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Physiological response to weight carrying in horses

- with emphasis on conformation and training of Icelandic horses

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Cover: Icelandic horse performing the weight carrying test at Wången, 2024. Photo: Denise Söderroos

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Abstract

There is an ongoing welfare debate regarding rider weight relative to horse size, but scientific knowledge is limited. This thesis aimed to examine the association between body measurements, and both subjectively and physiologically assessed weight carrying capacity in Icelandic horses. Further aims were to investigate whether weight carrying capacity can be estimated with an unridden standardised treadmill exercise test (SET) and to evaluate the effect of training on weight carrying capacity. Body measurements and body condition score (BCS) were collected in horses at breed evaluation field tests (BEFTh) and in tour riding and school horses. Sixteen hoses performed a SET and a ridden weight test, carrying 20 %, 25 %, 30 % and 35 % of their body weight (BW) in each step, respectively. Another 14 horses performed the weight carrying test before and after a 7-week unridden (n=7) or ridden (n=7) training period. Heart rate (HR) was measured during exercise, and blood samples were collected during exercise tests for analysis of plasma lactate concentration. BEFTh had a greater difference between height at withers and height at back and croup, a less difference between height at croup and back, and a lower BCS than TRh. Height was positively correlated with subjective weight carrying capacity. There was a large individual variation in physiological response to weight carrying, and several horses never reached the anaerobic threshold. Chest width was positively correlated with BW-ratio at the anaerobic threshold, and an “uphill” conformation, straight backline, and smaller hock circumference were also associated with greater weight carrying capacity. Speed at plasma lactate concentration 3 mmol/L at the SET was positively correlated with the BWR at a HR of 180 bpm at the weight carrying test. No other physiological parameters were correlated between the tests, and the SET used in this thesis might not be applicable in estimating weight carrying capacity. Plasma lactate concentration tended to be higher for the unridden training group and lower for the ridden group, after training, compared with before, indicating that ridden training is beneficial for weight carrying capacity.

Keywords: rider weight, exercise test, body measurements, tour riding, plasma lactate, weight carrying capacity, performance

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Sammanfattning

Det pågår en välfärdsdebatt om ryttarens vikt i förhållande till hästens storlek, men den vetenskapliga kunskapen i ämnet är begränsad. Avhandlingens syfte var att undersöka sambandet mellan kroppsmått och både subjektivt och fysiologiskt bedömd viktbärande förmåga hos Islandshästar. Vidare var syftet att undersöka om viktbärande förmåga kan uppskattas med ett standardiserat arbetstest (SET) på rullmatta och att utvärdera ett träningsprogram för viktbärande förmåga. Kroppsmått och hullpoäng samlades in från hästar som deltog i ett avelsvärderingstest (BEFTh) samt från och turridnings- och ridskolehästar (TRh). Sexton hästar genomförde ett SET och ett uppsuttet fyrastegs vikttest, med 20 %, 25 %, 30 % och 35 % av sin kroppsvikt (BW). Ytterligare 14 hästar genomförde vikttestet innan och efter en 7-veckors, antingen med ryttare (n=7) eller utan (n=7), träningsperiod. Hjärtfrekvensen (HF) mättes under arbete och blodprover togs under arbetstesten för analys av plasmalaktatkoncentration. BEFTh hade en större skillnad mellan mankhöjd och höjd vid rygg och kors, en mindre skillnad mellan höjd vid kors och rygg, och en lägre hullpoäng än TRh. Höjdmått var positivt korrelerade med subjektiv viktbärande förmåga. Bröstbredden var positivt korrelerad med förhållandet mellan ryttaren och hästens vikt (BWR) vid mjölksyratröskeln. En relativt hög manke jämfört med kors och rygg och en rak rygglinje var också associerade med bättre viktbärande förmåga. Hastigheten vid en plasmalaktatkoncentration på 3 mmol/L vid SET var positivt korrelerad med BWR vid en HF på 180 slag/min vid vikttestet. Inga andra fysiologiska parametrar korrelerade mellan testerna och ett SET som användes i denna avhandling är förmodligen inte lämplig för att uppskatta viktbärande förmåga. Plasmalaktatkoncentrationen tenderade att vara högre för hästar tränade utan ryttare och lägre för hästar tränade med ryttare efter träningsperioden jämfört med före, vilket indikerar att uppsutten träning är fördelaktigt för viktbärande förmåga.

Keywords: ryttarvikt, arbetstest, exteriör, turridning, plasmalaktat, viktbärande förmåga, prestation

Preface

The journey of this thesis started in the autumn 2019. A couple of months later, the covid-19 disease was discovered, widely spread and soon we were in the middle of a pandemic. Due to strong recommendations to not travel abroad during this time, the data collection in Iceland was postponed to 2021. Instead, I got more time for planning and searching for literature on the topic of my thesis, and the idea for Paper I was born, and data collection could soon be started in Sweden. Paper I was hence not included in the original plan but could in the end contribute with valuable knowledge and provided a valuable foundation for the further studies.

Dedication

Till Frans och Rio. Ni är mitt allt.

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. Söderroos, D., Stefánsdóttir, G.J., Gunnarsson, V., Rhodin, M., Ragnarsson, S. & Jansson, A. (2024). Body measurements in Icelandic horses used for two different purposes and the relationship to performance and usability. *Comparative Exercise Physiology*. 20 (1), 35-44. https://doi.org/10.1163/17552559-20230034

II. Söderroos, D., Stefánsdóttir, G.J., Ragnarsson, S., Gunnarsson, V. & Jansson, A. (2025). Physiological response to weight carrying and associations with conformation traits in Icelandic horses used for tour riding. *Acta Veterinaria Scandinavica*. 67, 35. https://doi.org/10.1186/s13028-025-00818-5

III. Söderroos, D., Stefánsdóttir, G.J., Ragnarsson, S., Gunnarsson, V. & Jansson, A. (2025). Relationship between weight-carrying capacity and performance in a standardized treadmill exercise test in horses. *Physiological Reports*. 13 (19), e70607. https://doi.org/10.14814/phy2.70607

IV. Söderroos, D., Connysson, M., Nilsson, E., Känsälä, N.A., Hedenström, U. & Jansson, A. The effect of a 7-week ridden vs. unridden training period on weight carrying capacity in horses (manuscript)

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The contribution of Denise Söderroos to the papers included in this thesis was as follows:

I. Methodology, planning and data collection together with co-authors, data analysis, writing of the original draft, editing together with co-authors, and responsibility for correspondence with the scientific journal.

II. Planning and data collection together with co-authors, data analysis, writing of the original draft, editing together with co-authors and responsibility for correspondence with the scientific journal.

III. Planning and data collection together with co-authors, data analysis, writing of the original draft, editing together with co-authors and responsibility for correspondence with the scientific journal.

IV. Planning, methodology and data collection together with co-authors, data analysis, writing of the original draft and editing together with co-authors.

List of tables

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Abbreviations

ATP	Adenosine triphosphate
BEFTh	Icelandic horses participating in a breed evaluation field test
BCS	Body condition score
BW	Body weight
BWR	Body weight ratio
BWR_{190}	Body weight ratio at a heart rate of 190 bpm
BWR_{La2}	Body weight ratio at a plasma lactate concentration of 2 mmol/L
BWR_{La3}	Body weight ratio at a plasma lactate concentration of 3 mmol/L
BWR_{La4}	Body weight ratio at a plasma lactate concentration of 4 mmol/L
HR	Heart rate
SET	Standardised exercise test
TRh	Icelandic horses used for tour riding and in riding schools
V_{150}	Velocity at a heart rate of 150 bpm
V_{200}	Velocity at a heart rate of 200 bpm
V_{La2}	Velocity at a plasma lactate concentration of 2 mmol/L
V_{La3}	Velocity at a plasma lactate concentration 3 mmol/L
V_{La4}	Velocity at a plasma lactate concentration of 4 mmol/L
VO_2	Oxygen uptake/consumption (ml/kg/min)

1. Introduction

1.1 Background

Evidence from dental wear caused by a bit shows that humans began riding horses approximately 6 000 years ago, mainly for transportation (Anthony *et al*., 1991). Later, horses were used in the cavalry and ridden by soldiers. In the early 20th century, it was reported that cavalry horses were required to carry approximately 25 % of their body weight (BW) (Carter, 1906). To be able to carry those weights, a cavalry horse was preferably around 152-160 cm high at the withers, with a BW of 430-500 kg. Horses in the Austrian cavalry carried at least 130 kg in total, and horses in the Japanese cavalry, on average 33 % of their BW (Carter, 1906). Ponies were described as having a great weight carrying capacity. Furthermore, conformation traits such as a short, well-muscled back, a broad chest, and, in general a great muscle mass were believed to be associated with a great weight carrying capacity (Carter, 1906).

To date, riding horses are used worldwide for leisure, sports and therapy. Horses are also used for draught, pack and ridden work, mainly in developing countries (Pritchard *et al*., 2005). In Sweden, there are around 430 riding schools and 105 000 leisure riders (Svenska Ridsport Förbundet, 2025). In addition to the use of horses for leisure riding and recreational purposes, training and competition in disciplines such as show jumping, dressage, eventing and endurance riding are popular (FEI, n.d.). Over 200 000 competition riders are entered in the Fédération Equestre Internationales database (FEI, n.d.), which is the international governing body of equestrian sports. In addition, the International Federation of Icelandic Horse Associations has over 80 000 members worldwide (FEIF, n.d.a).

Over the last decades, there has been an increased discussion about the public's attitude and acceptance towards the horse industry, a concept known as "social licence to operate" (Nelsen, 2006; Douglas *et al*., 2022; Heleski, 2023). In addition to the increased public concern for the horses' welfare in equestrianism, there is an ongoing welfare debate within the horse industry about how heavy the rider can be (Draper, 2017; Fischer, n.d.; Hippson, 2023). Furthermore, people are getting heavier, and the obesity rates are increasing (Thórsson *et al*., 2009; SCB, 2018; Flores-Ortiz *et al*., 2019). To enhance horse welfare, some tour riding companies and equestrian associations have implemented weight limits for riders (Stefánsdóttir *et al*., 2017a; Douglas *et al*., 2022). Also, some riding associations have implemented guidelines for the maximum rider weight. For example, Equestrian Australia (EA) and British Dressage (BD) recommend a maximum rider weight (including equipment) of 20 % of the horse's BW (EA, 2022; BD, 2023). Although the scientific evidence for the recommended maximum rider weight is scarce, the question of rider weight is important, for welfare and performance reasons, as well as for public acceptance (i.e. social licence to operate).

1.1.1 Rider weight and body weight ratio

Data on the BW of a typical rider (including both leisure and sports riders) and the BW-ratio (BWR) between the rider and the horse are limited. However, in the UK, a total 971 leisure and amateur riders over 18 years old (98 % females) responded to a survey about the BW of themselves and their horses (Challinor *et al*., 2021). The mean rider BW was 67 kg, ranging from 38 to 120 kg, and the mean BW of the horses was 549 kg, ranging from 250 to 1000 kg, resulting in a mean BWR of 12.5 %, excluding saddle weight. The majority (~ 60 %) of the riders had a normal body mass index, ~ 21 % were overweight, and ~ 10 % were obese. Only 0.8 % of the riders and their horses had a BWR above 20 %. The BW of riders in Iceland who participated in a breed evaluation field test for Icelandic horses was, on average 83 ± 11 kg, ranging from 59 to 112 kg (Stefánsdóttir *et al*., 2014). The average BW of the horses was 339 kg, and weight of the saddle and blanket was 8.7 kg (Stefánsdóttir *et al*., 2014), which resulted in a BWR of 27 %. A similar mean BW (83 kg) was reported in riders at 160 km endurance races, ranging from 56 to 119 kg (including all equipment), and the mean BWR was estimated to 20 % with a range from 15 to 31 % (Garlinghouse & Burrill, 1999). However, the mean BW of riders participating in the World Championship for Icelandic horses in 2023 was only 67 ± 11 kg, resulting in a mean BWR of 21.3 ± 2.9 kg, including the weight of rider and tack (Amplatz, 2026).

1.1.2 The Icelandic horse

The Icelandic horse (Figure 1) is a popular breed found worldwide (FEIF, 2024). More than 280 000 horses are registered in the studbook of origin for the Icelandic horse (WorldFengur, 2026), where almost 90 000 are found in Iceland and around 37 000 in Sweden (FEIF, 2025a). In Iceland, the horse breed has been present since the colonisation during the period 874-930 and has since then mainly been used as a riding and pack horse (Adalsteinsson, 1981). The breed is particularly known for the gaits tölt and flying pace (Adalsteinsson, 1981). Tölt is a 4-beat, lateral sequence, single-foot gait, generally without a suspension phase (Biknevicius *et al.*, 2006; FEIF, 2025b). The footfall sequence is left hind, left front, right hind and right front (FEIF, 2025b). The horse is relatively small with mean height at withers of around 140 cm and a BW of 330 – 370 kg, but is nevertheless often ridden by adult riders, some of them weighing over 100 kg (Stefánsdóttir *et al.*, 2014).

The Icelandic horse is used both for leisure and sports (FEIF, n.d.b). Apart from the private use, they are also used in tourism and in riding schools. Sport disciplines include, e.g. gait competitions, pace races, and dressage (FEIF, n.d.c). In Iceland, it is possible to rent a horse for either a shorter horseback riding session or during a longer period (Sigurðardóttir & Helgadóttir, 2015). Horses in Iceland are also used for trekking tours, which can take over 24 hours in total, including stops (Sigurðardóttir & Helgadóttir, 2015). However, in Sweden, the Icelandic horse is mainly used in riding schools and for shorter tour riding trips, apart from private use for sport and pleasure.

Figure 1. Icelandic horse. Photo: Julio Gonzalez

Breeding

The breeding program for Icelandic horses is aimed at preserving and improving the breed. The FEIF breeding assessment system was first described in detail in 1986, and today there is a global standard of the assessments (FEIF, 2025b). A breed evaluation field test for Icelandic horses includes three different parts: body measurements, conformation assessment and a ridden assessment where the horse can get a score from 5 to 10 (FEIF, 2025b). Body measurements include, e.g. height, chest and hip widths, and leg circumferences. The assessment of the conformation includes scoring of head, neck, withers, shoulders, back and croup, proportions, legs, hooves and mane and tail. In the assessment of riding abilities, tölt, slow tölt, trot, pace, gallop, ride ability, and general impression, along with walk are scored. The ride ability score includes willingness, co-operation and relaxation in the horse and is assessed during both riding and handling.

The breeding goal is to breed a robust horse with a height at withers of at least 138 cm and a conformation that promotes weight carrying capacity (FEIF, 2025b). For example, the ideal back is described to be broad and well-muscled, and the proportion of the horse should be "uphill" (FEIF, 2025b). An "uphill" conformation means that the withers are higher than the croup, which has been shown to be the most important conformation trait for riding abilities in a breed evaluation field test (Kristjansson *et al*., 2016). A greater height at withers, body length, chest width, and hip width were also examples of conformation traits associated with higher scores for riding abilities, with an optimum height at withers of 146 cm and a chest width of 40.6 cm (Kristjansson *et al*., 2016).

1.2 Previous research on weight carrying capacity

1.2.1 Physiological response

Although there is a frequent welfare debate about rider weight in the horse industry, the scientific knowledge about the effect of weight carrying in horses is scarce, not least on the physiological response. In this section, I will give an overview of previous research on weight carrying capacity in horses and briefly in other species.

In ponies, as well as in humans and donkeys, the energy cost increases with weight load (Pearson *et al*., 1998; Bastien *et al*., 2005), and has been shown to be higher in horses trotting loaded with 19 % of their BW, compared with being unloaded (Wickler *et al*., 2001). In addition to the increased energy cost, the preferred speed in trot was lower when they were carrying a load, compared with unloaded (Wickler *et al*., 2001). Generally, an increased weight load leads to an increased physiological response in the horse, as shown, e.g. by Stefánsdóttir *et al*. (2017a), where Icelandic horses carried a rider loaded with additional weights. The weight carrying test was performed in tölt, with four incremental steps in which horses carried 20 %, 25 %, 30 %, and 35 % of their BW, respectively. A fifth step was performed at a BWR of 20 % to ensure that the physiological response mainly reflected the different loads, rather than the accumulated effect of the exercise test. An increased weight load resulted in increased heart rate (HR), respiratory rate, and plasma lactate concentration in the horses. However, there was no effect on haematocrit levels, which were already elevated compared to rest at the first step, indicating that the splenic reservoir of red blood cells was fully emptied already during the first step (Persson, 1967). The BWR when horses reached a plasma lactate concentration of 4 mmol/L (i.e. the anaerobic threshold) was 22.7 %, with an individual range between 17-27.5 %. Similar results were observed in light riding horses carrying 15 %, 20 %, 25 %, and 30 % at four different occasions (Powell *et al.*, 2008). Heart rate, respiratory rate, and rectal temperature were higher after the test at 25 % and 30 % of their BW compared with at 15 % and 20 %, and plasma lactate concentration and serum creatine kinase were higher at BWR 30 % compared with lower BWRs. In another study, ponies walked on a treadmill with additional loads of 67 kg and 134 kg, in a randomised order, resulting in BWRs of around 32 % and 64 % for the two loads, respectively (McKeever *et al.*, 2005). Right atrial- and ventricular pressure were increased with increased weight carrying, but there was no significant effect on HR. A higher BWR has also been reported to increase plasma lactate concentration after a breed evaluation field test for Icelandic horses (Stefánsdóttir *et al.*, 2014).

Sloet van Oldruitenborgh-Oosterbaan *et al.* (1995) investigated whether the physiological response to treadmill exercise in Dutch Warmblood horses, either loaded with lead weights or a rider (both weighing 90 kg) differed. For both types of loads, horses had higher peak and recovery HR during exercise and higher plasma lactate concentrations after exercise, compared with unloaded exercise. However, the physiological response was not affected by the type of load (lead weights or rider). In contrast to the studies mentioned previously, HR in horses performing a dressage test with loads resulting in a BWR of 15-18.5 % on average was not affected by the load (Christensen *et al.*, 2020). Likewise, neither HR variability nor saliva cortisol concentration was affected by load. The absence of a load-related effect in that study may be explained by the relatively low BWR and exercise intensity, compared with the other studies within the field. Also, increased emotional stress due to a novel situation can influence, e.g. HR, potentially masking subtle effects of workload (Persson, 1967; King *et al.*, 1995). Furthermore, minor effects of the physiological response might fall within the method's accuracy limits.

1.2.2 Association with conformation

Although there is a general idea of the ideal conformation for weight carrying in horses, the scientific knowledge about this topic is limited. According to a survey sent to riders in the UK, BWR was higher for Welsh Type horses and their riders than for Warmblood horses and their riders (Challinor *et al*., 2021). This indicates either a belief of the riders that a “heavier” and more “robust” breed (such as the Welsh Type) can carry a heavier rider, or that the Welsh Type horses had lower BW than the Warmblood horses, resulting in a greater BWR. This is in line with the results of Forino *et al*. (2023), which studied the perceived ideal match between a rider and a horse, considering the rider’s body shape and horse breed. Riders with a curvier body shape and more body fat were more likely to be matched by dressage judges and equestrian coaches with a cob horse than riders with a lean body type.

In Icelandic horses, a broader back at the thoracolumbar region (i.e. higher back condition score) has previously been associated with the ability to carry a higher weight before reaching the anaerobic threshold (Stefánsdóttir *et al*., 2017a), indicating that a broad back is beneficial for weight carrying capacity. Similar results were found in light riding horses, where horses with a wider loin became less sore 24 h after weight carrying (Powell *et al*., 2008). Also, a greater cannon bone circumference as a percentage of loin width was correlated with less muscle soreness (Powell *et al*., 2008). However, Stefánsdóttir *et al*. (2017a) did not find a relationship between BWR at the anaerobic threshold and cannon bone circumference in Icelandic horses, nor for circumference of carpus and girth, height at withers and lowest point of the back and croup. Results on the relationship between conformation and weight carrying capacity in horses are thus somewhat inconsistent and need further research.

1.2.3 Effects of weight training

O´Connor *et al*. (2002) studied the effect of an incremental weight carrying training program on body measurements and size of *m. longissimus dorsi* in 18-30 months old stock-type horses compared with control horses, of similar ages, that performed the same training but without added weights. During the 78-day training period, which included 6 sessions/week, horses carried weights in a weight vest, starting at 4.5 kg and ending at 45 kg (mean BWR 12 %). Height at withers increased more in the weight-trained horses than in the controls, and hip height (i.e. height at the area between loin and croup) increased for the training group but not for controls. The greater increase in withers height was suggested to be due to an increased muscle tone primarily in the *m. serratus ventralis*, which is located in the forelimb region. The increase in hip height was suggested to be due to an increased muscle tone of the *m. gluteus medius*. However, the size of the *m. longissimus dorsi* did not change with weight training. In another study (with the same setup as above and possibly the same horses), the mineral content of the third metacarpal bone increased more in the weight-trained horses than in the controls (Nielsen *et al*., 2002). Furthermore, Heck *et al*. (1996) evaluated the effect of an 8-week weight carrying training program, including 3 sessions/week in two untrained ponies. At each training session, performed in walk, horses were loaded with lead weights in incremental increases until they showed signs of fatigue. At the end of the training period, the ponies were able to carry up to 200 kg (mean BWR 106 %) until fatigue, compared with 66 kg (mean BWR 35 %) at the beginning of the training. The ponies had also an increase in forelimb circumference and cross-sectional diameter of forelimb muscles in the end of the training period. However, the study did not include any control horses.

Although it was not weight training, gymnastic training in horses used for hippotherapy has been shown to improve gait quality while carrying riders resulting in a BWR up to 25 % (de Oliveira *et al*., 2020). Horses underwent training 4 days/week for 3 months, which, e.g. included walking over 40 cm-high poles, in addition to their usual training (therapeutic riding). The gymnastic training resulted in increased objective gait symmetry during ridden exercise compared with horses that performed only the therapeutic riding sessions.

1.2.4 Weight carrying capacity in other species

Donkeys

The donkey has a long history as a working animal, and today it is, e.g. used for transportation and riding in low and middle-income countries (Rodrigues *et al*., 2021). As already mentioned, the energy cost increases with weight load and is the same for ponies and donkeys (Pearson *et al*., 1998). However, the energy cost per unit load has been shown to decrease with increased weight (Pearson *et al*., 1998). A previous study measured the physiological response to three different loads (40 %, 50 % and 66 % BWR) in four walking donkeys (Legha *et al*., 2018). The authors concluded that donkeys may walk comfortably with loads up to a BWR of 50 %, but that a load resulting in a BWR of 66 % may induce early fatigue (i.e. within 4 hours). Similar results were reported by Pal *et al*. (2012), who found that donkeys walking with a load representing a BWR of 50 % did not show any visual signs of fatigue during a 4-hour exercise, including 1 hour of rest in the middle. However, they became clearly fatigued during 4 hours of continuous exercise while carrying the same weight. According to results from a survey that was sent to owners of working donkeys in Pakistan, over 87 % of the donkeys used to carry loads above 50 % BWR, and 25 % carried loads above 90 % BWR (Bukhari *et al*., 2022).

Humans

For humans, carrying heavy loads (usually in a backpack) is a common task, e.g. for military personnel, and the activity can last several hours (Faghy *et al*., 2022). According to a questionnaire, soldiers in the U.S. army who had previously been deployed to Afghanistan carried loads averaging 21.3 kg, corresponding to BWRs of 16.1 % for females and 26.4 % for males (Roy *et al*., 2012). However, loads above a BWR of 50 % were reported, and there was an increased risk for injuries if the average load exceeded 34.1 kg. Interestingly, the distance of load carriage was not associated with injury risk. In the Swedish military, it has been reported that some soldiers may carry a load as heavy as 80 kg (Sveriges Radio, 2011). As already mentioned for horses, the physiological response increases with increased weight load also in humans at walk (Borghols *et al*., 1978; Godhe *et al*., 2020). The increase in oxygen uptake (VO_2) during weight carrying can, however, be avoided if the carrier can reduce speed (Faghy *et al*., 2022). An increased weight load may also affect the gait characteristics in men and women (Silder *et al*., 2013). Walking with a load representing a BWR of 30 % was shown to increase the duration of the stance phase compared with walking unloaded, but there was no effect of load on step length or number of steps per minute (Silder *et al*., 2013).

Knowledge about how training influences the weight carrying capacity is of great importance. For example, the aerobic capacity, evaluated with a "beep test", has been shown to be associated with weight carrying capacity in humans (Robinson *et al*., 2018). However, it seems like a combination of resistance training, aerobic training and load carriage exercise is the most optimal to improve weight carrying capacity (Knapik *et al*., 2012). Earlier experience with weight carrying has been shown to be important for weight carrying capacity in men and women (Godhe *et al*., 2020), indicating that weight training is important for improving weight carrying capacity.

1.3 Exercise testing in horses

A standardised exercise test (SET) is generally used to evaluate the fitness of a horse (Valberg, 1996), and the performance in a SET has been shown to be correlated with true performance in Standardbred trotters (Leleu *et al*., 2005; Ringmark *et al*., 2017) and Warmblood horses (Bitschnau *et al*., 2010). The SET can be performed on a treadmill or in the field and is generally incremental in speed (Evans, 2008). The SET should be as standardised as possible, e.g. regarding environmental conditions, distance, speed, warm-up routine and timing of blood collection (Evans, 2008). The reason for evaluating the horse's fitness can, e.g. be to evaluate the effect of a training program (Evans, 2008). Usually, HR and plasma (or blood) lactate concentration are measured during a SET, where there is a linear relationship between HR and speed, whereas the lactate concentration increases exponentially with speed (Lindholm & Saltin, 1974; Persson & Ullberg, 1974). The working capacity of the horse can, e.g. be evaluated by estimating the V_{La4} (Bitschnau *et al*., 2010; Harkins *et al*., 1993; Jansson *et al*., 2021), which is the velocity at the anaerobic threshold (i.e. a plasma lactate concentration of 4 mmol/L). This parameter is correlated with true performance in Standardbred trotters (Couroucé *et al*., 1997; Leleu *et al*., 2005; Lindner, 2010; Ringmark *et al*., 2017) and Warmblood horses (Bitschnau *et al*., 2010), as well as the subjective athletic rating in polo horses (Harkins *et al*., 1993).

It is also common to estimate the velocity at a specific HR, e.g. 200 bpm (Dubreucq *et al*., 1995; Evans, 2008; Bitschnau *et al*., 2010), which is called V_{200}. Horses with greater exercise capacity generally have higher values of V_{La4} and V_{200} (Hodgson & Rose, 1994), and, usually, V_{La4} and V_{200} are similar, i.e. horses reach the anaerobic threshold at a HR of 200 bpm (Persson *et al*., 1991; Couroucé, 1999). Also, V_{La2} (i.e. the velocity at a plasma lactate concentration of 2 mmol/L) can be estimated and has been reported to be associated with the level of training in Warmblood horses (Bitschnau *et al*., 2010).

The haematocrit increases with increased speed during exercise due to release of splenic erythrocytes (Persson, 1967) and can be increased with the amount of training (Ringmark *et al*., 2015). In Standardbred trotters, the exercise haematocrit at 3 years of age has been associated with total earnings until 7 years of age (Ringmark *et al*., 2017). Therefore, haematocrit measurements can be valuable in a SET. In addition, VO_2 is a valuable measure when evaluating the fitness of the horse (Evans, 2008), however, this measure was not applied in the studies of this thesis due to the impracticality of the method (including the use of an oxygen mask).

1.3.1 Treadmill exercise tests

The use of an equine treadmill to measure the fitness of a horse was first described in 1967 by Persson and has since become a common method for evaluating a horse's fitness. A treadmill SET usually enables a controlled environment (e.g. ambient temperature, wind, and surface) and a controlled speed, which make the test well standardised. Another advantage is that the treadmill can be inclined (preferably up to 6 degrees ≈ 10 %) to increase the exercise intensity without using the horses' maximal running speed (Rose &

Hodgson, 1994). On the other hand, horses that are not accustomed to the treadmill might get a falsely high physiological response due to a stress reaction (King *et al.*, 1995). Therefore, it is important that horses are exercised on the treadmill for at least 1-2 sessions prior to testing to acclimatise (King *et al.*, 1995).

The working capacity of horses on a treadmill is usually evaluated at 3-4 incremental steps (Persson, 1967; Gottlieb *et al.*, 1988; Harkins *et al.*, 1993; Jansson *et al.*, 2021), but up to nine sets have been reported (Seeherman & Morris, 1990; Bitschnau *et al.*, 2010). Each step is performed for 60-120 s, after which the treadmill speed is increased (Rose & Hodgson, 1994). Speed and the number of sets are often predetermined, but the SET can also continue until a predetermined HR or lactate concentration (Bitschnau *et al.*, 2010) is reached. It is also possible to determine the horse's exercise capacity (e.g. by determining V_{La4}) on the treadmill before the SET to individually adjust the speed at each step (Jansson *et al.*, 2021). Heart rate is usually measured continuously during exercise, and blood can be collected using a venous catheter at the end of each step for later analysis of, e.g. lactate concentration, either from whole blood or plasma (Rose & Hodgson, 1994). In some studies, the SET were continued until the horse reached fatigue. For example, Essén-Gustavsson *et al.* (1999) used only one step at a fixed speed until fatigue, and Gottlieb *et al.* (1988) have described a SET including 2 min incremental steps until fatigue. In addition to the increases in speed for each step, reported by Gottlieb *et al.* (1988), as well as in other studies, the same author has also performed a draught incremental SET on a treadmill, with increasing draught resistance for each step until fatigue.

1.3.2 Field exercise tests

A field test is a SET performed in an environment the horse is used to, which is often the same as during competitions (Evans, 2008). Good reproducibility of field exercise tests has been demonstrated in Standardbred trotters (Dubreucq *et al.*, 1995), indicating that the physiological response to such tests is reliable, provided that conditions such as speed and environmental factors are similar. In the study by Dubreucq *et al.* (1995), the test included three incremental steps (in terms of speed) for 3 min/step and 1 min of walking between steps. The speed at each step was adjusted according to each horse's training status. The same setup during a field SET, regarding duration and number of sets, was recommended for French Standardbred trotters in another study, which also suggested that the last step should result in a blood lactate concentration above 4 mmol/L (Couroucé, 1999). In a Swedish study on Standardbred trotters, four incremental steps of 1000 m were included in the SET and blood samples were collected after each bout to determine V_{La4} (Ringmark *et al.*, 2015). Compared with a SET on a treadmill, it is more difficult to maintain a constant speed in field conditions, therefore, it may be more practical to include only one or two exercise bouts (Evans, 2008). For example, horses in the study by Ringmark *et al.* (2015) also performed a single-bout exercise test of 1600 m on a track, aiming to maintain the same speed throughout the bout, and a blood sample was collected within 1 min after exercise.

1.3.3 Weight carrying exercise tests

An exercise test to evaluate the weight carrying capacity of a horse generally includes several steps or sessions with different weight loads (Table 1), rather than adjustments in speed as in a SET used to evaluate the horse's general fitness. To ensure that the horses' responses are mainly affected by the different weight loads, it is important to maintain a constant speed during the exercise. The load can either be a rider (Sloet van Oldruitenborgh-Oosterbaan *et al.*, 1995; Dyson *et al.*, 2020), lead weights (Sloet van Oldruitenborgh-Oosterbaan *et al.*, 1995; McKeever *et al.*, 2005) or a combination (Powell *et al.*, 2008; Stefánsdóttir *et al.*, 2017a; Christensen *et al.*, 2020), and the test can be performed on a treadmill (Sloet van Oldruitenborgh-Oosterbaan *et al.*, 1995; McKeever *et al.*, 2005) or in the field (Powell *et al.*, 2008; Stefánsdóttir *et al.*, 2017; Christensen *et al.*, 2020) (Table 1). In the treadmill weight carrying test by McKeever *et al.* (2005), the ponies performed three steps at 1 min each at walk, carrying 0 kg, 67 kg, and 134 kg in a randomised order, with 2 min of rest between steps. The weights represented BWRs of 32 % and 64 %, respectively. Oldruitenborgh-Oosterbaan *et al.* (1995) also included three different bouts (unloaded, 90 kg rider, and 90 kg lead weights), but with 2-4 days between them. Each bout was performed in walk, trot and canter for a total of 21.5 min.

Horses in the study by Powell *et al*. (2008) performed a ridden submaximal weight carrying test in an indoor arena, including 4.8 km trotting and 1.6 km cantering at constant speeds, with different loads in separate sessions. A similar test was performed by Christensen *et al*. (2020), in which each of the three sessions (average weight load: 15.3 %, 17.2 %, and 18.5 % BWR, respectively) was performed on separate days and lasted ~ 5 min. In contrast, the Icelandic horses in the study by Stefánsdóttir *et al*. (2017a) performed the ridden test in tölt at a speed of 5.4 m/s on an oval track for five consecutive steps with ~ 5 min of rest in between steps. The test included four incremental steps at 20 %, 25 %, 30 % and 35 % BWR, plus an additional step at 20 % at the end, where each step was 642 m. However, a weight carrying test as described in the studies above is relatively time- and resource-consuming. Therefore, there is a need to develop an easy, standardised, and universally applicable unridden test.

Table 1. A subset of previous studies on weight carrying capacity in horses

	Year	Breed	Type of test	Steps/bouts (n)	Weight load	Type of weight
Sloet van Oldruitenborgh-Oosterbaan *et al*.	1995	Dutch Warmblood	Treadmill	3	0 and 90 kg	Rider/lead
Heck *et al*.	1996	Ponies	Treadmill	Until fatigue	44.5 + 22.3 kg*	Lead
McKeever *et al*.	2005	Ponies	Treadmill	3	0-134 kg	Lead
Powell *et al*.	2008	Light horses	Field	4	15-30 % BWR	Rider + lead
Matsuura *et al*.	2013a	Japanese	Field	12	80-130 kg	Rider + lead
Matsuura *et al*.	2013b	Taishuh ponies	Field	7	70-120 kg	Rider + lead
Matsuura *et al*.	2016	Yonaguni ponies	Field	9	0-70 kg	Lead
Stefánsdóttir *et al*.	2017	Icelandic	Field	5	20-35 % BWR	Rider + lead
Dyson *et al*.	2019	Mixed	Field	4	12-30 % BWR	Rider
Christensen *et al*.	2020	Mixed	Field	3	~15-18.5 % BWR	Rider + lead

Abbreviations: BWR = body weight ratio

*Starting at 44.5 kg with increments of 22.3 kg/step

1.4 Implications of weight carrying

1.4.1 Fatigue

As previously described, increased rider weight increases the physiological response in the horse (e.g. Powell *et al*., 2008; Stefánsdóttir *et al*., 2017a) and may, in turn, impair performance due to fatigue. Fatigue has been defined as the point at which the horse is no longer able to maintain the intended pace or intensity (Hodgson & Rose, 1994; Schuback *et al*., 1999). Previous results show that fatigue can increase stride length, stance duration, and joint excursion at the distal limbs during the stance phase at a fixed trotting speed (Johnston *et al*., 1999), which in turn may increase the risk of injury. The onset of fatigue during exercise is probably affected by several factors and can occur during both low- and high-intensity exercise. The contraction of a muscle is dependent on adenosine triphosphate (ATP), which can be produced either aerobically or anaerobically. During aerobic metabolism, ATP is produced via the tricarboxylic acid cycle and the electron transport chain in the presence of oxygen (Rivero & Piercy, 2008) and is the dominant energy pathway during endurance riding (Essén-Gustavsson *et al*., 1984; Ridgway, 1994). During anaerobic metabolism, ATP is produced in the absence of oxygen, either from creatine phosphate that is stored in the muscle, or via degradation of glucose in the glycolysis (Rivero & Piercy, 2008). If oxygen is available, the pyruvate molecules formed in the glycolysis are converted to acetyl-CoA and enter the tricarboxylic acid cycle. However, in the absence of oxygen, pyruvate is converted to lactate (Rivero & Piercy, 2008). The increase in plasma lactate concentration during anaerobic exercise is exponential, and at the point at which the plasma lactate production is greater than the removal (i.e. lactate accumulates), the anaerobic threshold is reached, which generally occurs at a plasma lactate concentration of 4 mmol/L (Rivero & Piercy, 2008). After that point, the concentration of plasma lactate will increase rapidly, and the horse will probably reach fatigue very soon. However, in a study by Ronéus *et al*. (2010), plasma lactate concentration was not associated with racing performance in Standardbred trotters, indicating that high plasma lactate levels are not necessarily detrimental to performance.

Although anaerobic metabolism is active at all exercise intensities (Gerard *et al*., 2014), it is, in combination with aerobic metabolism, particularly active during high intensity exercise (Schuback & Essén-Gustavsson, 1998), where the distribution of the two different energy pathways depends on the intensity and duration of the exercise (Lindholm *et al*., 1974; Gottlieb, 1989; Ridgway, 1994). This is related to which muscle fibre types that are recruited, where type I fibres have a high oxidative capacity (Henckel, 1983), low maximum velocity of shortening (i.e. slow twitch) (Rome *et al*., 1990), and a relatively low glycogen content (Henckel, 1983). In contrast, type II fibres can generate force rapidly (i.e. fast twitch), are less oxidative and have a higher glycogen content. Type IIA muscle fibres can produce ATP both aerobically and anaerobically due to their relatively high number of capillaries and mitochondria compared with type IIX, which has a low oxidative capacity and produces ATP mainly anaerobically. However, type IIX is the fibre type with the highest maximum velocity of shortening (Rome *et al*., 1990), which enables high power outputs for a limited time (Rivero & Piercy, 2008).

During high intensity exercise, muscle fatigue is suggested to be caused by a depletion of creatine phosphate (Hodgson & Rose, 1994) and ATP, a decrease in intramuscular pH, and accumulation of pyrophosphates (Rivero & Piercy, 2008). Also, the efflux of potassium from the muscle cell during a contraction, which increases with exercise intensity, may also induce muscle fatigue (Art & Lekeux, 2005). During submaximal exercise, intramuscular glycogen depletion may be associated with fatigue (Lindholm *et al*., 1974; Rivero & Piercy, 2008), and factors such as hyperthermia, motivation and depletion of fluid and electrolytes are suggested to onset fatigue during prolonged exercise of low intensity (Valberg, 1996; Rivero & Piercy, 2008). In addition to, e.g. high speed and prolonged exercise, it is also expected that weight carrying can onset fatigue in the horse. Whether fatigue occur or not, and which mechanisms that contributes to the fatigue (e.g. decreased pH or hyperthermia) may depend on rider weight, but also on, e.g. distance and speed in combination with the rider weight. In the study by Heck *et al*.

(1996), ponies walked loaded with weights, which was increased until fatigue. The signs of fatigue were reported as gait coordination, a decrease in fetlock angle, no return of HR to baseline between sets (within 60-90 s), or that the pony refused to continue walking despite human coaxing. Signs of fatigue has also been reported in donkeys walking with different loads (Legha *et al*., 2018). In that study, signs of fatigue included unwillingness to continue walking and un-coordination between hind- and forelimbs and was assessed to occur after 5 hours when they carried a load up to a BWR of 50 %. It is, however, not known to what extent horses during, e.g. riding lessons and trekking tours experience fatigue.

1.4.2 Risk for injuries and impaired welfare

Muscle fatigue is suggested to increase the risk for musculoskeletal injuries (Yoshikawa *et al*., 1994; Darbandi *et al*., 2023). It is hypothesised that the risk of muscle fatigue is increased during weight carrying, due to the increased workload, which in turn might increase the risk of injury. Furthermore, increased load carriage by men and women in the military is associated with increased injury risk (Knapik *et al*., 2004; Roy *et al*., 2012 & 2016), and it might be the same in horses, though the evidence is not as strong as in humans.

A previous study investigated risk factors for injuries and medical events in National Hunt horses in the UK (Pinchbeck *et al*., 2004). An increased rider weight was found to be associated with an increased risk for injuries and medical events, which included, e.g. musculoskeletal injuries, cardiovascular and respiratory problems, and heat exhaustion. However, the association was not significant when musculoskeletal injuries alone were included in the analysis (Pinchbeck *et al*., 2004). Some studies have also shown an effect of weight carrying on back health in horses. For example, a change in muscle soreness and tightness was observed in light riding horses 24 hours after carrying 30 % of their BW, compared with 24 hours before the test (Powell *et al*., 2008). It has also been reported that horses used for riding lessons in the Netherlands were more prone to suffer from back pain than those used for recreation and competition (Visser *et al*., 2014), possibly due to longer periods of weight carrying and/or greater rider weights. Kienapfel *et al*.

(2017) found an increased activity of the *m. longissimus dorsi*, and *m. rectus abdominis* in horses walking with a rider compared with unridden, but no increase was shown in trot and canter. However, the function and health of *m. longissimus dorsi*, assessed with acoustic myograph and multi-frequency bioimpedance, was not affected by BWR (17 %, 19 % and 27 %) in 10 horses of different breeds (Ejersted-Andersen & Harrison, 2019). It should be noted that the horses in the last-mentioned study were ridden by their usual riders and might therefore have been adapted to the rider's weight. In the future, studies examining the effects of several riders with different BWs on the same horse on muscle function and health would be of great interest.

There are some indications that increased rider weight also influences the horse's behaviour (Dyson *et al*., 2020), but this was not shown in the study by Christensen *et al*. (2020).

1.4.3 Locomotion

Several authors have investigated the effect of weight carrying on locomotion in horses. Compared with unridden exercise, ridden exercise increases the peak vertical ground reaction force (Clayton *et al*., 1999) and the lateral stance duration (i.e. duty factor) (Sloet van Oldruitenborgh-Oosterbaan *et al*., 1995) in the horse. Shorter strides and greater stride frequency were observed with an increased BWR in Icelandic horses tölting with a rider and additional weight load corresponding to a BWR of 20 %, 25 %, 30 % and 35 % (Gunnarsson *et al*., 2017). An increased BWR also increased duty factor and bipedal support, and decreased unipedal support. Lateral advanced placement, liftoff, height of front leg action, and symmetry were not affected by an increased BWR. In a study by Matsuura *et al*. (2013a), Japanese native horses carried a rider loaded with different weights, resulting in a total load of 80-130 kg. A lower symmetry in trot was observed when they carried 100 kg, 110 kg and 125 kg than when they carried 80 kg at the beginning of the test. The test ended with returning to a weight load of 80 kg, and the symmetry at that step did not differ from the symmetry measured at the greater loads (Matsuura *et al*., 2013a). Surprisingly, the 130 kg load did not decrease symmetry compared to the 80 kg load at the beginning of the test. Neither stride length was affected by the different loads. The authors concluded that the Japanese native horses could carry up to 29 % of their BW before any effects on locomotion could be observed. A similar study was conduted on the Taishuh pony, another Japanese breed (Matsuura *et al*., 2013b). The authors in that study concluded that the breed could carry up to 43 % of their BW before locomotion is affected. The same author (Matsuura *et al*., 2016) also analysed locomotion in Yonaguni ponies exposed to different weight loads. In that study, 33 % of the BW of the horse could be added before a lower symmetry and stability were observed, compared to when the horse was unloaded. On the contrary, horses performing a low-intensity dressage test did not show an increased gait asymmetry with increasing rider weight (Christensen *et al*., 2020).

2. Aims of the thesis

The overall aim of the thesis was to increase the knowledge of weight carrying capacity in horses, with emphasis on the Icelandic breed. Weight carrying capacity can be defined and measured in various ways, but in this thesis, it is evaluated based on the acute physiological response to weight carrying. The new knowledge can be useful for riders and horse owners to increase animal welfare and performance.

The specific aims were to:

- Compare body measurements of Icelandic horses used by tourist companies and riding schools (TRh) and Icelandic horses participating in a breed evaluation field test (BEFTh), and to evaluate the association between body measurements and subjective weight carrying capacity and usability in TRh (Paper I).
- Investigate the relationship between body measurements and the physiological response to a weight carrying field exercise test in Icelandic horses (Paper II).
- Investigate if it is possible to estimate weight carrying capacity in Icelandic horses with a traditional treadmill SET (Paper III).
- Investigate the effect of a 7-week ridden and unridden training program on weight carrying capacity in Icelandic horses (Paper IV).

3. Hypotheses

The following hypotheses were tested:

- Body measurements differ in some aspects between TRh and BEFTh, and the shape of the back is associated with subjectively evaluated weight carrying capacity in TRh (Paper I).
- A broad back is associated with greater weight carrying capacity than a narrow back (Paper II).
- The physiological response of a horse to an incremental SET on a treadmill (without rider and added weight) is associated with the individual's response to an incremental weight carrying testing in field conditions (Paper III).
- Seven weeks of unridden training, compared with ridden training, decreases the weight carrying capacity (Paper IV).

4. Materials and methods

Data were obtained in the summer 2020-2021 in Sweden (Paper I), at Hólar University, Iceland in October 2021 and 2022 (Paper II & III) and at the Swedish National Centre for the Education and Development of Harness racing and Icelandic horse riding, Wången, Sweden during summer 2024 (Paper IV). Paper IV was ethically approved by the Umeå Regional Ethics Committee, Sweden (diary number 5.2.18-17484/2020) and Paper II and III by the Icelandic Food and Veterinary Authority (Ref. No. 2109502). No invasive procedures were conducted in Paper I and therefore, no ethical approvement was required for that study.

4.1 Study designs

4.1.1 Paper I

This study was performed to compare body measurements between BEFTh and TRh and to evaluate the association between body measurements and subjectively evaluated weight carrying capacity and usability in TRh. Body measurements and body condition score (BCS) (Table 2) were collected in 48 BEFTh at two breed evaluation field tests in Romme, Sweden, and in 65 TRh at five different tour riding companies and riding schools (three in Sweden and two in Iceland, ≥ 9 horses/company). For TRh, height at withers, the lowest point of the back and the highest point of the croup were measured by two of the authors of the paper, whereas the corresponding measurements for BEFTh were collected by the ringmaster at the breed evaluation field tests. Body condition score was assessed on a scale from 1-9 in all horses according to the Henneke scale (Henneke *et al*., 1983), which were slightly modified (Ringmark *et al*., 2013; Jansson *et al*., 2021), where three body parts (ribs, back and tail head) were scored individually on a continuous scale and a mean value of the three body parts was calculated. Also, the shape (i.e. angle) of the back was measured with a flexible curve ruler, by the same person in all horses (Figure 2, Table 2). For BEFTh, data on height measurements, subjective scores for back and croup and riding ability assessed by breeding judges were obtained from WorldFengur (2022). For this thesis, data of body length, width of the chest, *pelvis* and hips, breast depth and circumference of *carpus* and *metacarpus* were also obtained from WorldFengur (2026).

A questionnaire was distributed to the owners of the TRh including questions about e.g. horses' age, sex and the following questions about subjective weight carrying capacity and usability as a TRh:

1. How do you think the horse manages long-distance tours over several hours (mostly walk with shorter distances with tölt, trot or gallop) with a rider (70-85 kg)?

2. How do you think the horse manages fast tölt (or gallop) for a longer distance (1-2 km) with a rider (70-85 kg)?

3. What is your opinion about the general weight carrying capacity of the horse?

4. How would you describe how the horse is working in general as a tour riding horse/school horse (e.g. time in duty, willingness, injuries, etc.)?

The questions were answered on a scale from 0-10.

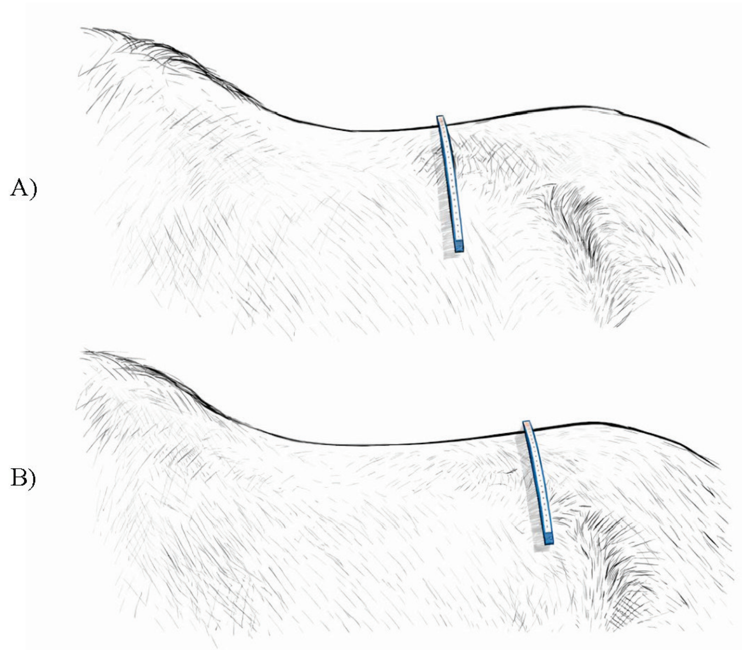

Figure 2. Measurements of back and loin angle using a flexible curve ruler placed at (A) the 18th thoracic vertebra identified by palpation of the last rib (i.e. back angle), and at (B) the height of the caudal part of the last rib (i.e. loin angle). The figure was created by ChatGPT5 and PowerPoint, 2026-02-25, and modified from Paper II.

4.1.2 Paper II

In total, 16 tour riding horses, from two different tour riding companies in Iceland, were included in this study, which investigated the association between the physiological response to weight carrying and conformation traits. Fourteen of the horses were divided into two groups, one including horses with a narrow back, i.e. a back score < 4.5 (median 4.25), and the other with horses with a broad back, i.e. a back score > 4.5 (median 4.90) (Figure 3) (Henneke *et al.*, 1983; Ringmark *et al.*, 2013). Body condition was scored as previously described for Paper 1, and body measurements were collected (Table 2). Back and loin angles were measured with a flexible curve ruler (Figure 2). All horses performed a ridden incremental weight carrying test, and physiological parameters were collected (see below).

Figure 3. Illustration (adapted from Paper II) of a back condition score of 4 and 5, based on the Henneke scale (Henneke *et al.*, 1983). The backs are illustrated from a caudal view, and the black dots symbolises the spine.

4.1.3 Paper III

This study aimed to investigate the relationship between the physiological response to weight carrying in the field and to a treadmill SET, in the same 16 horses as included in Paper II. Horses performed a SET on a treadmill 3 ± 1 days before they performed the ridden incremental weight carrying test (see below). Correlation analyses were performed between V_{180}, V_{190}, V_{La2}, V_{La3}, V_{La4} and recovery parameters collected at the SET, and BWR_{180}, BWR_{190}, BWR_{La2}, BWR_{La3}, BWR_{La4} and recovery parameters collected at the weight carrying test.

4.1.4 Paper IV

Fourteen horses performed a ridden incremental weight carrying test (see below) twice, with a 7-week training period in between the tests, to evaluate the effect of ridden and unridden training on the physiological response to weight carrying. Horses were randomly assigned to two training groups (ridden and unridden) and seven pairs were created, each including one horse from each group. The pairs were exercised side by side during the training sessions, where the unridden horse was led by the rider of the other horse in the same pair (see Fig. 1 in Paper IV). Two riders (BW 60 kg and 75 kg, respectively) alternated between the horses to limit any rider effect. The same pairs performed the exercise tests simultaneously, both ridden by two other riders than at the training sessions. During the 7-week training period, horses exercised 3 times/week outside in all gaits. Once a week, horses performed uphill and downhill exercise. Training was performed at a mean speed of 2.3 ± 0.5 m/s for 33 ± 7 min at a mean HR of 95 ± 17 bpm and peak HR of 169 ± 35 bpm. Mean and peak HR did not differ between training groups (P<0.05). Body condition score (Henneke *et al.*, 1983; Ringmark *et al.,* 2013) was measured in the horses three times during the study period (~ every 1.5 to 3 weeks) and was 6.0 ± 0.6, 2-3 days prior to the second exercise test, which did not differ between training groups or the BCS measured at the other occasions (P>0.05).

4.2 Horses and management

All horses included in the thesis were of the Icelandic breed and included both geldings and mares, as well as stallions (BEFTh in Paper 1). In Paper I, BEFTh was 8 ± 2 years old, and TRh was 14 ± 5 years old, and all had been in active training for at least 1 month prior to the study (except one BEFTh, which was lame). In Papers II and III, another 16 horses were included which were 10-22 years old and had been used in tours during the previous summer. The horses arrived at the university 10-12 days before the exercise test for acclimation and training, and were kept in individual boxes, outside in a paddock for 0-3 hours/day and pasture for 1-3 hours/day. Horses were ridden at least once and exercised on a treadmill 4-6 times during the preparation period and rested at least one day before exercise testing. Horses in Paper IV were 13 ± 3 years old, used for riding education and trained similarly at the Swedish National Centre for the Education and Development of Harness racing and Icelandic horse riding, prior to the study. During the study period, horses were kept in paddocks, except on test days, where they were kept in individual boxes. All horses, except three, completed the weight carrying test without any signs of injury (Papers II-IV). Two horses had minor oedema in the distal limbs, where one of them also had a small wound on the heel bulb at one of the forelimbs, and another horse showed mild soreness on one side of the thoracolumbar region (Paper II/III). In Paper IV, the degree of objectively evaluated asymmetry (measured with the Sleip AI® application) was the same after the training period as before (logistic regression, $P>0.05$).

4.3 Exercise tests

4.3.1 Ridden incremental weight carrying test

A ridden incremental weight carrying test was performed in Papers II-IV, as earlier described by Stefánsdóttir *et al*. (2017a). To avoid repeated testing, each horse completed the test on a single occasion for both Papers II and III, and the collected data were utilised in both studies. The exercise tests were performed on a ~ 260 m oval gravel track at Hólar University, Iceland (Papers II and III) and at the Swedish National Centre for the Education and Development of Harness racing and Icelandic horse riding (Paper IV) with four experienced riders (two in Iceland and two in Sweden), with a BW between 59-73 kg, for each rider, respectively. The exercise test included four steps, where horses carried approximately 20 %, 25 %, 30 % and 35 % of their BW in each step, respectively. The test was preceded by a mounted warm-up (~ 1.5 km) in walk and tölt, during which horses carried 20 % of their BW. Each step in the exercise test was performed for 2.5 coherent laps on the track in tölt at an intended speed of ~ 5.5 m/s, measured with a HR recorder and GPS device (Polar Vantage M and Polar M460, HR Monitor; Polar Electro Oy, Kempele, Finland). In Papers II and III, horses performed the test individually, whereas in Paper IV, horses were tested in pairs, and the riders followed a four-wheeler to facilitate speed control (Figure 4). Between each step, horses were stopped and the rider dismounted to add more weight (Figure 5) and collect a blood sample from the horse.

Figure 4. The ridden incremental weight carrying test performed by the horses in pairs (one from each training group) in Paper IV.

Figure 5. Lead weights added to the horse and the rider at the ridden incremental weight carrying tests (Paper II-IV). Photos: Denise Söderroos and Emma Nilsson

4.3.2 Standardised exercise test on a treadmill

In Paper III, horses performed a SET on a treadmill (Säto, Lövstabruk, Sweden) in trot, including four steps with increasing speed for each step, preceded by a 4 min warm-up in walk. The speed at the last step was individually adjusted and based on the estimated V_{200} from the last treadmill training session. Each step in the SET was performed for 1.5 min at a 6.25 % incline on the treadmill.

4.4 Data collection

4.4.1 Body measurements

Body measurements and BCS were collected in the horses in Papers I and II (Table 2). Body condition score was also collected in the horses in Paper IV (Table 2).

Table 2. Body measurements collected in the different papers

Body measurement	**Paper**
Height at withers (cm)	I, II
Height at lowest point at back (cm)	I, II
Height at highest point at croup (cm)	I, II
Height at withers – height at lowest point at back (cm)	I, II
Height at withers – height at highest point at croup (cm)	I, II
Height at highest point at croup – height at lowest point at back (cm)	I, II
Back length (cm)	II
Body length (cm)	II
Breast depth (cm)	II
Width of the chest (cm)	II
Width of the *pelvis* (cm)	II
Width of the hips (cm)	II
Circumference of *carpus* (cm)	II
Circumference of *metacarpus* (cm)	II
Circumference of hock (cm)	II
Circumference of *metatarsus* (cm)	II
Back angle (degrees)	I, II
Loin angle (degrees)	II
Body condition score[a]	I, II
Body condition score[b]	IV

[a]Assessed on a continuous scale of 1-9, including assessments of ribs, back and tail head (Henneke *et al*., 1983; Ringmark *et al*., 2013).

[b]Assessed on a continuous scale of 1-9, including assessments of six body parts (Henneke *et al*., 1983; Ringmark *et al*., 2013).

4.4.2 Physiological parameters

During the exercise tests (Papers II-IV) and training sessions (Paper IV), HR were measured continuously in the horses with a HR recorder (Polar Vantage M and Polar M460, HR Monitor; Polar Electro Oy, Kempele, Finland) and a mean value was calculated from the last 15 s in each step in the exercise test. Due to technical issues, HR data from the exercise test in Paper IV was not analysed. Prior to the exercise tests, resting values of HR (Papers II and IV), respiratory rate (Papers II and IV) and rectal temperature (Papers II-IV) were collected. The same parameters were collected also after 5 min of recovery (Papers II and IV), and respiratory rate was collected also after step 4 in the ridden incremental weight carrying exercise test in Paper IV. Blood samples were collected immediately after warm-up (Papers II and IV) and each step in the exercise tests (Papers II-IV), and after 5 min of recovery (Papers II and IV), for analyses of plasma lactate concentration and haematocrit. In Paper II, an additional blood sample was collected at rest. During the treadmill exercise test in Paper III, horses were equipped with a jugular catheter and blood was drawn at the end of each step. For this thesis, recovery parameters of HR, plasma lactate, haematocrit, respiratory rate and rectal temperature were collected after 2 min of walk and 3 min of standing also in the treadmill exercise test. Another blood sample was collected 24 h post-exercise for analyses of the muscle enzymes aspartate aminotransferase and creatine kinase (Papers II-IV).

4.5 Statistical analyses

Body weight ratio (at the weight carrying test) and speed (at the treadmill SET) at different plasma lactate concentrations and HRs were estimated for individual horses by obtaining the equation of the exponential regression between BWR (or speed) and plasma lactate concentration and the linear regression between BWR and HR, for each step in the exercise test (Papers II-IV).

Statistical analyses were performed in SAS software (version 9.4; SAS Institute Inc., Cary, NC, USA). A general linear model (GLM) was used to compare body measurements and BCS between BEFTh and TRh, including country and sex as fixed effects, and age as a continuous effect (Paper I). A similar model was used to investigate the effect of back shape on the physiological response to weight carrying in Paper II, including group (narrow vs. broad back), year and sex as fixed effects, and BCS as a continuous effect. When several samples were included in the analysis, a general linear mixed model (GLMM) was applied, including horse as a random effect and the interaction between group and sample as a fixed effect. Horses in Paper II were also divided into two different groups based on whether they had reached the anaerobic threshold or not. In Paper IV, a GLMM was used to analyse the effect of training group and occasion (before vs. after training period) on physiological parameters, including training group, occasion, rider and the interaction between training group and occasion as fixed effects, horse BW as a continuous effect and horse as a random effect. For analysis of average values from the exercise tests, the interaction effect between sample and occasion was also included in the statistical model.

Correlations were determined with Pearson's correlation test (Papers I-III). In addition, principal component analysis (PCA) was performed in Umetrics SIMCA (version 17.0.2; Sartorius, Goettingen, Germany) to further evaluate the relationship between physiological parameters at the treadmill SET and the ridden incremental weight carrying test in Paper III and the relationship between body measurements and discipline (BEFTh and TRh) in horses from Papers I and II. An exact Wilcoxon two-sample test was used to analyse the effect of back condition score, given the skewed distribution of residuals (Paper I). T-tests were generally used to compare physiological parameters between groups at rest and to compare weather conditions between occasions (Papers II-IV). Results were presented as mean ± standard deviation (SD) or least square mean (LSM) ± standard error (SE). Significance level was set at $P<0.05$ and tendency at $P<0.1$. Normal distribution of residuals was confirmed by visualisation and evaluation of qq-plots.

5. Main results

5.1 Body measurements in Icelandic horses used for two different purposes (Paper I)

All body measurements are presented in Table 2, and some of them differed significantly between TRh and BEFTh (Table 3). Height at withers tended to be greater ($P<0.1$) in BEFTh (142 ± 1 cm) than in TRh (140 ± 1 cm). Body condition score was higher ($P<0.05$) in TRh (5.8 ± 0.1) than in BEFTh (5.4 ± 0.1). The PCA, including body measurements (Table 2) collected from horses included in both Papers I and II, showed a clustering effect between BEFTh and TRh (Figure 6).

Table 3. Body measurements that differed between 65 Icelandic horses used for tour riding and in riding schools (TRh) and 48 Icelandic horses participating in a breed evaluation field test (BEFTh)

Body measurements	BEFTh	TRh	P-value
Height at highest point at croup (cm)	136 ± 1	138 ± 1	<0.05
Height at withers – height at lowest point at back (cm)	12 ± 0	10 ± 0	<0.0001
Height at withers – height at highest point at croup (cm)	6 ± 0	2 ± 0	<0.0001
Height at highest point at croup – height at lowest point at back	6 ± 0	8 ± 0	<0.05
Back angle (degrees)*	19 ± 1	15 ± 0	<0.0001

*Measured with a flexible curve ruler at the level of the 18th thoracic vertebra. A greater angle corresponds to a narrower back.

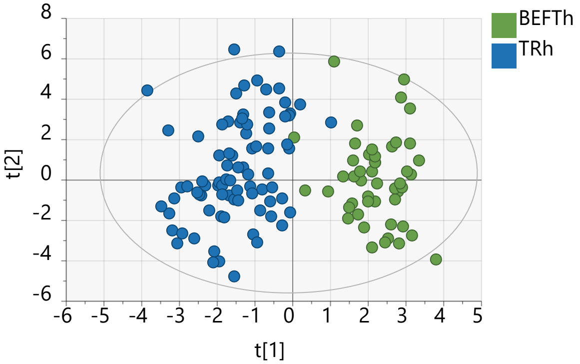

Figure 6. Score scatter plot of a principal component analysis model for body measurements (Table 2) collected in 48 Icelandic horses participating in a breed evaluation field test (BEFTh) and 81 Icelandic horses used for tour riding and in riding schools (TRh).

5.1.1 Relationship to subjectively evaluated performance

In TRh, height at withers was positively correlated with scores for subjectively evaluated weight carrying capacity (question 3, Figure 7) and subjective capacity for long-distance touring in walk and fast tölt (questions 1-2, $P<0.05$). Height at the lowest point at the back and the highest point at the croup were positively correlated with all questions in the same horses ($P<0.05$), including subjectively evaluated weight carrying capacity (Figure 7). Back condition score and angle were not correlated with subjectively evaluated weight carrying capacity in TRh or scores from the ridden assessments in BEFTh ($P>0.05$).

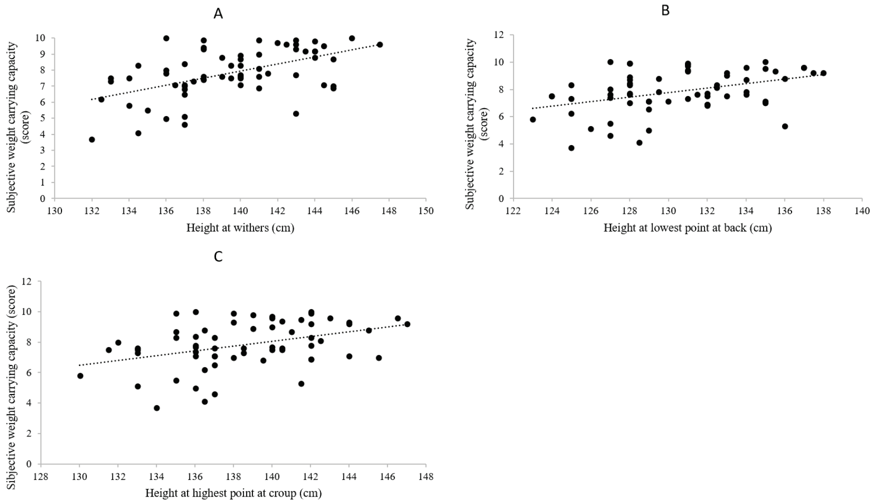

Figure 7. Relationship between subjectively evaluated weight carrying capacity and (A) height at the withers (r=0.53, P<0.0001), (B) height at the lowest point at the back (r=0.40, P<0.05) and, (C) height at the highest point at the croup (r=0.39, P<0.05) in 64 tour riding and school horses from 5 different companies.

5.2 Physiological response to weight carrying and the association with conformation (Paper II)

5.2.1 Response to weight carrying

There was a large variation in weight carrying capacity between individual horses. Four out of 15 horses (excluding one horse that was galloping in step 4) did not reach the anaerobic threshold, not even at the last step (BWR$_{35\%}$), whereas another horse reached the anaerobic threshold already at the first step (BWR$_{20\%}$). Plasma lactate concentration increased for each step (P<0.05), and the BWR in the horses was 31.4 ± 4.1 % when they reached the anaerobic threshold. Heart rate was higher at BWR$_{30\%}$ and BWR$_{35\%}$ than at $BWR_{20\%}$ and $BWR_{25\%}$, and haematocrit was higher at $BWR_{35\%}$ than in the other steps ($P<0.05$).

5.2.2 Association with conformation

No physiological parameter measured during the ridden incremental weight carrying test differed between horses with narrow backs and horses with broad backs ($P>0.05$). Chest width, the difference between height at withers and height at back and croup, the difference between height at croup and height at back, hock and *metatarsus* circumference were significantly ($P<0.05$) correlated with at least one of the physiological parameters measured during the weight carrying test (Table 4). Horses that reached the anaerobic threshold had higher BW (396 ± 7 kg) than horses that did not (357 ± 11 kg) ($P<0.05$).

Table 4. Correlations (r) between body measurements and physiological parameters in Icelandic horses performing a ridden incremental weight carrying test. Body measurements that were not significantly correlated with a physiological parameter are not included in the table

Body measurement (cm)	**BWR_{La2}**	**BWR_{La3}**	**BWR_{La4}**	**BWR_{180}**	**BWR_{190}**	**CK_{diff}**
	n=9	**n=12**	**n=10**	**n=5**	**n=5**	**n=16**
Chest width	0.01	0.26	**0.77**	-0.25	-0.25	-0.17
	P=0.99	P=0.42	**P=0.01**	P=0.68	P=0.69	P=0.53
Height at withers – Height at back	0.36	-0.08	-0.12	0.50	-0.27	**-0.52**
	P=0.35	P=0.81	P=0.73	P=0.39	P=0.66	**P=0.04**
Height at withers – Height at croup	**0.68**	0.33	-0.21	0.06	0.59	**-0.51**
	P=0.05	P=0.29	P=0.57	P=0.93	P=0.30	**P=0.05**
Height at croup – Height at back	**-0.71**	-0.57	0.16	0.74	**-0.92**	0.16
	P=0.03	P=0.05	P=0.67	P=0.15	**P=0.03**	P=0.55
Hock circumference	**-0.77**	0.17	0.28	0.72	-0.59	-0.34
	P=0.01	P=0.59	P=0.44	P=0.17	P=0.29	P=0.19
Metatarsus circumference	-0.60	-0.35	-0.20	**0.96**	-0.60	-0.21
	P=0.09	P=0.26	P=0.59	**P=0.01**	P=0.28	P=0.44

Abbreviations: $BWR_{La2, La3, La4}$ = body weight ratio at plasma lactate concentration 2 mmol/L, 3 mmol/L and 4 mmol/L, respectively, $BWR_{180,190}$ = body weight ratio at heart rate 180 bpm and 190 bpm, respectively, CK_{diff} = the concentration of creatine kinase 24 h post exercise minus the concentration at rest. Significant ($P<0.05$) correlations are shown in bold.

5.3 Relationships between body measurements

The relationships between body measurements and BCS collected in total 129 Icelandic horses from Papers I and II are shown in Figure 8. There was a positive correlation between hock circumference and chest width (n=16, r=0.57, P<0.05) and between hock circumference and BW (n=16, r=0.65, P<0.05), and a negative correlation between the difference between height at the withers and back and the difference between height at the croup and back (n=128, r=-0.43, P<0.0001). No other significant correlations were found between the body measurements that were correlated with at least one physiological parameter collected at the ridden incremental weight carrying test (P>0.05).

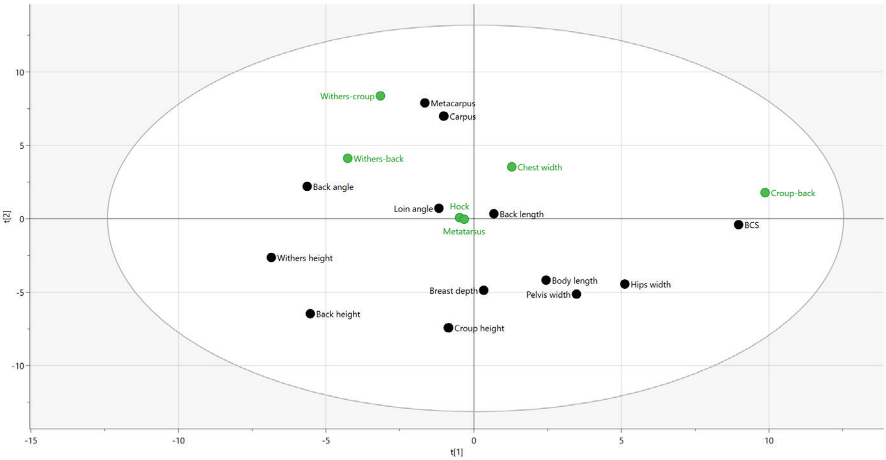

Figure 8. Score scatter plot of a principal component analysis model for body measurements (Table 2) collected in total 129 adult Icelandic horses. Body measurements with a green dot were significantly (P<0.05) correlated with at least one physiological parameter at a ridden incremental weight carrying test (Table 4).

5.4 Correlations between the physiological response at a weight carrying test and at a standardised treadmill exercise test (Paper III)

The speed at a plasma lactate of 4 mmol/L, determined from the SET, was estimated to 5.5 ± 0.5 m/s, and BWR_{La4}, determined from the weight carrying test, was estimated to 31.4 ± 4.1 %. These estimations were not correlated (n=5, P>0.05). However, the speed at a plasma lactate concentration of 3 mmol/L at the SET was positively correlated with BWR_{180} at the weight carrying test (n=5, r=0.92, P<0.05). There was also a tendency for a correlation between V_{190} and BWR_{190} (n=5, r=0.84, P<0.1). No recovery parameters measured 5 min post-exercise, except the value for haematocrit after both exercise tests (r=0.69, P<0.05), were correlated (P>0.05).

5.5 The effect of ridden and unridden training on weight carrying capacity (Paper IV)

There was a significant interaction effect between occasion (before and after the 7-week training period) and training group (ridden and unridden training) (P<0.05). The average plasma lactate concentration tended to be lower at the ridden incremental weight carrying test after the training period for the ridden group (3.2 ± 0.6 mmol/L), and higher for the unridden group (4.2 ± 0.6 mmol/L), compared with the concentration at the weight carrying test before the training period (3.7 ± 0.6 mmol/L in both groups, P<0.1). No other effect of the interaction between occasion and training group was found (P>0.05). However, there was a significant effect of rider on the average plasma lactate concentration (P<0.05).

6. Discussion

The overall aim of the thesis was to increase the knowledge about weight carrying capacity of horses, with emphasis on the Icelandic breed. Weight carrying capacity can be defined and measured in various ways, but in this thesis, it is evaluated based on the acute physiological response to weight carrying. This thesis contributes new and important knowledge on the subject, which can be valuable for horse owners to improve welfare and performance, as well as for further research. The studies were performed on Icelandic horses, but the results may also be applicable to other breeds. The studies showed a large variation in weight carrying capacity between individuals with similar training background, and several horses never reached the anaerobic threshold at the weight carrying test, not even at the last step carrying 35 % of their BW. Examples of horses with varying responses are shown in Figure 9. In Paper II, 27 % of the horses never reached the anaerobic threshold, and the corresponding number for the horses in Paper IV was 21 % in the test before the training, and 29 % after the training (data not shown).

Figure 9. (1A and 1B): Examples of tour riding horses showing great weight carrying capacity in Paper II, (1A): 22-year-old mare with height at withers of 134 cm and body condition score (BCS) of 4.7 (Henneke *et al*., 1983; Ringmark *et al*., 2013). (1B): 13-year-old gelding with height at withers of 137 cm and BCS of 5.8. These horses never reached the anaerobic threshold during the weight carrying test carrying up to 35 % of their body weight. (2A and 2B): Examples of tour riding horses evaluated to have low weight carrying capacity in Paper II, (2A): 15-year-old gelding with height at withers of 139 cm and BCS of 5.9. This horse reached the anaerobic threshold before the first step (carrying 20 % of its body weight). (2B): 10-year-old gelding with height at withers of 143 cm and BCS of 5. This horse reached the anaerobic threshold at a body weight ratio of 24.6 %. Photos: Anna Jansson and Denise Söderroos

6.1 Body measurements and associations with weight carrying capacity (Paper I and II)

There was a clear difference in body measurements between BEFTh and TRh, which was shown both with the GLM and PCA, where the latter included TRh from both Papers I and II. Body measurements that were associated with a physiological parameter collected at the weight carrying test in Paper II, and thus, associated with weight carrying capacity, were generally the same traits that previously were shown to be associated with higher scores for riding ability in breed evaluation field tests for Icelandic horses (Kristjansson *et al*., 2016). For example, it was indicated that an "uphill" conformation (i.e. larger difference between height at withers and height at back and croup) and a straight back (i.e. lower difference between height at croup and back) were favourable for weight carrying capacity in the horses in Paper II, and for riding ability in the study by Kristjansson *et al*. (2016). These body measurements have a rather low heritability (0.20-0.27) (Kristjansson *et al*., 2016), which means that environmental factors have a larger effect on the measurements than genetics, or that these measurements have a low repeatability. This could mean that it is possible to influence the difference between height at the front and height at the hind with training, although this has not yet been scientifically studied. Chest width was positively correlated with BWR_{La4} (Paper II), which may be due to the fact that the front limb supports most of the body mass during a step in tölt (Biknevicius *et al*., 2004). In comparison to unloaded exercise, the ground reaction force increases with load in trot, and the increase is greater for the front limbs than in the hind limbs (Schamhardt *et al*., 1991). Furthermore, a greater distance between the front limbs may enhance lateral balance. It was previously shown that the optimal chest width for riding abilities was 40.4 cm, which is broader than the mean width both for the horses in the study by Kristjansson *et al*. (2016) and the horses in Paper II (37.5 cm and 37 cm, respectively), and even as the broadest chest width of the horses in Paper II (39 cm). Icelandic horses placing top 10 in the World Championship had wider chests than the rest of the horses (Amplatz, 2026). Chest width has been shown to have a heritability of 0.4 in Icelandic horses (Kristjansson *et al*., 2016) and is thus influenced by both genetics and the environment. In comparison, height at withers has a high heritability (0.67), and the optimum height at withers for riding abilities is higher (146 cm)

(Krisjansson *et al.*, 2016) than the mean height at withers of Icelandic horses (140 cm, Stefánsdottir *et al.*, 2014) and the highest withers height measured in Paper II (144 cm). Height at withers, back and croup were all correlated with subjective weight carrying capacity (Paper I), but not with the objectively measured physiological response to weight carrying (Paper II). This could mean that horse owners and riders falsely evaluate higher horses as having a greater weight carrying capacity, which may impair the horse's welfare and performance.

The importance of the negative correlation between hock circumference and BWR_{La2}, which was found in Paper II, is not clear but may be due to the fact that horses that reached the anaerobic threshold had higher BW (see discussion below), and there was a positive correlation between BW and hock circumference. However, there was a positive correlation between chest width and hock circumference, which complicated interpretation of the results, and further studies on the association between body measurements and weight carrying capacity are therefore needed. *Metatarsus* circumference was positively correlated with BWR_{180} (Paper II), and although the correlation was strong, the analysis included only five horses, which reduces the reliability.

Although a broad and well-muscled back is generally perceived as favourable for weight carrying capacity, back condition score and angle were not associated with subjective weight carrying capacity (Paper I) or the physiological response to weight carrying (Paper II). This was an interesting finding since a broad back and loin have been associated with greater weight carrying capacity in previous studies (Powell *et al.*, 2008; Stefánsdóttir *et al.*, 2017a). In the study by O'Connor *et al.* (2002), a 78-day weight carrying training program did not increase the cross-sectional area of *m. longissimus dorsi* in the horses, and hence, other conformation traits and areas of other muscles may be of greater importance for weight carrying capacity. For example, a wider chest may, in addition to larger bones, be due to a larger muscle mass in that area, including e.g. the pectoral muscles. These muscles have been suggested to stabilise the proximal limb at the stance phase during a step (Payne *et al.*, 2005). However, the effect of training on the size of those muscles has, to my knowledge, never been studied. Also, increases in cross-sectional area of muscles in the forelimb were previously detected in ponies after an 8-week weight carrying training program (Heck *et al*., 1996). However, the horses in the study by O'Connor *et al*. (2002) carried loads up to only 45 kg, resulting in a maximum mean BWR of 12 %, which may also explain the lack of effect on the size of *m. longissimus dorsi.*

It seems that body measurements associated with greater weight carrying capacity in Icelandic horses are inherited to some extent and should be considered in breeding, but are also, to a large extent, influenced by the environment. In Paper I, it was shown that BEFTh were more "uphill" and had less difference between height at croup and back than TRh. This could be explained by less proper training in the TRh, combined with greater breeding success in BEFTh. It is also hypothesised that BEFTh are preselected, particularly based on riding qualities (Albertsdóttir *et al*., 2011). The horses that performed the weight carrying test in this thesis were able to complete it and some never reached the anaerobic threshold. In addition to conformation, a great weight carrying capacity is presumably associated with other parameters, such as training, which might have been a more important factor in those horses. Furthermore, TRh are probably also preselected based on traits desirable for a tour riding and school horse (Sigurðardóttir & Helgadóttir, 2015). It would, however, have been interesting to also evaluate the weight carrying capacity in BEFTh.

6.1.1 Effect of body condition score and body weight of the horses

It is anecdotally believed that a "heavy" and "robust" horse can carry heavier riders, without considering the BCS of the horse. An increased BCS has previously been reported to increase the physiological response to exercise in Icelandic horses (Jansson *et al*., 2021). In addition to the effect of BCS, an increased BW has been shown to impair aerobic capacity in humans (without carrying an additional load), regardless of whether the increase is due to increased body fat content or lean body mass (Maciejczyk *et al*., 2014). In this thesis, among other papers, the BWR during a weight carrying test is applied based on the principle that a heavier individual is capable of carrying a greater load (Bilzon *et al*., 2001; Pandorf *et al*., 2002; Godhe *et al*., 2020), which may partly be due to the well-established positive correlation between fat-free body mass and maximal oxygen uptake in men (Buskirk & Taylor, 1957). The same relationship has also been shown in Standardbred horses (Kearns *et al*., 2002). The same study found no correlation between fat mass and maximal oxygen capacity (Kearns *et al*., 2002). Furthermore, Lyons *et al*. (2005) suggested that body composition, calculated as the ratio between lean body mass and dead mass, which included both fat mass and the additional load, is an important factor when evaluating weight carrying capacity in men. A horse that is perceived to be "heavy" and "robust" might have a great fat mass, and not necessarily, a great fat free mass. This might lead to horses with higher BCS being evaluated to have a greater weight carrying capacity, which they might not have. In a Danish study, it was reported that 24 % of the studied Icelandic horses were overweight or obese, and that horse owners underestimate the BCS of their horses, compared with an experienced evaluator (Jensen *et al*., 2016). The relatively high prevalence of overweight and obese Icelandic horses might lead to an overestimation of the weight carrying capacity of many horses. In Paper I, results showed that TRh had higher BCS than BEFTh, which could complicate the evaluation of weight carrying capacity in those horses. However, BCS had no effect on the physiological response to weight carrying in the horses in Paper II, and similar results were found by Stefánsdóttir *et al*. (2017a). Horses that reached the anaerobic threshold during the weight carrying test had higher BW than those that did not (Paper II), but this was not affected by BCS. Furthermore, a greater BW was associated with a lower haematocrit in horses in Paper IV, consistent with results from Jansson *et al*. (2021). However, BCS collected 2-3 days prior to the weight carrying test after the training period was not correlated with haematocrit (Pearson's correlation test, $P>0.05$, data not shown). Although it is not fully clear, it was hypothesised that horses with a lower BW previously had been ridden by riders of a BW that resulted in a greater BWR than for heavier horses, and hence, been adopted to carry heavier riders.

6.2 Correlations between a weight carrying test and a standardised exercise test on a treadmill (Paper III)

The physiological response to a SET on a treadmill, which reflected the horse's aerobic capacity, did not show a clear correlation with the physiological response to weight carrying, as previously shown in humans (Robinson *et al*., 2018). For example, there was no correlation between V_{La4}, estimated from the SET, and BWR_{La4}, estimated from the weight carrying test. The velocity at a plasma lactate concentration of 4 mmol/L (i.e. V_{La4}) is a well-established estimation of fitness in horses (Bitschnau *et al*., 2010; Harkins *et al*., 1993; Jansson *et al*., 2021). However, there was a strong positive correlation between V_{La3}, estimated from the SET, and BWR_{180}, estimated from the weight carrying test. The reason and importance of this correlation need further investigation. It is not known whether V_{La4} and BWR_{180} are also correlated but unfortunately this correlation could not be analysed due to few observations (n=3). Also, a tendency for a positive correlation between V_{190} and BWR_{190} was found. The haematocrit at 5 min of recovery after the two different exercise tests was also positively correlated, suggesting that both tests mobilised a similar volume of erythrocytes from the spleen (Persson, 1967).

The low number of observations in some of the correlation analyses was due to large individual variation in performance in the two exercise tests, leading to the inability to determine one or more physiological parameters in some horses. For example, four horses never reached the anaerobic threshold at the weight carrying test, and the corresponding number for the SET was five, and these were generally not the same horses. In future studies, exercise tests are suggested to start at a lower intensity and end with a higher intensity than in the current papers, to enable a greater number of horses to be included in the analyses.

Due to the low number of observations in some of the correlation analyses and the lack of correlation between physiological parameters, except V_{La3} and BWR_{180}, the results of this paper were difficult to interpret. In contrast to the study by Robinson *et al*. (2018), Bilzon *et al*. (2001) did not find a correlation between aerobic capacity (VO_{2max}) and weight carrying capacity in humans. In humans, it is widely accepted that specificity in training is important for performance in several disciplines, although less specific training methods seem to enhance the specific performance to some extent (Foster *et al*., 1995; Baker, 1996; Rumpf *et al*., 2016). The specificity of training is hypothesised to also apply to horses (Castejon-Riber *et al*., 2017). It is probably, in addition to aerobic capacity, other parameters that are important for weight carrying capacity, such as specific training and conformation. Hence, it might not be possible to estimate weight carrying capacity in horses based on aerobic capacity alone. However, the importance of the significant correlation between V_{La3} and BWR_{180} needs further investigation, and the correlation between V_{La4} and BWR_{180} should also be studied. An exercise test that can, in a simple and standardised way, predict weight carrying capacity in individual horses could be useful for riding schools and tourist companies with many riders of different BWs. However, it may not be reliable to use a SET with the same protocol as in this paper to evaluate weight carrying capacity.

6.3 Training effects (Paper IV)

The 7-week training period was hypothesised to decrease the weight carrying capacity in the unridden training group due to the lack of weight load. For the ridden training group, no changes in weight carrying capacity were expected, since they performed similar training to that prior to the study. In general, exercise training increases aerobic capacity in horses and thus decreases lactate production at a given exercise intensity (Gottlieb *et al*., 1989; Lovell & Rose, 1991; Ronéus *et al*., 1994). In paper IV, horses in the ridden training group tended to have lower average plasma lactate concentrations after the training period, than before, indicating enhanced aerobic capacity. The effect of weight carrying training on aerobic capacity in horses has not been studied previously. However, Heck *et al*. (1996) showed that after 8 weeks of weight carrying training, ponies were able to carry a greater load until fatigue, suggesting improvements in aerobic capacity. In humans, a 10-week load carriage training program increased the predicted VO_{2max}, estimated by a "beep test" (Wills *et al*., 2019), indicating improvements in aerobic capacity. Improvements of the aerobic capacity can be due to circulatory adaptations such as increases in blood- (Persson, 1967; Knight *et al*., 1991) and red cell volume (Persson, 1967), but also skeletal muscle adaptations such as increases in mitochondrial density (Tyler *et al*., 1998), capillarisation of muscle fibres (Henckel, 1983; Essén-Gustavsson *et al*., 1989; Tyler *et al*., 1998), and activity of oxidative enzymes (Guy & Snow, 1977; Henckel, 1983; Essén-Gustavsson *et al*., 1989; Gottlieb *et al*., 1989). Furthermore, training can decrease the muscle fibre area (Henckel, 1983; Essén-Gustavsson *et al.*, 1989) and change the distribution of muscle fibre types within a muscle, mainly by increases in type IIA (Henckel, 1983; Gottlieb *et al.*, 1989; Lovell & Rose, 1991), and decreases in type IIB/X (Henckel, 1983; Gottlieb *et al.*, 1989) muscle fibres. An increased percentage of type IIA muscle fibres is associated with lower blood lactate levels after exercise (Valberg *et al.*, 1985), due to their high oxidative capacity (Henckel, 1983). In horses that underwent a draft-loaded training program, an increase in the percentage of type IIA muscle fibres, and a decrease in the percentage of type IIB muscle fibres were shown in the gluteus muscle already after two weeks of training (Gottlieb *et al.*, 1989). Also, the area of type IIA muscle fibres was increased after two weeks, whereas the area of type IIB muscle fibres increased after three months. A lower plasma lactate concentration as an effect of training may also be due to an increased activity of monocarboxylate transporters (MCT) (Koho *et al.*, 2006; Revold *et al.*, 2010; Kitaoka *et al.*, 2011), which are responsible for the transportation of lactate across cell membranes. An increase in fitness after a period of training may also be due to increased muscle buffering capacity (McCutcheon *et al.*, 1987; Sinha *et al.*, 1991), but this does not lead to a lower plasma lactate concentration.

With these adaptations, horses are able to run faster until they reach the anaerobic threshold (i.e. V_{La4} increases). It was suggested that these adaptations, or at least some of them, also occurred in the horses in Paper IV, based on the slight decrease in plasma lactate concentration after the ridden training period. An increase in mitochondrial density and capillaries in muscle fibres has been shown to occur within seven weeks of intensive training (Essén-Gustavsson *et al.*, 1989; Tyler *et al.*, 1998). An increase in citrate synthase (i.e. an oxidative enzyme involved in the tricarboxylic acid cycle) can be observed as early as after one week of training (Essén-Gustavsson *et al.*, 1989), and an increase in muscle buffering capacity after two weeks (Sinha *et al.*, 1991). A decrease in type IIA fibre area can be detected after five weeks (Essén-Gustavsson *et al.*, 1989), and blood volume can increase after six weeks of training (Knight *et al.*, 1991). However, a change in muscle fibre distribution may take several months (Henckel, 1983; Gottlieb *et al.*, 1989; Lovell & Rose, 1991). Considering the 7-week training period in Paper IV, circulatory and intramuscular adaptations may have occurred during that time, however, this period was probably insufficient to induce measurable changes in muscle fibre composition in the horses.

However, the exercise capacity of the horses was only evaluated during weight carrying, and it was not known if the training adaptations would have been detected also in a SET without weight loads. The specific weight training performed by the horses in Paper IV might have resulted in greater efficiency and reduced energy cost of weight carrying, e.g. through decreased muscle activity and increased anticipatory force (Huang *et al*., 2012), as well as locomotion adaptations (Finley *et al*., 2012). The anticipatory force is the force generated before an expected load or movement, based on prior experience (Marneweck & Grafton, 2020). Hence, the indications of enhanced weight carrying capacity in horses in the ridden training group may not be solely due to increased aerobic capacity.

In contrast to the ridden training group, horses in the unridden training group tended to have lower average plasma lactate concentrations after the training period than before. Although there was a small effect of unridden training, no apparent loss of weight carrying capacity was observed after the 7-week unridden training period. It is possible to detect an effect of detraining within seven weeks (Knight *et al*., 1991; Art & Lekeux, 1993; Tyler *et al*., 1996), but it might have been too short a period for these horses (Gottlieb-Vedi *et al*., 1995), especially since they were still in active training (Mukai *et al*., 2017). Interestingly, mean and peak HR did not differ between ridden and unridden horses during the training sessions. This, however, is in line with the previous study by Sloet van Oldruitenborgh-Oosterbaan *et al*. (1995), which found no difference in mean HR between unloaded and 90 kg loaded exercise. However, in contrast to the results in Paper IV, peak HR was higher in the loaded horses (Sloet van Oldruitenborgh-Oosterbaan *et al*., 1995).

6.4 Gaits in the exercise tests

All the ridden exercise tests in this thesis were performed in tölt. Tölt is an appreciated gait in Icelandic horses, well known for being more comfortable for the rider than trot. The comfort of the gait can be explained by the low dorsoventral movement of the horse's sacrum (Waldern *et al*., 2015). Tölt is therefore a popular gait during, e.g. trekking tours (Sigurdardóttir & Helgadóttir, 2015), and to apply the results to field conditions, tölt was used during the weight carrying tests in this thesis. However, in Paper III, trot was used at the SET at the treadmill, partly because that was the gait the horses generally chose. Earlier results showed that there are only minor differences in the physiological response to trot and tölt in adult trained Icelandic horses (Stefánsdóttir *et al*., 2015). The differences were only observed at low speed (3 m/s), not at 4 and 5 m/s (Stefánsdóttir *et al*., 2015). In my study (Paper III), the first step at the SET (i.e. the step performed at the lowest speed) was at 3.4 m/s, therefore, these minor differences between trot and tölt are probably not of importance in my study. Icelandic horses are either four- or five-gaited, where the five-gaited horses have the ability to pace, in addition to walk, trot, tölt and canter/gallop. Pace is a two-beat lateral gait, and the ability to express this gait is associated with a mutation in the *DMRT3*-gene (Andersson *et al*., 2012). The weight carrying test in Papers II and IV was aimed to be performed in tölt, but some of the horses had trouble keeping the tölt and showed either a "pacey-tölt" or "trotty-tölt". This is associated with the genotype, where Icelandic horses that are homozygous for the mutation have been shown to have easier to tölt (Jäderkvist *et al*., 2015) and a greater speed capacity in that gait (Kristjansson *et al*., 2014) compared with horses that are heterozygous for the mutation. Furthermore, the four-gaited horses (i.e. heterozygous) are prone to show a "trotty-tölt". In contrast, the tölt in five-gaited horses (i.e. homozygous) more often gets pacey under a rider (Jäderkvist *et al*., 2015). The physiological response to weight carrying might therefore have been affected by how easily the horse could maintain a clean-beat tölt.

6.5 Rider effect

In addition to rider weight, there is a general assumption in the horse industry that, e.g. rider experience and style may affect the physiological response in a horse. Previously, an effect of rider on the physiological response in Icelandic horses (Stefánsdóttir *et al*., 2015 and 2017b) and Warmblood dressage horses (Christensen *et al*., 2021) was reported. However, it was not excluded that the effect was due to differences in rider weight. In Paper IV, there was a significant effect of rider on the average plasma lactate concentration in the horses, where horses ridden by the taller rider (175 cm) had higher plasma lactate concentrations than the horses ridden by the shorter rider (167 cm). As far as I know, there are no previous studies investigating the effect of rider height on physiological response in horses. However, an increased rider height may impair the balance of both the rider and the horse, leading to an increased physiological response. The effect of the different riders may also be due to different riding styles. However, each horse was ridden by the same rider on both occasions (before and after training), therefore, the observed differences in plasma lactate concentration in the horses, between riders, may not reflect rider effects. Instead, it is possible that random allocation led to one rider being assigned horses with greater weight carrying capacity. In the future, it would be of great interest to study the effect of rider on the physiological response in the horse, including riders with the same BW and using a cross-over design.

6.6 Limitations of the studies

In Paper I, it was not the same person who collected the height measurements in BEFTh and TRh, which decreases the reliability of the results (Lamas *et al.*, 2007). However, the difference between two different measurements (e.g. height at the withers and height at the back) was considered to have a relatively high accuracy since it was always the same person who collected both measurements in the same horse. Furthermore, BCS and back angle were also measured by the same person in all horses. The main limitation of Papers II-IV was that some of the physiological parameters could not be estimated in some horses, due to a large variation in physiological response among the horses. For example, V_{LA4}/BWR_{La4} could not be estimated for horses that had already reached the anaerobic threshold at the first step of the exercise test, and the same parameters could not be estimated for those who never reached the anaerobic threshold. Also, there were some connection problems with the HR recorder, which led to missing HR data for some horses in Papers II and III. In Paper IV, it was not possible to perform any analyses of the HR during the weight carrying tests due to a significant loss of data. Similar problems with the HR recorder have also been reported in Standardbred horses (Ringmark, 2014). However, measures of plasma lactate concentration may be sufficient to detect training effects (Gottlieb *et al*., 1989; Lovell & Rose, 1991; Ronéus *et al*., 1994).

Another limitation of the studies was that the reproducibility of the weight carrying test was not known. Field exercise tests for Standardbred trotters have been found to have a good reproducibility (Dubreucq *et al*., 1995), but the reproducibility of field exercise tests including weight loads has never been tested. To evaluate, e.g. the effect of training, it is of importance that the tests are completely standardised regarding, e.g. speed, rider, and weather conditions. In Paper IV, six horses were excluded from the analyses of training effects, since there was a clear difference in speed between the two weight carrying tests (before and after training) for those horses.

7. Conclusions

- There was a clear difference in body measurements and BCS between BEFTh and TRh. For example, BEFTh had a more "uphill" conformation, a straighter backline and a lower BCS than TRh. The reasons for the differences are not known, but they may be due to preselection and different training.
- A greater height at the withers, back and croup was perceived by the owners of TRh as favourable for weight carrying capacity but was not associated with the physiological response to weight carrying.
- Back condition score and angle were not associated with subjectively evaluated weight carrying capacity or with the physiological response to weight carrying.
- A wider chest, "uphill" conformation, straight backline, and smaller hock circumference were associated with greater physiological weight carrying capacity.
- There were no clear correlations between the physiological responses during a SET on a treadmill and during a ridden incremental weight carrying field test. This shows that a SET is not reliable for estimating weight carrying capacity in horses and it also indicates that aerobic capacity may not explain weight carrying capacity. However, there was a strong correlation between V_{La3} (SET) and BWR_{180} (weight carrying test), and the importance of this correlation needs further investigation.
- After a 7-week training period, plasma lactate concentration tended to decrease in horses that performed ridden training, whereas it tended to increase in horses that performed unridden training. This indicates that weight carrying capacity may be enhanced with ridden training, but 7 weeks of unridden training seem sufficient to maintain most of it.
- There was a large individual variation in weight carrying capacity in the Icelandic horses observed in this thesis, and most showed a relatively low physiological response to weight carrying, and some never reached the anaerobic threshold.

8. Future research

Although the results of this thesis provided important new knowledge about weight carrying capacity of horses, there are still questions that need answers, and the results may be of great value for future research. For example, results from Paper IV indicated that ridden training is favourable for weight carrying capacity compared with unridden training. However, the horses were already used to carrying riders with different BWs, and it is not known whether it is possible to further improve their weight carrying capacity through an incremental weight carrying training programme, including loads heavier than they are used to. Only a few studies have previously evaluated the effect of weight carrying training in horses (Nielsen *et al*., 2002; O'Connor *et al*., 2002) and ponies (Heck *et al*., 1996). These studies indicated increased weight carrying capacity (Heck *et al*., 1996), muscle growth (O'Connor *et al*., 2002), and bone mineral density (Nielsen *et al*., 2002) after the training period. However, in one of the studies (Heck *et al*., 1996), only two ponies were included, and no controls that performed the same training without added weights were included. In the other studies (Nielsen *et al*., 2002; O'Connor *et al*., 2002), the maximum weight carried by the horses was only 45 kg, which is significantly lower than the average BW of a rider (Garlinghouse & Burrill, 1999; Stefánsdóttir *et al*., 2014; Challinor *et al*., 2021). A study evaluating the effect of incremental weight carrying training could provide further insight into how training affects the weight carrying capacity and practical advice for horse owners and riders to improve the horse's performance and welfare. Results from this thesis indicated that conformation influences weight carrying capacity in horses. However, it has never been scientifically studied whether the conformation traits found to be favourable for weight carrying capacity can be affected by training. It seems that both training and conformation are associated with weight carrying capacity, and it would be interesting to know whether these two parameters are connected. The association between conformation, training and weight carrying capacity should preferably also be studied in other breeds than the Icelandic horse. In addition to further investigation of the importance of the body measurements that were found to be favourable for weight carrying capacity in this thesis, the association between weight carrying capacity and other body measurements, such as hock angle, may also be relevant to investigate. A smaller hock angle has previously been associated with an increased risk for hindlimb lameness and degenerative joint disease in the hock in Icelandic horses (Axelsson *et al*., 2001). Furthermore, in Swedish Warmblood horses, a larger hock angle was found in élite dressage horses and showjumpers than in non-élite horses (Holmström *et al*., 1990). However, the effect of hock angle on weight carrying capacity has not been studied.

It is now well-known that an increased rider weight generally increases the physiological response and affects the locomotion of the horse. Theoretically, an increased physiological response, in addition to changes in gait parameters, will presumably negatively impact true performance, but studies testing this hypothesis are limited. However, the completion rate in horses participating in a 160 km endurance race was not affected by rider weight or BWR (Garlinghouse & Burrill, 1999). Furthermore, no differences in rider weight and BWR were found in the rider-horse combinations placing top 10 at the World Championship than the rest of the rider-horse combinations that were competing (Amplatz, 2026). In the last-mentioned study, the BWR ranged from 14-31 %. However, it is not known whether the performance of tour riding and school horses is affected by an increased rider weight.

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Popular science summary

How heavy can the rider be? That is a recurring question within the horse industry. It is of course important that riding horses have a great weight carrying capacity, both from a welfare perspective and for performance. An increased rider weight can increase the physiological response, alter the locomotion and possibly affect the behaviour and health of the horse. Although there are a lot of opinions about the topic, the scientific knowledge is limited. The Icelandic horse is a popular breed that are used for a various of purposes, such as gait competitions, pace races and leisure. However, despite their rather small size (height at withers around 140 cm), the breed is often ridden by adult riders, which emphasise a great weight carrying capacity in the breed. Weight carrying capacity can be defined and measured in various ways but is in this thesis based on the physiological response to weight carrying in the Icelandic horse. Results from this thesis is, however, probably applicable also on other horse breeds. The aim of the thesis was to examine the association between body measurements and the owner's opinion about the weight carrying capacity in the horse. Also, the association between body measurements and the physiological response to weight carrying was examined, as well as the effect of training on weight carrying capacity. A weight carrying test is usually performed using lead weights added to the rider and the horse, which requires access to weights and can be a safety issue. Therefore, an easy and safe method to estimate weight carrying capacity in the horse is of interest. It was investigated if a standardised unridden exercise test on a treadmill can be used to estimate weight carrying capacity. Such test could be used by, e.g. riding schools and tour riding companies. Body measurements and body condition score were collected in 48 Icelandic horses that participated in a breed evaluation field test and in 65 horses used for tour riding and in riding schools, and in another 16 horses that also performed an unridden exercise test on a treadmill and a ridden weight carrying test. The weight carrying test included four incremental steps in tölt, where the horses carried 20 %, 25 %, 30 % and 35 % of their own body weight in each step, respectively. To investigate the effect of training on weight carrying capacity, another 14 Icelandic horses were divided into two training groups; unridden and unridden training. Horses were exercised 3 times/week for 7 weeks, where the horses were exercised in pairs, one being ridden and the other one led by the rider. Weight carrying capacity was estimated with the ridden weight carrying test, before and after the training period. During all exercise tests and training sessions, heart rate was continuously measured in the horses, and blood samples were collected for each step during the exercise tests. As a measure of anaerobic metabolism, plasma lactate concentration was analysed from the blood samples.

Findings of the thesis

Horses participating in a breed evaluation field test had a greater difference between height at withers and height at back and croup (i.e. they were more "uphill"), a less difference between height at croup and back (i.e. straight backline), and a lower body condition score than tour riding and school horses. Tour riding and school horses with greater height at withers, back and croup were perceived, by the owners, to have a greater weight carrying capacity. Height measurements were, however, not correlated with physiological parameters at the weight carrying test in another 16 horses. This may lead to that the weight carrying capacity of taller horses are over-estimated by their owners, which in turn can impair horses' welfare and performance. Instead, a broader chest, "uphill" conformation, straight backline, and smaller hock circumference were associated with greater weight carrying capacity (i.e. lower physiological response to weight carrying). Although a broad and well-muscled back often is perceived as beneficial for weight carrying, back condition score and angle were not shown to be associated with weight carrying capacity in this thesis.

The speed in trot at the point at which the horse reached a plasma lactate concentration of 3 mmol/L at the treadmill exercise test was positively correlated with the body weight ratio (calculated as rider weight/horse body weight) at the point at which the horse reached a heart rate of 180 bpm. The importance of that correlation is not known and needs further investigation. However, a treadmill exercise test with the same protocol used in this thesis might not be reliable for estimating weight carrying capacity in individual horses. Plasma lactate concentration tended to be higher in horses in the unridden training group and lower for horses in the ridden group at the exercise test after the training period, compared with at the exercise test before training. This result indicates that ridden training is beneficial for weight carrying capacity.

Populärvetenskaplig sammanfattning

Hur tung får en ryttare egentligen vara? Det är en återkommande fråga inom hästbranschen. En god viktbärande förmåga är naturligtvis viktigt hos ridhästar, båda ur ett välfärdsperspektiv och för prestation. En ökad ryttarvikt kan öka det fysiologiska svaret, påverka rörelsemönstret och eventuellt påverka beteendet och hälsan hos hästen. Även om det finns många åsikter om ämnet är den vetenskapliga kunskapen begränsad. Islandshästen är en populär ras som används för en mängd olika ändamål, såsom gångartstävlingar, passlopp och rekreation. Trots att rasen är relativt liten (omkring 140 cm i mankhöjd) rids den ofta av vuxna ryttare, vilket understryker behovet av en god viktbärande förmåga. Viktbärande förmåga kan definieras och mätas på olika sätt, men baseras i denna avhandling på det fysiologiska svaret under ett viktbärande test hos Islandshästar. Resultaten från denna avhandling kan dock förmodligen även tillämpas på andra hästraser. Syftet med avhandlingen var att undersöka sambandet mellan kroppsmått och ägarens subjektiva uppfattning om hästens viktbärande förmåga. Även sambandet mellan kroppsmått och det fysiologiska svaret under ett viktbärande test undersöktes, liksom effekten av träning på viktbärande förmåga. Ett viktbärande test utförs vanligtvis med blyvikter som läggs på ryttaren och hästen, vilket kräver tillgång till vikter och kan vara en säkerhetsrisk. En enkel och säker metod för att uppskatta hästens viktbärande förmåga är av intresse, och därför undersöktes det om ett standardiserat arbetstest på rullmatta, utan ryttare, kan användas för syftet. Ett sådant test skulle kunna användas av till exempel ridskolor och turridningsföretag över hela världen. Kroppsmått och hullpoäng samlades in hos 48 Islandshästar som deltog i ett avelstest och hos 65 hästar som användes för turridning och i ridskolor, samt hos ytterligare 16 hästar som också utförde ett arbetstest på rullmatta och ett uppsuttet viktbärande test. Det viktbärande testet inkluderade fyra stegvisa ökningar av belastningen i tölt, där hästarna bar 20 %, 25 %, 30 % och 35 % av sin egen kroppsvikt i respektive steg. För att undersöka effekten av träning på viktbärande förmåga delades ytterligare 14 Islandshästar in i två träningsgrupper; träning utan ryttare och träning med ryttare. Hästarna tränades 3 gånger/vecka i 7 veckor, där hästarna tränades i par, den ena riden och den andra ledd av ryttaren. Den viktbärande förmågan uppskattades, före och efter träningsperioden, med hjälp av det viktbärande testet. Hästarnas puls mättes kontinuerligt under alla arbetstest och träningspass, och blodprover samlades in för varje steg i arbetstesten. Som ett mått på anaerob metabolism analyserades plasmalaktatkoncentrationen från blodproverna.

Resultat

Hästarna som deltog i ett avelsvärderingstest hade en större skillnad mellan mankhöjd och höjden vid ryggen och korset (dvs. högre framtill än baktill), en mindre skillnad mellan korshöjd och rygghöjd (dvs. rak rygglinje) och en lägre hullpoäng än turridnings- och skolhästarna. Turridnings- och skolhästarna med högre mankhöjd, rygghöjd och korshöjd uppfattades av ägarna ha en bättre viktbärande förmåga. Mankhöjd, rygghöjd och korshöjd som mättes på 16 andra hästar korrelerade dock inte med det fysiologiska svaret vid det viktbärande testet. Detta skulle kunna leda till att ägare överskattar den viktbärande förmågan hos högre hästar, vilket i sin tur kan ha en negativ påverkan på hästarnas välfärd och prestation. I stället associerades en bredare bröstvidd, en hög mankhöjd i förhållande till rygg- och korshöjd och en rak rygglinje med bättre viktbärande förmåga. Även om en bred och välmusklad rygg ofta anses som fördelaktig för att bära vikt så visades inget samband mellan ryggens hullpoäng eller vinkel och viktbärande förmåga i denna avhandling.

Hastigheten i trav när hästen nådde en plasmalaktatkoncentration på 3 mmol/L under arbetstestet på rullmatta var positivt korrelerat med kroppsviktsförhållandet (beräknat som ryttarens vikt/hästens kroppsvikt) när hästen nådde en puls på 180 slag/minut. Betydelsen av denna korrelation är oklar och behöver undersökas vidare. Resultaten indikerar också att ett rullmattetest med liknande protokoll som användes i denna avhandling förmodligen inte är pålitligt för att uppskatta viktbärande förmåga hos enskilda hästar. Plasmalaktatkoncentrationen under det viktbärande testet före träningsperioden tenderade att vara högre hos hästar som blev tränade i 7 veckor utan ryttare, och lägre för hästar som tränade med ryttare, jämfört med koncentrationen under testet före träningsperioden. Detta resultat indikerar att uppsutten träning är fördelaktigt för viktbärande förmåga.

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RESEARCH ARTICLE

Body measurements in Icelandic horses used for two different purposes and the relationship to performance and usability

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Abstract

Many horse breeds are used for a variety of tasks and studies have shown within breed variations in conformation depending on the task. The Icelandic horse is used for several tasks, e.g. leisure riding, competitions and tour riding. Research about conformation and relationship to subjectively assessed performance (usability) in Icelandic horses used by tourist companies and riding schools (TRh) are lacking. Back condition score has been shown to be associated with weight carrying capacity in the breed. However, the association between back condition score and angle and performance in Icelandic horses participating in a breed evaluation field test (BEFTh) and usability in TRh has not been investigated previously. The aim of the study was to compare body measurements in BEFTh and TRh and examine the relationship with riding ability in BEFTh and usability in TRh. Data of height at withers, back and croup, body condition score (BCS) and back angle were collected in 48 BEFTh (age 8 ± 2 years) and 65 TRh (age 14 ± 5 years). Transversal back angle at the 18th thoracic vertebra was determined using a flexible curve ruler. A questionnaire was used to evaluate the relationship between body measurements and owners' assessment of usability in TRh. The relationship between back condition score and angle and riding ability was evaluated in BEFTh. Compared with TRh, BEFTh had a greater difference between height at withers and height at back and croup, lower BCS and greater back angle ($P < 0.05$). In TRh, height were positively correlated with usability ($P < 0.05$). Back condition score and angle were not associated with riding ability in BEFTh or usability in TRh ($P > 0.05$). In conclusion, body measurements differs between BEFTh and TRh and further studies are needed to investigate if the same conformation traits are associated with good performance in BEFTh and usability in TRh.

Keywords

equine – breed evaluation field test – tour riding – back shape – weight carrying capacity

1 Introduction

Many horse breeds, such as the American Quarter Horse and Swedish Warmblood are used for a variety of tasks, and studies show that there are within breed variations in conformation depending on the task (Holmström *et al.*, 1990; Meira *et al.*, 2013). For example, Swedish Warmbloods used at riding schools have been shown to have a lower height at withers than elite showjumpers of the same breed (Holmström *et al.*, 1990). The Icelandic horse is also a multipurpose breed and it is used for several tasks, e.g. leisure riding, gait competitions,

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pace races and long-distance trekking tours, but there are no studies investigating a possible variation in conformation related to the use and the importance for performance. Knowledge about the influence of body measurements on performance can be of great relevance when selecting horses for a specific purpose, and thereby for animal welfare, equestrian business economics and breeding. However, in a study by Kristjansson *et al.* (2016) on Icelandic horses, the performance in a breed evaluation field test (BEFT) was affected by body format (relationship between body length and height at withers). A square body format was ideal for performance in tölt and a rectangular body format was ideal for pace, indicating that there might be variations in conformation depending on the task, also in Icelandic horses.

Weight carrying capacity is important in riding horses and the capacity seems to be associated with back shape (Powell *et al.*, 2008; Stefánsdóttir *et al.*, 2017). In the study by Powell *et al.* (2008), a negative correlation was found between loin width and muscle soreness after weight carrying in light riding horses. In another study, Icelandic horses with a higher body condition score (BCS) of the back (i.e. broader) were able to carry more weight before they reached the lactate threshold than horses with lower back condition score (Stefánsdóttir *et al.*, 2017). However, the latter was a small study and further studies are needed to determine the importance of back conformation on weight carrying capacity. Many Icelandic horses are used by tourist companies and are expected to carry riders with different weights, although the breed is relatively small (height at withers around 140 cm, Herbrecht *et al.*, 2020; Kristjansson *et al.*, 2016; Stefánsdóttir *et al.*, 2014). High weight carrying capacity is therefore of great importance in these horses. In addition, the Icelandic horse is the only breed available for riders in Iceland, since it is not allowed to import horses into the country (Icelandic Parliament, 1990).

In Icelandic horses participating in a BEFT (BEFTh), back conformation seems also to be important for performance (Albertsdóttir *et al.*, 2008; Rosengren *et al.*, 2021), and a subjective evaluation of back and croup is included in the conformation assessment (FEIF, 2023). To receive the highest score, the horse should have e.g. a broad, well-muscled back that is high in the front, a short loin and a long and well-muscled croup (FEIF, 2023). The score for back and croup has been found to exhibit a moderate genetic correlation to gait quality (Albertsdóttir *et al.*, 2008). Furthermore, a novel quantitative trait loci (QTL) has been associated with both back and croup conformation and lateral gait quality in Icelandic horses (Rosengren *et al.*, 2021). However, the influence of back condition score and angle on riding ability in a BEFT has not yet been studied and knowledge about this can be useful for horse owners and breeders.

To our knowledge, body measurements (i.e. height, back measurements and BCS) and weight carrying capacity of Icelandic horses used by tourist companies and riding schools (TRh) has not been described to date. It would be of interest to know if body measurements differ between TRh and BEFTh, and whether it is linked to subjectively assessed performance (usability) in TRh.

The aims of the present study were thus to (1) compare body measurements between BEFTh and TRh, (2) examine the relationship between body measurements and subjective weight carrying capacity and usability in TRh and (3) examine the relationship between back condition score and angle and riding ability in a BEFT. The hypotheses tested were that body measurements differs in some respects between BEFTh and TRh, and that back condition score and angle are associated with riding ability in BEFTh and subjective weight carrying capacity and usability in TRh.

2 Material and methods

Experimental design

Body measurement and BCS data on two groups of Icelandic horses (BEFTh and TRh) were used in the analysis. These data comprised measurements made during summer (May-September) 2020 and 2021. The data on BEFTh were obtained in two BEFTs, carried out in July 2020 and September 2021 in Romme, Sweden, while the data on TRh consisted of measurements made at five different tour riding companies and riding schools (three in Sweden, two in Iceland). A BEFT comprises three different parts; objective body measurements, subjective conformation assessment and a ridden assessment. The ridden assessment involves a subjective assessment of riding ability, which includes assessments of walk, tölt, slow tölt, trot, pace, gallop, canter, rideability and general impression, with each scored on a scale of 5-10 with 0.5 intervals (FEIF, 2023).

Horses

Forty-eight BEFTh (age 8 ± 2 years; 19 stallions, 3 geldings, 26 mares) and 65 TRh (age 14 ± 5 years; 47 geldings, 18 mares) were included in the study. Of the 65 TRh, 23 horses (age 13 ± 4 years; 17 geldings, 6 mares) were measured in Iceland and 42 horses (age 15 ± 6 years; 30

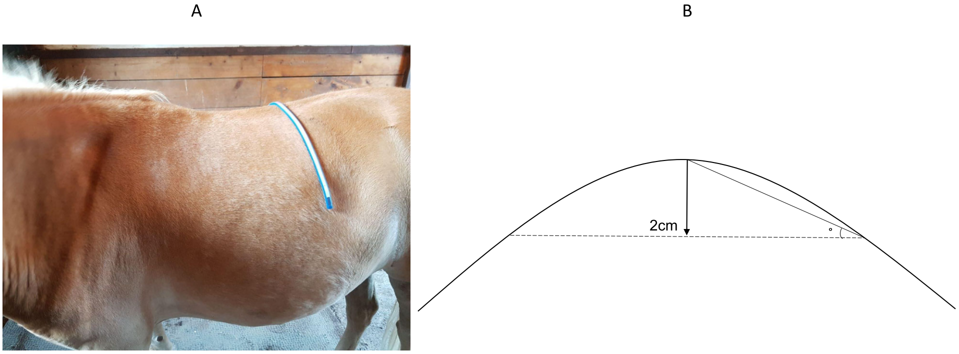

FIGURE 1 (A) Measurement of shape of the back with a flexible curve ruler placed at the level of the 18th thoracic vertebra. (B) Illustration of the drawn curve and the angle measured for both sides of the back.

geldings, 12 mares) were measured in Sweden. Of the 42 horses measured in Sweden all but 16 had at least one parent born in Iceland. All horses had been in active training (a continuous period of ridden training at least 2 days/week) for one month or longer before the measurements, except for one BEFTh that was lame at the time of the measurements and did not participate in the ridden assessment. In total three TRh had been participating 1-2 times in a BEFT previous in life.

Data collection

For BEFTh, body measurements were collected inside a stable (on a concrete floor) in conjunction with objective body measurements performed by a single certified person (ringmaster). The TRh were measured either inside a stable (on a concrete floor) or outside on pasture, on a level surface. Body condition score of all horses was measured on a scale of 1-9 using a modified version of the Henneke scale (Henneke *et al.*, 1983; Jansson *et al.*, 2021; Ringmark *et al.*, 2013), where three different body parts (ribs, back and tail head) are scored individually using a continuous scale. The overall BCS was calculated as a mean value from the three body parts. In addition, a mean value was calculated without the back condition score, since Icelandic horses seem to accumulate less fat along the back than at the other sites assessed (at least in moderately fleshy horses) (Henneke *et al.*, 1983; Jansson *et al.*, 2021). For TRh, height at withers, lowest point of the back and highest point of the croup were measured by two experienced persons using a measuring stick, according to FEIF (2023). For BEFTh, height measurements measured by the ringmaster and the subjective scores for back and croup and riding ability based on assessments by the breeding judges were obtained from WorldFengur (2023).

An objective measurement of the shape of the back was performed in both BEFTh and TRh using a flexible curve ruler (60 cm, Donau Elektronik GmbH, Metten, Germany), in addition to subjective back condition scoring (Ringmark *et al.*, 2013; Stefánsdóttir *et al.*, 2017). These measurements were performed by a single person for all horses included in the study. The ruler was positioned to follow the curve of the horse's back, perpendicular to the dorsal midline and at the level of the 18th thoracic vertebra (T18), identified by palpation of the ribs (Figure 1). The ruler was then removed carefully, placed on paper and the curve was sketched. The angle of the curve was measured using a goniometer placed on the paper at the top of the curve, with the angle measured 2 cm down from the top (Figure 1). The angle was measured for both the left and the right side of the back and a mean value was calculated. The CV was 2.1%, based on duplicate measurements on 68 horses. During the body measurements on BEFTh, the horses' owners and/or riders were asked how long the horse had been in active training (a continuous period of ridden training at least 2 days/week).

Questionnaire: horse owners' opinion about the usability of TRh

A questionnaire (Supplementary Materials and methods S1) was distributed to the owners (n = 5) of the 65 TRh, including questions about each horse's usability as a TRh; horse age and sex; how long it had been used in the present company; and time in active training since the last period of rest. Active training was defined as a continuous period of training 2 days/week or more often.

Using a visual analogue scale (VAS) of 0-10 (Grant *et al.*, 1999), where 0 is 'very bad' and 10 'very good', the horse owners were asked to estimate how well each horse managed long-distance tours and their opinion about the general weight carrying capacity of the horse (by adding a cross on a 10 cm line). The last question included a holistic assessment of the general function of the horse as a TRh (combining the owner's knowledge on the horse's time in duty, willingness and injury history). The VAS protocols were measured using a ruler with 0.1 cm precision.

Statistical analysis

Statistical analysis was performed in SAS software (version 9.4; SAS Institute Inc., Cary, NC, USA). Conformation traits and BCS in BEFTh and TRh were compared using the GLM (PROC GLM); $Y = \mu + a_i + b_j + c_k + d_l + e_{ijkl}$, where Y is observation, μ is mean value, a_i is the fixed effect of purpose (TRh or BEFTh), b_j is the fixed effect of country (measured in Iceland or Sweden), c_k is the fixed effect of sex, d_l is the continuous effect of age and e_{ijkl} is the residuals. For TRh, an additional analysis was performed where two age groups were created, one with horses aged ≤10 years (n = 15), and thus comparable to the age of BEFTh, and one with horses aged ≥11 years (n = 50). The TRh were also divided into three groups based on years of experience (years used in the present company): (1) 0-3 years (n = 21, age 11 ± 5 years), (2) 4-7 years (n = 23, age 13 ± 3 years) and (3) ≥8 years (n = 18, age 17 ± 4 years). When comparing body measurements and BCS between BEFTh and the two different age classes of TRh, and when analysing the association between years of experience and body measurements and BCS, purpose was replaced with age group (BEFTh, TRh age ≤10 years and TRh age ≥11 years) and experience group, respectively. Age (see Materials and methods), judges' scores for conformation and riding ability and scores from the questionnaire are presented as mean ± standard deviation (SD) and back condition score as mean and range. Other results are presented as least square mean (LSM) and standard error (SE). Pairwise comparisons were performed using a Tukey-Kramer test and the significance level was set at $P < 0.05$ and the tendency level at $P < 0.1$. Normal distribution of residuals was confirmed with qq-plots. For analysis of back condition score, the exact Wilcoxon two-sample test (PROC NPAR1WAY) was applied due to skewed distribution of residuals, that was unaffected by data transformation. When analysing skewed data including more than two samples, pairwise two-sided multiple comparison analysis was applied. This test was also used when analysing the association between years of experience and tail head condition score. Correlations were determined with Pearson's correlation test (PROC CORR).

3 Results

Comparison of body measurements and BCS in BEFTh and TRh

Tour riding and school horses had greater height at croup ($P < 0.05$), a smaller difference between height at withers and height at back and croup ($P < 0.0001$), and a larger difference between height at croup and height at back ($P < 0.05$) compared with BEFTh (Table 1). A tendency for greater height at withers was found in BEFTh compared with TRh ($P < 0.1$), but no difference was found in height at back ($P > 0.05$) (Table 1). BCS with and without back condition score and individual scores for back and ribs were higher in TRh than in BEFTh ($P < 0.05$) and back angle was smaller ($P < 0.0001$) (Table 1). A negative correlation ($r = -0.59$, $P < 0.0001$) was found between back condition score and back angle.

Body condition score and back condition score were higher ($P < 0.05$) in TRh aged ≥11 years (5.9 ± 0.1 and 4.75 (4-5), respectively) than in BEFTh (5.4 ± 0.1 and 4.75 (4-4.9), respectively). In TRh, body measurements and BCS were not associated with age class ($P > 0.05$). Tour riding and school horses with ≥8 years of experience (years in the present company) had a smaller ($P < 0.05$) difference between height at withers and height at back (8.5 ± 0.4 cm) than TRh with 4-7 years of experience (9.6 ± 0.3 cm) and 0-3 years of experience (10.0 ± 0.4 cm). Tour riding and school horses with 4-7 years of experience had higher ($P < 0.05$) ribs condition score (7.5 ± 0.2) than TRh with ≥8 years of experience (6.5 ± 0.3) as well as a higher mean BCS (6.2 ± 0.1 vs 5.7 ± 0.1, respectively) and BCS without back condition score (6.9 ± 0.1 vs 6.2 ± 0.2, respectively), but did not differ from TRh with 0-3 years of experience ($P > 0.05$). No other body measurement or BCS data was associated with experience ($P > 0.05$).

Questionnaire: horse owners' opinion about the usability of TRh

The TRh included in the study had been used in their company for between 3 months and 21 years (median 5 years) and all had been in active training for at least 3 months, except for one horse that was lame and was resting. Around half of the TRh (33/65, 51%) had been in active training for 6 months or longer. Information about how long the horse had been used in the com-

TABLE 1 Body measurements and body condition score (BCS)[1] recorded for 113 Icelandic horses used for two different purposes (LSM ± standard error, including effects of country, sex and age in the statistical model)

Body measurements and BCS	BEFTh[2] (n = 65)	TRh[3] (n = 48)	*P*-value
Height at withers (cm)	142 ± 1	140 ± 1	0.08
Height at lowest point at back (cm)	130 ± 1	131 ± 1	0.7
Height at highest point at croup (cm)	136 ± 1	138 ± 1	0.04
Height at withers – height at lowest point at back (cm)[4]	12 ± 0	10 ± 0	<0.0001
Height at withers – height at highest point at croup (cm)[4]	6 ± 0	2 ± 0	<0.0001
Height at highest point at croup – height at lowest point at back (cm)[4]	6 ± 0	8 ± 0	0.00
Ribs condition score	6.1 ± 0.2	6.8 ± 0.2	0.05
Tail head condition score	5.7 ± 0.1	5.9 ± 0.1	0.23
Back condition score[5]	4.75 (4-4.9)	4.75 (4-5)	0.01
BCS_{mean}	5.4 ± 0.1	5.8 ± 0.1	0.02
BCS_{mean} excl. back[6]	5.9 ± 0.2	6.4 ± 0.1	0.04
Back angle (degrees)[7]	19 ± 1	15 ± 0	<0.0001

1 Henneke *et al.* (1983).
2 Icelandic horses participating in a breed evaluation field test.
3 Tour riding and school horses.
4 Difference between two height measurements.
5 Values for back score are shown as median and range due to non-normal distribution.
6 Back condition score excluded from the mean.
7 Measured with a flexible curve ruler placed at the level of the 18th thoracic vertebra.

TABLE 2 Questions 1-4 in the questionnaire (in addition to questions about horse age, sex, how long it had been used in the present company and time in active training) and mean score based on answers from five horse owners and a total of 64 tour riding and school horses

Question	Score[1] (mean ± standard deviation)
1. How do you think the horse manages long-distance tours over several hours (mostly walk with shorter distances with tölt, trot or gallop) with a rider (70-85 kg)?	7.9 ± 1.5
2. How do you think the horse manages fast tölt (or gallop) for a longer distance (1-2 km) with a rider (70-85 kg)?	8.0 ± 1.5
3. What is your opinion about the general weight carrying capacity of the horse?	7.8 ± 1.6
4. How would you describe how the horse is working in general as a tour riding horse/school horse (e.g. time in duty, willingness, injuries, etc.)?	7.5 ± 2.1

1 From 0 (very bad) to 10 (very good) with a precision 0.1.

pany was missing for three TRh and information about the usability (questions 1-4, Table 2) was missing for one TRh. Answers to question 1 (regarding capacity for long-distance tours in mostly walk, Table 2), were not collected from one company in Iceland, since walk was not used during the tours according to the horse owner. All questions about the usability of TRh were scored ≥7.5 (Table 2).

There was a positive correlation between height at withers and scores for capacity for long-distance touring in walk and fast tölt (questions 1-2, $P < 0.05$) and general weight carrying capacity (question 3, $P < 0.0001$) (Table 3). Height at back and croup were positively correlated ($P < 0.05$) with all questions (questions 1-4, Table 3). No other body measurement and BCS data was correlated with scores from the questionnaire ($P > 0.05$). Age was negatively correlated with scores for question 1 (r = –0.45, $P < 0.05$), 2 (r = –0.39, $P < 0.05$) and 3 ($P < 0.05$, Figure 2). When excluding horses aged ≥20 years (n = 8), no relationship was found between age and scores for these questions ($P > 0.05$, Figure 2).

TABLE 3 Correlations (r) between body measurements and body condition score (BCS)[a] and owners' opinion about the usability of 64 tour riding and school horses

	Question 1[b]	Question 2[c]	Question 3[d]	Question 4[e]
Height at withers (cm)	0.46	0.39	0.53	0.22
	P = 0.00	P = 0.00	P =< 0.0001	P = 0.88
Height at lowest point at back (cm)	0.44	0.37	0.40	0.29
	P = 0.00	P = 0.00	P = 0.00	P = 0.02
Height at highest point at croup (cm)	0.44	0.39	0.39	0.36
	P = 0.00	P = 0.00	P = 0.00	P = 0.00
Height at withers – Height at lowest point at back (cm)[f]	–0.01	0.05	0.24	–0.14
	P = 0.93	P = 0.71	P = 0.06	P = 0.29
Height at withers – Height at highest point at croup (cm)[f]	–0.03	–0.00	0.21	–0.23
	P = 0.84	P = 0.98	P = 0.09	P = 0.07
Height at highest point at croup – Height at lowest point at back (cm)[f]	0.03	0.07	0.00	0.16
	P = 0.85	P = 0.60	P = 1.00	P = 0.20
Ribs condition score	0.04	0.03	0.03	–0.05
	P = 0.80	P = 0.84	P = 0.83	P = 0.68
Tail head condition score	–0.11	0.03	0.03	0.19
	P = 0.46	P = 0.81	P = 0.82	P = 0.14
Back condition score	0.05	0.11	0.07	–0.02
	P = 0.70	P = 0.38	P = 0.58	P = 0.90
BCS_{mean}	–0.00	0.05	0.04	0.03
	P = 0.98	P = 0.70	P = 0.74	P = 0.80
BCS_{mean} excl. back[g]	–0.01	0.03	0.03	0.04
	P = 0.94	P = 0.79	P = 0.79	P = 0.78
Back angle (degrees)[h]	–0.06	–0.11	–0.08	–0.11
	P = 0.70	P = 0.40	P = 0.52	P = 0.39

a Henneke *et al.* (1983).
b How do you think the horse manages long-distance tours over several hours (mostly walk with shorter distances with tölt, trot or gallop) with a rider (70-85 kg) (scale 0-10)?
c How do you think the horse manages fast tölt (or gallop) for a longer distance (1-2 km) with a rider (70-85 kg) (scale 0-10)?
d What is your opinion about the general weight carrying capacity of the horse (scale 0-10)?
e How would you describe how the horse is working in general as a tour riding horse/school horse (e.g. time in duty, willingness, injuries, etc.) (scale 0-10)?
f Difference between two height measurements.
g Back condition score excluded from the mean.
h Measured with a flexible curve ruler placed at the level of the 18th thoracic vertebra.

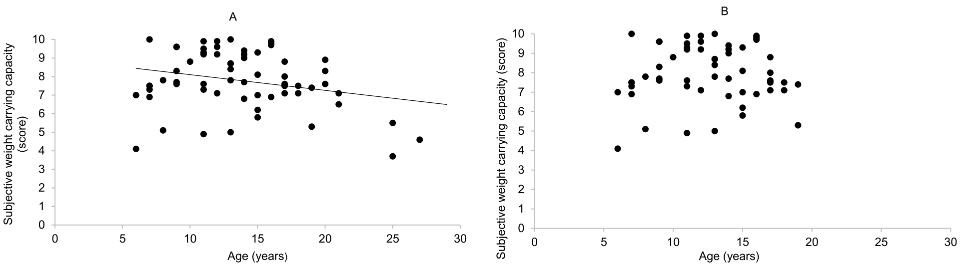

FIGURE 2 Relationship between horse age and owners' opinion about weight carrying capacity (question 3 – *What is your opinion about the general weight carrying capacity of the horse* (*scale 0-1*)) in (A) 64 tour riding and school horses (r = –0.26, $P < 0.05$). (B) Horses aged ≥20 (n = 8) are excluded ($P > 0.05$).

Association between back shape and performance in a BEFT and subjectively evaluated weight carrying capacity in TRh

Back condition score and back angle were not correlated with the scores from the ridden assessments in BEFT ($P > 0.05$), or with the subjective assessment of weight carrying capacity in TRh ($P > 0.05$, Table 3). The average judges' score for back and croup in BEFTh was 7.84 ± 0.53 and was positively correlated with total score for riding ability (r = 0.87, $P < 0.0001$).

4 Discussion

The results showed several differences in body measurements and BCS between BEFTh and TRh. Compared with TRh, BEFTh had a more uphill conformation (greater difference between height at withers and height at back and croup), which is known to be favourable for performance in a BEFT (Kristjansson *et al.*, 2016). In comparison with BEFTh, TRh had a greater back incline (greater difference between height at croup and back, where the croup is higher than the back), which has been shown to be unfavourable for riding ability in a BEFT (Kristjansson *et al.*, 2016). The anatomical reason for the more uphill conformation in BEFTh compared with TRh may be longer front legs, since long legs are desired (although not truly measured in a BEFT) according to the international breeding goal for Icelandic horses (FEIF, 2023). In addition, long and high strides with wide movements are rewarded in the gait assessment in BEFTs, and are presumably facilitated by longer legs. Length of the front legs has also been found to have a positive correlation with speed in walk, canter and pace in a BEFT, where speed was positively correlated with scores for all gaits except slow tölt and canter (Stefánsdóttir *et al.*, 2021). Furthermore, a novel QTL has been associated to leg length and lateral gait quality (Rosengren *et al.*, 2021).

The observed differences in body measurements between BEFTh and TRh are likely due to the theory that BEFTh are pre-selected, particularly based on riding qualities (Albertsdóttir *et al.*, 2011). Of all horses born in Iceland, only about 12% are assessed in a BEFT and a high heritability has been found for the trait 'participation in a BEFT' (Albertsdóttir *et al.*, 2011). In the same study, a strong genetic correlation was found between this trait and riding ability. This indicates that BEFTh are not a random sample of the Icelandic horse population. Accordingly, it can be assumed that TRh are often horses perceived to score low in a BEFT (for conformation and riding ability) and are instead used for tour riding and riding lessons due to other traits that are desirable for that task (Sigurðardóttir and Helgadóttir, 2015). Another hypothesis is that body measurements are affected by training, since the uses and work done by BEFTh and TRh differ and, anecdotal evidence suggests that training has effects on conformation. However, the effect of training on conformation traits has, as far we know, never been scientifically studied.

Compared with BEFTh, TRh had higher mean BCS, higher individual scores for ribs and back and smaller back angle. The lower mean BCS in BEFTh compared with TRh was not unexpected, and may be due to riders and owners of BEFTh prioritising lower body condition in order to get higher scores in the BEFT. 'Good body condition' is expected (FEIF, 2023), and performance in the ridden assessment in a simulated BEFT has also been shown to be improved in Icelandic horses with lower mean BCS (5.7) compared with horses with higher mean BCS (6.1) (Jansson *et al.*, 2021). The lower back condition score and greater back angle in BEFTh means that BEFTh had a 'thinner' back than TRh. This indicates that TRh had more fat deposited along the back or possibly a larger *m. longissimus dorsi* compared with BEFTh. Ultrasound scans of the back at the site of subjective back scoring and objective measurement of back angle are needed to determine the fat and muscle thickness of the back, but were not performed in this study.

A tendency for a greater height at withers in BEFTh compared with TRh was found in the present study. It has earlier been shown that height at withers has a bell-shaped relationship to performance in a BEFT, with an optimum height of 146 cm (Kristjansson *et al.*, 2016). This indicates that a relatively high height at withers is favourable for performance in a BEFT and is considerably greater than the mean height at withers (around 140 cm) for horses in the present study and in previous studies (Herbrecht *et al.*, 2020; Kristjansson *et al.*, 2016; Stefánsdóttir *et al.*, 2014).

Overall, horse owners were satisfied with the usability of their TRh, based on the relative high scores awarded in responses to all questions (mean score ranging from 7.5 to 8.0 on a scale of 0-10). However, it can be assumed that TRh with low usability have been excluded from the company before this study. A positive correlation was found between height at withers and the owners' opinion about usability during tours (questions 1-2) and weight carrying capacity (question 3). This indicates that height at withers is important for usability in TRh and not only for performance at breeding tests (Holmström and Philipsson, 1993; Kristjansson *et al.*, 2016; Stefánsdóttir *et al.*, 2021). However, height at withers has not been found to be correlated with weight carrying capacity in previous studies (Powell *et al.*, 2008; Stefánsdóttir *et al.*, 2017). In this study, the usability of the horses was evaluated by the owner and only reflected the owner's perspective, which might not be the same as the horse's physiological response during exercise. In addition, horses with greater height at withers are generally perceived to be able to carry larger riders, which may have resulted in owners scoring weight carrying capacity lower in horses with lower height at withers. Height at back and croup was also positively correlated with scores to all questions (questions 1-4), showing that greater height at back and croup was perceived as beneficial for usability in TRh, including weight carrying capacity. Height at croup has been shown to be correlated to performance in a BEFT, but not height at back (Kristjansson *et al.*, 2016). In comparison to findings in horses participating in a BEFT (Kristjansson *et al.*, 2016), the difference between height at withers and height at back and croup did not influence the horse owners' opinion about usability in TRh.

An interesting finding was that BCS did not influence the owners' opinion about usability in TRh, since this trait is reported to be important for performance in various breeds and disciplines (Garlinghouse and Burrill, 1999; Jansson *et al.*, 2021; Leleu and Cotrel, 2006).

The relationship between back measurements and performance in a BEFT has earlier been investigated by Kristjansson *et al.* (2016), but the association between back condition score and back angle and riding ability has not been investigated previously. In the present study, the subjective score for back and croup (obtained from WorldFengur) was positively correlated with riding ability in BEFTh, but no correlations between back condition score and angle and riding ability were found. In this study, no objective measurements of the croup were performed, so the possible association between croup measurements and riding ability in BEFTh and subjective evaluated weight carrying capacity in TRh was not examined. For BEFTh, a back condition score of less than a 4 or above 4.9 were not represented in our study and therefore, the association between an extremely thin or broad back on riding ability was not investigated. Furthermore, owners' opinion about weight carrying capacity in TRh did not correlate with back condition score and back angle, or with the incline of the back (e.g. an uphill conformation). Since TRh carry riders of different weights, knowledge about conformation traits that are beneficial for weight carrying would make it easier for owners when matching riders with horses. Further studies are therefore needed on this issue.

In the body condition scoring method used in this study (Ringmark *et al.*, 2013, modified from Henneke *et al.*, 1983), the back is given an individual score based on a visual assessment. However, this subjective scoring can lead to between-person differences, so, an objective method to measure the back of the horse is urgently needed. The flexible curve ruler (as we used in the present study) is easy to use, has high repeatability and can be used as a complement to subjective assessment. When the last rib is identified in order to find T18, the middle part of the rib can easily be palpated, except in extremely fat horses. However, it can be more difficult to follow the rib to its proximal part and conjunctive vertebra. As a complement to the flexible curve ruler, an objective method based on three-dimensional (3D) light-scanning could potentially be used in the future to measure cross-sectional area of the back (Tabor *et al.*, 2022).

Some body measurements and BCS data detected in TRh were associated to years of experience (years in the present company). Horses with ≥8 years of experience had a smaller difference between height at withers and height at back, and thus a less uphill conformation than horses with less experience. This did not seem to be affected by age, because no correlation was found between age and the difference between height at withers and height at back ($P > 0.05$, data not shown). The reason for the difference in body measurements and BCS between TRh with different duration of experience is unclear and, considering the relatively small sample size, it might be a coincidence.

Some differences in body measurements were also found between TRh measured in Iceland and TRh measured in Sweden, where horses in Iceland had lower height at back and croup than horses in Sweden ($P < 0.05$, data not shown, but included in the statistical model). The reason and the importance of that difference is unclear. However, height at withers did not differ between countries ($P > 0.05$), which is in agreement with observations on Icelandic competition horses in Denmark, Iceland, Sweden and Germany (Herbrecht *et al.*, 2020). Compared with TRh in Sweden, TRh in Iceland had a more uphill conformation (difference between height at withers and height at back and croup) ($P < 0.0001$) and a greater back angle ($P < 0.05$), which was more similar to the body measurements seen in BEFTh. This may indicate that breeding progress has been more successful in Iceland. However, only 16 of the horses measured in Sweden had parents where both of them were born in Sweden, which contradicts that it was an important genetic difference between horses in Sweden and horses in Iceland.

A limitation with the present study was the unequal distribution of sexes and the difference in mean age between BEFTh and TRh. However, age (included in the statistical model) as well as age class for TRh had no effect on body measurements and BCS ($P > 0.05$). As earlier reported for Icelandic horses (Stefánsdóttir *et al.*, 2014) and for Swedish Warmblood horses (Holmström *et al.*, 1990), geldings and stallions had greater height at withers than mares ($P < 0.05$, data not shown but included in the statistical model). Stallions had greater height at back, a greater difference between height at withers and height at croup, and lower tail condition score compared with mares ($P < 0.05$). They also had lower mean BCS and ribs condition score than geldings and mares ($P < 0.05$), which is in agreement with findings by Stefánsdóttir *et al.* (2014). Height at croup was greater in geldings than mares ($P < 0.05$). The differences between sexes may, to some extent, explain the differences in body measurements between BEFTh and TRh. Back condition score and back angle did not differ between the sexes ($P > 0.05$), so the difference in back shape between BEFTh and TRh may not be attributable to the unequal distribution of the sexes in our sample.

5 Conclusions

Several differences in body measurements and BCS were found between BEFTh and TRh, where BEFTh had a more uphill conformation, thinner backs (greater angle) and lower BCS compared with TRh. The body measurements in BEFTh were similar to that shown previously to be favourable for riding ability. In TRh, greater height at withers, back and croup were perceived favourable for usability and weight carrying capacity. Back condition score and angle were not associated to riding ability in BEFTh or to subjectively evaluated weight carrying capacity in TRh. However, further studies are needed to investigate if the same conformation traits are associated to good performance in BEFTh and usability in TRh.

Supplementary material

Supplementary material is available online at: https://doi.org/10.6084/m9.figshare.24850569

Materials and methods S1. Questionnaire.

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Authors' contribution

Conceptualisation and Methodology, A.J., D.S. and G.S.; Data curation, A.J., D.S., V.G. and G.S.; Formal analysis, D.S.; Project administration, D.S. and A.J.; Writing – original draft, D.S.; Writing – review and editing, A.J., D.S., V.G., G.S., S.R. and M.R.; Responsibility for the overall content, D.S. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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RESEARCH **Open Access**

Physiological response to weight carrying and associations with conformation traits in Icelandic horses used for tour riding

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Abstract

Background Weight carrying capacity is an important trait in riding horses and it may be associated with conformation. This study examined the physiological response to a ridden incremental weight carrying test in 16 adult Icelandic horses used for tour riding. Horses carried 20% ($BWR_{20\%}$), 25% ($BWR_{25\%}$), 30% ($BWR_{30\%}$) and 35% ($BWR_{35\%}$) of their body weight (BW) in tölt (~5.7 m/seconds, 640 m/step), and associations with body measurements and back conformation (score) were examined. Horses were divided into two groups (narrow or broad back) and body measurements were collected. Plasma lactate was analysed in blood samples collected after each step in the exercise test, an exponential equation was fitted, and BW-ratio was calculated for 2, 3 and 4 mmol/L (BWR_{La2}, BWR_{La3} and BWR_{La4}). Plasma creatine kinase (CK) and aspartate amino transferase (AST) were analysed at rest and 24 h post exercise.

Results Four out of 15 horses did not reach a plasma lactate concentration of 4 mmol/L, even at $BWR_{35\%}$. A positive correlation was found between chest width and BWR_{La4} and between the difference between height at withers and croup and BWR_{La2} ($P < 0.05$). Hock circumference and the difference between height at croup and back were negatively correlated with BWR_{La2} ($P < 0.05$). The change in CK from rest to 24 h post exercise was negatively correlated with the difference between height at withers and height at back and croup ($P < 0.05$).

Conclusions The physiological response to weight carrying was relatively low. A wider chest, "uphill" conformation, straight backline and smaller hock circumference were associated with weight carrying capacity, but group (narrow or broad back) was not.

Keywords Back, Body measurements, Equine, Rider weight, Weight carrying exercise test

Background

The Icelandic horse is a popular breed in numerous countries that is often used for tour riding and in riding schools. The breed is rather small, with mean height at withers around 140 cm and body weight (BW) 330–370 kg [1]. Compared with other breeds of similar size, the Icelandic horse is more often ridden by adult riders, creating a need for great weight carrying capacity in the breed. It is well known that increased weight carrying during exercise affects the physiological response [2–4] and gait parameters [5–7] in several horse breeds, including the Icelandic horse.

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Increased weight carrying might also influence the behaviour [7]. Some tour riding companies and equestrian associations have implemented weight limits of the rider intended to enhance the welfare of the horses [4, 8]. However, scientific knowledge about weight carrying capacity and associations with conformation is needed and could be useful e.g. in riding schools and in tour riding companies.

A previous study investigated the physiological response during a weight carrying exercise test in Icelandic horses used for higher riding education [4]. In that study, BW-ratio (BWR) between rider and horse was 20, 25, 30 and 35% and showed a positive correlation with magnitude of the physiological response in the horses. On average, the horses reached the lactate threshold (plasma lactate concentration 4 mmol/L) at BWR ~ 23%, but horses with higher back score (i.e. a broader back at the thoracolumbar region) appeared to reach the lactate threshold at higher BWR [4]. Similarly, another study [3] found that light riding horses with wider loins (measured at the cross-section between L1 and L2 vertebra) showed less muscle soreness and tightness 24 h after weight carrying compared with horses with narrower loins. A broad, well-muscled back is also anecdotally perceived to be beneficial for weight carrying capacity in horses and is rewarded in subjective conformation assessments in breed evaluation field tests (BEFTs) for Icelandic horses [9]. A recent study [10], which subjectively assessed weight carrying capacity in 65 Icelandic horses used for tour riding and in riding schools found that weight carrying capacity was positively correlated with height at withers, back and croup, but not with the difference between height at withers and height at back and croup. A greater difference between height at withers and height at back and croup ("uphill" conformation) is known to be important for riding ability in Icelandic horses participating in BEFTs [11]. Studies investigating the influence of conformation on weight carrying capacity are however scarce and the findings are not entirely consistent [3, 4, 10]. Further knowledge about this, and especially if it can be applied to individual horses, could be useful when matching riders with horses, and thus for animal welfare and performance.

The aims of the present study were to examine the physiological response to a ridden weight carrying exercise test in Icelandic horses used for tour riding and (i) associations with body measurements and (ii) the effect of a narrow and a broad back. It was hypothesised that a broad back is associated with improved weight carrying capacity.

Methods

Horses

The experimental study was conducted at Hólar University, Iceland, on two occasions in October 2021 and 2022. In total 16 horses (nine geldings, seven mares), aged 10–22 years and with BW 386 ± 32 kg recorded 1–3 days before the exercise test, were included in the analysis of the association between physiological response at a ridden weight carrying exercise test and body measurements. Prior to the study, horses were selected during visits to two tour riding companies (n = 4 and 12 horses, respectively), located near the university. All horses had been used in tours during the previous summer and occasionally during September. All were assessed by their owners as able to perform the planned ridden weight carrying exercise test. Half of the horses from each company were scored with a back score of < 4.5 (median 4.25), i.e. narrow back (N) and the other half, with the same work experience and of equal age, with a back score of > 4.5 (median 4.9), i.e. broad back (B) [4, 12], resulting in two different groups (Table 1). Back score has been shown not to be significantly affected by changes in overall body condition (scores 5.7–6.1) of Icelandic horses [13]. At the time of the experiment, back was scored lower (a score of 4.5) than in pre-selection in two horses initially included in group B. Therefore, these two horses were excluded from analysis of the effect of a narrow or broad back, which resulted in a total of 14 horses (N: n = 8, B: n = 6) included in that analysis (Table 1). The number of horses included in each group was determined from a power calculation based on results from a previous study [4].

Table 1 Back measurements, BCS[a] and age (mean ± SD) of 14 participating Icelandic horses

Variable	N[b]	B[c]	*P*-value
Back score[d]	4.25 (range 4.0–4.25)	4.90 (range 4.75–6.0)	< 0.05
Back angle (degrees)[e]	18.3 ± 1.0	14.5 ± 1.4	< 0.0001
Loin angle (degrees)[f]	16.5 ± 1.7	13.4 ± 1.1	< 0.05
BCS[a]	5.1 ± 0.5	6.2 ± 0.4	< 0.05
Age (years)	15 ± 4	15 ± 3	0.713

BCS body condition score

[a] Assessed on a continuous scale of 1–9, including assessments of ribs, back and tail head [12]

[b] Horses with narrow back (n = 8)

[c] Horses with broad back (n = 6)

[d] Values shown are median, due to non-normally distributed data

[e] Measured with a flexible curve ruler placed at the 18th thoracic vertebra

[f] Measured with a flexible curve ruler placed at the lumbar region at the level of the caudal part of the last rib

Preparation

The selected horses arrived at the university 9–12 days before the exercise test for acclimation and training (10 in 2021, six in 2022), except for two horses that arrived five and six days before the exercise test, respectively. The horses were housed in individual boxes and kept outside in a gravel paddock for 0–3 h/day and on pasture for 1–3 h/day. On the experimental day, the horses were kept in their boxes until the exercise test. At arrival and at least one more time during the preparation period, the horses were weighed (Tru-Test scales, Model 702; Tru-Test Ltd, Auckland, New Zealand) in order to adjust the amount of feed. In addition to pasture, hay was fed in the boxes three times/day (in total 0.75–1.0 kg dry matter (DM)/100 kg BW/day, with net energy and crude protein content 4.7 ± 0.8 MJ/kg and 155 ± 26 g/kg DM, respectively), based on recommendations of the minimum forage intake [14]. All horses had free access to salt blocks and water from automatic water bowls in the boxes. No feed was offered 2–3 h before the exercise test. All horses were ridden (by the same rider as in the exercise test) at least once during the preparation period and they were also exercised on a dry high-speed treadmill 4–6 times in walk and trot (< 30 min (min) at sub-maximal intensity, heart rate (HR) < 210 beats per minute (bpm)). All were rested for at least one day before the exercise test. To exclude any unhealthy and/or lame horses and evaluate if the exercise test had a negative impact on the health, a clinical examination was performed before the exercise test and 24 h after the test, by the same veterinarian who was blinded to groups. The examination included palpation of all four limbs and the thoracolumbosacral region, auscultation of the heart, using a stethoscope, and a flexion test of the limbs (including both proximal and distal joints) with a trot-up for approximately 50 m on gravel (all horses were shod).

Body measurements

Body condition score, angle of the thoracolumbar region and body measurements were collected.

Body condition score in the horses was assessed using a modified version of the Henneke scale [12, 15], where a separate score for ribs, thoracolumbar region (i.e. the back) and tail head was given on a continuous scale of 1–9. The overall BCS was calculated as a mean value from the three different body parts. The back was scored with an accuracy of 0.25 (Fig. 1), as described in a previous study [4]. The angle of the thoracolumbar region was measured by forming a flexible curve ruler (60 cm; Donau Elektronik GmbH, Matten, Germany) transversely over the back of the horse at two different sites: (i) at the 18th thoracic vertebra identified by palpation of the last rib (i.e. back angle), and (ii) at the height of the caudal part of the last rib (by palpating vertically from the rib up to the dorsal aspect of the lumbar region, i.e. loin angle; Fig. 2). The centre of the

(A)

(B)

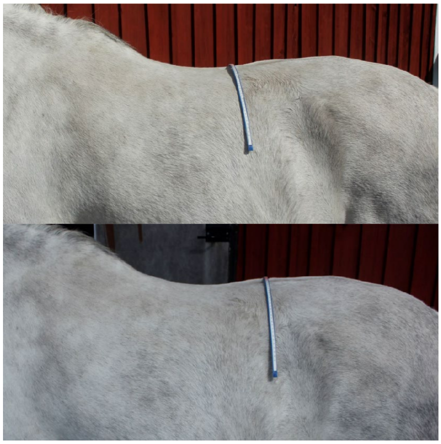

Fig. 2 Measurement of the thoracolumbar region at two different sites using a flexible curve ruler. Flexible curve ruler placed at (**a**) the 18th thoracic vertebra identified by palpation of the last rib (i.e. back angle) and (**b**) at the height of the caudal part of the last rib (by palpating vertically from the rib up to the dorsal aspect of the lumbar region) (i.e. loin angle)

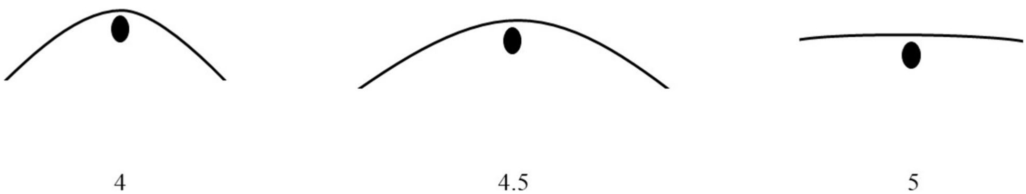

Fig. 1 Illustration of the thoracolumbar region of the back with different condition scores. Scores are ranging from 4 to 5 with 0.25 increments (a score of 4.25 and 4.75 are not shown in the figure) as described in a previous study [4] and based on the Henneke scale [12]. The backs are illustrated from a caudal view, and the black dots symbolises the spine

ruler was marked to ensure accurate positioning on the vertebra. The ruler was then removed carefully and placed onto a paper and the resulting curve was drawn. A horizontal line, extending from the left to the right side of the curve, was drawn 2 cm below the top of the curve. The angle between the top and the left and right side of the curve, at the level of the drawn line, was measured with a goniometer (15 cm; Primed, Halmstad, Sweden; Fig. 3) and a mean value was calculated from both sides of the curve. The within coefficient of variation (CV) for measurements of the angle at the 18th thoracic vertebra using the flexible curve ruler was in a previous study 1.2%, based on duplicate measurements on 68 horses [10]. The angle measurements were performed by this same person in the current study.

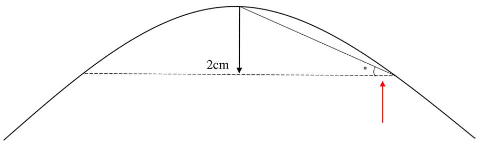

Fig. 3 Curve from measurements of the thoracolumbar region on Icelandic horses using a flexible curve ruler. The angle (red arrow) of the region was measured from the drawn curve, using a goniometer [10]

Height at the highest point of the withers (highest thoracic vertebra), height at the lowest point of the back, height at the highest point of the croup (*tubera sacrale*), body length and breast depth were measured with a measuring stick. Body length was measured from the point of the shoulder (*tuberculum majus humeri*) to the caudal end of the hindquarters (horizontally to *tuber ischiadicum*) and breast depth was measured from the withers and straight down to the breastbone (*sternum*). Width of the chest between the points of the shoulders (*tuberculum majus humeri*), width of the *pelvis* between the points of the *pelvis* (*tubera coxae*), and width of the hips between the hip joints (*articulatio coxae*) were measured with a calliper. The maximum circumference of *carpus* and hock (*tarsus*), the minimum circumference of *metacarpus* and *metatarsus*, and back length were measured with a measuring tape. The circumference of the hock was measured around *tuber calcanei* and at the angle of the distal hock joints, and back length was measured from the cranial part of *tubera sacrale* to the highest point of the withers (Fig. 4).

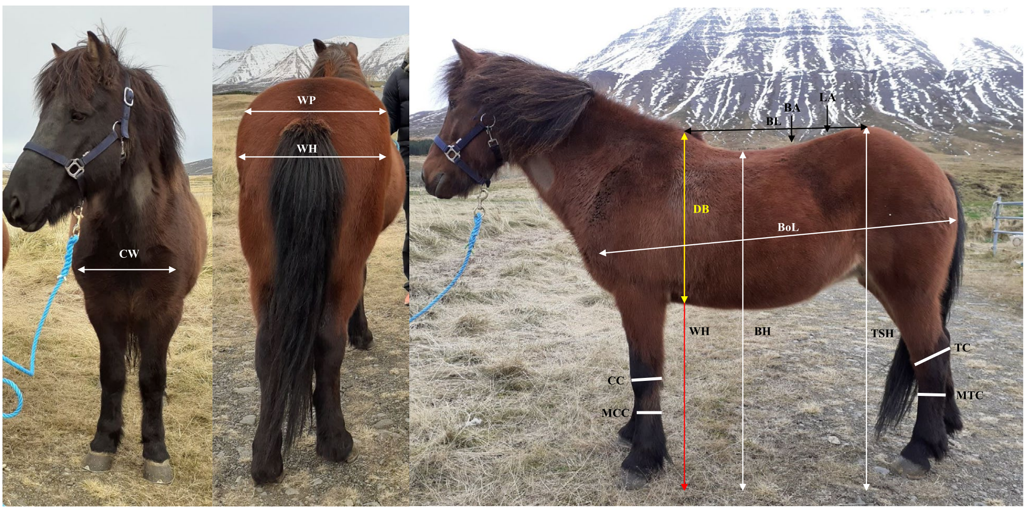

Fig. 4 Body measurements collected in 16 Icelandic horses. The measurements were: height at withers (highest thoracic vertebra) (yellow + red arrow) (WH), height at the lowest point of the back (BH), height at the highest point of the croup (*tubera sacrale*) (TSH), back length (BL), measured from the cranial part of *tubera sacrale* to the highest point of the withers, body length (BoL), measured from *tuberculum majus humeri* to the caudal end of the hindquarters (horizontally to *tuber ischiadicum*), breast depth (DB) (yellow arrow), measured from the withers and straight down to *sternum*, chest width (CW), measured between the points of the shoulders (*tuberculum majus humeri*), width of the *pelvis* between the points of the *pelvis* (*tubera coxae*) (WP), width of the hips between the hip joints (WH), maximum circumference of *carpus* (CC) and hock (*tarsus*) (TC) and minimum circumference of *metacarpus* (MCC) and *metatarsus* (MTC). Notice that the figure only describes the measurements and not the experimental conditions (experimental measurements were performed indoors on concrete floor and with horses in even body position)

All body measurements were made one or two days before the exercise test, with the horse standing square on a concrete floor, by the same person and at approximately the same time during the day for all horses (Table 2).

Exercise test

A ridden incremental weight carrying exercise test [4], was performed outdoors on a 257 m oval gravel track during two (2021) or three (2022) consecutive days. Equal number of horses from each group (N or B) performed the test in 2021 and 2022, to limit the effect of year. Horses from each group performed the test in alternating order, to limit effects of e.g. time of the day and weather conditions. In 2021, one male rider (73 kg, 178 cm) rode all horses, while in 2022, one female rider (70 kg, 165 cm) rode all horses. Both were advanced riders with a BSc degree in riding and riding teaching from Hólar University. The exercise test (total distance 2.9 ± 0.1 km) consisted of four steps with increasing weight carried by the horse for each step (see below) and 2.5 coherent laps on the track were ridden for each step. The horses carried 20.5 ± 1.4% of their BW in step 1 ($BWR_{20\%}$), 25.3 ± 0.4% in step 2 ($BWR_{25\%}$), 30.3 ± 0.3% in step 3 ($BWR_{30\%}$) and 35.4 ± 0.7% in step 4 ($BWR_{35\%}$). The weight carried in the exercise test was based on BW measured 1–3 days before the exercise test. The test was ridden on the left hand in tölt, at an average speed of 5.7 ± 0.2 m/seconds (s), which did not differ between the groups ($P > 0.05$). To facilitate adjustment of the speed, one person recorded the time between markings on the track, using a stopwatch, and regularly informed the rider via wireless communication (earpiece) if the intended speed (~ 5.5 m/s, i.e. similar to the mean speed measured in a previous study [4]) was maintained.

The exercise test was preceded by a mounted warm-up (total distance 1.6 ± 0.1 km) carrying the same weight as in step 1. The warm-up consisted of 5–7 min walking (1.8 ± 0.2 m/s) and 1.1 ± 0.1 km in tölt (4.9 ± 0.3 m/s). After the warm-up and between each step, horses were stopped and the rider dismounted for 7.0 ± 2.6 min to add weights and for collection of a blood sample.

Two different saddles were used (weight 6.0 kg and 8.4 kg, respectively), depending on the intended weight load. The heavier saddle (Ástund Super; Ástund, Reykjavík, Iceland) was specially adapted (by the producing company Ástund) with bags sewn onto the flaps where it was possible to add lead weights up to 8 kg on each side. In addition, two different saddle pads (weight 2.0 kg and 13.5 kg, respectively), extra-heavy stirrups (4 kg each) and a vest designed for scuba diving where lead weights (up to 16 kg) could be added to pockets. Due to discomfort for the rider, a weight vest specially designed for CrossFit® was used instead of the scuba diving vest during the experiment in 2022. To avoid imbalance, weights were added evenly on both sides. For the three horses with the greatest BW, during step 4 ($BWR_{35\%}$) a backpack filled with sand (up to 16 kg) was carried by the rider, either on the back or in front, in order to reach the intended weight. In 2022, two horses from group N and one horse from group B had boots on the front hooves (155–170 g each) in order to keep a clear-beat tölt during the exercise test.

Ambient temperature and wind speed were recorded continually at an automatic weather station (Model WH-1080; Clas Ohlson, Insjön, Sweden) located ~ 100 m from the riding track, and did not differ between years ($P > 0.05$). Values when the horse left the stable for the exercise test were noted. In the middle of each experimental day (10.00–13.00), median ambient temperature was 5.4 °C (range – 4.7–6.3 °C) and median wind speed was 2.7 m/s (range 0–8 m/s). Data on of wind speed were missing for one day, but it was not unusually windy on that day.

Table 2 Body measurements collected in 16 Icelandic horses

Variable (cm)	Mean ± SD	Range
Height at withers	138 ± 4	134–144
Height at back	127 ± 3	122–131
Height at croup (*tubera sacrale*)	136 ± 3	131–142
Height at withers–Height at back	11 ± 2	8–14
Height at withers–Height at croup (*tubera sacrale*)	3 ± 2	0–8
Height at croup (*tubera sacrale*)–Height at back	9 ± 2	4–11
Back length[a]	77 ± 3	71–83
Body length[b]	145 ± 3	141–153
Breast depth[c]	66 ± 2	62–70
Width of the chest[d]	37 ± 2	33–39
Width of the *pelvis*[e]	49 ± 2	45–53
Width of the hips[f]	45 ± 2	43–49
Circumference of *carpus*[g]	29 ± 1	27–31
Circumference of *metacarpus*[h]	19 ± 1	18–21
Circumference of hock[g]	36 ± 1	34–38
Circumference of *metatarsus*[h]	21 ± 3	18–31
Format of the horse[i]	7 ± 3	1–15

[a] Measured from the cranial part of *tubera sacrale* to the highest point of the withers

[b] Measured from *tuberculum majus humeri* to the caudal end of the hindquarters (horizontally to *tuber ischiadicum*)

[c] Measured from the withers and straight down to *sternum*

[d] Measured between the points of the shoulders (*tuberculum majus humeri*)

[e] Measured between the points of the *pelvis* (*tubera coxae*)

[f] Measured between the hip joints (*articulatio coxae*)

[g] Maximum circumference

[h] Minimum circumference

[i] Difference between body length and height at withers

Data collection

Heart rate, speed and distance were recorded continuously in the horses, using a HR recorder and GPS device (Polar Vantage M, HR Monitor; Polar Electro Oy, Kempele, Finland) from before the horses left the stable to 5 min after the exercise test. According to the manufacturer's technical specification, the accuracy of measured speed was ± 2 km/h and of measured distance ± 2%. The HR recorder and GPS device had a sampling rate of one measurement/s. Data from the HR recorder were imported into Microsoft Excel 2016 (Microsoft, Redmond, WA, USA) and a mean HR-value for the last 15 s in each step of the exercise test was calculated. During rest (before leaving the stable) and after 5 min of recovery, HR was noted directly in the HR recorder. Respiratory rate (RR) was measured by counting number of breaths for 15 s during rest and after 5 min of recovery. Rectal temperature (RT) was measured at rest and after a 5 min recovery, using a digital thermometer (Omron; HealthCare, Europe).

Blood sampling and analysis

Blood samples were collected in lithium heparin tubes (BD Vacutainer®, Plymouth, UK) at rest (2–6 days before the exercise test), immediately after warm-up and each step in the exercise test and after 5 min of recovery. Local anaesthesia was given before venipuncture (20 mg/mL, Xylocaine; AstraZeneca, Södertälje, Sweden). After collection, the blood samples were directly placed on ice. Hematocrit was measured (within one hour) in all samples except those collected at rest and after warm-up in 2022, using capillary glass tubes and centrifugation (8 min, 21,913 × g, Cellokrit; AB Lars Ljungberg & Co, Stockholm, Sweden). Duplicate analyses were performed, and the mean value was used in statistical analysis. To ensure that all horses reached, or were close to, the lactate threshold during the exercise test, blood lactate concentration was analysed directly after the exercise test in the samples collected after step 4 (Lactate Pro 2 analyser; Arkray, Kyoto, Japan). Horses with low (< ~ 3 mmol/L) blood lactate concentrations were re-tested two days later (n = 2) with higher final BWR, and data on physiological parameters from the second exercise test were used in statistical analysis. Results from the Lactate Pro 2 analyser were not reported or used in the statistical analysis (see plasma lactate below).

Plasma was separated by centrifugation (10 min, 3000 rounds/min; Hettich, Tuttlingen, Germany) and stored at − 18 °C until further analysis. Plasma lactate was analysed by the laboratory at the Swedish University of Agricultural Sciences (SLU), in duplicate with an YSI 2500 Biochemistry Analyzer (YSI, Yellow Springs, Ohio, USA, CV = 1.6%), and a mean value was used for statistical analysis. Aspartate amino transferase (AST) and creatine kinase (CK) were analysed by SLU University Animal Hospital, in duplicate with a Chemistry Analyser (DxC 700 AU; Beckman Coulter, Indianapolis, USA, CV for AST = 0.3% and CK = 0.6%) in samples collected 2–6 days before the exercise test and ~ 24 h after the exercise test.

Statistical analysis and calculations

Body weight ratio at a plasma lactate concentration of 2 mmol/L (BWR_{La2}), 3 mmol/L (BWR_{La3}) and 4 mmol/L (BWR_{La4}) were estimated for individual horses in Microsoft Excel version 2016 (Microsoft, Redmond, Washington, USA) by obtaining the equation of the exponential regression between BWR and plasma lactate concentration for each step in the exercise test (Additional file 1). In one horse, a substantial part of step 4 was performed in gallop (and at a higher speed than the other steps). In another horse, the lactate threshold was reached already before the first step and therefore, BWR_{La2}, BWR_{La3} and BWR_{La4} were not estimated for these two horses. The BWR when the horse reached a HR of 180 bpm (BWR_{180}) and 190 bpm (BWR_{190}) were estimated for individual horses in Microsoft Excel version 2016, by obtaining the equation of the linear relationship between BWR for each step and the mean HR of the last 15 s in each step (Additional file 1). For one horse, HR data were lost in steps 2 and 3 due to connection issues with the HR recorder, while for another horse, there was no linear increase in HR, and these data were omitted from the analysis. In addition to BWR_{180} and BWR_{190}, BWR_{200} was estimated initially, but was not included in the final analysis due to few observations (i.e. the majority did not reach a HR of 200 bpm).

Statistical analyses were performed using SAS (version 9.4; SAS Institute Inc., Cary NC, USA). The effect of group on BWR_{La2}, BWR_{La3}, BWR_{La4} and physiological parameters in individual samples was analysed with a general linear model (PROC GLM) using the following model (i): $Y = \mu + a_i + b_j + c_k + d_l + e_{ijkl}$ where Y is observation, μ is mean value, a_i is fixed effect of group, b_j is fixed effect of year, c_k is fixed effect of sex, d_l is continuous effect of BCS and e_{ijkl} is the residuals (see statistical code in Additional file 1).

When several samples were included in the analysis, the effects of group and sample on physiological parameters were analysed with a general linear mixed model (PROC MIXED), adjusted for repeated measurements, and including the same fixed effects as in model (i), the interaction effect between group and sample and horse as a random effect. Speed was included as a continuous effect when analysing HR data, but was excluded from the other analyses since it had no effect in those ($P > 0.05$). Ambient temperature and wind speed were initially included in model (i) when analysing RR and RT after 5 min of recovery and BWR was initially included in the statistical model as a continuous effect when analysing physiological parameters. However, they had no effect (P > 0.05) and were therefore excluded from the final model.

Since several horses did not reach the lactate threshold, the horses were divided into two groups based on whether they reached the lactate threshold or not during the weight carrying exercise test. To investigate possible differences in body measurements between these groups, the following general linear model (PROC GLM) was applied (ii): $Y = \mu + a_i + b_j + c_k + e_{ijk}$, where Y is observation, μ is mean value, a_i is fixed effect of group, b_j is fixed effect of sex, c_k is continuous effect of age and e_{ijk} is the residuals (see statistical code in Additional file 1).

A *t*-test was used to compare weather conditions between years and the angle of the thoracolumbar region, BCS, age, BWR for each step in the exercise test and physiological parameters at rest between groups. Comparison of back score between groups was performed with a Wilcoxon rank sum test. Possible group effects on speed measured by the HR recorder were analysed with a general linear mixed model (PROC MIXED), adjusted for repeated measurements (iii): $Y = \mu + a_i + b_j + c_k + e_{ijk}$ where Y is observation, μ is mean value, a_i is fixed effect of group (N or B), b_j is fixed effect of sample, c_k is random effect of horse and e_{ijk} is the residuals (see statistical code in Additional file 1). Year (2021 or 2022) was initially included in model (iii) but was not significant and was removed from the final model.

Data on physiological parameters are presented as least square mean (LSM) ± standard error (SE) and values for BWR_{180}, BWR_{190} and BWR_{La4} when including all horses and other parameters as mean ± standard deviation (SD), unless anything else is stated. Correlations between body measurements and physiological parameters (BWR_{180}, BWR_{190}, BWR_{La2}, BWR_{La3}, BWR_{La4} and the difference in AST and CK levels between rest and 24 h post exercise) were determined using Pearson's correlation test. Normality of residuals was confirmed by visual assessments of QQ-plots. The significance level was set at P < 0.05.

Results

All horses except three completed the study with no signs of injury. Two horses (one from each group) had minor oedema in the distal limbs one day after the exercise test, and one of them (from group N) also had a small wound on the heel bulb at the left forelimb. Both these horses reached or exceeded the lactate threshold during the exercise test. Another horse, from group N, showed mild soreness on one side of the thoracolumbar region on the day after the exercise test. That horse also reached the lactate threshold during the exercise test. Plasma AST was higher before exercise (8.7 ± 0.4 µkat/L) compared with 24 h after the exercise test (8.2 ± 0.4 µkat/L; P < 0.05), but plasma CK did not differ between these time points (P > 0.05). In the horse with mild soreness, post exercise plasma AST (7.2 µkat/L) was near the median (7.1 µkat/L, range 6.1–16.4 µkat/L). A similar pattern was observed for CK (5.5 µkat/L, compared with median 6.6 µkat/L, range 3.8–25.3 µkat/L).

Physiological responses to the weight carrying exercise test

Four out of 15 horses (excluding horse 16, which performed a substantial part of step 4 in gallop) did not reach the lactate threshold, i.e. not even at $BWR_{35\%}$, and thus BWR_{La4} could not be estimated. One horse reached the lactate threshold already in step 1 and another six horses had plasma lactate concentration > 2 mmol/L in step 1 (and were therefore excluded from the analysis of BWR_{La2} and BWR_{La3}). It was possible to estimate BWR_{180} and BWR_{190} for a total of five horses, respectively, since the other horses did not reach these HR values (n = 5) or had higher HR already in step 1 (n = 9). Mean BWR_{180} and BWR_{190} was 26.2 ± 3.4% and 26.8 ± 4.7%, respectively.

Response in all horses, irrespective of group

Plasma lactate concentration (n = 14 horses) increased (P < 0.05) for each step in the exercise test (Fig. 5) and BWR_{La4} was 31.4 ± 4.1% (range 24.6–36.5%, n = 10 horses). Heart rate (n = 14 horses) was higher (P < 0.05) at $BWR_{30\%}$ and $BWR_{35\%}$ compared with $BWR_{20\%}$ and $BWR_{25\%}$ (Fig. 5, P < 0.05). Hematocrit (n = 14 horses) was higher (P < 0.05) in $BWR_{35\%}$ than in the other steps (Fig. 5). Respiratory rate and RT (n = 14 horses) were higher (P < 0.0001) after 5 min of recovery (82 ± 4 breaths/min and 38.5 ± 0.1 °C, respectively) than before exercise (30 ± 4 breaths/min and 37.0 ± 0.1 °C, respectively).

Group responses

Body weight ratio at plasma lactate concentration of 2 mmol/L, BWR_{La3} and BWR_{La4} did not differ between the groups N and B (Table 3, P > 0.05). Plasma lactate concentration and hematocrit also did not differ between the groups (P > 0.05), based on samples from all steps (1–4) during the exercise test or individual samples. However, for the hematocrit there was a significant interaction (P < 0.05), and in group B, the hematocrit was higher (P < 0.05) in $BWR_{35\%}$ than in $BWR_{20\%}$ and $BWR_{25\%}$, and this was not observed in group N (P > 0.05). Also, hematocrit was higher (P < 0.05) in $BWR_{30\%}$ than in $BWR_{20\%}$ in group B. The overall HR during the exercise test (recorded during steps 1–4) and in individual samples did not differ between the groups (P > 0.05). Respiratory

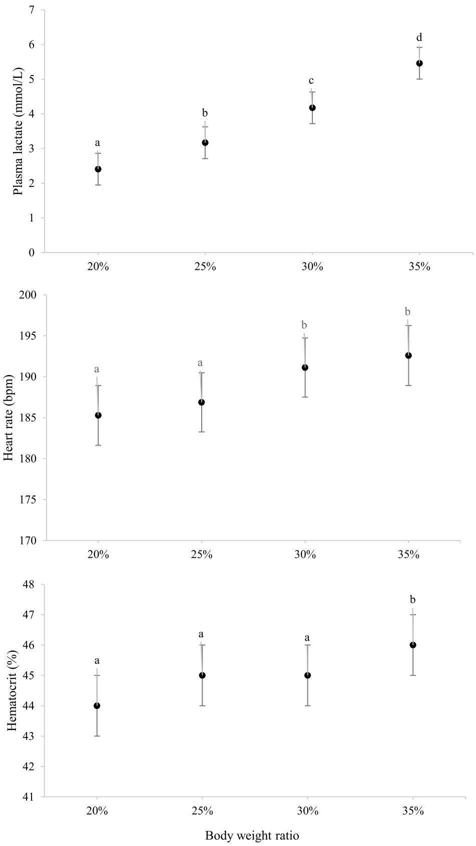

Fig. 5 Physiological responses recorded in 14 Icelandic horses during a ridden exercise test. Horses carried 20, 25, 30 and 35% of their body weight (LSM ± SE). Different letters (**a**–**d**) indicate differences between body weight ratio values (P < 0.05)

Table 3 Physiological responses in Icelandic horses during an incremental weight carrying test (LSM ± SE)

Physiological parameter	n	N[a]	B[b]	*P*-value
BWR_{La2}[c] (%)	8	27.4 ± 5.1	21.4 ± 6.9	0.642
BWR_{La3}[c] (%)	12	29.3 ± 2.6	26.5 ± 3.5	0.606
BWR_{La4}[c] (%)	10	31.3 ± 2.5	29.7 ± 2.9	0.734
$Hematocrit_{exercise}$[d] (%)	14	45 ± 1	44 ± 0.9	0.581
$Hematocrit_{step\ 4}$	14	46 ± 1	46 ± 1	0.642
$RR_{recovery}$[e] (breaths/min)	14	77 ± 8	86 ± 10	0.570
$RT_{recovery}$[e] (°C)	14	38.7 ± 0.2	38.2 ± 0.2	0.121
CK_{24h}[f] (µkat/L)	14	7.6 ± 1.1	7.1 ± 1.4	0.796
AST_{24h}[f] (µkat/L)	14	8.9 ± 0.7	7.5 ± 0.9	0.321
CK_{diff}[g] (µkat/L)	14	0.2 ± 0.7	1.6 ± 0.9	0.337
AST_{diff}[g] (µkat/L)	14	− 0.6 ± 0.4	− 0.3 ± 0.5	0.321

LSM least square mean

[a] Horses with narrow back (n = 8), i.e. a back score < 4.5 (median 4.25) [12]

[b] Horses with broad back (n = 6), i.e. a back score > 4.5 (median 4.90) [12]

[c] Body weight ratio at plasma lactate concentration of 2, 3 and 4 mmol/L

[d] Average hematocrit including all samples from the exercise test (steps 1–4)

[e] Respiratory rate (RR) and rectal temperature (RT) recorded 5 min post exercise

[f] Plasma creatine kinase (CK) and aspartate amino transferase (AST) levels recorded 24 h post exercise

[g] Difference between levels at rest and 24 h post exercise (post exercise minus rest)

rate and RT recorded at rest and after 5 min of recovery also did not differ between the groups (Table 3, P > 0.05). Group had no effect on CK and AST levels or on the change in AST and CK levels from rest to 24 h post exercise test (Table 3, P > 0.05).

Correlations between physiological responses and body measurements

Chest width was positively correlated (r = 0.77, P < 0.05) with BWR_{La4} (Fig. 6). Body weight ratio at plasma lactate concentration of 2 mmol/L was positively correlated (r = 0.68, P < 0.05) with the difference between height at withers and height at croup (*tubera sacrale*), and negatively correlated (P < 0.05) with the difference between height at croup (*tubera sacrale*) and height at back (r = − 0.71) and hock circumference (r = − 0.77; Fig. 6). The difference between height at croup (*tubera sacrale*) and height at back was also negatively correlated with BWR_{190} (r = − 0.92, P < 0.05), and tended to be negatively correlated with BWR_{La3} (r = − 0.57, P = 0.05). *Metatarsus* circumference was positively correlated with BWR_{180} (r = 0.96, P < 0.05). The change in CK levels between rest and 24 h post exercise (post exercise minus rest) was negatively correlated with the difference between height at withers and height at back (r = − 0.52, P < 0.05) and croup (*tubera sacrale*) (r = − 0.51, P < 0.05).

Differences in body measurements in horses that reached the lactate threshold and those that did not

Horses that reached the lactate threshold had higher BW (396 ± 7 kg) than horses that did not (357 ± 11 kg) (P < 0.05), but there were no other differences in body measurements or BCS between horses that reached the lactate threshold and those that did not (P > 0.05).

Discussion

To our knowledge, this is the first study to examine weight carrying capacity and the relationship to conformation in Icelandic horses used by tourist companies. Overall, the physiological response of the horses to weight carrying was relatively low, with average lactate levels of 5.5 mmol/L, HR < 195 bpm at the highest load,

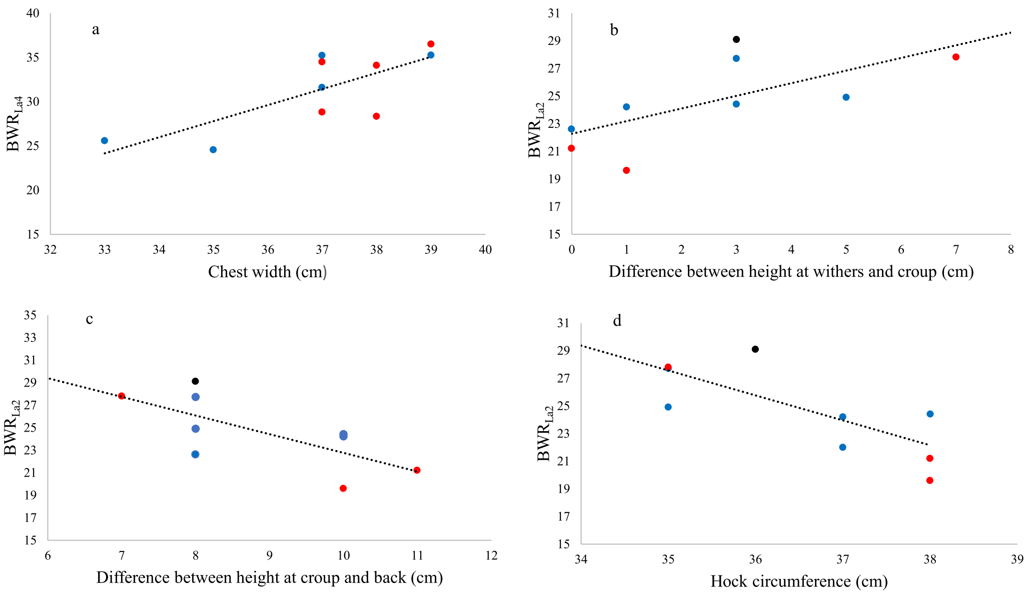

Fig. 6 Relationships between physiological parameters and body measurements in Icelandic horses performing a weight carrying test. The figure shows the relationship between **a** body weight ratio (BWR) at the lactate threshold (BWR_{La4}) and chest width ($r = 0.77$, $P < 0.05$), and between BWR at a plasma lactate concentration of 2 mmol/L (BWR_{La2}) and **b** the difference between height at withers and height at croup (*tubera sacrale*) ($r = 0.68$, $P < 0.05$), **c** the difference between height at croup (*tubera sacrale*) and height at back ($r = -0.71$, $P < 0.05$) and **d** hock circumference ($r = -0.77$, $P < 0.05$). Blue dots represent horses with narrow back (back score < 4.5), red dots horses with broad back (back score > 4.5) and black dots horses with a back score of 4.5 [12]

mean $BWR_{La4} > 30\%$, and four horses not even reaching the lactate threshold, despite carrying 35% of their BW. The response was also low compared with that observed in a previous study on Icelandic horses used for higher riding education, where eight horses reached the lactate threshold at an average BWR of ~ 23% [4]. The relatively low physiological response was unexpected, since the horses carried in total 120–160 kg in the last step ($BWR_{35\%}$), which is considerably heavier than the average weight of Scandinavian woman and men [16, 17] or of riders participating in BEFTs [1]. The horses in the present study were used to carry tourists of different body weights during long-distance tours (common distance 20–40 km/day for several days, where each horse carries a rider for approximately 7–10 km/day [18]), and compared with the Icelandic horses used for riding education studied previously [4], they presumably performed a different type of physical training and might have been physiologically and biomechanically adapted to carry heavier riders. In humans, weight carrying capacity seems to be associated with earlier experience of weight carrying [19], but no such study has been performed on horses. There are indications that Icelandic horses participating in a BEFT are pre-selected [20], and it might be the same for the horses in the current study, where the selection performed by the tour riding companies was based on qualities suitable for tour riding. A previous study showed that several body measurements differ between Icelandic horses participating in a BEFT and tour riding and school horses, but the importance of these differences and the underlying reasons are not known but were hypothesised to be due to e.g. pre-selection and training [10]. However, there was some variation in the physiological response of the horses in this study. For example, one horse was hypothesised to have reached the maximum HR at $BWR_{20\%}$ (i.e. a linear increase was not observed) and another horse reached the lactate threshold already before $BWR_{20\%}$. Similar variation in weight carrying capacity was detected in a previous study on a group of horses that had all been trained similarly [4]. The authors hypothesised that the underlying reason for the variation could be due to genetic factors [4].

As expected, the physiological response increased with increased BWR, which may in some respects be explained by an exercise duration effect. However, in the previous study [4], an additional step of $BWR_{20\%}$ was added in the end of the exercise test to investigate if the increased physiological response was due to an accumulated physiological effect or increased weight load. Plasma lactate concentration was shown to be lower in the last step compared with $BWR_{35\%}$ and HR was reduced to the same level as recorded at the first step [4], indicating that the increased physiological response was mainly due to an increased weight load.

The physiological response was similar for the two groups of horses (N and B) and no physiological parameter differed between the groups or was correlated with back score or angle of the thoracolumbar region. The angle measurements were performed in order to objectively assess back conformation, in addition to the subjective back score. Horses in group B (i.e. with broad back) had higher mean BCS compared with horses with narrow back, which was a limitation of the study since higher BCS is associated with increased physiological response in Icelandic horses [13]. However, no physiological parameter was correlated with BCS in the present study. Higher back score and lower angle of the thoracolumbar region (i.e. broader back) could be due to greater fat deposition at the thoracolumbar region, rather than a larger *m. longissimus dorsi*. However, the thoracolumbar region does not seem to be the primary location for fat deposition in moderately fleshy Icelandic horses [13]. To assess the effect of muscle mass on the back on weight carrying capacity, the size of *m. longissimus dorsi* should preferably be determined with ultrasound on horses with a similar overall BCS/body fat percentage.

Some body measurements were found to be associated with physiological parameters. For example, chest width was positively correlated with BWR_{La4}. A wider chest in horses with higher BWR_{La4} may be due to that the front limbs supports the majority of the body mass during a step in tölt [21]. It has also been shown that the ground reaction force in Dutch Warmblood horse's increases with a rider compared with trotting unmounted [22], which may indicate importance of a wide chest for weight carrying. Horses with wider chests may have a greater muscle mass in the chest area (although this was not truly measured in the present study), which in theory could be favourable for weight carrying. Lateral balance might also be enhanced with a greater distance between the front limbs. A wide chest has been shown to be favourable for riding ability in a BEFT, where the optimum width for highest subjective score for riding ability was found to be 40 cm, based on data from over 10 000 horses [11].

The difference between height at withers and height at croup (*tubera sacrale*) was positively correlated with BWR_{La2} and negatively correlated with the change in CK from rest to 24 h post exercise. In addition, there was a negative correlation between both BWR_{La2} and BWR_{190} and the difference between height at croup (*tubera sacrale*) and height at back (referred to as "back incline" in a previous study [11]). Back incline also tended to be negatively correlated with BWR_{La3}. Also the difference between height at withers and height at back was negatively correlated with the change in CK. This may indicate that an "uphill" conformation and a straight backline are favourable for weight carrying capacity, at least in the Icelandic horse. An "uphill" conformation and a smaller back incline (i.e. straight backline) have been shown to be associated with higher scores for riding ability in a BEFT [11] and are rewarded in the conformation assessment [9].

In summary, conformation traits found to have the strongest correlation with a physiological parameter and/or correlated with several physiological parameters, and thus considered as the most important conformational traits for weight carrying capacity, were: a wide chest, "uphill" conformation, straight backline and smaller hock circumference. Hock circumference was collected in addition to the equivalent joint measurement of *carpus* that are made at BEFTs for Icelandic horses [9]. A too small *carpus* circumference is described as an undesired trait [9]. However, it should be noted that a correlation does not necessarily mean that there is a causality, and it is hypothesised that the correlation between chest width and BWR_{La4} have a greater causality (see discussion above) than e.g. the correlation between hock circumference and BWR_{La2}. Considering the small number of horses (n = 5) in which BWR_{190} could be estimated, the importance of correlations to that parameter needs to be further investigated.

Interestingly, horses that reached the lactate threshold during the exercise test had higher BW (but not higher BCS) than horses which did not reach the lactate threshold. One possible explanation is that horses with lower BW had previously been ridden by heavier riders, relative to their own BW, and were adapted to higher BWR. This might also explain why smaller hock circumference (i.e. a smaller horse) was associated with greater weight carrying capacity. However, similar results have not been reported in previous studies on horses. Icelandic horses with higher BW have earlier been reported to show an increased physiological response during exercise [13]. However, those horses also had higher BCS and body fat percentage. In addition to BCS and body fat percentage, BW may also be affected by e.g. muscle mass and height. In humans, it has been reported that an increase in BW impair aerobic capacity (VO_{2max}), regardless of whether the increase is due to an increase in body fat content or in lean body mass [23]. However, BW was not associated with any other physiological parameter in the present study.

One day after the exercise test, an additional blood sample was taken to measure plasma concentrations of muscle enzymes (AST and CK) as an indicator of unaccustomed exercise [24, 25]. Unexpectedly and in contrast to earlier findings [4], plasma AST concentration was higher before the test than at 24 h after. The reason for this is unclear, but all horses performed sub-maximal treadmill exercise for several days in a row, with the last exercise bout occurring 1–6 days before collection of the blood sample in rest. Horses with fewer days between exercise and collection of the blood sample in rest had higher values of muscle enzymes (data not shown). The training intensity on the treadmill was relatively low, but the horses were not accustomed to that type of exercise, which may have led to unusual muscle utilization and associated leakage of enzymes from muscle cells to the blood stream. It has been shown that weekly repeated exercise reduces the increase in muscle enzymes in serum after exercise [24]. The horses in the present study were used to carry riders of different weights, which may explain the lack of increased plasma muscle enzymes after the ridden exercise test. However, the resting plasma AST level (8.7 ± 0.41 µkat/L) was only slightly higher than the resting reference value range (3.1–6.2 µkat/L [26]). Hence, the difference between levels before the test and at 24 h after might not be of any biological relevance. To reduce the effect of the previous treadmill training and of individual variation, the difference in AST and CK measured before the exercise test and 24 h after was calculated and used in correlation analysis.

Limitations of this study are the number of horses included, in total and in the two groups, and that several physiological parameters could not be estimated. However, the groups were only applied in the assessment of a narrow and broad back and not in the evaluation of the effect of other body measurements.

Conclusions

The physiological response to weight carrying in the tour riding horses used in this study was relatively low compared with earlier findings. In 27% of the horses, the lactate threshold was not reached although BWR exceeded 35%. A wider chest, "uphill" conformation, straight backline and smaller hock circumference were associated with improved weight carrying capacity (BWR_{La4} or BWR_{La2}), but group (narrow or broad back) had no effect on weight carrying capacity. However, further controlled studies are needed to confirm effects of conformation in individual horses on weight carrying capacity.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13028-025-00818-5.

Additional file 1 (Equations and statistical codes. File format: Microsoft Word.)

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Author contributions

DS performed the formal analysis, collected data and wrote the original draft. GJS, SR, VG and AJ designed the experiment and collected data. All authors participated in the editing process. All authors have read and approved the final version of the manuscript.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study was carried out under Reg. 460/2017 on the protection of animals used for scientific purposes, as permitted by the Icelandic Food and Veterinary Authority, Ref. No. 2109502.

Consent for publication

Written consent for publication of photos of the horses was obtained from the horse owners.

Prior publication

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Competing interests

The authors declare that they have no competing interests.

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ORIGINAL ARTICLE

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Relationship between weight-carrying capacity and performance in a standardized treadmill exercise test in horses

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Abstract
Weight-carrying capacity is important in riding horses both for performance and welfare, yet there is no standardized method to estimate individual horses' weight-carrying capacity. This study investigated the correlation between the physiological response during a (i) standardized incremental exercise test (SET) on a treadmill and a (ii) ridden incremental weight-carrying exercise test (WET). Sixteen horses (15 ± 3 years) performed both tests, including four steps with increased speed or weight load, respectively. Body weight ratio (BWR) in the WET was 20%, 25%, 30%, and 35% in each step, respectively. Blood samples were collected after each step, and heart rate (HR) was recorded. The velocity (SET) and BWR (WET) at a HR of 180 and 190 bpm and plasma lactate concentration of 2, 3, and 4 mmol/L were estimated. There was a correlation ($r = 0.92$, $p < 0.05$) between the velocity at a plasma lactate concentration of 3 mmol/L (V_{La3}) in the SET and the BWR at a HR of 180 bpm (BWR_{180}) in the WET, but no other correlations were found. In conclusion, the SET was not applicable to estimate weight-carrying capacity in the horse. Further studies should investigate the importance of the correlation between V_{La3} and BWR_{180}.

KEYWORDS
anaerobic threshold, equine, exercise physiology, rider weight, treadmill

1 | INTRODUCTION

Rider weight may impair the performance (Dyson et al., 2019; Gunnarsson et al., 2017; Stefánsdóttir, Gunnarsson, Roepstorff, et al., 2017) and influence the behavior of the horse (Dyson et al., 2019); thus, a great weight-carrying capacity is of significant importance in riding horses. It is frequently discussed in the horse industry how heavy the rider can be, especially on Icelandic horses, and some riding schools and tour riding companies have introduced a weight limit for the rider (Douglas et al., 2022; Stefánsdóttir, Gunnarsson, Roepstorff, et al., 2017). Knowledge about assessing weight-carrying capacity in individual horses, easily and standardized, could be useful, for example, for riding schools and other companies supplying riding services.

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The effect of weight carrying has earlier been examined with different types of ridden weight-carrying exercise tests on several horse breeds (Christensen et al., 2020; Dyson et al., 2019; Gunnarsson et al., 2017; Matsuura et al., 2016; Matsuura, Irimajiri, et al., 2013; Matsuura, Sakuma, et al., 2013; Powell et al., 2008; Stefánsdóttir, Gunnarsson, Roepstorff, et al., 2017; Van Oldruitenborgh-Oosterbaan et al., 1995). In addition to these studies, Van Oldruitenborgh-Oosterbaan et al. (1995) and McKeever et al. (2005) examined the effect of weights mounted on horses using a treadmill. In those studies, weight-carrying capacity was evaluated by the physiological response (Christensen et al., 2020; McKeever et al., 2005; Powell et al., 2008; Stefánsdóttir, Gunnarsson, Roepstorff, et al., 2017; Van Oldruitenborgh-Oosterbaan et al., 1995), evaluation of muscle soreness (Powell et al., 2008), locomotion analysis (Dyson et al., 2019; Gunnarsson et al., 2017; Matsuura et al., 2016; Matsuura, Irimajiri, et al., 2013; Matsuura, Sakuma, et al., 2013; Van Oldruitenborgh-Oosterbaan et al., 1995), and behavior assessment (Christensen et al., 2020; Dyson et al., 2019). However, there is no "gold standard" method to estimate weight-carrying capacity in horses. Furthermore, exercise tests with added weights require access to weights and that they are performed under standardized conditions (regarding physical environment, speed, distance, etc.). Adding a large amount of weight to the rider and/or the horse could also be a safety issue and a potential injury risk. Therefore, a standardized and safe method to estimate weight-carrying capacity in individual horses that can be implemented worldwide is of interest. The method could, for instance, be used by riding schools and tour riding companies where there is a large variation in rider weight, but also to describe weight-carrying capacity in individual horses for sale. Anecdotally, the conformation of a horse is often considered when estimating weight-carrying capacity, and a few studies have evaluated the effect of conformation on weight-carrying capacity (Powell et al., 2008; Söderroos et al., 2025; Stefánsdóttir, Gunnarsson, Roepstorff, et al., 2017). However, the evidence of the associations between conformation traits and weight-carrying capacity is weak. With today's knowledge, estimating weight-carrying capacity only by the conformation is unreliable.

Standardized incremental treadmill exercise tests (SETs) are commonly used to evaluate the fitness of the horse by, for example, estimating the anaerobic threshold (V_{La4}) (Bitschnau et al., 2010; Harkins et al., 1993; Jansson et al., 2021). The estimated V_{La4} (either on a treadmill or at field conditions) has been shown to correlate with true performance in both Standardbred trotters (Leleu et al., 2005; Ringmark et al., 2017) and Warmblood horses (Bitschnau et al., 2010). However, it is not known if the general aerobic capacity in a horse is associated with weight-carrying capacity and if it is possible to estimate weight-carrying capacity with a SET without any additional weight. In humans, it has been shown that aerobic fitness (estimated with a "beep" test) is correlated with weight-carrying capacity (Robinson et al., 2018), and the theory is that the same applies to horses.

The study aimed to investigate if the estimation of physiological parameters (e.g., V_{La4}) from an incremental SET on a treadmill could be used to estimate weight-carrying capacity in horses. The hypothesis was that the physiological response during a SET is associated with weight-carrying capacity.

2 | MATERIALS AND METHODS

The study was conducted at Hólar University, Iceland, in October 2021 and 2022. All horses performed two exercise tests: an incremental SET on a treadmill and a ridden incremental weight-carrying exercise test (WET).

The study was carried out under Reg. 460/2017 on the protection of animals used for scientific purposes, as permitted by the Icelandic Food and Veterinary Authority, Ref. No. 2109502.

2.1 | Horses and preparation

In total, 16 Icelandic horses (seven mares and nine geldings) aged 15 ± 3 years (range 10–22 years), BW 386 ± 32 kg (range 339–452 kg), were included in the study (10 in 2021 and 6 in 2022). The number of individuals was estimated with a power calculation, with a 5% significance level, 80% power, and an expected correlation coefficient of 0.7, based on previous results (Robinson et al., 2018). The horses were owned by tour riding companies located near the University. All horses had been actively used in tours the previous summer (and occasionally in September) and were estimated by their owners to be fit enough to perform the planned exercise tests. Approximately 1 week before the experiment started, horses arrived at the University for acclimation and training (Figure 1). The horses were stabled in individual boxes and kept outside in a gravel paddock for 0–3 h/day and on pasture for 1–3 h/day. Hay (4.7 ± 0.8 MJ/kg net energy and 155 ± 26 g/kg DM crude protein) was fed three times/day in the boxes. The daily amount was individually adjusted (0.75–1.00 kg DM/100 kg BW) based on recommendations from National Research Council (2007) regarding the minimum forage intake. Horses had free water access from automatic water bowls and 2 kg salt blocks in the boxes. No feed was offered within 3 h before the exercise tests.

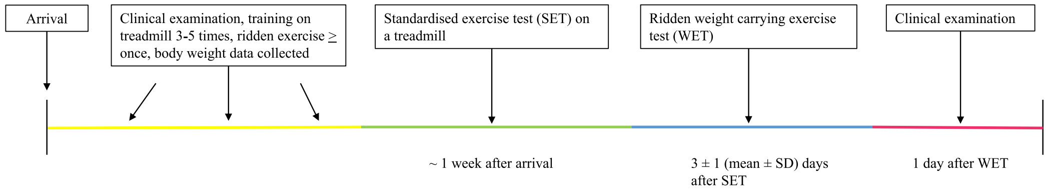


FIGURE 1 The timeline of the experiment, including two different exercise tests (SET and WET) and a preparation period.

At least once during the preparation period, horses were ridden by the same rider that rode them in the WET in order to get used to the horses. All horses were trained on the treadmill (Säto, Lövstabruk, Sweden) at a submaximal intensity 3–5 times before the SET to acclimate to the treadmill. The treadmill training was performed in walk and trot (although some horses were occasionally tölting), including periods with uphill inclination (6.25%) of the treadmill. During the last training session on the treadmill, horses were equipped with a heart rate (HR) monitor (Polar Vantage M; Polar Electro Oy, Kempele, Finland), and the speed where the individual horse reached or exceeded a HR of ~200 bpm was noted and applied in the last step of this individual's SET. It has been reported that the speed at which HR 200 bpm is reached is close to the anaerobic threshold (Persson et al., 1991).

Prior to the SET, horses were clinically examined by a veterinarian, including auscultation of heart sounds, palpation of the limbs and the thoracolumbosacral region, and a flexion test with a trot up on a gravel road. A similar examination was performed ~24 h after the WET (Figure 1).

2.2 | Standardized treadmill exercise test

After the preparation period (~1 week after arrival), horses performed a sub-maximal SET (Figure 1). The SET was performed on the treadmill and consisted of four steps with increasing speed (individual basis, see above) for each step (Jansson et al., 2002, 2021; Nyman et al., 2002; Persson, 1967; Persson et al., 1991) (Table 1). The SET was preceded by a 4-min warm-up in walk on the treadmill before the immediate start of step 1. Each exercise step lasted for 1.5 min before the speed was increased for the next step. In one horse, the last step was only 45 s (due to refusal to go forward). The test was aimed to be performed in trot, but some horses occasionally performed steps in tölt and two horses performed step 4 in canter. The SET was finished with a 2-min walk and 3 min of standing on the treadmill. The speed was manually determined during all steps in the SET by dividing the distance (belt length × number of revolutions) by the time measured for four revolutions. Immediately after both SET and WET, the lactate concentration in blood collected at step 4 (see below) was measured using a Lactate Pro 2 analyzer (Arkray, Kyoto, Japan). Horses with concentrations <3 mmol/L were re-tested the day after (SET, $n=3$), and data from the second test were used in statistical analysis.

TABLE 1 Description of the standardized treadmill exercise test (SET) performed in trot, including velocity (m/s) and duration (min) for each activity.

Activity	Velocity (m/s, mean ± SD)	Duration (min)
Warm-up walk		4
Step 1[a]	3.4 ± 0.3	1.5
Step 2[a]	4.3 ± 0.4	1.5
Step 3[a]	5.1 ± 0.4	1.5
Step 4[a]	6.0 ± 0.4	1.5
Walk	1.7 ± 0.0	2
Standing		3

[a]With a 6.25% incline.

The ambient temperature in the room during the SET was 13.0 ± 0.5°C.

2.3 | Ridden incremental weight-carrying exercise test

A WET was performed outside on an oval gravel track (257 m) 3 ± 1 days after the SET (Figure 1). One male professional rider and riding teacher (73 kg, 178 cm) rode horses tested in 2021, and one female riding teacher (70 kg, 165 cm) rode the horses in 2022.

The test was preceded by a mounted warm-up (1.6 ± 0.1 km), including walk (1.5 to 2.1 m/s) for 5–7 min and 1.1 ± 0.1 km tölt (5.3 ± 0.3 m/s). The WET (total distance 2.9 ± 0.1 km, including short distances of walk to get to the predetermined start position of the test) consisted of four steps in tölt (5.7 ± 0.2 m/s, ~640 m/step, duration = ~1.9 min/step) with increasing weight carrying in each step. The WET was ridden on the left hand in all horses. The time between markings on the track was recorded using a stopwatch to facilitate speed adjustment. The rider was regularly informed via wireless communication (earpiece) if the intended speed (~5.5 m/s) was kept. A higher speed was recorded in step 4 (5.8 ± 0.1 m/s) compared with the other steps (5.6–5.7 ± 0.1 m/s), and a lower speed was recorded in step 1 (5.6 ± 0.1 m/s) than in step 2 (5.7 ± 0.1 m/s) and step 3 (5.7 ± 0.1 m/s) ($p < 0.05$). Horses carried in average 20.5 ± 1.4% ($BWR_{20\%}$), 25.3 ± 0.4% ($BWR_{25\%}$), 30.3 ± 0.3% ($BWR_{30\%}$), and 35.4 ± 0.6% ($BWR_{35\%}$) of their BW at the four steps, respectively. After the warm-up and between each step, horses were stopped, and the rider dismounted for 5.4 ± 1.1 min to add weights and collect blood samples. Two horses were retested 2 days after the WET due to low blood lactate concentrations (~<3 mmol/L) at step 4.

Two different saddles (6 kg and 8.4 kg, respectively) were used in the test, depending on the intended weight load. The heavier saddle (Ástund Super; Ástund, Reykjavík, Iceland) had bags attached to the flaps where it was possible to add lead weights (up to 8 kg on each side). To increase the weight further, two saddle pads (13.5 kg and 20 kg, respectively), extra heavy stirrups (4 kg each), and a weight vest designed for scuba diving, filled with lead weights (up to 16 kg) inside pockets, could also be added. Due to discomfort for the rider, a weight vest specially designed for CrossFit® was used instead of the scuba diving vest during the experiment in 2022. Weights were evenly added on both sides to avoid imbalance. In three horses at the last step, the rider also carried a backpack filled with sand (up to 16 kg), either on the back or in the front. Another three horses had boots on the front hooves (155 g–170 g each) to keep a clear-beat tölt.

Ambient temperature and wind speed were registered with an automatic weather station, located ~100 m from the riding track and were noted when the horse left the stable for the WET. In the middle of each experimental day (10 AM-13 AM), the ambient temperature was 3.1 ± 4.5°C, and the wind speed was 3.6 ± 3.3 m/s. Registrations of wind speed were missing for 1 day, but it was not unusually windy that day.

2.4 | Data collection

During both of the exercise tests, HR was measured continuously with a HR recorder (Polar Vantage M; Polar Electro Oy, Kempele, Finland). Velocity was also measured with the HR recorder (GPS) during the WET. Recordings from each step during the exercise tests were exported to Microsoft Excel 2016 (Microsoft, Redmond, WA, USA), and the mean velocity in each step was calculated, as well as the mean HR at the last 15 s in each step.

Rectal temperature (RT) was measured with a digital thermometer (Omron; HealthCare, Europe) before the SET and WET and was 37.3 ± 0.3°C and 37.1 ± 0.4°C, respectively.

2.5 | Blood sampling and analyses

Before entering the treadmill (20–45 min prior to the exercise test), a catheter was placed in the jugular vein, and blood was drawn at the end of each step during the SET. In the WET, blood was collected by venipuncture after each step in the exercise test. Local anesthesia (20 mg/mL, Xylocaine; AstraZeneca, Södertälje, Sweden) was given before catheterisation and venipuncture. After sampling, blood was directly placed on ice and later analyzed for hematocrit (8 min, 21,913 × g, Cellokrit, AB Lars Ljungberg & Co, Stockholm, Sweden). Duplicate analyses were performed, and a mean value was used for the statistical analysis. The hematocrit value for one sample was missing in step 4 at the SET. Plasma was separated by centrifugation (10 min, 3000 rounds/min, Hettich, Tuttlingen, Germany) and stored at −18°C until lactate analysis. Plasma lactate was analyzed (YSI 2500 Biochemistry Analyzer, YSI, Yellow Springs, Ohio, USA, CV = 1.6%) in duplicate, and a mean value was used for statistical analysis.

2.6 | Statistical analysis and calculations

Velocity at a HR of 180 bpm (V_{180}) and 190 bpm (V_{190}) was estimated for individual horses in Microsoft Excel 2016 (Microsoft, Redmond, WA, USA) by applying the following equation and linear relationship between velocity and mean HR of the last 15 s in each step in the SET:

$$y = a + bx,$$

where y is the HR (180 or 190 bpm), a is the HR at a velocity of 0 m/s, b is the slope, and x is the velocity at $y = 180$ or 190 bpm.

A similar procedure was performed to estimate BWR_{180} and BWR_{190} (BWR at a HR of 180 and 190 bpm, respectively) in the WET. Also, V_{200} and BWR_{200} were determined but not statistically analyzed due to few observations (i.e., several horses did not reach a HR of 200 bpm during the WET ($n = 10$) and the SET ($n = 4$), respectively).

The velocity at the treadmill where the horses reached a plasma lactate concentration of 2, 3, and 4 mmol/L (V_{La2}, V_{La3}, and V_{La4}, respectively) was estimated by obtaining the following equation of the exponential relationship between velocity and plasma lactate concentration for each step in the SET:

$$y = a \times e^{bx}$$

TABLE 2 Physiological parameters recorded during an incremental standardized exercise test (SET) on an inclined (6.25%) treadmill and a ridden incremental weight-carrying exercise test on a track (WET) in 16 Icelandic horses.

SET			WET		
Parameter	*n*	Mean ± SD	Parameter	*n*	Mean ± SD
V_{180}[a] (m/s)	14	4.7 ± 0.5	BWR_{180}[a] (%)	5	26.2 ± 3.4
V_{190}[b] (m/s)	14	5.3 ± 0.5	BWR_{190}[b] (%)	5	26.8 ± 4.7
V_{La2}[c] (m/s)	14	4.4 ± 0.4	BWR_{La2}[c] (%)	9	24.6 ± 3.0
V_{La3}[d] (m/s)	14	5.2 ± 0.5	BWR_{La3}[d] (%)	12	28.4 ± 4.2
V_{La4}[e] (m/s)	9	5.5 ± 0.5	BWR_{La4}[e] (%)	10	31.4 ± 4.1
$Hematocrit_{step4}$[f] (%)	15	46 ± 4	$Hematocrit_{35\%}$[f] (%)	16	46 ± 2

[a]Velocity or body weight ratio, that is, rider weight as a percentage of the horse's body weight (BWR) at a heart rate (HR) of 180 bpm.
[b]Velocity or BWR at a HR of 190 bpm.
[c]Velocity or BWR at a plasma lactate concentration of 2 mmol/L.
[d]Velocity or BWR at a plasma lactate concentration of 3 mmol/L.
[e]Velocity or BWR at a plasma lactate concentration of 4 mmol/L.
[f]Analyzed from samples collected at step 4/$BWR_{35\%}$.

where y is the plasma lactate concentration (2, 3 or 4 mmol/L), a is the lactate concentration at a velocity of 0 m/s, b is the slope, and x is the velocity at $y = 2$, 3 or 4 mmol/L.

The same procedure was applied to estimate the BWR when the horse reached a plasma lactate concentration of 2, 3, and 4 mmol/L (BWR_{La2}, BWR_{La3}, and BWR_{La4}, respectively) during the WET. Data was missing in cases where horses had a HR > 180, 190, or 200 bpm or a plasma lactate concentration >2, 3 or 4 mmol/L already at the first step or when these values were not reached during the tests (see Table 2 for *n*). In addition, data was missing for one horse with no linear HR increase during the WET.

Principal component analysis (PCA) (Abdi & Williams, 2010) was performed in Umetrics SIMCA (version 17.0.2; Sartorius, Goettingen, Germany) and other statistical analyses in SAS (version 9.4; SAS Institute Inc., Cary NC, USA).

The relationship between physiological parameters recorded at the SET and WET was evaluated using Pearson's correlation test and visualization of a loadings plot for a PCA model. Data were scaled to unit variances before the PCA (Groth et al., 2013).

Possible differences in velocity between steps in the WET were analyzed with a general linear mixed model (PROC MIXED):

$$Y = \mu + a_i + b_j + e_{ij}$$

where Y is the observation, μ is the mean value, a_i is the fixed effect of step, b_j is the random effect of horse, and e_{ij} is the residuals.

Normality of residuals was evaluated by observing qq-plots. Data are presented as mean ± SD and the velocity at the different steps in the WET as LSM ± SE.

3 | RESULTS

3.1 | Correlations between the physiological response at the standardized treadmill exercise test and the ridden incremental weight-carrying test

Mean values of physiological parameters recorded at the SET and WET are presented in Table 2, and a visualization of the relationships between all recorded physiological parameters (presented as loadings) during the exercise tests is shown in Figure 2. No correlations between the corresponding physiological parameters recorded at the SET and WET were found (Table 3, $p > 0.05$). According to the loadings scatter plot for the PCA model, BWR_{180} seemed to be positively correlated with V_{La2}, V_{La3}, and V_{La4} (Figure 2), but only the correlation between V_{La3} and BWR_{180} was significant (Pearson's correlation test, Figure 3, $r = 0.92$, $p < 0.05$). No other combination of the physiological parameters was correlated ($p > 0.05$).

4 | DISCUSSION

This is the first study examining the association between aerobic and weight-carrying capacity in the horse by performing two different exercise tests. There was no correlation between V_{La4} and BWR_{La4} (i.e., the anaerobic threshold for each test) or other corresponding physiological parameters recorded at the SET and the WET. However, there was a strong correlation between V_{La3} and BWR_{180}. The reason for and the importance of the correlation between the lactate response at the SET and the HR response at the WET are unclear and need further investigation.

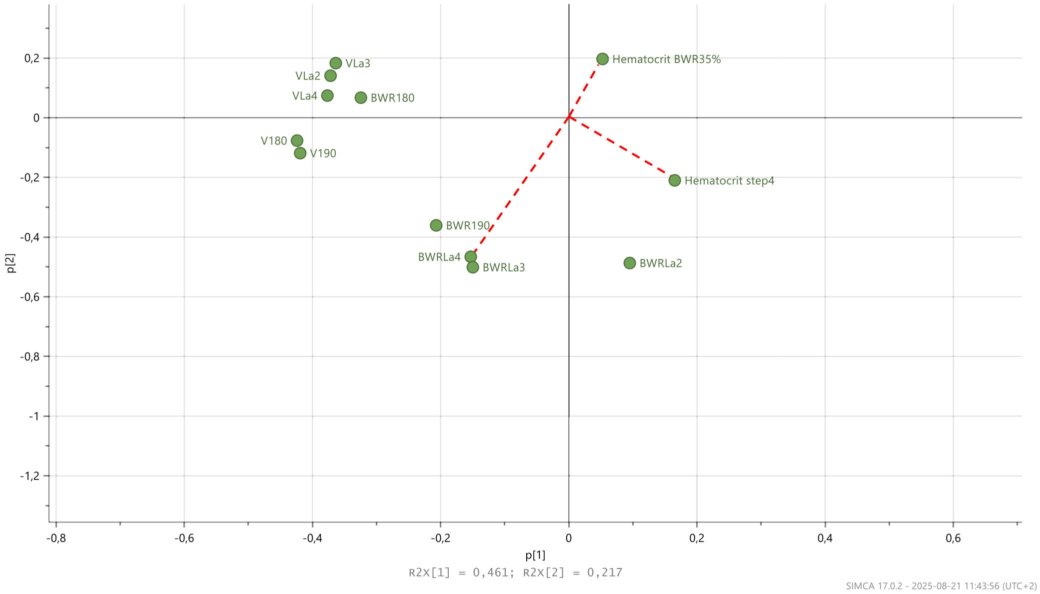


FIGURE 2 Results of a principal component analysis (PCA) that visualizes correlations between variables collected at an incremental standardized treadmill exercise test (SET) and at a ridden incremental weight-carrying exercise test on a track (WET) in 16 Icelandic horses. Variables close to each other are positively correlated, for example, velocity (SET) at a heart rate of 180 bpm (V180) and 190 bpm (V190). Variables opposite each other, forming an angle near 180 degrees, for example, hematocrit analyzed from samples collected at step 4 in the WET (BWR35%) and body weight ratio at the anaerobic threshold in the WET (BWRLa4), are negatively correlated. Variables situated close to 90 degrees from each other, for example, hematocrit analyzed from samples collected at step 4 in the SET (Hematocrit step4) and the WET (Hematocrit 35%), are unlikely to be correlated.

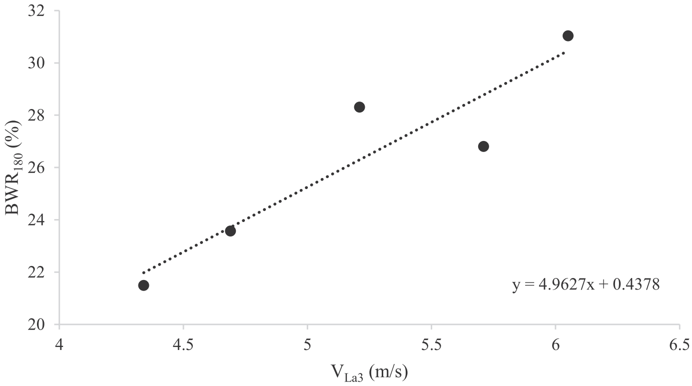
TABLE 3 Correlations (*r*) between physiological parameters recorded during an incremental standardized exercise test (SET) on an inclined treadmill and a ridden incremental weight-carrying exercise test on a track (WET) in 16 horses.

Physiological parameter (SET)	Physiological parameter (WET)	*n*	Correlation coefficient (*r*)	*p* Value
V_{190}[a]	BWR_{190}[a]	5	0.84	0.07
V_{La2}[b]	BWR_{La2}[b]	7	−0.40	0.37
V_{La3}[c]	BWR_{La3}[c]	10	0.17	0.63
V_{La4}[d]	BWR_{La4}[d]	5	−0.04	0.94

[a]Velocity or body weight ratio (BWR) at a heart rate of 190 bpm.
[b]Velocity or BWR at a plasma lactate concentration of 2 mmol/L.
[c]Velocity or BWR at a plasma lactate concentration of 3 mmol/L.
[d]Velocity or BWR at a plasma lactate concentration of 4 mmol/L.

The physiological response to the two exercise tests varied among the horses, where some horses showed a relatively low physiological response even at the last step. On the contrary, some horses showed a relatively high physiological response already at the first step in the exercise tests. For example, several horses already had a HR > 180 or 190 bpm at the first step (particularly in the WET), where one horse exceeded 200 bpm. In contrast, several horses did not reach the anaerobic threshold and/or a HR of 200 bpm, not even at the last step in the exercise tests. Interestingly, horses that did not reach 200 bpm, neither at the SET nor at the WET ($n = 3$), were all 15 years or older. This could mean that they were not able to reach a HR of 200 bpm, at least not the horses that were older than 17 years, due to the age-dependent decline in peak (Stefánsdóttir, Gunnarsson, Ragnarsson, & Jansson, 2017) and maximum HR (Betros et al., 2002). A potential age effect is important to consider in future studies evaluating the response to different exercise tests. For one horse, a linear increase of HR was

FIGURE 3 The linear relationship between the velocity at a plasma lactate concentration of 3 mmol/L in an incremental standardized treadmill exercise test (SET) and body weight ratio (BWR) at a heart rate (HR) of 180 bpm in a ridden incremental weight-carrying exercise test on a track (WET) in Icelandic horses ($r = 0.92$, $p < 0.05$, Pearson's correlation test).



not observed in the WET, and it was hypothesized that the maximum HR (or close to it) was already reached during the first step. Accordingly, several horses had missing data and correlations between V_{180} and BWR_{180} and between V_{200} and BWR_{200} were not determined in this study due to few observations ($n < 5$). In addition, the correlation between V_{La4} and BWR_{La4} could only be analyzed for five horses. However, for all horses except four (where three had technical or experimental problems), at least one of the corresponding physiological parameters (e.g., V_{La4} and BWR_{La4}) could be analyzed. Furthermore, it was generally not the same horses that did not reach the anaerobic threshold during the SET and the WET, respectively. One of the horses that did not reach the anaerobic threshold during the WET had, in contrast, already reached it at the first step in the SET, which illustrates the lack of correlation between the corresponding physiological parameters. With the exception of the potential effect of high age that precludes observations at a HR of 200 bpm, the missing data was not considered to be biased.

In order to increase the number of horses that physiological parameters can be estimated for in future studies, some adjustments of the intensity of the exercise tests might be required. A lower intensity at the beginning of the tests (e.g., start with BWR < 20%) and a greater intensity at the end (BWR > 35%) will most likely increase the number of physiological parameters that can be estimated. However, from a practical perspective, it can be challenging to find a rider with a BW low enough to get a BWR < 20%, and it requires a lot of added weights at the end of the test, which highlights the difficulties estimating weight-carrying capacity with a field test. Furthermore, younger horses than those included in the current study (age 15 ± 3 years, range 10–22 years) should preferably be studied.

The limited number of observations was certainly a weakness of the study. However, it is of interest to develop a standardized method to assess the weight-carrying capacity on an individual basis. Therefore, if correlations are weak, an increased number of horses studied might not have been relevant.

According to the results of this study, it is not clear that weight-carrying capacity is associated with general aerobic capacity in the horse. A SET is typically used to estimate the aerobic capacity in the unmounted horse (Seeherman & Morris, 1990; Harkins et al., 1993; Marc et al., 2000; Bitschnau et al., 2010; Jansson et al., 2021), while the WET aims to estimate the weight-carrying capacity. In both of the tests, the physiological response is expected to increase for each step as the exercise intensity increases, either by an increase of speed (SET) or an increase of weight (WET), which was also observed (data not shown). The scientific knowledge about weight-carrying capacity in horses and the influence of, for example, conformation or training is scarce. Horses included in this study were all used to carry riders during long-distance tours and are expected to have a great weight-carrying capacity. The exercise intensity during a typical tour has not been scientifically investigated but is probably relatively low considering the long distances that often are covered (Sigurðardóttir & Helgadóttir, 2015). Icelandic horses used for other purposes, such as breed evaluation field tests (BEFTs) or pace racing, are instead expected to perform during a relatively short period at a high exercise intensity (Stefánsdóttir et al., 2014; Stefánsdóttir, Gunnarsson, Ragnarsson, & Jansson, 2017). Contrary to our hypothesis, horses with great aerobic capacity might not have a great weight-carrying capacity and vice versa. The horses in this study that had a relatively low weight-carrying capacity, compared to the general aerobic capacity, might previously have been ridden by riders with a lower BW than those with a greater weight-carrying capacity. It is well known that aerobic capacity can be improved with training, and the same is suggested for weight-carrying capacity. However, it has not yet been scientifically studied in the horse. In humans, it seems like strength, power, and aerobic capacity (estimated with a "beep" test) are all important qualities for weight-carrying capacity, with the strongest correlation between aerobic and weight-carrying capacity (Robinson et al., 2018). However, aerobic capacity (i.e., performance in the "beep" test) was based on when the participant became exhausted and was not able to continue the test (Robinson et al., 2018) and not on objectively measured physiological parameters as in our study. Contrary to the results by Robinson et al. (2018), Bilzon et al. (2001) did not find a relationship between aerobic and weight-carrying capacity in humans. In that study, VO_{2max} (measured at an exercise test on a treadmill) was not associated with the exercise duration of a run with 18 kg external weight. However, heavier people were able to carry the weight for a longer distance (Bilzon et al., 2001). In our study, the weight load was based on a percentage of the individual horse's BW to avoid any effect of body mass.

In addition to the theory that weight-carrying capacity is affected by training, it may also be influenced by the conformation. Earlier studies indicate that a broad back (Stefánsdóttir, Gunnarsson, Roepstorff, et al., 2017) and loin (Powell et al., 2008) are favorable for weight-carrying capacity. It has also been shown that body measurements in Icelandic horses used for tour riding and in riding schools and horses participating in a BEFT differ (Söderroos et al., 2024). In a recent study, a wider chest, "uphill" conformation (i.e., higher in the front than in the hind), a straight backline, and a smaller hock circumference were associated with weight-carrying capacity in Icelandic horses, but not back shape (Söderroos et al., 2025).

As discussed above, a limitation of the current study was the substantial amount of missing data due to a great variation in physiological response among the horses. In an earlier study of weight-carrying capacity in Icelandic horses, the mean BWR_{La4} was 23%, where the greatest value was 27.5% (Stefánsdóttir, Gunnarsson, Roepstorff, et al., 2017). Therefore, it was unexpected that several horses in the present study did not reach the anaerobic threshold, although carrying 35% of their BW. In two horses, HR was higher in step 1 than in step 2 in the SET, and the value for step 1 was therefore removed. The relatively high HR values in step 1 for these horses were hypothesized to be explained by a stress reaction despite at least three training sessions on the treadmill before the SET. King et al. (1995) have recommended at least 1–2 training sessions prior to testing, but these horses might have needed more. Similar observations were found by Jansson et al. (2021). Another weakness was that the SET and WET were performed in different gaits (trot and tölt, respectively). Tölt is often used in tours and may limit the movement of the rider in comparison to trot. Therefore, tölt was used in the WET in this study. On the other hand, trot was more practical for the SET since it was the most common gait the horses chose when running freely on the treadmill. However, we have earlier shown that there are no differences in the physiological response between tölt and trot at the velocity used in the present study (Stefánsdóttir et al., 2015).

4.1 | Relevance for the Icelandic horse breed community

The Icelandic horse is a popular riding horse breed that is present worldwide (International Federation of Icelandic Horse Associations (FEIF), 2024) and used for various tasks. Despite their rather small size, with a mean height at withers of around 140 cm and a mean BW of 330–370 kg, they are often ridden by adult riders, some of them weighing over 100 kg (Stefánsdóttir et al., 2014). Due to their relatively small size in proportion to their riders, a great weight-carrying capacity is especially important in these horses. Therefore, knowledge about how weight-carrying capacity can be estimated easily and standardized in individual Icelandic horses is warranted. Such a test could be useful for, for example, tourist companies and riding schools with many horses and riders with varying BWs.

5 | CONCLUSIONS

A strong correlation between V_{La3} and BWR_{180} was found, but no other physiological parameter measured at the SET was associated with weight-carrying capacity. The results indicate that a SET on a treadmill, with a similar protocol as in this study, might not be applicable for estimating weight-carrying capacity in the horse. It is still somewhat unclear if aerobic capacity is associated with weight-carrying capacity in the horse. Further studies are needed to investigate the importance and applicability of the significant correlation between the plasma lactate response at the SET and the HR response at the WET.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

ETHICS STATEMENT

The study was carried out under Reg. 460/2017 on the protection of animals used for scientific purposes, as permitted by the Icelandic Food and Veterinary Authority, Ref. No. 2109502.

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This thesis aimed to investigate weight carrying capacity in Icelandic horses. The results showed that training and some conformational traits may affect weight carrying capacity, and that conformation differs between Icelandic horses used for different purposes. Furthermore, an unridden standardised incremental exercise test on a treadmill appeared not to be indicative of the horses' weight carrying capacity.

Denise Söderroos received her doctoral education at the Department of Animal Biosciences, Swedish University of Agricultural Sciences (SLU). She received her MSc in Agricultural Science – Animal Science from SLU.

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