*., 2002; Pađen *et al*., 2014). The results in this thesis were also supported by findings of Persson & Ullberg (1974) in Standardbred trotters where stallions were suggested to have higher aerobic capacity than mares and geldings, and findings in Thoroughbred and Standardbred horses that males were faster than females (Árnason, 2001; Mukai *et al*., 2003) and have lower HR than females (Mukai *et al*., 2003). One more reason for the superior performance in stallions in Paper I might be lower body fat content compared with mares, as indicated by lower BCS (2.9 vs. 3.1, respectively; $P<0.001$; BCS scale 1 to 5 according to Stefándóttir and Björnsdóttir, 2001). Furthermore, there is greater selection of males than females into the BEFT, as more than 90% of young colts in Iceland are castrated before the age of 2 years and very few geldings (mainly progeny from elite parents) attend the BEFT (Albertsdóttir *et al*., 2011). Only two geldings were measured in this study and because of the low number of individuals, geldings were excluded from the analysis. It can also be speculated whether stallions were more (better) trained than the mares or whether this is a true gender difference (with stallions having greater fat-free muscle mass, more muscle strength and higher aerobic capacity) or both. In human athletes, it is commonly accepted that there are gender differences such as greater muscle mass, less fat tissue, more muscle strength and higher aerobic capacity in males that contribute to superior performance (Lewis *et al*., 1986). Some of those gender differences are driven by different hormonal levels, *e.g.* testosterone (McArdle *et al*., 2015). Increased lean body mass has also been related to successful performance in horses (Kearns *et al*., 2002; Fonseca *et al*., 2013). In Paper I, stallions received higher scores for riding abilities than mares, which is in agreement with Árnason (1984), and blup-values for Icelandic horses are adjusted for effect of sex (Árnason, 1984). However, if stallions were better trained than mares, the reasons could be that stallions: 1) play more as youngsters (Sigurjónsdóttir *et al*., 2003), thus training themselves; 2) might often start earlier in training and need more training after initiation of riding as they are more energetic (as when younger), perhaps because of a true sex effect (*e.g*. hormones); and 3) are more valuable than mares (Ólafsdóttir, 2012), more strongly selected at a young age (Albertsdóttir *et al*., 2011) and therefore more effort and time might be spent on training them. However, according to the riders who scored each horse for preparation before the BEFT (scale 1 to 10; 1 = badly and 10 = very well prepared), stallions were not better prepared than mares (7.3 vs. 7.2, RMSE=1.5; P=0.66). However, this estimation did not evaluate the amount and time spent on training of each horse.

Further studies on sex differences concerning training and of true sex effect on performance of the Icelandic horse are of interest.

6.2.4 Effect of age groups (4, 5, 6 and ≥7 years)

There has been an ongoing discussion in recent years among horse owners and trainers on whether the BEFT is too demanding, especially for younger horses (4- to 5-year-olds). There were few effects of age in Paper I. However, the 4-year-old horses had lower haematocrit and haemoglobin values and higher post exercise respiratory rate than the older horses, although they were ridden a shorter distance, for a shorter duration and at lower peak speed ($P<0.1$). The 4-year-old horses also had significantly lower total score for riding abilities than the older horses, which is consistent with earlier findings (Árnason, 1984, T. Árnason, personal communication, 2014). These results indicate lower aerobic capacity and that the riders might have deliberately spared the 4 yr old horses. Likely, the 4-year-old horses which attend the BEFT are naturally gifted with balance at the gaits although carrying a rider, and the rider just rides them without much demands through the BEFT. A lower proportion of 4-year-old horses, compared with older age classes, attend the BEFT (Albertsdóttir *et al*., 2011; Worldfengur, 2015), and that might indicate higher preselection of this youngest group.

The lower haematocrit values are in accordance with earlier findings on Standardbred horses in training, where the haematocrit increased up to the age of 4 and 5 years in mares and stallions, respectively (Persson *et al*., 1996). In the BEFT study (Paper I), Hb and Hct increased numerically up to ≥7 years of age and both 4- and 5-year-old horses had significantly lower Hct than ≥7-year-old horses, indicating improved fitness with higher age. However, if an increase in age was associated with more experienced and better-trained horses, more signs of improved fitness could be expected (*e.g*. reduced HR). The lack of such signs might indicate that the general level of fitness in this population did not improve much after 5 years of age. The score for riding abilities was also not different between age groups ≥5 years old. That is not in agreement with Árnason (1984; personal communication 2014), who states that both total score and score for riding abilities generally increase with increasing age class (4, 5, 6 and ≥ 7 yr) within each sex. However, it could also be the case that more horses in the older age groups were less talented and might have spent more energy on showing good gaits. Our results (Paper I) do not indicate that the BEFT was more physically demanding for the 4-year-old horses than the older age groups. However, to really measure whether the BEFT was too strenuous for the horses in general (all age groups), they should be followed for a longer recovery period and clinical examination before and 24 and 48 h after the BEFT together with blood sampling should be carried out. The examination should be performed blind (the examiner should not know the age, the scores or the physiological response to the BEFT) and should include palpation/examination of neck, back and legs (evaluating muscle soreness), with a whole limb flexion test. Blood sampling should be done for analysis of plasma lactate concentration and muscle enzymes (CK and AST), the concentrations of which can indicate muscle damage and fitness.

6.2.5 Effect of increased CK and AST after the BEFT on performance

The significant increase in CK and AST activity after the BEFT (Paper I) confirms findings in an earlier study on high intensity exercise (Snow *et al.*, 1983a). There was a wide variation in CK and AST both before and after the BEFT (Paper I), and there were high correlations between before and after values for CK ($r=0.84$; $P<0.001$) and AST ($r=0.91$; $P<0.001$). In addition, CK and AST values were correlated before ($r=0.40$; $P<0.001$) and after the BEFT ($r=0.36$; $P<0.001$). These correlations indicate that horses which had high values of CK and AST before the BEFT also had so after it. The high values could also indicate that some horses might have had changes in muscle permeability or muscle damage both before and after the BEFT, as some before values were considerable higher than normal reference resting values (MacLeay, 2010; McGowan & Hodgson, 2014). Of the 266 horses tested, 4-17% had higher CK values and 33-69% had higher AST values before the BEFT than the normal resting reference values. Elevated CK and AST activity has been related to performance and is suggested to decrease the prospects of optimal performance (McGowan, 2008; MacLeay, 2010). However, in a study on endurance horses (Kerr & Snow, 1983), many good performers had high increases in only CK activity, leading those authors to conclude that increased plasma CK and AST activity alone should not be used to score a horse's performance. There were negative correlations between CK activity after the BEFT and score for tölt ($r=-0.12$; $P=0.04$) and between the magnitude of the increase in CK during the BEFT and score for tölt (r=-0.13; P=0.04). There was also a negative correlation between CK activity after the BEFT and score for form under rider (r=-0.14; P=0.03). These correlations were weak, but indicate that high levels of CK may affect performance negatively in the Icelandic horse. No correlations were found between AST activity and scores.

Speed and distance in the BEFT also affected CK, with a 14 U/L increase in CK for every 1 km/h increase in speed, but the change in magnitude of CK was 74 U/L lower for every km ridden. Possible explanations for the latter relationship are that fitter horses were ridden longer and/or that horses with higher concentrations were not ridden longer because the riders perceived these horses to be already tired. The increase in CK activity with higher speed probably reflects increased permeability of muscle cells and efflux of these enzymes from muscle groups that have been highly (even maximally) utilised (Snow *et al.*, 1983a).

6.2.6 Relationship between speed, distance, physiological parameters and judgement scores

In order to relate speed, distance and physiological response measured during and after the BEFT to performance at the gaits during BEFT, these were correlated to the scores (total score for riding abilities, score for walk, tölt, trot, pace, gallop, spirit and form under rider). Interestingly, despite the variation shown in the BEFT in terms of gaits, distance and velocity, there were correlations, although weak (r<0.37), between judgement scores and some physiological parameters. Total score for riding abilities and the score for pace were positively correlated with plasma lactate (r=0.27 and r=0.36, respectively; P<0.001). Total score for riding abilities was correlated with average speed during the BEFT (r=0.22; P<0.001), peak speed during the BEFT (r=0.25; P<0.001) and distance ridden in the BEFT (r=0.25; P<0.001). The score for gallop and that for spirit were also positively correlated with peak speed during the BEFT (r=0.23 and r=0.21, respectively; P<0.001). Together, this shows that fast horses were awarded higher scores, which fits with the judging scale (FEIF, 2002). Similarly, previous studies showed that faster horses had higher plasma lactate concentrations after true performance (racing) (Räsänen *et al.*, 1995) and maximal exercise (Bayly *et al.*, 1987). Interestingly, total score for riding abilities was positively correlated with distance covered in the BEFT. It is possible that the best horses were generally ridden a longer distance, but it is also possible that to achieve a high score, each gait must be shown fully for 150-200 m (*e.g.* 150-180 m are required for the highest score in pace; FEIF, 2002). The highest negative correlation was found between the score for walk and peak HR in the BEFT (r= -0.36; P<0.001), and the score for walk was also negatively correlated with average HR during the BEFT (r= -0.31; $P<0.01$) and average recovery HR 5 min post the BEFT (r= -0.24; $P<0.001$). It could be the case that the horses with a better walk showed it for a longer distance, resulting in lower average and recovery HR, or that the more cool/relaxed/fit horses walked better and had lower peak HR. Several more correlations were found ($r\geq0.2$ and <0.3; $P<0.05$), *e.g.* between total score for riding abilities, score for pace, score for spirit, and haematocrit and haemoglobin. These relationships could all indicate that increased aerobic performance is important for high scores.

6.2.7 Relationship between leg injuries and plasma lactate concentration

Health checks are carried out in all international BEFTs (FEIF, 2002). Immediately after a horse finishes the riding assessment in the BEFT, there is an obligatory shoe and health check (legs and mouth). If a horse has any injuries or blood, this is recorded in the international studbook and database (Worldfengur, 2015), together with the scores from the judgement. Blood in the mouth is registered specially and leg injuries according to location: left or hind leg, hoof, pastern, leg or elbow. The leg injuries are also estimated and recorded depending on severity, where 1 = minor to sore, 2 = significant. Of the 266 horses included in Paper I, no horse was recorded as having blood in the mouth and 19 horses (7%) had leg injuries (interference, cross-firing) after finishing the BEFT (first assessment). The main reason for these leg injuries in general is probably that at fast speed in the lateral gait pace, a hind foot hits the diagonal front foot, therefore it is often referred to as cross-firing. Factors affecting leg injuries in the BEFT have been reported and one of these is pace (Sigurdsson, 2006). Interestingly, horses with leg injuries had significantly higher plasma lactate concentration than horses with no leg injuries (lsmean ± SE: 18.7 ± 1.2 vs. 15.6 ± 0.5 mmol/L, respectively; P=0.0146; using model 4 from Paper I). It is not known when in the BEFT a horse received an injury. Therefore it is not known whether plasma lactate concentration increased because of the injury (stress factor) or whether a horse received the injury because of high plasma lactate concentration. If leg injuries occurred because of high lactate values, explanations could be that horses were not fit enough for the BEFT or that riders did not know the limits of the horse's performance, or both. It is known that reduced pH, inhibition of enzymes important for glycolysis and impaired contraction of muscles follow high lactate concentrations and can all lead to fatigue and myalgia (MacLeay, 2010). In humans, high lactate values in muscle can disturb the contraction mechanism within the muscle and thus affect coordination capacity and increase the risk of injury. Therefore humans are advised to avoid technical exercises when they have high lactate values (Janssen, 2001).

6.2.8 Body weight of Icelandic horses trained for BEFT

The BW of the Icelandic horse has been measured using a scale in several studies (Árnason & Bjarnason, 1994; Ragnarsson, 2009; Matthíasdóttir, 2012; Hoffmann *et al*., 2013). In those studies the average BW was in the range 364-379 kg. However, this thesis is the first work to present BW for a large number of Icelandic horses assumed to be in top training condition, *i.e*. ready to perform the BEFT (Paper I). The average BW found in Paper I (mean ± SD: 339 ± 19 kg) was slightly lower than the BW usually reported for Icelandic horses (350-370 kg). Based on my experience after measuring large numbers of riding horses at different times of the year (at Holar University College), there can be a considerable difference in the BW of a riding horse, which is in fleshier BCS when it starts in training in the autumn (October to November) than when it has reached competition condition (moderate) in the spring (May to June) (unpublished data).

6.3 Comparison of tölt and trot (Paper II)

To the best of my knowledge, Paper II is the first study to compare the physiological response to tölt and trot at the same speed in the same horses. Contradicting the starting hypothesis, there were only minor differences in physiological response to tölt and trot in the group of experienced adult Icelandic horses studied. The differences found between the two gaits were: 1) at the slowest speed tested (3.0 m/s) for two physiological parameters (plasma lactate and haematocrit), which were higher at tölt than trot, and 2) during recovery, when there was prolonged recovery of haematocrit and respiratory rate, a slower decrease in rectal temperature and a tendency for prolonged recovery of plasma lactate concentration (P=0.0675) after tölt. However, the differences observed were so small for all parameters that if discussed singly, with respect to methodology (measurement accuracy), physiological impact and practical relevance, they must be considered to be of little or no importance. Nevertheless, the overall number of these differences between the gaits was too large to be ignored, as they all pointed in the same direction. These results raise questions for further research, such as whether the minor differences seen (Paper II) would be more pronounced if longer distances were ridden. Furthermore, by testing both gaits on several types of track surface (only one type of track surface was used in Paper II), a more broad answer would be given to the question of whether tölt is more physiologically demanding than trot, thus strengthening or weakening (even disproving) the indications in Paper II. Moreover, the head, withers and neck position of horses is of relevance, but in Paper II the riders were instructed to ride the horses as passively on both gaits as possible, just to keep the horse in balance on the gait with a clear beat and at the intended speed. However, the head and neck carriage in balanced tölt is generally higher than in trot. This increases demand, alters muscle activation in the neck (Wijnberg *et al*., 2010) and shifts weight to the hind limbs (part of collection; Weishaupt *et al*., 2006, 2009). As tölt is often ridden with a lower head and neck position during initial stages of training than in competition, it would be of interest to research how different positions of the head, neck and withers of horses affect the physiological response within tölt.

Recently, the ‘gait keeper’ gene (A) was reported to affect training ability of tölt in Icelandic horses and to determine the gait a horse chooses when running free in pasture (Jäderkvist *et al*., 2015). Horses which did not carry the gene (CC) or carried only one copy of it (CA) were more difficult to train to tölt than horses carrying two copies of the gene (AA). The AA horses also showed lateral gaits (tölt and pace) more frequently when running free and during initial training than CA and CC horses (Jäderkvist *et al*., 2015). The eight horses used in Paper II were not analysed for their ‘gait keeper’ genotype but, based on their pedigree and gait abilities, are probably all AA except one, which is most likely CA. Their blup values were not different between tölt and trot (mean ± SD: 108 ± 3 vs. 107 ± 8, respectively; $P>0.05$) (Worldfengur, 2015), and all had blup value >100 for pace except one horse (blup 90), that which most likely has the genotype CA. When planning the experiment (Paper II), we were aware that the natural ability of the horses to tölt could be important (*e.g.* clear tölt, pacey and trotty). However, the aim was not to compare different groups of horses (*e.g.* genetics, age, training background) and therefore a uniform group of school horses was used, all bred, trained and kept at the same place all their life. That should have helped to answer if there were real differences in physiological response to the two gaits within this group of horses in this particular test (speed, distance, track etc.). However, at the same time the results cannot be generalised to all groups of Icelandic horses and to all types of environmental circumstances (track, speed, distance). In light of the effect of the “gait keeper” gene on training ability for tölt (Jäderkvist *et al*., 2015), it would be of interest to compare the physiological response to tölt and trot in Icelandic horses with different genotypes, *i.e.* AA, CA and CC horses.

6.4 Flying pace is a demanding gait

To the best of my knowledge, physiological response to a 100 m simulated pace race with a flying start had not been measured before Paper III. Papers I and III showed that flying pace is an energetically expensive (high ATP turnover) and demanding gait for the Icelandic horse, as it is ridden in the BEFT and a 100 m simulated pace race. This confirmed the starting hypothesis in Paper III, together with anecdotal evidence (Björnsson & Sveinsson, 2006), and also results from a pilot study (Bjarnadóttir, 2010) where HR (mean ± SD: 182 ± 14 bpm) during a 60 m pace race with a flying start was higher than mean HR in four other indoor sport disciplines (T1, F1, V1 and round-up; see Table 4) in Icelandic horses.

The plasma lactate levels at end of the simulated 100 m flying pace race were correlated with the earlier best time of the horses during 100 m pace race competitions (Paper III). Furthermore, plasma lactate concentration at end of pace run (I) was correlated with speed of run I ($r=0.68$; $P=0.0053$) and speed of pace run II ($r=0.63$; $P=0.0290$) (data not shown in Paper III). These results show that faster pace race horses have higher plasma lactate values after pace races (maximum speed is expected). That is supported with results from Standardbred trotters, where lactate concentrations (blood) after maximal exercise were related to true performance and were higher in faster horses (Räsänen *et al.*, 1995). Those authors suggested that taking blood samples after a maximal exercise (trotting race) might be a useful predictor of the anaerobic capacity of athletic horses.

Plasma lactate concentration after the second pace run (II) was similar to that measured in Icelandic horses after a BEFT (Paper I) and after 5 min recovery it was similar to that measured after 8 min recovery in Standardbred pacers after races of 1760 and 2160 m (Evans *et al.*, 2002). These two comparisons confirm that this short pace race (100 m) was a highly demanding exercise. Based on the results from Paper III, it is clear that the metabolic requirements for the short pace races in Icelandic horses (100, 150 and 250 m) differ from those in most other horse disciplines, which mainly require aerobic metabolism (Marlin & Nankervis, 2002; Gerard *et al.*, 2014) but might be similar to those estimated for Quarterhorse races (Gerard *et al.*, 2014). Therefore training of anaerobic capacity is probably of the utmost importance for success in pace race competitions for Icelandic horses. Pace trainers of Icelandic horses commonly use interval and uphill training and training in canter/gallop (Jansson *et al.*, 2014), which are all logical training methods to activate the anaerobic metabolic system. Based on our studies on Icelandic pace race horses it is suggested that during training, as with Quarterhorses, it is important to maintain the proportion of IIB fibres and glycolytic capacity in the muscles of the horses, soundness and mentality, with less emphasis on endurance conditioning (Nielsen, 2014).

6.5 Weight carrying capacity of the Icelandic horse

In Papers I-IV, there was an effect of rider, with increased physiological response as BWR of rider to horse increased. However, in Papers II-III it was not possible to say whether this was an effect of weight, riding technique or both. In Paper I (BEFT), there was both a random effect of rider and an effect of BWR. In Paper IV (weight carrying), which was designed to estimate the effect of the rider's weight, the physiological response increased as BWR increased from 20 to 35% which was in agreement with our hypothesis, with the fundamental law of physics (Newton's second law) and with earlier studies on weight carrying in other riding horses (Thornton *et al.*, 1987; Sloet van Oldruitenbourgh-Oosterbaan *et al.*, 1995; Powell *et al.*, 2008). To the best of my knowledge, Paper IV is the first study to measure the physiological response to increased BWR in Icelandic horses and also the first study where a weight threshold at which lactate rapidly accumulates (W_4) has been assessed in a group of horses. Based on the results, it is likely that the continuous time at which these horses could have stayed at tölt (at this same speed) would have been limited at BWR >23% without rapid accumulation of lactate (and hydrogen ions), which would limit muscle contractability and lead to fatigue (MacLeay, 2010). However, there was considerable individual variation in W_4 (range 17.0-27.5%) despite the use of an uniform group of horses, which indicates that individual and genetic factors could have a substantial effect on W_4 and weight carrying capacity. The lack of correlation between body size and W_4 showed that body size is not a simple and decisive parameter for weight carrying capacity. The conformation of the topline (back, loin) might be of importance for weight carrying, as W_4 increased with back BCS (Paper IV). This was supported by results from Powell *et al.* (2008) that post exercise muscle soreness was worse in horses with narrower loins. Length of back of the Icelandic horse is evaluated indirectly and subjectively in the conformational score for proportion (FEIF, 2002). Rather short body format (body length minus height at withers) is reported to have a positive effect on riding abilities in Icelandic horses and is suggested to be related to length of the midsection, at least in some cases (Kristjánsson, 2014). Weight on the back is a challenge increasing extension (hollowing) of the back (de Cocq *et al.*, 2004; van Weeren, 2014). Therefore it is logical to assume that length of the back might be important and that *e.g.* too long a back might indicate weakness (except it might be compensated for by stronger muscles, type IIB). The height of the front back, incline of the back line (uphill, downhill) and connection between the back and croup are all considered relevant for performance of the Icelandic horse (Kristjánsson, 2014).

Other studies indicate that BCS of the horse might be more important for performance than BWR (Garlinghouse & Burrill, 1999) and also that rider balance and technique (de Cocq *et al*., 2010; Peham *et al*., 2010) and coupling between carrier and load may affect energetic cost (de Cocq & van Weeren, 2014). The weight carrying capacity of horses is probably a multifaceted and complex phenomenon. In Paper IV it is suggested that, long-term health and locomotion symmetry should be used for estimation of weight carrying capacity, because short-term responses (locomotive and physiological) showing deviations from normal/symmetrical conditions, could be part of the training adaptation process. However, further research is needed to relate short- and long-term physiological response to long-term health (*e.g*. back, legs) and locomotion.

6.6 Resting and peak HR

6.6.1 Resting HR (Papers II, III and IV)

Resting HR of horses is usually in the range 25 to 40 bpm in a relaxed horse (Marsland, 1968; Hodgson, 2014a). The resting HR of the horses in Papers II, III and IV was (mean ± SD) 35 ± 4, 35 ± 5, and 36 ± 2 bpm, respectively, and the range was 23-44 bpm. Thus the resting HR of Icelandic horses can be concluded to lie in a similar range as resting HR in other horses.

6.6.2 Peak HR (Papers I and III)

Maximal HR (HR_{max}) has been reported to lie between 204 and 254 bpm (Krzywanek *et al*., 1970; Seeherman & Morris, 1990). HR_{max} in Icelandic horses has not been measured definitively, but it is highly likely that most of the horses in the BEFT reached HR_{max} at some point in the test, as the HR_{peak} was 224 ± 9 bpm (range 195-238 bpm; n=102), which was similar to the maximal HR observed in racing Thoroughbreds (range 210-238 bpm; Krzywanek *et al*., 1970) and Standardbreds (range 210-238 bpm; Åsheim *et al*., 1970). In Paper III (pace race), there was a strong negative correlation between horse age and HR_{peak}, which is in agreement with Betros *et al*. (2002) who showed a decrease in maximal HR with age. HR_{peak} of the horses in the pace study (Paper III) was in the lower range of HR_{max} reported by Åsheim *et al*. (1970) and Krzywanek *et al*. (1970), which might be because the horses did not reach HR_{max} or because of their comparatively high age (≥8 yr) compared with the horses in the studies mentioned (2-9 yr). Together, the results on

HR_{peak} from Papers I and III indicate that HR_{max} in Icelandic horses is in a similar range and behaves in a similar way (decrease with age) as in other horses.

6.7 Resting, peak and maximum haematocrit

The peak haematocrit levels reached in Papers I, III and IV (see section 5.5.1) were low compared with those measured after high intensity exercise in the field at similar time points in *e.g.* Standardbred trotters (mean ± SE: 60 ± 1 %; Jansson & Dahlborn, 1999) and Thoroughbreds (mean: 63 ± 1 %; Evans *et al*., 1993). It has been shown that haematocrit values are numerically highest during maximum exercise (at fatigue) and start to decline immediately as the intensity of exercise decreases (Bayly *et al*., 2006). Therefore blood samples have to be collected during intensive exercise to evaluate true maximum haematocrit levels in the Icelandic horse. It is known that maximum haematocrit in Standardbred and Thoroughbred racehorses can reach 60-68% post high intensity exercise (Persson, 1983; Snow *et al*., 1983b; Evans *et al*., 1993) and 60% in Quarterhorses (Reynolds *et al*., 1993). Most of the increase in Hct during exercise is related to splenic release, but there is also an effect of substantial fluid shifts out of plasma during exercise (Persson, 1967; Carlson, 1983). Maximum reference values of haematocrit for different horse breeds are not easy to find in the literature, apart from for Thoroughbreds, Standardbreds and Quarterhorses. However, the blood circulatory capacity of different horse breeds has been related to spleen and heart weight, with racing breeds (Thoroughbreds and Standardbreds) having significantly ($P<0.01$) greater relative spleen size than other breeds (stock types, Arabian and draft types) and significantly ($P<0.01$) greater relative heart size than both stock and draft types (Kline & Foreman, 1991). This could indicate that horse breeds other than racing types, *e.g.* the Icelandic horse, might also have lower maximum Hct, but this needs further study.

There is more information available on normal resting haematocrit values for different groups of horses (age, breed, training), which are reported to be in the range 28-47% (Kingston & Hinchcliff, 2014; McGowan & Hodgson, 2014). Recently, haematocrit and haemoglobin values at rest in Icelandic horses in Austria were reported (Leidinger *et al*., 2015) and were in a similar range to those obtained in this thesis (Table 10 and Table 11). Resting haematocrit values of Icelandic horses (Table 10) were also within the range reported for other horse breeds (Kingston & Hinchcliff, 2014; McGowan & Hodgson, 2014), while haemoglobin values (Table, 11) were in the lower range of those reported for other horse breeds (range 115-157 g/L; McGowan & Hodgson, 2014).

Table 10. *Haematocrit (%) in Icelandic horses at rest and after different exercise tests in Papers I-IV, and at rest in other studies*[4,5]

Paper, reference /age of horses	Horses	n[1]	n[2]	At rest mean ± SD	At rest range	n[3]	At end of exercise mean ± SD	At end of exercise range
I, / 4 to 9 year	Stallions	86	86	39 ± 4	27 - 50	86	49 ± 3	41 - 55
I, / 4 to 11 year	Mares	180	180	34 ± 3	25 - 42	180	43 ± 2	36 - 50
II, / 13 to 18 year	Geldings and mares	8	31	33 ± 3	28 - 38	28	41 ± 3	35 - 46
III, / 8 to 18 year	Geldings and mares	8	16	33 ± 2	29 - 36	13	44 ± 3	40 - 48
IV, / 15 to 19 year	Geldings and mares	8	8	34 ± 1	28 - 38	8	44 ± 1	42 - 46
[4] / 5 to 19 year	Geldings and mares	58	58	32 ± 3	27 - 40			
[5] / 3 to 27 year	Geldings, mares and stallions	132	132		29 - 39			

[1]Number of horses

[2]Number of measurements at rest

[3]Number of measurements after exercise

[4]Sigríður Björnsdóttir (unpublished results for Icelandic riding horses)

[5]Leidinger *et al*. (2015)

Table 11. *Haemoglobin (g/L) in Icelandic horses at rest and after the breed evaluation field test (BEFT) in Paper I and at rest in other studies*[4,5]

Paper, reference/ Age of horses	Horses	n[1]	n[2]	At rest mean ± SD	At rest range	n[3]	After end of BEFT mean ± SD	After end of BEFT range
I, 4 to 9 year	Stallions	86	85	140 ± 16	110-197	86	176 ± 12	150-202
I, 4 to 11 year	Mares	180	168	122 ± 12	95-151	180	158 ± 10	95-151
[4] / 5 to 19 year	Geldings and mares	58	58	119 ± 13	95-150			
[5] / 3 to 27 year	Geldings, mares and stallions	134	134		102-142			

[1]Number of horses

[2]Number of measurements at rest

[3]Number of measurements after exercise

[4]Sigríður Björnsdóttir (unpublished results for Icelandic riding horses)

[5]Leidinger *et al*. (2015)

6.8 Comparison of recovery (Papers I-IV)

The recovery pattern of HR in Paper I-IV was similar to that described earlier for horses, *i.e*. decreasing in a bi-exponential manner with faster initial and slower secondary decay (Rugh *et al.*, 1992). This pattern can be seen in Figure 6 of this thesis and was also seen in individual HR curves in Papers I-IV (data not shown). It is probably more common to measure HR at a certain time point of recovery (*e.g.* using a stethoscope) rather than during long recovery periods. Figure 5 shows the results during different time periods (during 5 min, during the 5th min and during the last 15 s of the 5th min). On comparing average HR during the 5th min and the last 15 s of the 5th min, the difference was only one HR beat (Student's t test, data not shown). This difference was statistically significant but is not of biological or practical value. These results show that statistically significant differences within a large dataset are not always of practical value when used on an individual basis, but might be of value to show differences between methods (or measurements in different periods) or groups.

The only parameter measured during recovery in Paper I (BEFT) was HR during 5 min (Figures 5 and 6), which together with the physiological response during and after the BEFT indicated that this exercise test was of higher intensity than those in Papers II-IV.

Comparison of recovery parameters (Table 8) between Papers II-IV (tölt vs. trot; pace race; weight carrying) showed that the horses took longer to recover after the pace race than the two other exercise tests. The recovery patterns of the other two tests (tölt vs. trot and weight carrying) were similar, but HR recovered more slowly and plasma lactate more quickly in Paper II (tölt vs. trot) than in Paper IV (weight carrying), and haematocrit was higher during recovery in Paper IV (although it was back to resting level after 30 min in both Papers II and IV). The recovery after the tölt vs. trot study (Paper II) and the weight carrying study (Paper IV) was compared separately (data not shown), as the same horses (except one) were used in both. Based on the physiological response (HR peak, plasma lactate, haematocrit, BF) which were higher in the weight carrying study ($P<0.05$; data not shown), it is suggested that the horses were at least as quick to recover in that study (weight carrying). The weakness in this comparison is that the tests were performed 24 months apart, which could of course have affected the response of the horses.

The regressions between plasma lactate concentration and recovery HR indicated that by recording recovery HR 15 to 30 min post exercise, trainers of Icelandic horses can get a rough estimate of the plasma lactate concentration after exercise and during recovery. Based on the results in this thesis, it can be speculated that if recovery HR is ≥70 bpm after 15 min, then the exercise has probably generated well above the lactate threshold (at least >10 mmol/L). However, further data are needed to support this suggestion.

6.9 Use of Polar HR monitor for HR recordings

As mentioned in section 6.2.1, the literature on physiological parameters is limited during true competition in horses and it is lacking more on some parameters (*e.g*. HR) than others (*e.g*. lactate) (Table 3). One of the reasons is that competitors are not eager to participate in research during competition when aiming for other goals, *e.g*. records, earnings, prizes. However, there might be more reasons, *e.g*. methodological. The most common method for measuring HR in horses during exercise is to use Polar HR monitors (Munsters *et al*., 2014), which have been developed for use in humans (Parker *et al*., 2010). Comparison of data from Polar HR monitors with data from electrocardiograms (ECG) has shown that the two systems can be used interchangeably in stationary horses (Ille *et al*., 2014), but not in moving or exercising horses (Parker *et al*., 2010). The experience from Papers I-IV when using Polar HR monitor for recordings in a group of exercising horses was that data have to be evaluated visually and only reliable data used (Figure 9). In Paper I, HR recordings from 102 out of 266 (38%) horses during the BEFT were used, after setting the criterion of using only HR recordings where at least 80% of the curve was estimated to be reliable. Similarly Ringmark (2014) reported that 1093 out of 2003 (55%) HR recordings during training sessions in Standardbred horses remained after discarding HR curves which did not comply with the set criterion. Our success in measuring HR during the exercise tests depended to some extent on how controllable the study circumstances were (real vs. experimental), *e.g*. the possibility of checking the connection of the electrodes and skin, but also whether an elastic girth with inbuilt electrodes or the ‘equine H2 electrode base set’ was used. The latter type needed to be fixed to the girth of the saddle and was thus not as appropriate when measuring private horses (more interference), but more often gave reliable HR recordings.

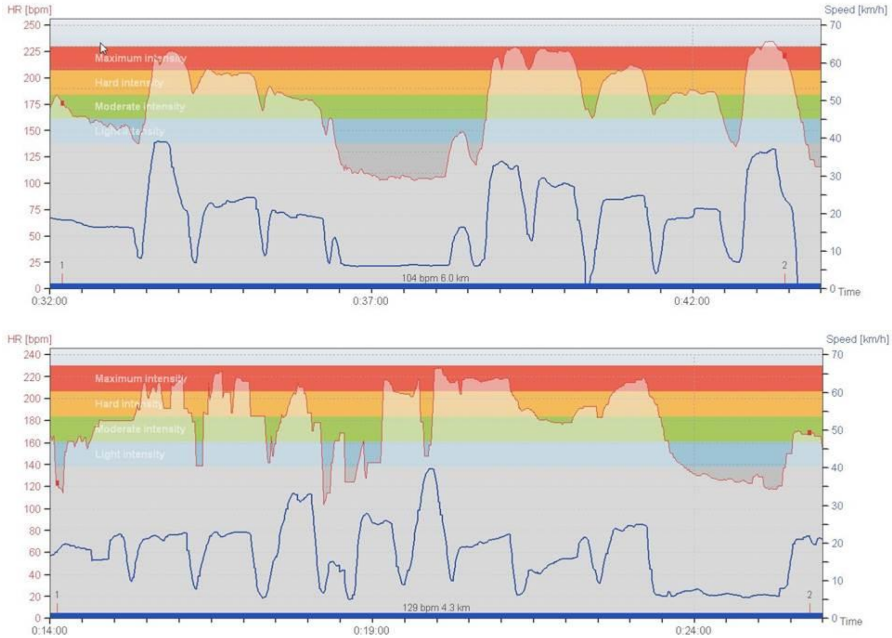

Figure 9. Screen shots from the software Polar Pro Trainer 5 Equine Edition for heart rate and speed curves in two horses during a breed evaluation field test. Time (min) is on the x-axis, heart rate (bpm) on the y-axis and speed (km/h) on the z-axis. The red line shows the heart rate and the blue line shows the speed. The above heart rate curve is of good quality but the below is not usable because of low quality in the former half part (straight lines and lost connectivity *e.g.* at the fastest speed). The coloured background of the figures showing light, moderate, hard and maximum exercise was set by the programme, but not on the basis of the results from the breed evaluation field test.

7 Conclusions

The overall conclusions drawn based on the work presented in this thesis were that several of the exercise sessions typically performed by Icelandic riding horses include high intensity exercise and anaerobic metabolism, and that both high aerobic and anaerobic capacity might improve performance. Detailed conclusions were that:

- The riding assessment in a breed evaluation field test is a high-intensity exercise and for some horses maybe even a supramaximal exercise.

- Aerobic fitness was higher in stallions than in mares, but the extent to which this was due to genetic and environmental effects, respectively remains unknown.

- Age had a limited effect on physiological response in a breed evaluation field test, although 4-year-old horses had lower aerobic capacity than older age groups (5-, 6- and ≥7-year-olds). Peak HR decreased with increasing age, although that appeared to impose no limitation for pace horses performing short-term high-intensity exercise.

- It is suggested that horses attending the riding assessment in the BEFT should be trained both aerobically and anaerobically in order to achieve their best performance and for their general well-being.

- There were only minor differences in physiological response to tölt and trot in a group of experienced adult Icelandic horses.

- A simulated 100 m pace race was a high intensity exercise, during which anaerobic metabolism was crucial for performance. This indicates that training of anaerobic metabolism is important for good performance in pace horses.

- There was an effect of rider on physiological response during exercise in Icelandic horses. Increased body weight ratio of rider to horse increased HR, plasma lactate concentration and breathing frequency.

- Trained and experienced Icelandic riding horses may exceed their lactate threshold at tölt and trot at medium speed (~5.5 m/s) at BWR common for Icelandic horse-rider combinations. However, there was great individual variation in the lactate threshold between horses. Training at or above the lactate threshold is of value for improving both aerobic and anaerobic metabolism, but trainers should be aware that these conditions will cause fatigue more rapidly than if speed and/or BWR are lower.

- By recording recovery HR 15 to 30 min post exercise, trainers of Icelandic horses can get an estimate of post exercise plasma lactate concentration, reflecting the extent of anaerobic metabolism and workload.

Overall, the results in this thesis suggest that trainers of Icelandic horses could benefit in their work from including information on exercise physiology, *e.g.* using HR recordings during training and recovery, and regular exercise testing in planned training programmes.

8 Future research

Further studies are needed on recovery of Icelandic horses after the BEFT, competition disciplines and exercises. The BEFT was indicated here to be a high intensity exercise for the horses in general and maybe even a supramaximal exercise for some. Therefore it is of utmost importance for the welfare of the horses to follow them over a longer recovery period after the BEFT. That would provide information needed to adjust the training programme before the BEFT and also to develop the BEFT to allow proper evaluation of the horses and to support the welfare of the breed. The same applies to the competition disciplines for the Icelandic horse, but for these more studies are also needed on the physiological response.

There is a lack of information on current training strategies for Icelandic horses. Further information relating the training background to performance during the BEFT and competition disciplines would be valuable. It would also be worthwhile to evaluate whether training of horses for the BEFT, for pace races and for more of the competition disciplines could be improved by including more information on exercise physiology in the training programmes, compared with conventional training strategies, both in a short- and long-term perspective.

There is a need for studies on the long-term effect of different body weight ratios of rider to horse on health of the Icelandic horse. Based on Paper IV, the Icelandic horse is able to carry riders of increasing body weight ratio of rider to horse (20-35%) at tölt at medium speed for a short distance. The horses recovered quickly from the test and were symmetrical and without muscle soreness and damage 24 and 48 hours after the test. However, data on long-term effect of riders of different weights on leg health (*e.g.* joints), back and locomotion are important for better management, welfare and health of the Icelandic horse.

It was suggested earlier in this thesis that field exercise tests might have advantages over treadmill exercise tests in the two main categories of exercise test (gait competitions and the BEFT) most often performed by the Icelandic horse. However, basic studies are lacking on *e.g.* maximum values of haematocrit and HR during exercise in the Icelandic horse, and those studies would be preferable to perform on a treadmill.

Low peak haematocrit values were measured in this thesis and it is important to know whether this is breed-related, training-related or both. Another question is whether Icelandic horses can benefit from earlier conditioning training (1-3 yr) before being introduced to riding (3.5-4 yr) in order to increase aerobic capacity (*e.g.* haematocrit). Such studies should examine whether the late introduction of organised training of Icelandic horses overlooks the possibility for physiological improvement (*e.g.* increased Hct) at a younger age *e.g.* planned conditioning without a rider.

9 Svensk sammanfattning

Islandshästen är en populär hästras och finns idag i mer än 30 länder. Totalt finns det ca 250 000 islandshästar och i Sverige är det den tredje största hästrasen med ca 27 000 individer. Islandhästen är speciell på det sätt att många individer kan utföra fem olika gångarter jämfört med bara tre som de flesta andra hästraser kan. Utöver skritt, trav och galopp kan rasen också tölta och gå i passgång. Tölt är en 4-taktig gångart utan svävningsfas (alltid en hov i marken) som de flesta islandshästar kan utföra om de får träna på det. Passgång är en 2-, eller ibland något 4-taktig gångart (benen på samma sida rör sig samtidigt framåt) som har en svävningsfas och som många islandshästar också kan utföra.

Islandshästen används på många olika sätt, både för fritidsridning i skog och mark men också i olika typer av tävlingar där de flesta innebär att de skall visa upp sina gångarter. Islandshästen rids av både barn och vuxna men är mindre i förhållande till många andra raser som rids av vuxna. Den har en mankhöjd runt 140 cm och väger vanligtvis runt 350 kg. Det har i olika sammahang diskuterats hur mycket en islandshäst orkar bära men det har hittills inte funnits några studier på det. Faktum är, att trots att islandshästen är så populär så har det inte tidigare funnits några undersökningar av hur de påverkas fysiologiskt av arbete och hur de återhämtar sig. Den här avhandlingen innehåller fyra studier som belyser det arbetsfysiologiska svaret hos islandshästar som utför några vanliga ”islandshästaktiviteter”.

Studie I – Effekter av ridmomentet i ett avelsvärderingstest

Islandshästen har, sedan den kom till Island med människan för ca 1000 år sedan, använts som rid- och packdjur. Sedan ungefär 65 år tillbaka sker också ett målmedvetet internationellt avelsarbete för att utveckla den som ridhäst. Viktiga mål är att hästarna under ridning skall röra sig lätt, i ren takt och med långa steg och höga frambensrörelser i de olika gångarterna och dessutom kunna visa gångarterna i olika hastigheter. Ett ridmoment ingår därför i avelsvärderingen av såväl hingstar som ston. I den här studien undersöktes det arbetsfysiologiska svaret hos 266 privatägda islandshästar som deltog i en avelsvärdering på Island. Momentet tog i genomsnitt drygt 9 min att utföra och hästarna avverkade under den tiden en sträcka på 2,9 km med en medelhastighet på 17,8 km/h. Den genomsnittliga vikten på ryttare (plus sadel) var 27,5 % av hästarnas kroppsvikt. Medelpulsen var 184 slag/min, toppulsen 224 slag/min och mjölksyrakoncentrationen efter ridmomentet 18 mmol/l. Mer än en tredjedel av ridmomentet utfördes vid en puls över 200 slag/min. Hingstar hade lägre puls och mjölksyrakoncentration än ston trots att de reds i högre hastighet. Hingstar hade också en högre andel röda blodkroppar i blodet (indikator på syrebärande kapacitet) än ston. Åldern (variation från 4 till 11 år) hade nästan ingen betydelse för det arbetsfysiologiska svaret men 4-åringar hade lägre andel röda blodkroppar än äldre hästar. Det fanns ett positivt samband mellan hästarnas poäng för ridbarhet och mjölksyrasvaret och andelen röda blodkroppar, d.v.s. poängen för ridbarhet ökade med mjölksyrakoncentrationen och andelen röda blodkroppar efter ridmomentet. Sammanfattningsvis visar studien att ridmomentet i avelsvärderingen för islandshästar är ett högintensivt arbete och att stor aerob kapacitet kan påverka bedömningen i positiv riktning. Den här kunskapen bör användas för att utveckla träningsprogram som utvecklar islandshästars aeroba kapacitet. Att hingstar verkade ha större aerob kapacitet än ston har tidigare observerats hos andra raser. Det fanns ingen möjlighet att följa hästarnas återhämtning i den här studien mer än fram till 5 minuter efteråt. Med de observationer vi har gjort fram till dess och den kunskap vi har om återhämtning hos andra hästar så är det troligt att t.ex. puls och mjölksyrekoncentrationen var tillbaka till vilonivåer inom en timme men för att återställa t.ex. muskelenergidepåerna är det troligt att dessa hästar behövde 2-3 dagars återhämtning.

Studie II – En jämförelse av det fysiologiska svaret mellan tölt och trav i tre hastigheter

Det behövs i allmänhet mer träning för att få en islandshäst att tölta i ren takt med lätthet och balans en längre sträcka med ryttare än att trava och det har därför föreslagits att tölt kan vara en mer fysiskt krävande gångart än trav, men det har hittills inte undersökts. I den här studien har det arbetsfysiologiska svaret i trav och tölt jämförts hos åtta välutbildade skolhästar (ålder 13-18 år) på Holar University College. Jämförelsen gjordes på en sträcka om 642 m och i samma hastighet. Tre olika hastigheter undersöktes, från ”långsam” trav och tölt (3 m/s) till en hastighet då traven kan betraktas som ”ganska snabb” (5 m/s, nära gränsen för vad många islandshästar klarar i trav, men tölta kan de göra snabbare). Hästarna gjorde testen två gånger, med två olika ryttare. Ryttarna hade instruktioner att rida med så lite hjälper som möjligt. Viktbelastningen (ryttare plus sadel) motsvarade i genomsnitt 27,5 % av hästarnas kroppsvikt. Resultaten visade att hästarna inte bildade någon större mängd mjölksyra i någon av gångarterna så länge hastigheten var lägre än 5 m/s men att mjölksyratröskeln överskreds något vid den högsta hastigheten. Studien visade också att om det fanns några statistiska skillnader mellan trav och tölt i det arbetsfysiologiska svaret så var de mycket små, nästan försumbara. Det skillnader som observerades pekade dock alla i samma riktning, d.v.s. att tölt krävde mer arbete och kanske mer anaerobt arbete (mjölksyrabildande). Dessa observationer är också logiska, eftersom studien visade att stegfrekvensen var högre i tölt än i trav (94 steg/min i trav jämfört med 106 steg/min i tölt), d.v.s. fler muskelkontraktioner måste göras i tölt än i trav. Flera studier behöver dock göras för att bättre förstå hur olika hästar (t.ex. unghästar, otränade, vältränade och hästar med olika genetisk bakgrund) påverkas av tölt och vilken betydelse t.ex. sträckan och underlaget har.

Studie III – Effekter av ett simulerat passlopp

Snabb passgång kallas ibland för ”flygande pass”. Tävlingar i flygande pass är den äldsta tävlingsformen man känner till på Island och som fortfarande utövas. Till skillnad från andra hästraser där kapplöpning är vanligt (t.ex. fullblod och travhästar) finns ingen kunskap om vilken arbetsfysiologisk belastning en passtävling för islandshästar innebär och hur lång tid det tar för dem att återhämta sig. I den här studien simulerades ett lopp i 100 m flygande pass. Nio hästar som tränats för passtävlingar användes. Alla hästar utom en hade också sedan flera år tidigare passrekord noterade i den internationella tävlingsdatabasen (i stamboken, www.worldfengur.com) och 14 dagar innan studien gjordes deltog alla hästar i en riktig passtävling. Det simulerade loppet genomfördes två gånger med två olika ryttare (vikt inklusive sadel motsvarande 28,1 % av kroppsvikten) och med 3 dagars vila mellan. I denna typ av passtävling har ekipagen två försök att få en godkänd tid på 100 m (loppet har flygande start, d.v.s. ekipagen har 50 m på sig fram till startlinjen att accelerera och komma in i rätt gångart). Alla hästar i studien lyckades att få minst ett godkänt försök. Hastigheten under loppen var 10,4 m/s och det gick lika snabbt i det andra försöket som i det första. Medelpulsen under loppen var 98 % av hästarnas observerade maxpuls och mjölksyrakoncentrationen var 12 mmol/l efter det första försöket och 18 mmol/l efter det andra. Det fanns ett negativt samband mellan hästarnas mjölksyrakoncentration under det simulerade loppet och deras rekord i den internationella tävlingsdatabasen, d.v.s. ju bättre rekord (kortare tid på 100 m) desto högre mjölksyrakoncentration i loppet. Andelen röda blodkroppar i blodet var ganska låg (ca 44 %) om man jämför med andra kapplöpningshästar (som kan ha över 60 %). De här resultaten visar att det är den anaeroba kapaciteten (den som sker utan syre) som är avgörande för passhästens prestation. Att snabba hästar bildar mycket mjölksyra är logisk eftersom de snabbaste muskelfibrerna får sin energi från en metabolisk process som innebär att mjölksyra bildas. Studien visade också att hästarnas maxpuls sjönk med stigande ålder, d.v.s. maxpulsen sjönk med 8 slag/min för varje 5 års ökning i åldern. Hög ålder skulle därför kunna påverka prestationen negativt (förmågan att arbeta aerobt, d.v.s. med god syreförsörjning) men våra resultat antyder dock att detta inte behöver vara en begränsning eftersom anaerob energiförsörjning verkar vara viktig. Detta antagande kan man också finna stöd för i medelåldern på de tio bästa hästarna i de fem senaste världsmästerskapen, som är 13 år, och från en annan studie där tränare uppger att den bästa ålder för en passhäst är mellan 11 och 16 år.

Hästarna i den här studien behövde mer än 30 minuter på sig för att återhämta puls, andning, mjölksyrakoncentration och rektaltemperatur. Sammanfattningsvis visar studien att ett 100 m passlopp är ett högintensivt arbete och att förmågan att rekrytera snabba muskelfibrer och bilda mycket mjölksyra är viktigt för prestationsförmågan.

Studie IV – Effekter av ryttarens vikt på det arbetsfysiologiska svaret
Det har i olika sammanhang diskuterats hur mycket en islandshäst egentligen orkar bära men det har hittills inte funnits några studier på det. I den här studien fick åtta hästar genomföra ett arbetstest där ryttaren och sadelns vikt succesivt ökades (med hjälp av blyvikter) från 20 % av hästens kroppsvikt, till 25, 30 och 35 %. I ett sista steg av testet togs vikterna bort och hästen bar 20 % en andra gång. Detta steg utfördes för att bedöma i vilken utsträckning arbetstestet visade effekten av den akuta viktsbelastningen (varje stegökning) och inte den ackumulerade effekten av hela testet. Det avslutande steget visade också att mätvärden som puls och andel röda blodkroppar (som i stor utsträckning speglar den akuta arbetsbelastningen) gick tillbaka till samma nivå som i början av testet. Åtta välutbildade skolhästar från Holar University College användes och alla viktsbelastningar testades i tölt (5,4 m/s) under 642 m med 5 min paus mellan (för påsättning av vikter och blodprovstagning). Pulsen ökade linjärt med ökad viktsbelastning och mjölksyrakoncentrationen ökade exponentiellt. Det här mönstret är känt sedan tidigare från liknande tester på andra hästar men där man istället för att öka vikten som hästarna bär vanligtvis ökar hastigheten. Den intensitet (hastighet eller annan belastning) där man observerar en snabb ansamling av mjölksyra i blodet (vid 4 mmol/l) brukar kallas för mjölksyratröskeln. Arbetets intensitet avgör hur länge arbetet

kan pågå och arbeten under mjölksyratröskeln kan i teorin pågå i flera timmar (sedan kan mentala aspekter sätta stopp tidigare). Arbeten vid eller över mjölksyratröskeln kan inte pågå i flera timmar (snarare minuter) utan återhämtning, eftersom musklernas arbetsförmåga påverkas av bland annat mjölksyrabildningen. Hur fort musklerna påverkas beror bland annat på hur vältränad individen är men också på andra individuella egenskaper. I den här studien kunde vi skatta en mjölksyratröskel i form av en viktsbelastning. Vid viktsbelastningen 22,7 % nådde hästarna i genomsnitt 4 mmol/l men det var en stor individuell variation (17,0 - 27,5 %). Det fanns ingen koppling mellan hästarnas storlek och mjölksyratröskeln men formen på ryggen verkade spela roll. Ju smalare över ryggen (se figur 1) desto lägre mjölksyratröskel. Det var nog inte bara vikten i sig som gjorde att mjölksyrakoncentrationen ökade med ökad viktsbelastning. Hästarna minskade också steglängden och för att hålla samma hastighet måste sålunda stegfrekvensen öka. Det innebär att hästarna gjorde fler och snabbare muskelkontraktioner vilket också kan öka mjölksyrabildningen. Hästarna hade återhämtat puls och andning inom 30 minuter men mjölksyrakoncentrationen var fortfarande något högre än före testet. Hästarnas koncentration av två specifika muskelenzymer (CK och AST, som kan användas som indikatorer på muskelskada) mättes före och 2 dagar efter testet. Resultaten visade inga signifikanta effekter av arbetet. Alla hästar genomgick också en klinisk undersökning både före och 2 dagar efter testet och inga nya, större kliniska fynd gjordes dagarna efter testet. Sammanfattningsvis visade studien att denna grupp av hästar klarade testet bra och att de kunde arbeta med huvudsakligen aerob energiförsörjning upp till en viktsbelastning om 22,7 % men att den individuella variationen var stor. Hästens storlek verkade inte vara avgörande för det arbetsfysiologiska svaret men eventuellt kan en välutvecklad ryggmuskulatur vara viktig för att en islandshäst skall kunna bära tyngre ryttare under en längre tid.

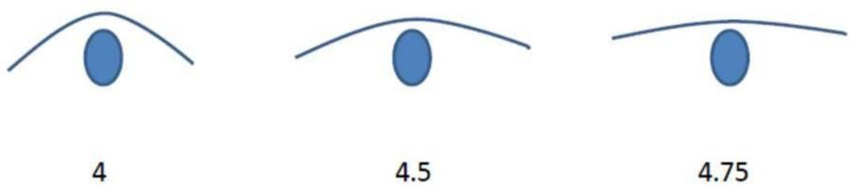

Figure 10. Ryggens profil sett bakifrån eller framifrån och dess poängbedömning (4-4,75). Den ovala pricken illustrerar hästens ryggrad. Ju högre poäng hästarna hade desto högre mjölksyratröskel.

Sammanfattande slutsatser

Den övergripande slutsatsen av det här avhandlingsarbetet är att många av de arbeten som islandshästen gör innebär högintensivt arbete där både aerob och anaerob energiförsörjning är viktigt för prestationsförmågan. De fysiologiska svaren på ridmomentet i avelsvärderingen och passlöpet påminner om de svar man kan se hos trav-, galopp- och fälttävlanshästar efter träning och tävling. Den här kunskapen går att använda för att utveckla träningsprogram för att bättre förbereda islandshästar för t.ex. ridmomentet i avelsvärderingen och för passlopp. Det är viktigt både för att minska risken för fysisk och mental ohälsa och för att utveckla hästarnas prestationsförmåga. Resultaten visar också att beroende på omständigheterna (ryttarens vikt och arbetets hastighet t.ex.) så kan även hobbyhästens arbete vara intensivt och över hästens mjölksyratröskel (medium tölt med en vikt motsvarande > 27 % av kroppsvikten t.ex). Det kan vara bra för att utveckla både hästens aeroba och anaeroba kapacitet men tränare och ryttare skall också vara medvetna om att denna typ av arbete ger trötthetssymptom snabbare än om hastigheten eller viktsbelastningen är lägre.

I samtliga studier har ryttarens vikt spelat roll för pulsen och mjölksyrabildningen men det går inte att ge en generell rekommendation för ”hur mycket vikt som är för mycket”. I alla experimentella studier i denna avhandling var viktsbelastningen över 27 % och av de totalt 25 hästar som ingick fanns det, med ett undantag, inga tecken på att hästarna blivit trötta. Detta stämmer med observationer från t.ex. distansrittlopp där hästarnas hull verkar vara viktigare för prestationsförmågan än viktsförhållandet mellan ryttare och häst (högt hull sänker prestationen). Det behövs dock mer forskning kring vilken betydelse hästarnas kroppsbyggnad och muskelansättning har för viktbärande förmågan.

I studierna som handlade om effekten av tölt och trav, passloppet och ryttarens vikt fanns ett samband mellan mjölksyrakoncentrationen efter arbete och hästarnas återhämtningspuls efter 15 till 30 minuter. Det betyder att återhämtningspulsen var högre ju högre mjölksyrakoncentration hästarna haft. Denna kunskap kan tränare och ryttare använda för att få en uppfattning om hur intensiv ett träningspass varit. I de här studierna hade hästar som haft höga mjölksyrakoncentrationer (> 10 mmol/l) en puls > 70 slag/min efter 15 minuters vila.

10 Íslensk samantekt

Íslenski hesturinn er vinsæll reiðhestur sem finnst í meira en 30 löndum. Í heiminum eru um 250 þúsund íslenskir hestar og hann er t.d. þriðja stærsta hestakynið í Svíþjóð með um 27 þúsund hross. Íslenski hesturinn er sérstakur að því leyti að flestir einstaklingar innan kynsins hafa fimm gangtegundir á meðan hestar í flestum öðrum hestakynjum hafa þrjár gangtegundir. Til viðbótar við fet, brokk og stökk, hefur íslenski hesturinn tölt og skeið. Tölt er fjórtakta gangtegund án svifs (alltaf a.m.k. einn fótur á jörðu) og flestir íslenskir hestar geta tölt. Skeið er hliðstæð gangtegund með svifi og er tvítakta eða örlítið fjórtakta, og margir íslenskir hestar skeiða en ekki allir.

Íslenski hesturinn er bæði þjálfaður til hefðbundinna útreiða (t.d. á víðavangi og í skógum víða erlendis) og fyrir ólíkar keppnisgreinar sem yfirleitt eru sérhæfðar fyrir gangtegundir hans. Bæði fullorðnir og börn ríða íslenska hestinum en hann er minni en mörg önnur hestakyn sem fullorðnir ríða. Hann er um 140 cm á hæð á herðar og vegur um 350 kg. Staðreyndin er að þrátt fyrir að íslenski hesturinn sé svo vinsæll sem raun ber vitni, þá hafa hingað til ekki verið gerðar neinar rannsóknir á því hvað líkamlega álagið á hann er í reið og keppni við ólíkar aðstæður og hvernig hann jafnar sig eftir það. Þessi ritgerð inniheldur fjórar rannsóknir sem lýsa líkamlegri svörun íslenska hestsins við álagi sem er algengt að setja hann í.

Rannsókn I – Líkamlegt álag í reiðdómi í kynbótasýningu

Síðan íslenski hesturinn kom til Íslands með landnámsmönnum fyrir um 1100 árum síðan hefur hann verið notaður til burðar og enn frekar til reiðar. Skipulagt ræktunarstarf hófst í byrjun 20 aldarinnar en frá um 1950 má segja að markvisst hafi verið farið að rækta hann sem reiðhest fyrst á Íslandi og svo síðar á alþjóða vísu. Áhersluatriði í ræktuninni eru meðal annars að í reið sé hesturinn léttstígur, mjúkgengur, takthreinn, skreflangur, hafi háan fótaburð og ráði við mismunandi hraða á gangtegundunum. Þess vegna eru kynbótahross bæði stóðhestar og hryssur metin í reiðdómi undir knapa. Í þessari rannsókn var mælt líkamlegt álag hjá 266 hrossum sem voru sýnd í reið í kynbótadómi á Íslandi. Reiðdómurinn tók að meðaltali rúmar 9 mínútur og hrossunum var riðið að meðaltali 2.9 km á meðalhraðanum 17.8 km/klst. Hlutfall þunga knapa með hnakk af þunga hestsins var að meðaltali 27.5%. Meðalpúlsinn var 184 slög/mín, meðaltal hæsta púls var 224 slög/mín og meðalmagn mjólkursýru eftir reiðdóminn var 18 mmól/L. Púlsinn var yfir 200 slög/mín meira en þriðja hlutann af reiðdómnum. Stóðhestar höfðu lægri púls og minna magn af mjólkursýru en hryssur þrátt fyrir að þeim væri riðið hraðar. Stóðhestarnir höfðu líka hærra hlutfall rauðra blóðkorna í blóði (mælikvarði á getu til að flytja súrefni) en hryssur. Aldur (breytileiki 4 til 11 vetra) hafði takmörkuð áhrif á líkamlega álagið en 4 vetra hross höfðu minna magn af rauðum blóðkornum í blóði en hross í eldri aldursflokkunum (5, 6, 7v og eldri). Það var jákvætt samband á milli aðaleinkunnar fyrir hæfileika og mjólkursýrumagns, og á milli aðaleinkunnar fyrir hæfileika og magns af rauðum blóðkornum. Það þýðir að hæfileikaeinkunnin var hærri eftir því sem mjólkursýran var hærri og eftir hærra magni af rauðum blóðkornum. Samantekið sýnir rannsóknin að reiðdómurinn í kynbótasýningu hjá íslenskum hrossum er mikið líkamlegt álag og að öflug loftháð efnaskipti geta haft jákvæð áhrif á árangurinn (einkunnir). Þessa þekkingu ber að nýta af þjálfurum til að haga þjálfuninni þannig að hún auki loftháð efnaskipti. Það að stóðhestar hafi öflugri loftháð efnaskipti en hryssur hefur komið fram áður í öðrum hestakynjum. Það var ekki mögulegt í þessari rannsókn að fylgjast með hrossunum lengur en 5 mínútur eftir reiðdóminn þegar þau voru að jafna sig (í endurheimt). Miðað við athuganir okkar til þessa og þá þekkingu sem við höfum á því hvernig hestar af öðrum kynjum jafna sig eftir líkamlegt álag, þá er líklegt að púlsinn og mjólkursýran hefðu verið komin í hvíldargildi á innan við klukkutíma en til að endurhlaða orkubirgðir vöðvanna er líklegt að þessi hross hefðu þurft 2-3 daga.

Rannsókn II - Samanburður á líkamlegu álagi á tölti og brokki á sama hraða

Almennt þarf íslenski hesturinn lengri þjálfun til að tölta á hreinum takti í jafnvægi töluverða vegalengd með knapa, heldur en til að brokka. Þess vegna hefur tölt almennt verið talið meira líkamlega krefjandi fyrir hesta en brokk, en það hefur hingað til ekki verið rannsakað. Í þessari rannsókn var borið saman líkamlegt álag á tölti og brokki hjá átta vel þjálfuðum fullorðnum skólahestum (13-18 vetra) við Háskólann á Hólum í Hjaltadal. Samanburðinn var gerður á sama hraða, þar sem fyrsti samanburðurinn var á hægri ferð (3 m/s), síðan á heldur meiri hraða (4 m/s) og loks á góðri milliferð (um 5 m/s) sem er nálægt mesta hraða sem margir íslenskir hestar fara á brokki en oft komast þeir heldur hraðar á tölti. Riðnir voru 642 m á hverjum hraða. Hestarnir voru prófaðir tvisvar á hvorri gangtegund. Notaðir voru tveir knapar sem báðir riðu öllum hestunum á báðum gangtegundum. Knaparnir fengu fyrirskipun um að ríða eins hlutlaust og þeim var unnt, en halda hestunum á réttum takti og hraða. Hlutfall þunga knapa með hnakk af þunga hestanna var að meðaltali 27.5%. Á meðan hraðinn var lægri en 5 m/s mynduðu hestarnir ekki mikla mjólkursýru hvorki á tölti eða brokki, en mjólkursýran fór yfir mjólkursýruþröskuldinn (4 mmól/L) á mesta hraðanum (5 m/s). Rannsóknin sýndi einnig að þó það finndist lítilsháttar tölfræðilega marktækur munur á líkamlega álaginu milli gangtegundanna þá var hann afar lítill, nánast hverfandi. En munurinn sem fannst benti þó allur í sömu átt, þ.e.a.s. að tölt krefðist heldur meiri vinnu og þá ef til vill meiri loftfirrtrar vinnu (mjólkursýrumyndandi) heldur en brokk. Þessar athuganir eru líka studdar af því að það kom fram í rannsókninni að skreftíðnin á tölti er hærri en á brokki (94 skref/mín á brokki miðað við 106 skref/mín á tölti á minnsta hraðanum), þ.e.a.s. það þurfti fleiri vöðvasamdrætti á tölti en á brokki. Það þarf þó að gera frekari rannsóknir til að skoða hvernig líkamlegt álag er á tölti í samanburði við á brokki hjá ólíkum hópum hesta (t.d. unghrossum, óþjálfuðum, velþjálfuðum og háð erfðaefni t.d. skeiðgeninu) og einnig hvaða þýðingu vegalengdin sem riðin er og undirlagið sem riðið er á, hafa.

Rannsókn III – Líkamlegt álag á 100 flugskeiði, samjöfnuður við keppni

Skeið á mikilli ferð er gjarnan kallað flugskeið, af því hesturinn svífur milli þess að hliðstæðir fætur snerta jörðu. Kappreiðar á skeiði eru elsta keppnisform á íslenskum hestum sem vitað er um og eru enn við lýði. Ólíkt því sem þekkist varðandi kappreiðar hjá öðrum hestakynjum (t.d. enska fullblóðshestinum og sænska brokkaranum) þá eru engar rannsóknir á hversu mikið líkamlega álagið er við skeiðkappreiðar hjá íslenskum hestum eða hversu lengi þeir eru að jafna sig líkamlega eftir þær. Í þessari rannsókn var sett upp 100 m flugskeið sem líkti eftir því hvernig það fer fram í keppni. Níu hestar þjálfaðir sérstaklega sem skeiðhestar voru notaðir. Allir hestarnir nema einn áttu skráðan árangur í keppni í 100 m flugskeiði frá síðustu þremur árum áður en rannsóknin hófst og 14 dögum fyrir rannsóknina tóku þeir allir þátt í keppni í 100 m flugskeiði. Í þessari rannsókn tók hver hestur þátt í 100 m flugskeiði (samjöfnuði við keppni) tvisvar sinnum, með þriggja daga hvíld á milli. Notaðir voru tveir knapar sem báðir riðu öllum hestunum einu sinni. Hlutfall þunga knapa með hnakk af þunga hests var að meðaltali 28.1%. Í 100 m flugskeiði eru farnir tveir sprettir til að reyna að ná gildum tíma og það er fljúgandi start. Það þýðir að hesturinn getur farið á hvaða gangtegund sem er að 50 m startlínunni en þarf að vera á skeiði yfir línuna og síðan er hesturinn tímamældur næstu 100 m sem þurfa að vera á skeiði þar til yfir marklínuna, til að fá gildan sprett. Allir hestarnir í rannsókninni voru að minnsta kosti með einn gildan sprett með hvorn knapa. Meðalhraðinn á sprettunum var 10.4 m/s og það var ekki munur á hraðanum á fyrri og seinni spretti. Meðalpúlsinn var 98% af hæsta púlsi sem mældist hjá hestunum meðan á sprettunum stóð og mjólkursýrumagnið var 12 mmól/L eftir fyrri sprettinn og 18 mmól/L eftir seinni sprettinn. Það fannst neikvætt samband milli mjólkursýru eftir seinni sprettinn og besta tíma hestanna úr fyrri keppni í 100 flugskeiði, þ.e.a.s. þeim mun hærri sem mjólkursýran var eftir seinni sprettinn þeim mun betri (lægri) tíma áttu hestarnir í keppni áður. Hlutfall rauðra blóðkorna í blóði var frekar lágt (ca 44%) ef það er borið saman við það sem þekkist í öðrum keppnishestum (sem geta haft yfir 60%). Þessar niðurstöður sýna að það eru loftfirrtu efnaskiptin (þau sem gerast án súrefnis) sem eru afgerandi um árangur hestanna í skeiðkappreiðum. Það að hraðir hestar myndi mikla mjólkursýru er rökrétt af því að hröðu vöðvaþræðirnir fá sína orku frá efnaskiptum þar sem mjólkursýra myndast. Rannsóknin sýndi líka að hámarkspúls hestanna lækkaði með hækkandi aldri, þ.e.a.s. hann lækkaði um 8 slög/mín fyrir hverja 5 ára aukningu í aldri. Hár aldur gæti þess vegna haft neikvæð áhrif á líkamlega getu (getan til loftháðrar vinnu, þ.e. að flytja og nota súrefni) en niðurstöður okkar benda þó til að það þurfi ekki að vera takmörkun af því að loftfirrt efnaskipti eru svo mikilvæg. Þessu til stuðnings má einnig benda á að meðalaldur tíu fljótustu hestanna í 100 flugskeiði á síðustu fimm heimsmeistaramótum er um 13 vetra og í annarri rannsókn kom fram að þjálfarar á íslenskum skeiðhestum telja þá ná bestum árangri í keppni á aldrinum 11 til 16 vetra.

Hestarnir í þessari rannsókn þurftu meira en 30 mínútur til að endurheimta hvíldarpúls, öndun, hvíldargildi mjólkursýru og líkamshita. Samantekið sýnir rannsóknin að 100 m flugskeið er mikið líkamlegt álag og getan til að virkja hraða vöðvaþræði og mynda mikla mjólkursýru er mikilvæg fyrir árangurinn.

Rannsókn IV - Áhrif af þunga knapa á líkamlegt álag

Það hefur verið rætt í ýmsu samhengi hversu mikinn þunga íslenskur hestur getur borið en hingað til hafa ekki verið gerðar neinar rannsóknir á því svo vitað sé. Í þessari rannsókn voru notaðir átta hestar og einn knapi, og hestarnir voru settir í þjálfunarpróf þar sem þungi knapans með hnakk var smám saman aukinn (með því að bæta við blýi) frá 20% af þunga hestsins, til 25, 30 og 35%. Í einu þrepi til viðbótar og því síðasta á þjálfunarprófinu var 20% þunginn endurtekinn. Þetta síðasta þrep var gert til að sjá að líkamlega svörunin (t.d. púls) sem kom fram endurspeglaði fyrst og fremst þungann sem var prófaður í hvert skipti en ekki uppsöfnuð áhrif af öllu þjálfunarprófinu. Þetta síðasta þrep sýndi líka að púls og hlutfall rauðra blóðkorna (sem að stórum hluta sýnir raunverulegt álag) lækkaði og gildin voru þau sömu og þegar 20% var prófuð í byrjun á þjálfunarprófinu. Átta vel þjálfaðir skólahestar frá Háskólanum á Hólum voru notaðir og þjálfunarprófið fór fram á tölti (5.4 m/s) og 642 m voru riðnir með hverja þyngd, með um 5 mínútna pásu á milli þyngda til að bæta við vigt og taka blóðsýni. Púlsinn jókst línulega með þunga og mjólkursýran með veldisaukningu (exponential). Það er sama svörun og þekkist áður úr sambærilegum þjálfunarprófum hjá öðrum hestum þar sem það er oftast hraðinn sem er aukinn milli þrepa en ekki þunginn. Það erfiði þjálfunarinnar (t.d. hraði eða þungi) þar sem mjólkursýra byrjar að safnast hratt upp í blóði (við 4 mmól/L) hefur verið kallað mjólkursýruþröskuldur. Erfiði þjálfunarinnar (hraði, þungi) hefur áhrif á hversu lengi þjálfunin getur haldið áfram, og þjálfun undir mjólkursýruþröskuldinum getur fræðilega haldið áfram í marga klukkutíma (þó andlegir þættir geti stöðvað það). Hins vegar getur þjálfunin uppundir eða yfir mjólkursýruþröskuldinum ekki haldið áfram í margar klukkustundir (frekar einhverjar mínútur) án hvíldar, af því að geta vöðvanna til vinnu ræðst meðal annars af áhrifum frá magni af mjólkursýru. Hversu hratt mjólkursýran dregur úr getu vöðvanna til vinnu ræðst meðal annars af því hversu vel þjálfaður hesturinn er en einnig af öðrum einstaklingsbundnum þáttum. Í þessari rannsókn lögðum við mat á við hvaða hlutfall milli þunga knapa (með hnakk) og hests mjólkursýruþröskuldinum var náð. Þegar hlutfallið milli þunga knapa með hnakk og hests var 22.7% var mjólkursýran að meðaltali 4 mmól/L en það var mikill einstaklingsbreytileiki milli hesta (17.0 til 27.5%). Það fannst ekki samband á milli stærðar hestanna og við hvaða hlutfall þeir náðu mjólkursýruþröskuldinum en það fannst samband á milli lögunar á baki (vöðvafylling í baki) hestanna og hlutfalls þar sem mjólkursýruþröskuldinum var náð. Þeim mun rýrari (minni vöðvafylling) sem þeir voru yfir bakið þeim mun lægra var hlutfallið þar sem mjólkursýruþröskuldinum var náð (sjá mynd 1). Það var þó ekki bara að uppsöfnun á mjólkursýru, ykist með hærra hlutfalli milli þunga knapa og hests, því hestarnir minnkuðu einnig skreflengdina með auknum þunga og til að halda sama hraða þurftu þeir þá að auka skreftíðnina. Það þýðir að þeir þurftu að gera fleiri og tíðari vöðvasamdrætti sem einnig jók uppsöfnun mjólkursýru. Hestarnir höfðu endurheimt hvíldarpúls og öndun eftir 30 mínútna hvíld (endurheimt) að loknu þjálfunarprófinu en mjólkursýran var enn heldur hærri en fyrir þjálfunarprófið. Styrkur tveggja ensíma í vöðvum (CK og AST sem notast sem mælikvarði á vöðvaskemmdir) var mældur fyrir og 1 og 2 dögum eftir þjálfunarprófið. Niðurstöðurnar sýndu engin marktæk áhrif af þjálfunarprófinu á styrk þessara ensíma. Allir hestarnir voru einnig heilbrigðisskoðaðir bæði fyrir og 1 og 2 dögum eftir þjálfunarprófið. Þeir voru almennt heilbrigðir bæði fyrir og eftir prófið og engar nýjar breytingar fundust dagana eftir þjálfunarprófið. Samantekið sýndi þessi rannsókn að þessi hestar áttu auðvelt með þjálfunarprófið og að þeir gátu unnið fyrst og fremst með loftháðum efnaskiptum upp að 22.7% hlutfalli milli þunga knapa og hests, en einstaklingsbreytileikinn var mikill hvað það varðar. Stærð hestanna reyndist ekki vera afgerandi fyrir líkamlegu svörunina sem þeir sýndu við þjálfunarprófinu en mögulega getur verið að vel vöðvað bak geti verið mikilvægt til að íslenskir hestar geti borið þyngri knapa lengur.

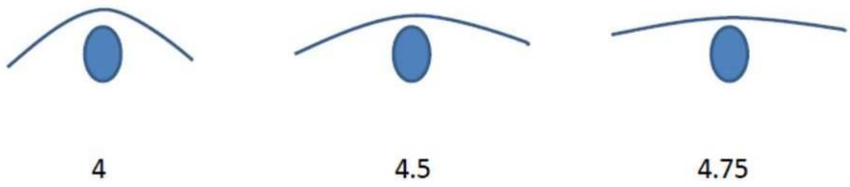

Figure 11. Bak hestsins séð aftan eða framan frá og stig sem það fékk fyrir fyllingu (4-4.75). Stóri depillinn sýnir hryggsúluna. Hestar með hærri stig fyrir bakið höfðu hærri mjólkursýruþröskuld.

Samantekin lokaorð

Meginniðurstöður úr rannsóknum þessarar ritgerðar eru að mörg af þeim líkamlegu verkefnum (t.d. kynbótasýning, 100 m flugskeið) sem lögð eru fyrir íslenska hestinn eru líkamlega erfið þar sem bæði loftháð og loftfirrð orkuefnaskipti eru mikilvæg fyrir árangurinn. Líkamlega svörunin (álagið) sem mældist í kynbótasýningu og 100 m flugskeiði líkist líkamlegri svörun sem hefur mælst hjá veðhlaupahestum á brokki og stökki og í keppnishestum í víðavangshlaupi (eventing), bæði eftir þjálfun og keppni. Niðurstöður þessarar ritgerðar er hægt að nota til að þróa frekar þjálfunaráætlanir fyrir íslensk hross þannig að þau sé betur þjálfuð til að takast á við t.d. kynbótasýningu eða skeiðkappreiðar. Það er mikilvægt til að bæði draga úr líkum á líkamlegum meiðslum og neikvæðum andlegum áhrifum og til að efla líkamlega getu hrossanna. Niðurstöðurnar sýna líka að það er háð aðstæðum (t.d. hraða hestsins og þunga knapa) hvort hestar sem notaðir eru til almennra útreiða (tómstundahestar) eru undir miklu líkamlegu álagi. Tómstundahesturinn getur verið að vinna mikið líkamlegt erfiði, sem er yfir mjólkursýruþröskuldinum, þegar hann er t.d. á góðri milliferð á tölti eða brokki og þegar hlutfall milli þunga knapa (með hnakk) og hests er >27%. Það getur verið gott til að byggja upp bæði loftháð og loftfirrt orkuefnaskipti en þjálfarar og knapar ættu einnig að vera meðvitaðir um að þannig þjálfun/vinna þreytir hestinn fyrr en ef riðið er hægar eða hlutfall þunga knapa og hests er lægra.

Í öllum rannsóknunum hafði þungi knapans áhrif á púlsinn og mjólkursýrumagnið en það er ekki hægt að segja til um „hversu mikill knapaþungi er of mikill þungi“. Í öllum uppsettu tilraununum í þessari ritgerð var meðaltal þunga knapans með hnakk yfir 27% af þunga hestsins og af þeim samtals 25 hestum sem tóku þátt í þessum tilraunum, var ekki hægt að álykta að þeir væru eftir sig, að undanteknum einum hesti. Það stemmir við niðurstöður úr rannsókn á erlendum hestum í þolreiðarkeppni þar sem álitið var að holdafar hestanna væri meira afgerandi fyrir árangur þeirra í keppninni heldur en hlutfallið milli þunga knapa og hests (sem lá á bilinu 15-31%). Aukið fitumagn (hátt holdastig) á hestunum hafði neikvæð áhrif á árangur þeirra. Það vantar þó meiri rannsóknir á hvernig líkams- og vöðvabygging hesta hefur áhrif á getu þeirra til að bera knapa.

Í rannsóknunum á samanburði á tölti og brokki, á 100 flugskeiði og á áhrifum af þunga knapa, fannst samband á milli styrks mjólkursýru strax eftir álagið og púls hestanna 15 og 30 mínútum eftir að álagi lauk (í endurheimt). Það þýðir að eftir því sem púlsinn var hærri 15 og 30 mín eftir að þjálfun lauk þeim mun hærri hafði mjólkursýran verið strax eftir álagið. Þessa vitneskju geta þjálfarar og knapar notað til að fá mælikvarða á hversu erfið þjálfunin var. Í þeim rannsóknum sem hér voru gerðar höfðu hestarnir sem voru með háan styrk mjólkursýru (> 10 mmól/L) strax eftir álag, púls sem var ≥70 slög/mín eftir 15 mín endurheimt.

11 References

Adalsteinsson, S. (1981). Origin and conservation of farm animal populations in Iceland. *Journal of Animal Breeding and Genetics (Zeitschrift fur Tierzuchtung und Zuchtungsbiologie)*, 98, pp. 258-264.

Ainsworth, D.M. (2014). Lower airway function: responses to exercise and training. In: K.W. Hinchcliff, R.J. Geor & A.J. Kaneps, (eds). *Equine exercise physiology, the science of exercise in the athletic horse*. Philadelphia, PA USA: Elsevier Saunders, pp 193-209.

Ainsworth, D.M. & Cheetham, J. (2010). Disorders of the respiratory system. In: Reed, S.M., Bayly, W.M. & Sellon, D.C. (eds). *Equine Internal Medicine*, 3rd ed. St.Louis, USA: Saunders Elsevier, pp. 290-371.

Albertsdóttir, E., Eriksson, S., Sigurdsson, Á. & Árnason, T. (2011). Genetic analysis of “breeding field test status” in Icelandic horses. *Journal of Animal Breeding and Genetics*, 128, pp. 124-132.

Andersson, L.S., Larhammar, M., Memic, F., Wootz, H., Schwochow, D., Rubin, C.J., Patra, K., Arnason, T., Wellbring, L., Hjälm, G., Imslad, F., Petersen, J.L., McCue, M.E., Mickelson, J.R., Cothran, G., Ahituv, N., Roepstorff, L., Mikko, S., Vallstedt, A., Lindgren G., Andersson, L.& Kullander, K. (2012). Mutations in DMRT3 affect locomotion in horses and spinal circuit function in mice. *Nature*, 488, pp. 642-646.

Andrews, F.M., Geiser, D.R., White, S.L., Williamson, L.H., Maykuth, P.L. & Green, E.M. (1995). Haematological and biochemical changes in horses competing in a 3 star horse trial and 3-day-event. *Equine Veterinary Journal*, 27 (S20), pp. 57-63.

Art, T., Amory, H., Desmecht, D. & Lekeux, P. (1990a). Effect of show jumping on heart rate, blood lactate and other plasma biochemical values. *Equine Veterinary Journal,* 22(S9), pp. 78-82.

Art, T., Desmecht, D., Amory, H. & Lekeux, P. (1990b). Synchronization of locomotion and respiratory in trotting ponies. *Zentralblatt fur Veterinarmedizin, Reihe A*, 37(2), pp. 95-103.

Attenburrow, D.P. (1982). Time relationship between the respiratory cycle and limb cycle in the horse. *Equine Veterinary Journal*, 14(1), pp. 69-72.

Árnason, T. (1984). Genetic studies on conformation and performance of Icelandic toelter horses. IV. Best linear unbiased prediction of ten correlated traits by use of an 'animal model', *Acta Agriculturae Scandinavica*, 34, pp. 450-462.

Árnason, T. (2001). Trends and asymptotic limits for racing speed in Standardbred trotters. *Livestock Production Science,* 72, pp. 135-145.

Árnason, T. & Bjarnason, T. (1994). Growth, development and size of Icelandic toelter horses. Icelandic Agricultural Sciences, 8, pp. 73-83.

Åsheim, A., Knudsen, O., Lindholm, A., Rülcker, C. and Saltin, B. (1970). Heart rates and blood lactate concentrations of Standardbred horses during training and racing. *Journal of the American Veterinary Medical Association*, 157(3), pp. 304-312.

Åstrand, P.O. (1952). Experimental studies of physical working capacity in relation to sex and age. Copenhagen: E. Munksgaard. p. 171.

Bayly, W.M., Grant, B.D. & Pearson, R.C. (1987). Lactate concentrations in Thoroughbred horses following maximal exercise under field conditions. In: Gillespie J. R. & Robinson, N.E. (eds) *Equine Exercise Physioloy 2*. Davis California: ICEEP Publications, pp. 426-437.

Bayly, W.M., Kingston, J.K., Brown, J.A., Keegan, R.D., Greene, S.A. & Sides, R.H. (2006). Changes in arterial, mixed venous and intraerythrocytic concentrations of ions in supramaximally exercising horses. *Equine Veterinary Journal, Supplement*, 36, pp. 294-297.

Bárðarson, S. (2008). *Gæðinga*-competition (Gæðingakeppni). FEIF homepage http://www.feif.org/Sport/G%C3%A6%C3%B0ingakeppni.aspx [Assessed 10 July 2015]

Betros, C.L., McKeever, K.H., Kearns, C.F. & Malinowski, K. (2002). Effects on ageing and training on maximal heart rate and VO_{2max}. *Equine Veterinary Journal*, 34, pp. 100-105.

Bjarnadóttir, S. (2010). Stöðumat keppnishesta í Meistaradeild KS. [Estimation of Icelandic competition horses in KS Masterclass]. *BSc Thesis*. Holar University College and Agricultural University of Iceland. http://skemman.is/item/view/1946/7557 [Assessed 12 July 2015]

Björnsdóttir, S., Frey, R., Kristjansson, T. & Lundström, T. (2014). Bit-related lesions in Icelandic competition horses. *Acta Veterinaria Scandinavica*, 56, pp. 40.

Björnsson, G.B. & Sveinsson H.J. (2006). *The Icelandic horse*. Reykjavík, Iceland: Mál og menning.

Bjørnstad, G. & Røed, K. H. (2001). Breed demarcation and potential for breed allocation of horses assessed by microsatellite markers. *Animal Genetics*, 32, pp. 59-65.

Boggs, D.F. (2002). Interactions between locomotion and ventilation in tetrapods. Review. *Comparative Biochemistry and Physiology Part A*, 133, pp. 269-288.

Brandt, R.B., Siegel, S.A., Waters, M.G. & Bloch, M.H. (1980). Spectrophotometric assay for D-(-) lactate in plasma. *Analytical Biochemistry*, 102, pp. 39-46.

Brody, S. (1945). Bioenergetics and growth. New York: Rheinhold.

Butler, P.J., Woakes, A.J., Smale, K., Roberts, C.A., Hillidge, C.J., Snow, D.H., & Marlin, D.J. (1993). Respiratory and cardiovascular adjustments during exercise of increasing intensity and during recovery in Thoroughbred racehorses. *The Journal of Experimental Biology*. 179, pp. 159-180.

Carlson, G.P. (1983). Thermoregulation, fluid and electrolyte balance. In: Snow D.H., S.G.B. Persson & R. J. Rose (eds). *Equine Exercise Physiology 1*. Cambridge UK: Granta Editions. pp. 291-309.

Čebulj-Kadunc, N., Božiĉ, M., Kosec, M., & Cestnik, V. (2002). The influence of age and gender on haematological parameters in Lipizzan horses. *Journal of Veterinary Medicine Series A* 49, 217-221.

Coenen, M., Kienzle, E., Vervuert, I. & Zeyner, A. (2011). Recent german developments in the formulation of energy and nutrient requirements in horses and the resulting feeding recommendations. Review. *Journal of Equine Veterinary Science*, 31, pp. 219-229.

Cottin, F. Metayer, N., Goachet, A.G., Julliand, V., Slawinski, J., Billat, V. & Barrey, E. 2010. Oxygen consumption and gait variables of Arabian endurance horses measured during a field exercise test. *Equine Veterinary Journal*, 42(Suppl. 38), pp. 1-5.

Couroucé, A. (1999). Field exercise testing for assessing fitness in French Standardbred Trotters. *The Veterinary Journal*, 157(2), pp 112-122.

Couroucé, A., Barrey, G.E., Auvinet, B. & Rose, R.J. (1999). Comparison of exercise tests in French trotters under training track, racetrack and treadmill conditions. *Equine Veterinary Journal* (Supplement), 30, pp. 528-532.

Couroucé-Malblanc, A. & Hodgson, D.R. (2014). Clinical exercise testing. In: D.R. Hodgson, K.H. McKeever, & C.M. McGowan (eds). *The athletic horse, principles and practice of equine sports medicine*. 2. ed. USA: Elsevier Saunders. pp. 366-378.

Couroucé-Malblanc, A. & van Erck-Westergren, E. (2014). Exercise testing in the field. In: Hinchcliff, K.W., Kaneps, A.J. & Geor, R.J.(eds). *Equine sports medicine and surgery*. 2. ed. UK: Elsevier Saunders. pp 25-42.

Dalin, G., Magnusson, L.E., & Thafelin, B.C. (1985). Retrospective study of hindquarter asymmetry in Standardbred trotters and its correlation with performance. *Equine Veterinary Journal*, 17(4), pp. 292-296.

de Cocq, P., van Weeren, P. R. & Back, W. (2004). Effects of girth, saddle and weight on movements of the horse. *Equine Veterinary Journal*, 36, pp. 758-763.

de Cocq, P., Duncker, A. M., Clayton, H. M., Bobbert, M. F., Muller, M. & van Leeuwen, J. L. (2010). Vertical forces on the horse‘s back in sitting and rising trot. *Journal of Biomechanics*, 43, pp. 627-631.

de Cocq, P. & van Weeren, P. R.. (2014). Functional biomechanics: Effect of the rider and tack. In: D.R. Hodgson, K.H. McKeever, & C.M. McGowan (eds). The athletic horse, principles and practice of equine sports medicine. 2. ed. USA: Elsevier Saunders. p. 293-298.

Eaton, M.D., Evans, D.L., Hodgson, D.R. & Rose, R.J. (1995). Effect of treadmill incline and speed on metabolic rate during exercise in Thoroughbred horses. *Journal of Applied Physiology*, 79(3), pp. 951-957.

Eto, D., Hada, T., Kusano, K., Kai, M. & Kusunose, R. (2004). Effect of three kinds of severe repeated exercises on blood lactate concentrations in Thoroughbred horses on a treadmill. *Journal of Equine Science*, 15(3), pp. 61-65.

Evans, D. (2008). Exercise testing in the field. In: Hinchcliff, K.W., Geor, R.J. & Kaneps, A.J., (eds). *Equine Exercise Physiology. The science of exercise in the athletic horse*. Philadelphia, USA: Elsevier. pp. 12-27.

Evans, D.J. & Rose, R.J. (1986). Method of investigation of the accuracy of four digitally-displaying heart rate meters suitable for use in the exercising horse. *Equine Veterinary Journal*, 18(2), pp. 129-132.

Evans, D.L., Harris, R.C. & Snow, D.H. (1993). Correlation of racing performance with blood lactate and heart rate after exercise in Thoroughbred horses. *Equine Veterinary Journal*, 25(5), pp. 441-445.

Evans, D.L., Priddle, T.L. & Davie, A.J. (2002). Plasma lactate and uric acid responses to racing in pacing Standardbreds and relationships with performance. *Equine Veterinary Journal* (Supplement), 34, pp. 131-134.

FEIF (2002). FEIF rules for Icelandic Horse Breeding (FIZO, 2015). http://www.feiffengur.com/documents/fizo15.pdf [Assessed 13 April 2015]

FEIF (2012a). Prefix to the "gæðingakeppni." http://www.feiffengur.com/documents/G%C3%A6%C3%B0ingakeppni%202012.pdf [Assessed 3 February 2015].

FEIF (2012b). Feif rules for Icelandic Horse Sport Events (FIPO, 2012). http://www.feiffengur.com/documents/fipo2012_2.pdf [Assessed 23 May 2013].

FEIF (2015a). Facts and figures. http://www.feif.org/FEIF/Factsandfigures.aspx [Assessed 4 June 2015]

FEIF (2015b). Feif rules for Icelandic Horse Sport Events (FIPO, 2015). http://www.feiffengur.com/documents/fipo2015.pdf [Assessed 4 June 2015]

FEIF (2015c). Vision and Mission of FEIF. http://www.feif.org/FEIF/VisionandMission.aspx [Assessed 4 June 2015]

Ferraz, G.C., Soares, O.A.B., Foz, N.S.B., Pereira, M.C. & Queiroz-Neto, A. (2010). The workload and plasma ion concentration in a training match session of high-goal (elite) polo ponies. *Equine Veterinary Journal*, 42(suppl. 38), pp. 191-195.

Fonseca, R.G., Kenny, D.A., Hill, E.W. & Katz, L.M. (2010). The association of various speed indices to training responses in Thoroughbred flat racehorses measured with a global positioning and heart rate monitoring system. *Equine Veterinary Journal*, 42(Suppl. 38), pp. 51-57.

Fonseca, R.G., Kenny, D.A., Hill, E.W. & Katz, L.M. (2013). The relationship between body composition, training and race performance in a group of Thoroughbred flat racehorses. *Equine Veterinary Journal*, 45(5), pp. 552-557.

Foreman, J.H. & Rabin, D. (1984). Determination of accuracy of a digitally displaying equine heart rate meter. *Journal of Equine Veterinary Science*, 4, pp. 161-163.

Franklin, S.H., van Erck-Westergren, E. & Bayly, W.M. (2012). Respiratory responses to exercise in the horse. Review. *Equine Veterinary Journal*, 44, pp. 726-732.

Franklin, S. & Allen, K. (2014). Laboratory exercise testing. In: Hinchcliff, K.W., Kaneps, A.J. & Geor, R.J. (eds). *Equine sports medicine and surgery*. UK: Elsevier Saunders. pp. 11-24.

Garlinghouse, S.E. & Burrill M.J. (1999). Relationship of body condition score to completion rate during 160 km endurance races. *Equine Veterinary Journal*, 31, pp. 591-595.

Gehlen, H., Haubold, A., Rohn, K. & Stadler, P. (2008). Influence of subclinical findings on cardiac parameters in Icelandic horses. *Berliner und Münchener tierärztliche Wochenschrift*, 121(3-4), pp. 137-144.

George, J.W. & O'Neill, S.L. (2001). Comparison of refractometer and biuret methods for total protein measurement in body cavity fluids. *Veterinary Clinical Pathology*, 30(1), pp. 16-18.

Gerard, M.P., de Graaf-Roelfsema, E., Hodgson, D.R. & van der Kolk, J.H. (2014). Energetic considerations of exercise. In: D.R. Hodgson, McKeever K.H. & McGowan C.M. (eds.)*The athletic horse, principles and practice of equine sports medicine*. 2. ed. USA: Elsevier Saunders, pp. 19-33.

Gramkow, H.L. & Evans, D.L.(2006). Correlation of race earnings with velocity at maximal heart rate during a field exercise test in Thoroughbred racehorses. *Equine Veterinary Journal,* 38(S36), pp.118-122.

Hargreaves, B.J., Kronfeld, D.S. & Naylor, J.R. (1999). Ambient temperature and relative humidity influenced packed cell volume, total plasma protein and other variables in horses during an incremental submaximal field exercise test. *Equine Veterinary Journal*, 31(4), pp. 314-318.

Harris, E.A. (1958). Exercise tolerance tests. *The Lancet*, 272(7055), p. 1068.

Harris, P.A. & Snow, D.H. (1990). Some factors influencing plasma AST/CK activities in Thoroughbred racehorses. *Equine Veterinary Journal*, 22(S9), pp. 66-71.

Harris, R.C., Martin D.J, Snow, D.H. & Harkness, A. (1991). Muscle ATP loss and lactate accumulation at different work intensities in the exercising thoroughbred horse. European *Journal of Applied Physiology*, 62, pp. 235-244.

Harris, P., Marlin, D.J., Davidson, H., Rodgerson, J., Gregory, A. & Harrison, D. (2007). Practical assessment of heart rate response to exercise under field conditions. *Equine and Comparative Exercise Physiology*, 4(1), pp. 15-21.

Heffron, C.J. & Baker, G.J. (1979). Observations on the mechanism of functional obstruction of the nasopharyngeal airway in the horse. *Equine Veterinary Journal*, 11(3), 142-147.

Hines, M.T. (2010). Clinical approach to commonly encountered problems. In: Reed, S.M., Bayly, W.M. & Sellon, D.C. (eds). *Equine Internal Medicine*, 3rd ed. St.Louis, USA: Saunders Elsevier, pp. 91-147.

Hodgson, D.R. (2014a). The cardiovascular system: anatomy, physiology, and adaptations to exercise and training. In: Hodgson, D.R., McKeever, K. H. & McGowan, C.M. (eds). *The athletic horse, principles and practice of equine sports medicine.* 2 ed. USA: Elsevier Saunders. pp. 162-173.

Hodgson, D.R. (2014b). Thermoregulation. In: Hodgson, D.R., McKeever, K. H. & McGowan, C.M. (eds). *The athletic horse, principles and practice of equine sports medicine.* 2 ed. USA: Elsevier Saunders. pp. 108-124.

Hodgson, D.R. & Foreman, J.H. (2014). Comparative aspects of exercise physiology. In: Hodgson, D.R., McKeever, K. H. & McGowan, C.M. (eds). *The athletic horse, principles and practice of equine sports medicine.* 2 ed. USA: Elsevier Saunders. pp. 9-17.

Hodgson, D.R. & McGowan, C. (2014). An overview of performance and sports medicine. In: Hodgson, D.R., McKeever, K. H. & McGowan, C.M. (eds). *The athletic horse, principles and practice of equine sports medicine.* 2 ed. USA: Elsevier Saunders. pp. 1-8.

Hodgson, D.R., McCutcheon, L.J., Byrd, S.K., Brown, W.S., Bayly, W.M., Brengelmann, G.L., & Gollnick, P.D. (1993). Dissipation of metabolic heat in the horse during exercise. *Journal of Applied Physiology*, 74(3), pp. 1161-1170.

Hoffmann, G., Bentke, A., Rose-Meierhöfer, S., Ammon, C., Mazetti, P. & Hardarson, G.H. (2013). Estimation of the body weight of Icelandic horses. *Journal of Equine Veterinary Science*, 33, pp. 893-895.

Holmström, M. (1990). Variation in conformation of Swedish Warmblood horses and conformational characteristics of élite sport horses. *Equine Veterinary Journal*, 22, pp. 186-193.

Hugason, K. (1994). Breeding of Icelandic toelter horses: an overview. *Livestock Production Science*, 40, pp. 21-29.

Hörnicke, H., Weber, M. & Schweiker, W. (1987). Pulmonary ventilation in Thoroughbred horses at maximum performance. In: Gillespie, J. & Robinson, N.E. (eds). *Equine Exercise Physiology 2*. San Diego California: ICEEP, Publications, pp. 216-224.

Ille, N., Erber, R., Aurich, C. & Aurich, J. (2014). Comparison of heart rate and heart rate variability obtained by heart rate monitors and simultaneously recorded electrocardiogram signals in nonexercising horses. *Journal of Veterinary Behavior*, 9(6), pp. 341-346.

Janssen, P. (2001). *Lactate threshold training*. USA: Human Kinetics.

Jansson, A. & Dahlborn, K. (1999). Effects of feeding frequency and voluntary salt intake on fluid and electrolyte regulation in athletic horses. *Journal of Applied Physiology*, 86(5), pp. 1610-1616.

Jansson, A., Hedenström, U. & Ragnarsson, S. (2014). A survey of training regimes used by top trainers of the Icelandic pace racing horse. *Comparative Exercise Physiology*, 10, pp. 253-257.

Jäderkvist, K., Holm, N., Imsland, F., Árnason, T., Andersson, L., Andersson, L.S. & Lindgren, G. (2015). The importance of the DMRT3 ”Gait keeper” mutation on riding traits and gaits in Standardbred and Icelandic horses. *Livestock Science*, 176, pp. 33-39.

Judson G.J., Frauenfelder, H.C. & Mooney, G.J. (1983). Biochemical changes in thoroughbred racehorses following submaximal and maximal exercise. In: Snow D.H., S.G.B. Persson & R. J. Rose eds. *Equine exercise physiology 1*. Cambridge UK: Granta Editions. pp. 408-415.

Kearns, C.F., McKeever, K.H., Kumagai, K. & Abe, T. (2002). Fat-free mass is related to one-mile race performance in elite Standardbred horses. *The Veterinary Journal*, 163, pp. 260-266.

Keenan, D.M. (1979). Changes of blood metabolites in horses after racing with particular reference to uric acid. *Australian Veterinary Journal*, 55, pp. 54-57.

Kenney, W.L., Wilmore, J.H. & Costill, D.L. (2012). *Physiology of sport and exercise*, 5.ed. USA: Human Kinetics.

Kerr, M.G. & Snow, D.H. (1983). Plasma enzyme activities in endurance horses. In: Snow D.H., S.G.B. Persson & R. J. Rose eds. *Equine exercise physiology* 1. Cambridge UK: Granta Editions. pp. 432-440.

Kingston, J.K. (2008). Hematologic and serum biochemical responses to exercise and training. In: Hinchcliff, K.W., Geor, R.J. & Kaneps, A.J., (eds). *Equine Exercise Physiology. The science of exercise in the athletic horse*. Philadelphia, USA: Elsevier. pp. 398-409.

Kingston, J. & Hinchcliff, K.W. (2014). Appendix 1a. Reference ranges for red cell variables in athletic horses. In: Hinchcliff, K.W., Kaneps, A.J. & Geor, R.J. (eds). *Equine sports medicine and surgery*. 2.ed. China: Elsevier Saunders. pp. 1245-1247.

Kingston, J.K., Soppet, G.M., Rogers, C.W. & Firth, E.C. (2006). Use of a global positioning and heart rate monitoring system to assess training load in a group of Thoroughbred racehorses. *Equine Veterinary Journal*, 38(S36), pp. 106-109.

Kline, H. & Foreman, J.H. (1991). Heart and spleen weights as a function of breed and somatotype. In: Persson, S.G.B., Lindholm, A. & Jeffcott, L.B. (eds). *Equine Exercise Physiology 3*, Davis California: ICEEP Publications, pp. 17-21.

Kristjánsson, Þ. (2014). Riding ability in Icelandic horses. –Effect of conformation and the “Gait keeper” mutation in the DMRT3 gene. *PhD thesis*. Agricultural University of Iceland, Hvanneyri.

Krzywanek, H., Wittke, G., Bayer, A. & Borman, P. (1970). The heart rates of Thoroughbred horses during a race. *Equine Veterinary Journal*, 2(3), pp. 115-117.

Lafortuna, C.L., Reinach, E.& Sabiene, F. (1996). The effects of locomotor-respiratory coupling on the pattern of breathing in horses. *Journal of Physiology*, 492 (2), pp. 587-596.

Leidinger, E.F., Leidinger, J., Figl, J., Rumpler, B. & Schwendenwein, I. (2015). Application of the ASVCP guidelines for the establishment of haematologic and biochemical reference intervals in Icelandic horses in Austria. *Acta Veterinaria Scandinavica*, 57, 30. [open access online BioMed Central]

Lekeux, P., Art, T., Linden, A., Desmecht, D. & Amory, H. (1991). Heart rate, hematological and serum biochemical responses to show jumping. In: Persson, S.G.B., Lindholm, A. & Jeffcott, L.B. (eds). *Equine Exercise Physiology 3*, Davis California: ICEEP Publications, pp. 385-390.

Lewis, D.A., Kamon, E. & Hodgson, J.L. 1986. Physiological differences between genders. Implications for sports conditioning, review. *Sports Medicine*, 3, pp. 357-369.

Lindholm, A. & Saltin, B. (1974). The physiological and biochemical response of Standardbred horses to exercise of varying speed and duration. *Acta Veterinaria Scandinavica*, 15, pp. 310-324.

Ludvigsen, C.W., Thurn, J.R., Pierpont, G.L. & Eckfeldt, J.H. (1983). Kinetic assay for D(-)-lactate, with use of a centrifugal analyzer. *Clinical Chemistry*, 29(10), pp. 1823-1825.

MacLeay, J.M. (2010). Disorders of the musculoskeletal system. In: Reed, S.M., Bayly, W.M. & Sellon, D.C. (eds). *Equine Internal Medicine*, 3rd ed. St.Louis, USA: Saunders Elsevier, pp. 488-544.

Maddison, R. & Mhurchu, C.N. (2009). Global positioning system: a new opportunity in physical activity measurement. Review. *International Journal of Behavioral Nutrition and Physical* Activity, 6:73, pp. 1-8. [open access online BioMed Central]

Manso Filho, H.C., Manso, H.E.C.C.C., McKeever, K.H., Duarte, S.R.R. & Abreu, J.M.G. (2012). Heart rate responses of two breeds of four-gaited horses to a standardized field gaited test. *Comparative Exercise Physiology*, 8(1), 41-46.

Marchant-Forde, R.M., Marlin, D.J. & Marchant-Forde, J.N. (2004). Validation of a cardiac monitor for measuring heart rate variability in adult female pigs: accuracy, artefacts and editing. Physiology & Behavior, 80(4), pp. 449-458.

Marlin, D. & Nankervis, K. (2002). *Equine Exercise Physiology*. UK: Wiley-Blackwell.

Marlin, D.J., Scott, C.M., Schroter, R.C., Mills, P.C., Harris, R.C., Harris, P.A., Orme, C.E., Roberts, C.A., Marr, C.M., Dyson, S.J. & Barrelet, F. (1996). Physiological responses in nonheat acclimated horses performing treadmill exercise in cool (20°C/40%RH), hot dry (30°C/40%/RH) and hot humid (30°C/80%RH) conditions. *Equine Veterinary Journal, Supplement*, 22, pp. 70-84.

Marsland, W.P. (1968). Heart rate response to submaximal exercise in the Standardbred horse. *Journal of Applied Physiology*, 24, pp. 98-101.

Matthíasdóttir, S. (2012). Lífþungi íslenskra reiðhrossa áætlaður út frá skrokkmálum. [Body weight of Icelandic riding horses estimated from body size measurements]. *BSc Thesis*. Holar University College and Agricultural University of Iceland. http://skemman.is/item/view/1946/13299 [Assessed 13 July 2015]

McArdle, W.D., Katch, F.I. & Katch, V.I. (2015). *Exercise Physiology*. 8.ed. USA:Wolters Kluwer.

McCutcheon, L.J. & Geor, R.J. (2008). Thermoregulation and exercise-associated heat stress. In: Hinchcliff, K.W., Geor, R.J. & Kaneps, A.J., (eds). *Equine Exercise Physiology. The science of exercise in the athletic horse*. Philadelphia, USA: Elsevier. pp. 382-396.

McGowan, C. (2008). Clinical pathology in the racing horse: The role of clinical pathology in assessing fitness and performance in the racehorse. *Veterinary Clinics of North America: Equine Practice*, 24(2), pp. 405-421.

McGowan, C.M. & Hodgson, D.R. (2014). Hematology and biochemistry. In: Hodgson, D.R., McKeever, K. H. & McGowan, C.M. (eds). *The athletic horse, principles and practice of equine sports medicine.* 2 ed. USA: Elsevier Saunders. pp. 56-68.

McKeever, K.H. & Lehnard, R.A. (2014). Physiology of acid-base balance and fluid shifts with exercise. In: Hodgson, D.R., McKeever, K. H. & McGowan, C.M. (eds). *The athletic horse, principles and practice of equine sports medicine.* 2 ed. USA: Elsevier Saunders. pp. 69-87.

McKenzie, E.C. (2014). Hematology and serum biochemistry of the equine athlete. In: Hinchcliff, K.W., Kaneps, A.J. & Geor, R.J. (eds). *Equine sports medicine and surgery*. 2.ed. China: Elsevier Saunders. pp. 921-929.

McMiken, D.F. (1983). An energetic basis of equine performance. *Equine Veterinary Journal*, 15(2), pp. 123-133.

Medbø, J.I., Mamen, A., Holt Olsen, O. & Evertsen, E. (2000). Examination of four different instruments for measuring blood lactate concentration. *Scandinavian Journal of Clinical and Laboratory investigation,* 60(5), pp. 367-380.

Ministry of Fisheries & Agriculture (2011). Regulation on the origin and breeding of the Icelandic horse. http://www.feiffengur.com/documents/RegulationOriginBreeding.pdf [Assessed 5 May 2015]

Morgan, K., Funkquist, P. & Nyman, G. (2002). The effect of coat clipping on thermoregulation during intense exercise in trotters. *Equine Veterinary Journal, Supplement*, 34, pp. 564-567.

Mukai, K., Takahashi, T., Hada, T., Eto, D., Kusano, K., Yokota, S., Hiraga, A. & Ishida, N. (2003). Influence of gender and racing performance on heart rates during submaximal exercise in Thoroughbred racehorses. *Journal of Equine Science*, 14(3), pp. 93-96.

Mukai, K., Takahashi, T., Eto, D., Ohmura, H., Tsubone, H. & Hiraga, A. (2007). Heart rates and blood lactate response in thoroughbred horses during a race. *Journal of Equine Science*, 18(4), pp. 153-160.

Munsters, C.B.M., van Iwaarden, A., van Weeren, R. & Sloet van Oldruitenborgh-Oosterbaan, M.M. (2014). Exercise testing in Warmblood sport horses under field conditions. Review. *The Veterinary Journal*, 202(1), pp. 11-19.

Nielsen, B. D. (2014). Training the racing Quarterhorse. In: Hodgson, D.R., McKeever, K. H. & McGowan, C.M. (eds). The athletic horse, principles and practice of equine sports medicine. 2 ed. USA: Elsevier Saunders. pp. 354-360.

NRC (2007). *Nutrient requirements of horses*. 6th revised edition. Washington D.C., National Academies Press.

Ólafsdóttir, S. (2012).Söluverðmæti íslenskra hrossa. Athugun á verðmætasköpun við sölu á íslenskum hrossum. [Marketing prize of Icelandic horses. Observation of factors affecting marketing prize]. *MSc Thesis*. Hvanneyri: Agricultural University of Iceland.

Pađen, L., Gomerčič, T. Đuras, M., Arbanasič, H. & Galov, A. (2014). Hematological and serum biochemical reference values for the Posavina and Croatian coldblood horse breeds. *Acta Veterinaria-Beograd*, 64(2), pp. 200-212.

Parker, M., Goodwin, D., Eager, R.A., Redhead, E.S. & Marlin, D.J. (2010). Comparison of Polar® heart rate interval data with simultaneously recorded ECG signals in horses. *Comparative Exercise Physiology*, 6(4), pp. 137-142.

Peham, C., Kotschwar, A. B., Borkenhagen, B., Kuhnke, S., Molsner, J., & Baltacis A. (2010). A comparison of forces acting on the horse´s back and the stability of the rider´s seat in different positions at the trot. *The Veterinary Journal*, 184, pp. 56-59.

Persson, S.G.B. (1967). On blood volume and working capacity in horses. *Acta Veterinaria Scandinavica*, supplement, 19, 1-189.

Persson, S.G.B. (1968). Blood volume, state of training and working capacity of race horses. *Equine Veterinary Journal*, 1(2), pp. 52-62.

Persson, S.G.B. (1983). The significance of haematological data in the evaluation of soundness and fitness in the horse. In: Snow D.H., S.G.B. Persson & R. J. Rose (eds). *Equine Exercise Physiology 1*. Cambridge UK: Granta Editions. pp 324-327.

Persson, S.G.B. & Ullberg, L.E. (1974). Blood volume in relation to exercise tolerance in trotters. *Journal of the South African Veterinary Association*, 45(4), pp.293-299.

Persson, S.G.B., Essén-Gustavsson, B., Lindholm, A., McMiken, D. & Thornton, J.R. (1983). Cardiorespiratory and metabolic effects of training of Standardbred yearlings. In: Snow D.H., S.G.B. Persson & R. J. Rose (eds). *Equine Exercise Physiology 1*. Cambridge UK: Granta Editions. pp. 458-469.

Persson, S.G.B., Funkquist, P. & Nyman, G. (1996). Total blood volume in the normally performing Standardbred Trotter: age and sex variations. *Journal of Veterinary Medicine Series A*, 43, pp. 57-64.

Powell, D.M., Bennett-Wimbush, K., Peeples, A. & Duthie, M. (2008). Evaluation of indicators of weight-carrying ability of light riding horses. *Journal of Equine Veterinary Science*, 28, pp. 28-30.

Prince, A., Geor, R., Harris, P., Hoekstra, K., Gardner, S., Hudson, C. & Pagan, J. (2002). Comparison of the metabolic responses of trained Arabians and Thoroughbreds during high- and low-intensity exercise. *Equine Veterinary Journal, Supplement*, 34, pp. 95-99.

Promerová, M., Andersson, L.S., Juras, R., Penedo, M.C.T., Reissmann, M., Tozaki, T., Bellone, R., Dunner, S., Hořín, P., Imsland, F., Imsland, P., Mikko, S., Modrý, D., Roed, K.H., Schwochow, D., Vega-Pla, J.L., Mehrabani-Yeganeh, H., Yousefi-Mashouf, N., Cothran, E.G., Lindgren, G. & Andersson, L. (2014). Worldwide frequency distribution of the *"Gait keeper"* mutation in the DMRT3 gene. *Animal Genetics*, 45(2), pp. 274-282.

Pösö, A.R. (2002). Monocarboxylate transporters and lactate metabolism in equine athletes: A review. *Acta Veterinaria Scandinavica*, 43, pp. 63-74.

Pösö, A.R., Lampinen, K.J. & Räsänen, L.A. (1995). Distribution of lactate between red blood cells and plasma after exercise. *Equine Veterinary Journal*, 18, pp. 231-234.

Ragnarsson, S. (2009). Digestibility and metabolism in Icelandic horses fed forage-only diets. *PhD thesis*. Uppsala, Sweden: Swedish University of Agricultural Sciences.

Räsänen, L.A., Lampinen, K.J. & Pösö, A.R. (1995). Responses of blood and plasma lactate and plasma purine concentrations to maximal exercise and their relation to performance in Standardbred trotters. *American Journal of Veterinary Research*, 56(12), pp. 1651-1656.

Revington, M (1983a). Haematology of the racing Thoroughbred in Australia 1: Reference values and the effect of excitement. *Equine Veterinary Journal*, 15(2), pp. 141-144.

Revington, M. (1983b). Haematology of the racing Thoroughbred in Australia 2: Haematological values compared to performance. *Equine Veterinary Journal*, 15(2), pp. 145-148.

Reynolds, J. A., Potter, G.D., Odom, T.W., Vogelsang, M.M., Smith, W.B., Nielsen, B.D., Senor, D.M. & Bird, E.H. (1993). Physiological responses to training and racing in two year old Quarter horses. *Journal of Equine Veterinary Science*, 13(10), pp. 543-548.

Ringmark, S. (2014). A forage-only diet and reduced high intensity training distance in Standardbred horses. *PhD Thesis.* Uppsala, Sweden: Swedish University of Agricultural Sciences.

Ringmark, S., Lindholm, A., Hedenström, U., Lindinger, M., Dahlborn, K., Kvart, C. & Jansson, A. (2015). Reduced high intensity training distance had no effect on V_{La4} but attenuated heart rate response in 2-3-year-old Standardbred horses. *Acta Veterinaria Scandinavica* , 57, 17.

Ronéus, N., Essén-Gustavsson, B., Lindholm, A. & Persson, S. (1999). Muscle characteristics and plasma lactate and ammonia response after racing in Standardbred trotters: relation to performance. *Equine Veterinary Journal*, 31, pp, 170-173.

Rugh, K. S., Jiang, B., Hatfield, D.G., Garner, H.E. & Hahn, A.W. (1992). Mathematical modelling of post-exercise heart rate recovery in ponies. *Biomedical Sciences Instrumentation*, 28, pp. 151-156.

Schutz, Y. & Chambaz, A. (1997). Could a satellite-based navigation system (GPS) be used to assess the physical activity of individuals on earth ? *European Journal of Clinical Nutrition* 51, pp. 338-339.

Schutz,Y. & Herren, R. (2000). Assessment of speed of human locomotion using a differential satellite global positioning system. *Medicine and Science in Sports and Exercise*, 32(3), pp. 642-646.

Seeherman, H.J. & Morris, E.A. (1990). Methodology and repeatability of a standardised treadmill exercise test for clinical evaluation of fitness in horses. *Equine Veterinary Journal*, 22(S9), pp. 20-25.

Serrano, M.G., Evans, D.L. & Hodgson, J.L. (2002). Heart rate and blood lactate responses during exercise in preparation for eventing competition. *Equine Veterinary Journal*, Supplement, 34, pp. 135-139.

Sides, R., Bayly, W., Kirkpatrick, R., Renner, E., Gough, K., Katz, L. & Evans, D. (2014). Evaluation of masks for field testing of exercising horses (abstract). *Equine Veterinary Journal Supplement*, 46, p.2.

Sigfusson, V. (2003). Longevity in Icelandic horses: length of life and reasons for culling and death. *MSc.Thesis*. Uppsala: Swedish Agricultural University.

Sigurdsson, F.M. (2006). Ágrip hjá íslenskum kynbótahrossum. [Leg injuries in Icelandic breeding horses]. *BSc Thesis*. Hvanneyri: Agricultural University of Iceland. http://skemman.is/item/view/1946/16846 [Assessed 14 July 2015]

Sigurjónsdóttir, H., van Dierendonck, M.C., Snorrason, S. & Thórhallsdóttir, A. G. (2003). Social relationships in a group of horses without a mature stallion. *Behaviour*, 140(6), pp. 783-804,

Silva, F.S., Melo, S.K.M., Manso, H.E.C.C.C., Abreu, J.M.G. & Manso Filho, H.C. (2014). Heart rate and blood biomarkers in Brazilian gaited horses during a standardised field gaited test. *Comparative Exercise Physiology*, 10(2), pp. 105-111.

Sloet van Oldruitenborgh-Oosterbaan, M.M. & Clayton, H.M. (1999). Advantages and disadvantages of track vs. treadmill tests. *Equine Veterinary Journal*, 31(S30), pp. 645-647.

Sloet van Oldruitenborgh-Oosterbaan, M., Wensing, T. & Breukink, H.J. (1987). Standardized exercise test on a track to evaluate fitness and training of saddle horses. In: Gillespie, J. & Robinson, N.E. (eds). *Equine Exercise Physiology 2*. Davis California: ICEEP, Publications, pp. 68-76.

Sloet van Oldruitenborgh-Oosterbaan, M.M., Barnevald, A., & Schamhardt, H.C. (1995). Effects of weight and riding on workload and locomotion during treadmill exercise. *Equine Veterinary Journal*, 27, pp. 413-417.

Snow, D.H., Mason, D.K., Ricketts, S.W. & Douglas, T.A. (1983a). Post-race blood biochemistry in Thoroughbreds. In: Snow, D.H., Persson, S.G.B. & Rose, R.J. (eds) *Equine Exercise Physioloy 1*. Cambridge UK: Granta Editions, pp. 389-399.

Snow, D.H., Ricketts, S.W. & Mason, D. K. (1983b). Haematological response to racing and training exercise in Thoroughbred horses, with particular reference to the leucocyte response. *Equine Veterinary Journal*, 15(2), pp. 149-154.

Statistics Iceland (2015). Agriculture. Livestock from 1980. http://www.statice.is/Statistics/Fisheries-and-agriculture/Agriculture [Assessed 4 June 2015]

Steel, J.D. & Whitlock, L.E. (1960). Observations on the haematology of Thoroughbred and Standardbred horses in training and racing. *Australian Veterinary Journal*, 36(4), pp. 136-142.

Stefánsdóttir, G.J. & Björnsdóttir, S. (2001). Body condition scoring of horses (Mat á holdafari hrossa). *Eiðfaxi-Ræktun*, special issue, Reykjavík, Iceland. Vol, 1, pp. 60-65.

Stefánsdóttir, G.J., Ragnarsson, S. & Jansson, A. (2012). A comparison of a portable blood lactate analyser and laboratory plasma analysis of blood samples from exercised horses. *Comparative Exercise Physiology*, 8(3/4), pp. 227-231.

Stefánsdóttir, G.J., Ragnarsson, S., Gunnarsson, V. & Jansson, A. (2014a). Physiological response to a breed evaluation field test in Icelandic horses. *Animal*, 8(3), pp. 431-439.

Stefánsdóttir, G., Kullberg, N.M. & Jansson, A. (2014b). Relationship between judges′ comments on pace and horses′ plasma lactate concentration in an official breed evaluation field test in Icelandic horses. Abstract 41. *Equine Veterinary Journal*, 46(Supplement 46), p. 14.

Stock, K.F. & Distl O. (2006). Genetic correlations between conformation traits and radiographic findings in the limbs of German Warmblood riding horses. *Genetics Selection Evolution*, 38, pp. 657-671.

Teixeira-Neto, A.R., Ferraz, G.C., Moscardini, A.R.C., Albernaz, R.M., Gondin, M.R. & Queiroz-Neto, A. (2012). Do hematologic constituents really increase due to endurance exercise in horses. *Pesquisa veterinária brasileira*, 32(9), pp. 951-956.

Thornton, J., Pagan, J., & Persson, S. (1987). The oxygen cost of weight loading and inclined treadmill exercise in the horse. In: Gillespie J. R. & Robinson, N.E. (eds) *Equine Exercise Physioloy 2*. Davis California: ICEEP Publications, pp. 206-215

Valberg, S. & Essén-Gustavsson, B. (1987). Metabolic response to racing determined in pools of type I, IIA and IIB fibres. In: Gillespie J. R. & Robinson, N.E. (eds) *Equine Exercise Physioloy 2*. Davis California: ICEEP Publications, pp. 290-301.

Vermeulen, A.D. & Evans, D.L. (2006). Measurements of fitness of Thoroughbred racehorses using field studies of heart rate and velocity with a global positioning system. *Equine Veterinary Journal*, 38(S 36), 113-117.

Vilá, C., Leonard, J. A., Götherström, A, Marklund, S., Sandberg, K., Lidén, K., Wayne, R. K., & Ellegren, H. (2001). Widespread origins of domestic horse lineages. *Science,* 291, pp. 474-477.

Volfinger, L., Lassourd, V., Michaux, J.M., Braun, J.P. & Toutain, P.L. (1994). Kinetic evaluation of muscle damage during exercise by calculation of amount of creatine kinase released. *American Journal of Physiology, regulatory, integrative and comparative physiology,* 266: R434-441.

Wanderley, E.K., Manso Filho, H.C., Manso, H.E.C.C.C., Santiago, T.A. & McKeever, K.H. (2010). Metabolic changes in four beat gaited horses after field marcha simulation. *Equine Veterinary Journal*, 42(Suppl. 38), pp. 105-109.

Weishaupt, M. A., Wiestner, T., von Peinen, K., Waldern, N., Roepstorff, L., van. Weeren, R., Meyer, H., & Johnston, C.(2006). Effect of head and neck position on vertical ground reaction forces and interlimb coordination in the dressage horse ridden at walk and trot on a treadmill. *Equine Veterinary Journal,* 38 (Supplement 36), pp. 387-392.

Weishaupt, M. A., Byström, A., von Peinen, K., Wiestner, T., Meyer, H., Waldern, N., Johnston, C., van Weeren, R. & Roepstorff, L. (2009). Kinetics and kinematics of the passage. *Equine Veterinary Journal*, 41(3), pp.263-267.

Weishaupt, M.A., Waldern, N.M., Amport, C., Ramseier, L.C. & Wiestner, T. (2013). Effects of shoeing on intra- and inter-limb coordination and movement consistency in Icelandic horses at walk, tölt and trot. *The Veterinary Journal*, 198, pp. e109-e113.

White, S.L., Williamson, L.H., Maykuth, P., Cole, S. & Andrews, F. (1995). Heart rate and lactate concentration during two different cross country events. *Equine Veterinary Journal*, 27, (suppl. 18), pp. 463-467.

Wijnberg, I.D., Sleutjens, J., Van der Kolk, J.H. & Back, W. (2010). Effect of head and neck position on outcome of quantitative neuromuscular diagnostic techniques in Warmblood riding horses directly following moderate exercise. *Equine Veterinary Journal*, 42 (Supplement 38), pp. 387-392.

Williams, R.J., Chandler, R.E. & Marlin, D.J. (2009). Heart rates of horses during competitive dressage. *Comparative Exercise Physiology,* 6(1), pp. 7-15.

Wilson, R.G., Isler, R.B. & Thornton, J.R. (1983). Heart rate, lactic acid production and speed during a standardised exercise test in Standardbred horses. In: Snow, D.H., Persson, S.G.B. & Rose, R.J. (eds) *Equine Exercise Physioloy 1.* Cambridge UK: Granta Editions, pp. 487-496.

Worldfengur (2015). The studbook of origin for the Icelandic horse. www.worldfengur.com [Assessed 5 May 2015]

Yamano, S., Eto, D., Hiraga, A. & Miyata, H. (2006). Recruitment pattern of muscle fibre type during high intensity exercise (60-100% VO_{2max}) in Thoroughbred horses. *Research in Veterinary Science*, 80, pp. 109-115.

Zobba, R., Ardu, M., Niccolini, S., Cubeddu, F., Dimauro, C., Bonelli, P., Dedola, C., Visco, S. & Parpaglia, M.L.P. (2011). Physical, haematological and biochemical responses to acute intense exercise in polo horses. *Journal of Equine Veterinary Science*, 31, pp. 542-548.

Þórsson, B., Aspelund, T., Harris, T. B., Launer, L.J. & Guðnason, V. (2009). Trend in body weight and diabetes in forty years in Iceland. *Icelandic Medical Journal* (Læknablaðið), 95(4), pp. 259-266.

Acknowledgements

I gratefully thank the funders of the work in this thesis: the Stock Protection Fund for the Icelandic horse, the Developmental Fund for Icelandic Horse Breeding, the Pálmi Jónsson Natural Conservation Fund and Hólar University College

Many individuals, both humans and horses, contributed to the work in this thesis and they are all gratefully acknowledged. The work behind this thesis would never have been done by one individual.

My sincerest thanks to:

My main supervisor and friend Anna Jansson. To my mind you are a perfect supervisor, with great knowledge and interest, logical and clear thinking and explanations, and importantly always making things simple! You were quick to respond to all my questions and emails (which have been very, very many!), good at listening, discussing, arguing, guiding and promoting creative thinking. You are my model for how to handle my own students. I am really grateful of having had the chance to work with you, I have learned a lot from you and I hope we can continue to work together on the Icelandic horse in the future.

My co-supervisors Lars Roepstorff, Sveinn Ragnarsson and Jan-Erik Lindberg for enlightening and inspiring discussions and giving me support and help when needed.

Skúli Skúlason, rector at Hólar University College, and Víkingur Gunnarsson, head of the equine department at Holar, for giving me the opportunity to start work on my PhD. Later Erla Björk Bjarnadóttir, rector at Hólar, and Sveinn Ragnarsson, head of the equine department at Holar, gave me the opportunity to continue my PhD studies. Thank you all for your support and encouragement.

Riders, riders' assistants, owners of horses and staff at the breed evaluation field test at Sauðárkrókur on 29 April 2011 and at Hella between 30 May and 9 June 2011 for their collaboration and valuable work.

The research team at Sauðárkrókur: Höskuldur Jensson, Pieter de Gouw, Sveinn Ragnarsson, Víkingur Gunnarsson and Sigríður Ólafsdóttir for collaboration and valuable work.

The research team at Hella: Eggert Gunnarsson, Heiða Sigurðardóttir, Johanna Karin Knutsson, Pieter de Gouw, Sigríður Ólafsdóttir, Rósa Kristinsdóttir, and Anna Jansson for collaboration and valuable work.

Eyþór Einarsson, Pétur Halldórsson and Óðinn Örn Jóhannsson for their valuable support and assistance at the breed evaluation field tests at Hella and Sauðárkrókur.

Guðlaugur Antonsson and Kristinn Guðnason for assisting and supporting in many ways.

The Institute of Experimental Pathology at Keldur University of Iceland for support and help.

The Horse Breeders' Association in Iceland and the Farmers' Association in Iceland for support and help.

The Healthcare centre at Sauðárkrókur for lending us a haematocrit centrifuger.

Gunnar Óskarsson for making and painting the sticks for the riding track.

Bergur Gunnarsson for constructing the platform on the scale for weighing the horses.

Eggert Gunnarsson and Höskuldur Jensson for their valuable assistance.

Vilhjálmur Svansson for all his help, *e.g.* finding Eggert Gunnarsson for me for the Hella work, and for assisting with the export papers for the blood samples between Iceland and Sweden.

Pieter de Gouw for being my right hand from March to June 2011, and assisting me in many ways with all the planning, collection and handling of the data from Sauðárkrókur and Hella. I still benefit from all the technical things you took care of and taught me!

The research team working on the experiments at Holar 2012, Þórdís Anna Gylfadóttir, Þorsteinn Björnsson, Erlingur Ingvarsson, Höskuldur Jensson, Gestur Júlíusson, Ásta Kara Sveinsdóttir, Heiða Sigurðardóttir and Anna Jansson, for collaboration and valuable work.

The research team working on the experiment at Holar 2014, Höskuldur Jensson, Fredrica Fagerlund, Erla Heiðrún Benediktsdóttir, Bjarni Dagur Jóhannsson, Lars Roepstorff, Víkingur Gunnarsson and Anna Jansson, for collaboration and valuable work.

Ingólfur Kristjánsson and Eysteinn Steingrímsson for all kinds of assistance in the stable and at the riding track, during experimental work at Holar 2012 and 2014.

All the horses for taking part in the research work at Sauðárkrókur and Hella and the indispensible schoolhorses at Holar: Bokki, Brenna, Bósi, Drift, Eldborg, Eyrir, Freki, Grótta, Hetja, Kjarni, Rán, Stígur, Þáttur, Þeli, Þjósti, Þórdís, Þrándur and Þúsöld.
The mare Gígja and Ingólfur on the tractor are thanked for managing not to destroy the experimental work at Hólar 2012 after an unforgettable show. Special thanks to Steini who did not fall off!

All my coworkers at Hólar University College for their motivation, help and support.

Helgi Thorarensen for assistance in many ways, help in statistics, valuable discussions and arranging a haematocrit centifuger for the experiment 2014.

Broddi Reyr Hansen for technical assistance.

All the people, not least the other PhD students, at the Department of Animal Nutrition and Management for their friendly approach and support. I feel very welcome at Ultuna and like the international environment, getting to know people from here and there in the world along with the nice Swedish people!

The staff at SLU library and IT-stöd for great and indispensible service.

Johan Karlson for technical assistance and his great help in getting me a new computer, as otherwise I would probably be far from finishing my writing.

Margareta Emanuelson and Sara Österman for all their support and kindness.

Maria Neil and Helena Wall for their friendly assistance of all kinds through my PhD study.

Margareta Norinder for all her kindness and help through my PhD study.

Anna-Greta Haglund for the analysis of plasma lactate and all her valuable help.

Claudia von Brömssen for building up my statistical knowledge (in her great course) and for indispensible statistical help.

Cecilia Kronqvist for her assistance and being a good company in the office.

Marianne Lövgren for her assistance with papers for my PhD study.

Malin Connysson and Sara Ringmark for support, discussions and friendship.

The Clinical Pathology Laboratory, University Animal Hospital at SLU (Ingrid Lilliehook and Ann-Christine Folker), for analysis of muscle enzymes (CK and AST).

Ástund, Reykjavík, for the help with adjustment of the saddle in the weight carrying study.

Sighvatur Sævar Árnason and University of Iceland, for lending a haematocrit centrifuger.

Mary McAfee for her great assistance with English correction of the papers and the thesis.

Þorvaldur Kristjánsson for assistance with information.

Óðinn Örn Jóhannsson for the cover photo and kindly allowing me to use it.

Gísli Gíslason for kindly accepting to be on the cover photo.

Þórdís Anna Gylfadóttir, Þorsteinn Björnsson, Erlingur Ingvarsson and Fredrica Fagerlund for training of the horses for the experiments at Holar and also for kindly accepting to be on photos in this thesis.

Þorkell Magnússon for technical assistance with the cover photo.

Dimitri at Repro printing service SLU for kind guidance, helpfulness, and printing of the thesis.

Að lokum vil ég þakka öllum mínum nánustu fyrir allan stuðninginn og áhugann.

Sérstakar þakkir fá móðir mín og faðir minn heitinn fyrir heilsteypt uppeldi, fyrir að kenna mér að vinna og að hafa alla tíð hvatt mig og stutt mig við það sem ég hef tekið mér fyrir hendur. Mamma fær kærar þakkir fyrir að veita okkur fjölskyldunni mikilvægan stuðning í hrossabúskapnum og fyrir að hafa verið bústjóri með sóma á Kagaðarhóli hin síðari ár, ekki hvað síst síðasta vetur.

Einnig fá öll hrossin mín fyrr og síðar þakkir fyrir ómetanlegar stundir sem þau hafa gefið, ekki minnst í hestaferðunum á sumrin, og fyrir að gefa mér margháttaða reynslu og þekkingu sem ekki verður fengin nema í samskiptum við hesta.

Síðast en ekki síst fær elsku fjölskyldan mín sem er mér ómetanleg, þau Víkingur, Sigríður Vaka og Ari Óskar, ástarþakkir fyrir alla hvatninguna, hjálpina og stuðninginn í gegnum allt doktorsnámsferlið.