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Horse stables in the 21st century

- aspects of management, behaviour and health

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Cover: Horses resting in the lying hall in the active open barn at National Equine Centre Strömsholm.

(photo: Linda Kjellberg)

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– aspects of management, behaviour and health

Abstract

Housing horses in open barns is becoming increasingly popular, with positive effects on social interaction and free movement that can improve horse welfare. However, many horse owners are concerned that group housing may lead to more injuries, less lying time and obesity. This thesis evaluated the effects of group housing horses an active open barn on behaviour and welfare in terms of health, rest and feeding.

Horses at the Swedish National Equestrian Centre sites Strömsholm and Flyinge were studied. Health indicators such as lameness and colic were found to be lower for horses kept in the active open barn than in single boxes. Horses in the active open barn had a higher incidence of injuries due to kicks, but this did not lead to more days lost from training. Therefore, concerns about injuries in this system do not appear to be warranted. Comparisons of lying halls with different lying areas revealed that smaller lying halls led to shorter lying times compared with larger lying halls and single boxes. Greater available area in the lying hall also increased lying bouts and use of lying halls. Due to intra-individual variation, four measurements per horse were needed to establish a mean value for forage intake rate.

In conclusion, keeping horses in an active open barn affects horse health and lying behaviour. Lameness and colic may decrease, probably due to free movement in the active open barn. To increase lying time among group-housed horses, the space requirement is likely to be larger, not smaller, than in individual boxes.

Keywords: lying behaviour, feed intake rate, welfare , group housing, time-budget

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Häststall på 2000-talet – skötsel, beteende och hälsa

Referat

Intresset för grupphållning av hästar ökar. Grupphållningssystemen kan leda till förbättrad välfärd för hästar då möjligheten för dem att utrycka sociala beteenden samt att röra sig fritt ökar. Men många hästägare oroar sig för att hästarna ska skada varandra, att de inte ska få tillräckligt med vila samt få för mycket eller för lite foder. Syftet med denna avhandling var att utvärdera hur skötsel, vila och utfodring i en aktiv grupphästhållning påverkade beteendet och hälsan hos hästarna.

Hästar på riksanläggningarna Strömsholm och Flyinge studerades. Frekvensen av skador som hälta och kolik tycktes lägre för hästarna i den aktiva grupphästhållningen jämfört med uppstallning i box. Att inhysa hästar i en aktiv grupphästhållning ökade risken för skador i form av sparkar men utan att öka antal sjukskrivningsdagar och den oro som finns hos många hästägare verkar därför inte vara befogad. En ligghall enligt lagstiftningens minimimått ledde till mindre liggtid jämfört med större ligghallar eller en individuell box. Större liggyta i ligghallen innebar också längre liggperioder och en ökad användning av ligghallen. På grund av stor variation mellan och inom individer behövdes fyra mätningar av ättiden för varje häst för att fastställa ett medelvärde för att ställa in ättiden grovfoderautomaterna.

Att inhysa hästar i en aktiv grupphästhållning påverkade hästarnas hälsa och liggbeteende. Fri rörelse under dygnet verkade minska förekomst av hälta och kolik. För att få motsvarande liggtid som i ensambox är det troligt att utrymmesbehovet i en ligghall är större, inte mindre, än i boxen.

Nyckelord: liggbeteende, ättid, hälsa, grupphästhållning, hästvälfärd, dygnsbudget

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Dedication

Till Tero

Till pappa, som var med när denna resa startade och som jag hade velat vara med här idag

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. Kjellberg, L. and Morgan, K. (2021). Introduction to automatic forage stations and measurement of forage intake rate in an active open barn for horses. Animal, vol 15 (3), 100152.

II. Kjellberg, L., Yngvesson, J., Sassner, H and Morgan, K. (2021). Horses' Use of Lying Halls and Time Budget in Relation to Available Lying Area. Animals, vol 11 (11), 3214.

III. Kjellberg, L., Sassner, H. and Yngvesson, J. (2022) Horses' resting behaviour in shelters of varying size compared with single boxes. Applied Animal Behaviour Science, vol 254, 105715.

IV. Kjellberg, L., Dahlborn, K., Roepstorff, L. and Morgan, K. Frequency and nature of injuries among horses housed in an active open barn compared with single boxes. (manuscript)

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

The contribution of Linda Kjellberg to the papers included in this thesis was as follows:

I. Involved in planning study design and data collection, shared responsibility for analysis and interpretation, preparing manuscript, critically revising the article with input from co-authors.

II. Study design, data collection, analysis and interpretation, preparing manuscript, critically revising the article with input from co-authors.

III. Study design, data collection, analysis and interpretation, preparing manuscript and critically revising.

IV. Study design, data collection, took part in data analysis for summarizing the results, interpretation, and preparing manuscript.

Abbreviations

REM	Rapid eye movement
DM	Dry Matter

Short glossary

Active open barn	A housing system similar to an open barn, but with automatic feeding stations providing access to an individual ration through a chip attached to each horse for identification. An active open barn also has planned pathways to desired areas for water, rest, play and rolling, to increase free movement.
Lying hall	Defined as a building with a roof and at least three walls. If there is a fourth wall, it has one or more openings to enable free movement in and out of the building. Synonymous with shelter.
Open barn	A housing system for keeping horses in groups, comprising a lying area under roof (lying hall) and outdoor paddock. Feeding can be *ad libitum* or restrictive. Synonymous with loose housing.
REM-sleep	Rapid eye movement sleep. Synonymous with paradoxical sleep.

1. Introduction

1.1 General introduction

Keeping horses in open barns is becoming more popular in many countries (Svala 2008; Fors-Jardin & Wännman Kvantenå 2017). Open barn housing systems allow the horses to have more social contact (Yarnell *et al*. 2015) and physical activity (Rose-Meierhöfer *et al*. 2010). Group housing has also been shown to have a positive effect on learning in young horses during training (Rivera *et al*. 2002; Søndergaard & Ladewig 2004) and is therefore considered preferable to boxes for young horses (Häggmar & Svensson 2020). Yngvesson *et al*. (2019) found health benefits such as fewer respiratory problems and colic among horses kept in open barns in riding schools compared with horses housed in tie-stalls or single boxes, possibly due to the group-housed horses having more outdoor movement and access to water and spending daytime in the paddock all year round. However, some horse owners still prefer to keep their horses in single boxes, due to concerns about injuries in group housing (Kemstedt 2010; Wallberg 2010; Hartmann *et al*. 2015).

Open barns can differ in their design and management. The simplest construction consists of a lying hall, enclosed pasture around the hall and forage fed ad libitum. Around two decades ago, a mechanised open barn system for horses with individual timed automatic feeding stations and a solid surface in the paddock, to encourage movement without trampling, was developed (HIT Active Stable®, Schauer® Active Horse). This housing system can be suitable for urban horse-keeping with limited area to meet horses' basic needs for foraging and movement and can now be found in at least 1300 stables throughout Europe (J. Fåke, Active Stable® Sverige, pers.

comm. 2022; C. Brandt, Schauer Agrotronic, pers. comm. 2022). In Sweden, active open barns are found in 40 stables (J. Fåke, pers. comm. 2022; M. Lund, Bopil, pers. comm. 2022). However, in Sweden and in other countries in Europe, the most common housing system is still individual boxes (Knubben *et al*. 2008a; Visser & Van Wijk-Jansen 2012; Hockenhull & Creighton 2015; Swedish Board of Agriculture 2018). There is a trend in Europe against keeping horses in tie-stalls and they are banned in Iceland, Austria, Denmark, Switzerland and Germany (Lundmark Hedman 2020). Under Swedish law ([3 ch. § 4 DFS 2007:6]), tie-stalls have not been permitted in new horse stables since 2007 (Swedish Animal Welfare Agency 2007. Around 17,500 (5%) Swedish horses are still kept in tie-stalls, but with a clear trend towards systems with horses moving freely (Swedish Board of Agriculture 2018). In Sweden, open barns are now used on 20% of all horse farms, including riding schools, where some or all horses on the farm are housed according to Swedish Board of Agriculture (2018).

From a historical point of view, free-ranging was long a common way for keeping horses for both stallions and mares, starting in Roman times and continuing into the 19th century (C. Svala, Swedish University of Agricultural Sciences pers. comm. 2022). Free ranging of horses stopped due to legislation in the late 19th century requiring animals to be fenced in, although valuable and working horses may have been kept in tie-stalls already in the Bronze and Iron Age to be quickly accessible. For military horses, tie-stalls have been the most common housing system since medieval times (Waxberg 1973; Ståhlberg 1988). However, open barns for working horses have long been recommended to farmers (Helmenius *et al*. 1955), with the head of the veterinary college in Stockholm, Sweden, in the 1940s recommending that young horses in particular be group housed (Vennerholm 1946).

Riding school staff often work in the riding arena, the office and the stables, and studies on riding instructors' working environment have shown that 60-90% experience work-related pain (Hultgren & Ivarsson 2007; Löfqvist *et al*. 2009). Group housing reduces working hours for stable staff compared with keeping horses in single boxes (Söderman & Fransson 2018), *e.g*. Fyhr & Pirooz (2022) observed a time saving of 21 minutes per horse and day. The time saving in open barns is mainly due to the potential for greater mechanisation of feeding and mucking out (Adolfsson & Geng 2010).

Working with horses poses a risk of injuries due to animal-related accidents (Löfqvist *et al*. 2009; Carmichael II *et al*. 2014; Swanberg *et al*. 2015). Carmichael II *et al*. (2014) found that although more injuries arose in conjunction with riding than with handling horses (n=61 vs. n=16), handlers had a higher percentage of severe head injuries (13%) than riders (3%)). The severe injuries were mostly linked to kicks from horses (Carmichael II *et al*. 2014; Swanberg *et al*. 2015). Taking horses to and from pastures or stables, grooming horses, walking and leading horses, and feeding were identified as tasks with the highest risk of injury (Swanberg *et al*. 2015).

1.2 Horse welfare

The welfare of an animal can be defined as the individual's state to experience and cope with its environment (Broom 1991). One way to evaluate welfare is using the Five Domains model (nutrition, environment, health, behaviour and mental state), emphasising the importance of positive mental state (Mellor & Beausoleil 2015). This model asserts that horses have a need for foraging, social contact with conspecifics and movement, and should enjoy good health. These were the factors studied in this thesis (Figure 1). For horses an open barn with automatic feeding stations and lying halls with restricted lying area, it is important to determine how management affects horse welfare.

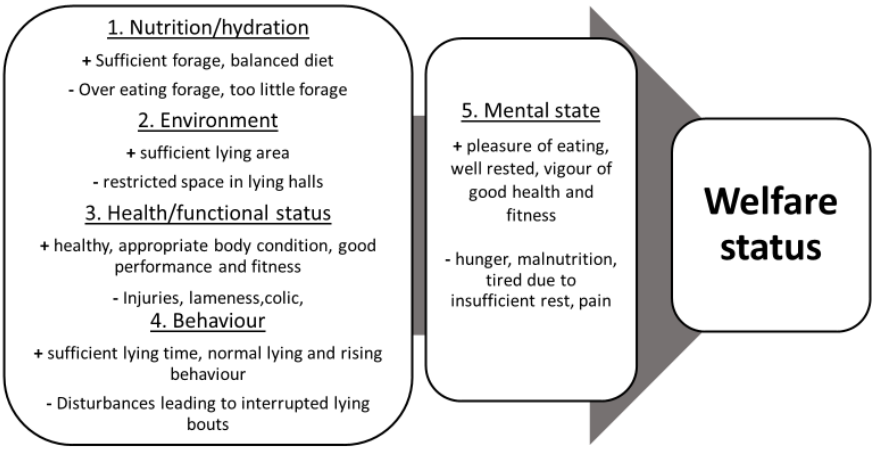

Figure 1. The figure shows in what way the model of the Five domains (Mellor & Beausoleil 2015) is interpreted in this thesis

Ensuring high welfare standard for domesticated animals has become more important and is closely connected to ethics, politics and scientific issues (Carenzi & Verga 2009). One common way to ensure horse welfare is to use protocols to measure welfare indicators from the animal's perspective (Wageningen UR 2012; Dalla Costa *et al*. 2016; Viksten *et al*. 2017; Sommerville *et al*. 2018). However, since the horse population includes livestock, work, sport, leisure and pet animals, these welfare indicators represent a large array of more or less adapted environmental conditions (Lesimple 2020). Visser *et al*. (2014) identified horses used in riding schools as being at risk of back pain and lameness, and horses used for recreation as being at risk of higher body condition score. Therefore, welfare indicators that distinguish between chronic and temporary states in horses, such as pain, emotion or acute stress, must be identified (Lesimple 2020).

In recent years, horse welfare has also become a crucial consideration in discussions regarding Social Licence to Operate for the horse industry (Duncan *et al*. 2018; Hampton *et al*, 2020; Heleski *et al*. 2020). This has three components, legitimacy, credibility and trust, and can be explained as the informal unwritten approval granted by civil society to *e.g*. the horse industry to keep operating. From an ethical perspective, it may therefore be argued that the horse industry has a responsibility to protect animal wellbeing, not only in preventing suffering, but also in promoting positive emotional states, as concluded by Mellor & Burns (2020). A survey by Viksten (2016) investigating Swedish horse owners' decision-making on horse welfare found that their most prominent considerations regarding welfare were feeding, housing, paddock size and horse health. These are thus important welfare areas for horse owners.

1.3 Feeding behaviour

Eating and chewing are important components of horse health and welfare. Przewalski horses (*Equus ferus przewalskii*) have been found to spend around 60-70% of their time grazing (Boyd 1991), while feral horses (brumbies) spend 73-81% of their time grazing (Berman 1993). Domesticated Coldblooded horses spend on average 60% of their time grazing each day (Fleurance *et al*. 2001). In domesticated New Forest ponies and free-living Connemara ponies, most foraging has been found to occur in early morning and late afternoon (Tyler 1972; Collery 1974), with animals grazing for 30 minutes to four hours per bout (Tyler 1972). Ponies on grazing spend around one-third of their time grazing at night (Kern & Bond 1972). In one study, Warmblood horses fed hay ad libitum spent 52% of each 24-hour-period feeding, divided into 12 meals ranging in duration from 42 to 168 minutes (Dulphy *et al*. 1997).

Feeding leisure horses forage ad libitum can result in obese horses, accompanied by problems such as laminitis and equine metabolic syndrome (Chapman 2014). Therefore, many horses are fed restrictively. In active open barns, the feed ration is individual and the risk of obesity is lower if each horse has a correctly timed ration. Restricted feeding can result in stereotypic behaviour (McGreevy *et al*. 1995). Body condition score, general condition and health status can be used as welfare indicators (Lesimple 2020). Hoffman *et al*. (2012) found that horses in an active open barn maintain their body condition score during the housing season. However, few previous studies have compared the health of horses kept in open barns with the health of those in conventional housing.

Horses on pasture usually eat at the same time (Sweeting *et al*. 1985). In an active open barn with individual feeding stations, it is difficult to express this behaviour. Some studies have examined horse feeding behaviour around feeding stations (Gülden & Büscher 2017; Gülden *et al*. 2018). Gülden & Büscher (2017) found that an acoustic signal followed by a compressed air stimulus reduced blocking time, while Gülden *et al*. (2018) found that blocking behaviour around concentrate stations could be reduced by lowering the number of portions to three per day.

1.3.1 Forage intake rate

Nutrition is an important welfare issue and automatic feeding stations must ensure that the horses' requirements for forage and nutrients are met, in order to maintain good health. The automatic forage feed stations in active open barns control the individual daily ration of forage in minutes. However, recommended feeding times for these housing systems are based on averages, which means that the ration will not be optimal for individual horses. Studies on forage intake rate show great variation between individual horses, with the time taken for intake of 1 kg hay dry matter (DM) varying from 29 to 77 minutes in different studies (Dulphy *et al*. 1997; Müller & Udén 2007; Brøkner *et al*. 2008). Intake of silage is reported to vary from 30 to 47 minutes per kg DM in different studies (Abrahamsson 2012; Müller &

Udén 2007). Müller (2011) found that feed intake rate for haylage could vary between eating occasions depending on harvesting date. These results indicate that there is wide variation between individuals, which must be considered in the management regime when allocating forage according to time.

Automatic feeding stations are a novel feeding routine for many horses, which could interfere with their ability to fulfil their nutritional needs. Horses have been shown to have a food motivation in pressing a lever multiple times to obtain feed, which is needed to help them learn a new feeding routine, but the degree of motivation differs between individuals (Olczak *et al*. 2018). Over time, some horses seem to become more reluctant to perform the expected task if the reward is too low or the feed is less palatable (Ninomiya *et al*. 2007; Olczak *et al*. 2018). However, there is limited information on how to introduce horses to an automatic feeding station and how forage intake rate varies in horses using automatic individual forage stations.

1.4 Resting behaviour

Another important welfare issue for the horse is the opportunity to lie down and to get enough sleep. Feral horses have been observed to lie down in general for 0.5-2 hours during each 24-hour-period (Kownacki *et al*. 1978; Duncan 1980; Duncan 1985; Sigurjonsdottir *et al*. 2012). Foals and young horses (2-3 years) have been reported to lie down for longer (Duncan 1980). Individually stalled horses usually lie down for 3-5 hours per 24-hour period (Dallaire & Ruckebusch 1974; Dallaire 1986; Köster et al. 2017). Lying time for horses in open barns is reported to vary from one to two hours (Fader & Sambraus 2004; Rose-Meierhöfer *et al*. 2010; Hoffmann *et al*. 2012). Lying time is reported to vary due to several factors, such as lying area (Raabymagle & Ladewig 2006; Burla *et al*. 2017), bedding (Pedersen *et al*. 2004; Baumgartner *et al.* 2015; Vikberg & Fredriksson 2015; Köster *et al*. 2017); rank (Fader & Sambraus 2004; Hoffmann *et al*. 2012) and exercise (Caanitz 1991).

Horses perform four stages of activity: wakefulness, drowsiness, slow-wave sleep and rapid eye movement (REM) sleep (Dallaire & Ruckebusch 1974; Dallaire 1986; Williams *et al*. 2008). Most sleeping time is spent standing and horses can manage without recumbency for several days, but eventually they must lie down (Dallaire 1986). During REM sleep, horses need to support their head on the ground and therefore REM sleep can only be achieved in lateral recumbency, or in sternal recumbency if the muzzle is in contact with the ground (Williams *et al*. 2008). Mean lateral recumbency is reported to be 30-70 minutes per 24-hour-period (Fuchs *et al*. 2018; Greening *et al*. 2021) and at least 20 minutes in lateral recumbency are needed to fulfil the need for REM sleep (Greening *et al*. 2021). Horses with reduced REM sleep have been found to collapse (Fuchs et al. 2018), sometimes repeatedly (Lyle *et al*. 2010). Impaired sleep can have an impact on spatial memory (Greening *et al*. 2021) and potentially on immunosuppression (Besedovsky *et al*. 2012). A study by Keleman *et al*. (2021) did not find any connection between recumbency and impaired welfare due to lameness, but horses with clinically established REM deficit had shorter lying time. Horses with sleep deprivation have been observed to extend recumbency in the days following clinical treatment (Bertone 2006). Hence sleep is crucial for horse welfare and is also important for the usability of the horse. Monitoring horses' lying time can be used as a way to compare different housing systems from a welfare perspective (Auer *et al*. 2021).

1.4.1 Recumbency in relation to housing and lying area

Housing and available lying area affect lying time and lying behaviour. Fader & Sambraus (2004) found that the size of lying area provided influenced the duration of lying down, with horses in open barns with a small lying area (4.6 m^2 per horse) lying down for a significantly shorter period (59 ± 48 minutes) than horses with access to a larger lying area (10.0 m^2 per horse, 103 ± 73 minutes; 17.3 m^2 per horse, 134 ± 37 minutes). In two of the open barns in that study, the lying area was divided into two lying halls and the lying time in those halls did not differ significantly (Fader & Sambraus 2004). Group-housed horses are reported to show more lateral recumbency with increasing lying area (Burla *et al*. 2017). Raabymagle & Ladewig (2006) found that lying time was shorter in smaller boxes [(1.5 x withers of the horse)^2 m^2] compared with larger boxes [(2.5 x withers of the horse)^2 m^2]. A study in an open barn with broodmares found that the proportion of the herd using the lying hall increased with a reduced number of horses, which in practice increased the available lying area from 7 to 17 m^2 (Nilsson 2006). Swedish animal welfare legislation ([3 ch. § 18 SJVFS 2019:17]) stipulates that the lying area in open barns must be a minimum of 8 m^2 per horse (80% of a single box) for large horses (defined as height at withers of over 1.71 m) when horses are fed outside the lying hall and 10 m^2 when they are fed inside (Swedish Board of Agriculture 2019).

The study by Raabymagle & Ladewig (2006) also found that the number of lying bouts increased with space in single boxes. According to Kjellberg & Rundgren (2010), horses kept in tie-stalls have more, and shorter, lying bouts than when kept in single boxes. Lying behaviour in open barn systems is also affected by rank, where high-rank animals have been observed to have longer lying duration (Hoffman *et al*. 2012). Rolling in horses prior to rising has been observed to decrease with increasing space (Raabymagle & Ladewig 2006) and in tie-stalls compared with single boxes (Kjellberg & Rundgren 2010). In contrast, Hansen *et al*. (2007) observed more rolling prior to rising in horses on pasture than when kept in stables.

1.4.2 Recumbency in relation to bedding

Bedding material seems to be another factor affecting lying time, for horses stabled in boxes and horses in open barns (Baumgartner *et al*. 2015). Extending the area of soft bedding material in lying halls, using materials such as straw or wood shavings, has been shown to increase lying time and lying duration (Burla *et al*. 2017). However, providing edible bedding (*i.e*. straw) in lying halls has been shown to lead to more lying bouts being interrupted by herd members (Baumgartner *et al*. 2015). Werhahn *et al*. (2010) also found that foraging increases on straw bedding and therefore could be a risk factor in interrupted lying bouts in lying halls. Baumgartner *et al*. (2015) compared lying time in a herd of 56 horses in an active open barn with one lying hall bedded with half shavings and half rubber mats and another lying hall bedded with sand and found that the horses spent the longest lying time on shavings (74.3 ± 2.87 minutes), followed by rubber mats (62.3 ± 2.27 minutes) and sand bedding (43.0 ± 2.33 minutes). Using rubber mats instead of wood shavings in single boxes led to shorter lying time in a study by Vikberg & Fredriksson (2015).

Bedding material has an impact on lying behaviour (Köster *et al*. 2017; Pedersen *et al*. 2004; Ninomiya *et al*. 2008; Ilvonen & Segander 2014; Vikberg & Fredriksson 2015). Horses housed in single boxes have been observed to lie longer in lateral recumbency on straw than on shavings (Pedersen *et al*. 2004) or pelleted shavings (Ilvonen & Segander 2014). However, using wood shavings in lying halls can result in longer lateral recumbency than on straw or straw pellets (Köster *et al*. 2017). Horses in single boxes on coconut husks have been shown to spend longer in lateral recumbency than when sawdust is used as bedding (Ninomiya *et al*. 2008).

1.5 Use of lying halls

Horses' use of lying halls seems to be determined partly by the weather, *e.g*. wet and windy conditions have been shown to increase the use of lying halls (Michanek & Bentorp 1996; Mejdell & Bøe 2005; Heleski & Murtazashvili 2010). Christensen *et al*. (2022) found that horses' use of shelter increased during warm summer days, possibly to avoid biting insects. Feral horses also exhibit this behaviour, seeking both shade and shelter from insect harassment (Keiper & Berger 1982), as well as protection from wind and rain (Tyler 1972). Lying halls also seemed to be used more at night in several studies (Michanek & Bentorp 1996; Nilsson 2006, Christensen *et al*. 2018). In a study during wintertime, two free-ranging thoroughbred fillies in Sweden spent on average 7 hours and 25 minutes per 24-hour period in a lying hall (Michanek & Bentorp 1996). Those fillies spent more time in the lying hall at night and their usage at night was not affected by the weather, but their use of the lying hall in daytime increased on rainy and windy days. Heleski & Murtazashvili (2010) found that rain or snow, in combination with wind exceeding >2.2 m/s, increased the use of shelters during daytime. Christensen *et al*. (2022) found that horses' use of shelters increased on warm summer days (21.7 °C) and on days with a high horsefly incidence. As Keiper and Berger (1982) suggest, avoiding insect harassment may be the factor causing horses to seek shelter during hot weather, and not the temperature itself.

Designing lying halls with two entrances instead of one has been found to increase the use of lying halls (Christensen *et al*. 2018). Lying halls with two entrances had also larger groups of horses visiting at the same time. Hildebrandt *et al*. (2021) compared different lying halls and observed that lying halls with a tarpaulin skin were preferred over a metal hall with smaller entrances.

Individual spacing is another factor that could influence the use of lying halls. Several studies have observed differences in use of lying halls between individual horses (Christensen *et al*. 2018; Hildebrandt *et al*. 2021). Fader & Sambraus (2004) found a connection between rank and a horse's lying time in lying halls and concluded that rank could be a cause of differences between individuals in use of lying halls. Keiper & Sambraus (1986) found that stallions observed in that study spent most of their time at 1-10 m distance from other horses. Mares tended to require less individual space, because they were broodmares with offspring nearby. Differences in individual spacing, with foals found to be more willing to share space than older horses (Heleski & Murtazashvili 2010), indicate that the adult horse's individual spacing requirement are likely to be >1 m. Nilsson (2006) found that broodmares housed in an open barn used the lying hall in turns when number of mares increased, suggesting that they divided themselves into subgroups. These differences in use of lying halls indicate that the area and horse rank within the group affect usage for the group and also for individual horses.

1.6 Injuries and risk of injuries among group housed horses

Agonistic behaviours are generally low among free-ranging horses (Fureix *et al*. 2012). In open barns, some risk factors for agonistic behaviour have been identified, such as lack of space, restricted feeding and group composition (Jörgensen *et al*. 2009, Christensen *et al*. 2011; Flauger & Kreuger 2013; Burla *et al*. 2016; Majecka & Klawe 2018). Injuries as a result of being kicked by another horse can be severe (Knubben *et al*. 2008b). However, the incidence of severe injuries in established groups of horses seems to be low, indicating that group composition is important (Lehmann *et al*., 2006).

Increasing paddock area can decrease aggressive behaviour (Majecka & Klawe 2018), while an available area of 106 m² per horse or less increases the level of aggression in the herd (Flauger & Krueger 2013). When the available area reaches 331 m² per horse or more, aggressions cease (Flauger & Krueger 2013). Domesticated horses have been found to show agonistic behaviour in connection with feeding, and especially prior to feeding, while aggressive behaviour during feeding decreases with increasing duration of hay availability (Burla *et al*. 2016). Other studies report less agonistic behaviour with forage fed continuously compared with restricted feeding (Benhajali *et al*. 2009; Jørgensen *et al*. 2011). Lexing & Östling (2016) found that horses in an active open barn expressed more agonistic behaviour than other behaviours around the individual feeding stations and that they spent more time in the area around the forage stations. Therefore individual feeding stations could potentially increase the risk of injuries.

Mixing horses and changing management seem to increase the risk of injuries (Knubben *et al*. 2008b). Christensen *et al*. (2011) found that regrouping led to more aggressive behaviour until a new hierarchy was established and that the horses did not seem to become accustomed to constant regrouping. Letting horses familiarise by placing them in boxes next to each other before entering the paddock together seems to decrease the risk of injury (Hartman *et al*. 2009). Young stallions stabled singly showed more aggressive behaviour when released into a group of other horses compared to stallions which were group stabled in the same period (Christensen *et al*. 2002). The singly stabled horses also expressed more friendly interactions such as play fighting and social grooming.

To reduce the risk of injuries, some horse owners avoid herds with mixed sex, although several studies have found no differences in agonistic behaviour between mixed-sex and simple-sex herds (van Dierendonck *et al*. 2004; Jørgensen *et al*. 2009) or no differences in agonistic behaviour between all-mare and all-gelding herds of Icelandic horses (Vervaecke *et al*. 2007). However, Majecka & Klawe (2018) observed some differences in social interactions in different herd compositions, indicating that the individuals kept in each herd are important for the level of aggression.

Lameness not caused by trauma is a common diagnosis in equine veterinary practice (Penell *et al*. 2005). For lameness in sport horses, the main risk factors have been identified as surface in training areas, training regime and age (Murray *et al*. 2010; Lönell *et al*. 2013; Egenvall *et al*. 2013). As pointed out earlier in this thesis, group-housed horses have also been shown to have fewer respiratory problems and colic than those housed in tie-stalls or single boxes, perhaps due to more outdoor movement and access to water all day (Yngvesson *et al*. 2019). Visser *et al*. (2014) identified use of horses in riding schools as a risk factor for back pain and lameness, and use of horses for recreation as a risk factor for higher body condition score.

1.7 Physical activity

In several studies, housing condition and free movement have been shown to be important components of horse welfare, behaviour and health status (McGreevy *et al*. 1995; Visser *et al*. 2008; Hartmann *et al*. 2012; Hoffman *et al*. 2012; Lesimple *et al*. 2020). The concept of an active open barn was developed around 2000/2001 (HIT Active Stable® 2022). Besides providing automated feeding stations and opportunities for social contacts, this housing system is designed to encourage the horses to increase movement, by providing pathways to desired areas for feeding, water, resting, play and rolling (HIT Active Stable® 2022; Schauer Agrotronic n.d.). Studies of horses housed in active open barns show increased activity compared with horses in conventional open barns (Rose-Meierhöfer *et al*. 2010). Hoffmann *et al*. (2012) found that using automatic concentrate feeding stations leads to more movement among horses. The positive impact of daily periods of free movement in a paddock on horse welfare, which are associated with an increase in oxytocin levels, suggests a possible increase in positive emotions (Lesimple *et al*. 2020). Increased movement daily have also been observed to improve bone density (Graham-Thiers *et al*. 2013) and led to fewer motion asymmetries after a long period on pasture (Jobusch 2022). Young horses kept on pasture moved around 8 km per day compared to around 2 km per day by two reference horses housed in single boxes and daytime in paddock indicating the influence by housing system on horses' activity (Hästen i Skåne 2022). Still, horses housed in the same kind of housing systems on pasture have been found to differ in their daily movement, indicating other influences such as ground conditions (Keller *et al*. 2022; Sassner *et al*. 2022).

2. Aims of the thesis

The overall aim of this thesis was to evaluate the effect of management regime in active open barns on the behaviour and welfare of group-housed horses in terms of health, rest and feeding.

Specific research issues were:

- ✓ How long does it take to train horses to use an automatic forage feeding station?
- ✓ How can individual forage intake rate be established for horses fed from a time-based automatic forage feeding station?
- ✓ How does the use of lying halls depend on available lying area?
- ✓ How does available lying area in lying halls affect the use of lying hall, horses' lying and rising behaviour and interaction between horses?
- ✓ How does an active open barn affect the horses' health and general condition?

3. Material and methods

This chapter provides a summary of the materials and methods used in Papers I-IV. More detailed descriptions can be found in the individual papers.

3.1 Horses

The horses studied were all school horses at the National Equine Centre Strömsholm (Strömsholm) (Papers I-IV) and National Equine Centre Flyinge (Flyinge) (Paper II). All horses were well-accustomed to each housing system and all had spent at least two months in the open barn before the studies started, except in sub-study 1 in Paper I, where the horses were introduced to the feeding station. All horses at Strömsholm used in Papers I-IV (and in additional follow-up studies) were Swedish Warmblood, aged 3-20 years, and used in the Bachelor's degree programme in equine studies at the Swedish University of Agricultural Sciences. The horses used in Papers I-III were geldings, while those used in Paper IV were a mixture of geldings and mares. The older horses (≥7 years) were trained to compete in dressage (advanced M-level) or showjumping (1.2-1.3 m), while the younger horses (3-6 years) were being trained in both dressage and showjumping. The horses at Flyinge, aged 6-21 years, used in Paper II were all geldings and Swedish Warmblood, except for one horse which was a North Swedish draft horse. All horses at both sites were exercised 5-6 times a week.

3.2 Facilities

The horses were housed in a single-box system (3 m x 3.5 m) and spent 2-4 hours in a paddock or were housed in an active open barn. The single-box system and the active open barn at Strömsholm were used in all studies and the active open barn at Flyinge was used in Paper II. These active open barns are designed for 24-25 horses and consist of one paddock, six automatic forage feeding stations, one concentrate station and automatic watering bowls. That at Strömsholm has four lying halls, with a total lying area of 23 m^2 per horse (Figure 2). Three of the smaller lying halls are designed as sheds with one open side and the larger one has four walls with three openings on one side. The active open barn at Flyinge has one lying hall (lying area 10 m^2 per horse) with four walls with four openings (Figure 3). All lying halls are bedded with straw. At Strömsholm, the paddock size is 3600 m^2 (for 24 horses), giving 150 m^2 per horse, and at Flyinge it is 3500 m^2 (for 25 horses), giving 140 m^2 per horse.

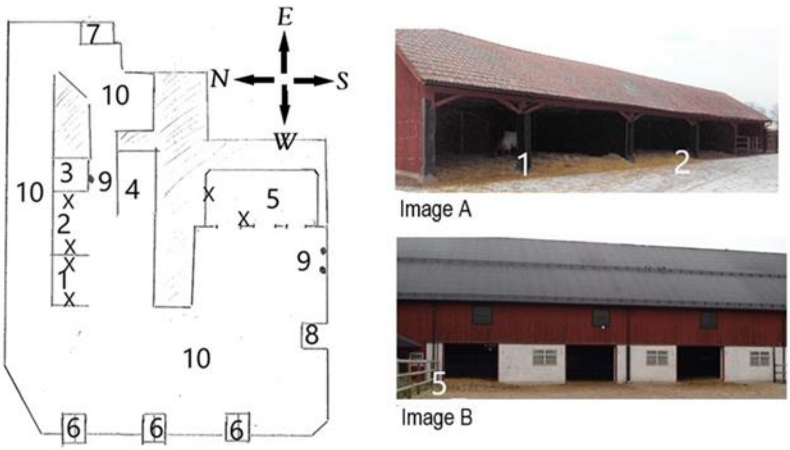

Figure 2. Detailed design of the open barn and lying halls at the National Equine Centre Strömsholm. 1) Lying hall with 80 m^2 open front (image A) used in treatments 2 and 3 in Papers II & III. 2) Lying hall 2 with 100 m^2 open front used in treatment 3. 3) Acclimatisation box. 4) Lying hall not used in the studies. 5) Lying hall (280 m^2) with four sides with three openings (image B), used in treatment 4 in Papers II & III. 6) Automatic forage stations. 7) Automatic concentrate station. 8) Hay bar (not used in the studies). 9) Watering bowls. 10) Paddock. X) Cameras.

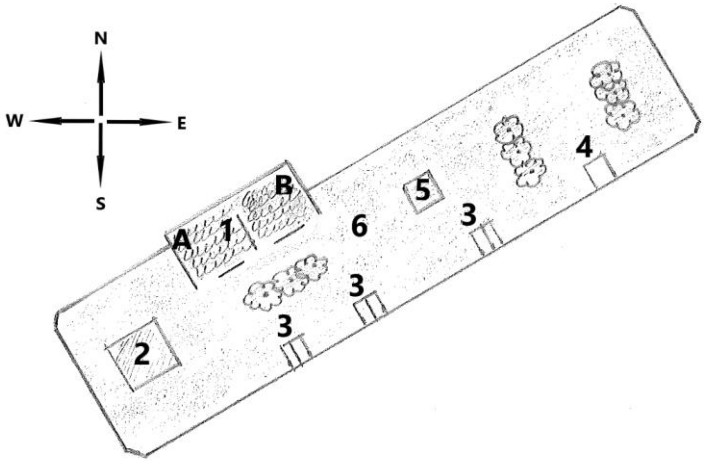

Figure 3. Detailed layout of the open barn at the National Equine Centre Flyinge. 1) Lying hall, 2) roller pit, 3) automatic forage stations, 4) concentrate station, 5) hay bar, 6) paddock, A: camera 1, B: camera 2.

3.3 Study design

3.3.1 Paper I

In sub-study 1 in Paper I, 22 horses were introduced to an automatic forage feeding station (Figure 4) using a training programme comprising four steps: 1) Approach the feeding station (led initially), 2) learn how to find feed, 3) accept rear gate closing and 4) learn how to open the exit gate. A protocol was established for each horse, to note how many training sessions were needed for each step. A horse was considered ready to be released into the system when it had accepted the automatic forage feeding station and could perform the steps described without assistance from a trainer. Recording of daily forage feeding time started as soon as the horse was released. A horse was considered to have learned the system when it reached 90% of its pre-programmed daily feeding time, calculated by the computer integrated in the system.

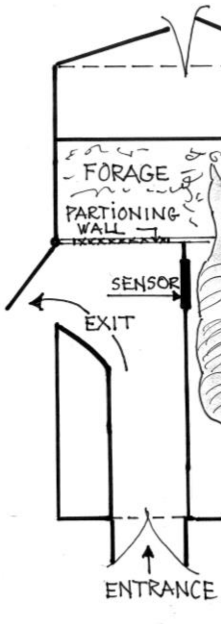

Figure 4. Illustration of the transponder-controlled forage feeding stations used in both active open barns, displaying the horse's position and passage (drawing by K, Morgan).

In sub-study 2 in Paper I, intake rate of haylage in 31 Swedish Warmblood geldings, aged 3-18 years, was measured in two consecutive sub-parts (2a, 2b). In sub-part 2a, 20 horses were tested in pairs, with 10 horses housed in a single-box system and 10 horses in an active open barn. Measurements were performed in a series of eight tests. In each test, the horses were fed 3 kg of their usual haylage in a wide hay-bag for 20 minutes, divided into two 10-minute parts. After completing each feeding session, the remaining haylage including waste was weighed again and the forage intake rate for each horse was calculated in minutes per kg DM. In sub-part 2b, only horses housed in an active open barn were tested. Eleven geldings were tested in pairs in an automatic feeding station, in two series of seven tests comparing two methods to establish the most efficient way to measure the individual forage intake rate. Seven repetitions were conducted for each method.

3.3.2 Paper II

Time-budgets and lying time were registered in two groups of horses divided in two sub-studies. Lying halls with available lying areas of 8 m^2, 15 m^2 and 18 m^2 per horse were used to study horses' use of lying halls using video recording. In sub study 2 in Paper II, a lying hall with lying area of 28 m^2 per horse was added (but not reported in Paper II). The behaviours registered in both sub-studies were sternal recumbency; lateral recumbency; standing rest; standing attentive; foraging; active; walk; other; not in lying hall; not in active open barn/box. No video recordings were performed outside the lying areas.

In sub-study 1 in Paper II, the group of horses consisted of 18 geldings, aged 6-21 years, housed in an active open barn with one lying hall with an available lying area of 15 m^2 per horse (at Flyinge). Two methods were used. In Method 1, the number of horses inside the lying hall was logged every hour. In Method 2, all behaviours for five randomly chosen focal horses were logged each minute when they spent time in the lying hall. Sub-study 1 was carried out during two weekends in late October 2015-early November 2015, when the temperature ranged from +12 to +14 °C in daytime and from +2 to +8 °C at night.

In sub-study 2 in Paper II, the group of horses consisted of 10 horses, aged 3-18 years, normally housed in an active open barn with three lying halls (Strömsholm). Behaviour was recorded for eight horses kept in single boxes with area 10.5 m^2 (control, treatment 1), or in lying halls with lying area of 8 m^2, 18 m^2 and 28 m^2 per horse (treatments 2-4). Each period consisted of 10 days, divided into seven days of acclimatisation followed by three days of video recording. All observations were logged with scan sampling in 5-minute blocks. The study took place from 1 February to 1 May 2016. The temperature during the first period (single boxes) varied from -2 to +1 °C in daytime and from -5 to 0 °C at night. The temperature in the second period varied from +5 to +15 °C in daytime and -2 to +4 °C at night, that in the third period from +5 to +8 °C in daytime and -1 to 0 °C at night, and that in the fourth period from +12 to +15 °C in daytime and 0 to +3 °C at night.

3.3.3 Paper III

The lying and rising behaviour of eight horses and disturbances by other horses when lying down were recorded continuously using video recording in Paper III. The behaviours recorded were sternal recumbency, lateral recumbency, standing up with no rolling behaviour, standing up after a half roll, standing up after a full roll, disturbance and forced to stand up. No video recordings were made when the horses were outside lying area in the paddock.

The study was carried out simultaneously, and using the same four treatments, periods and video recordings, as described for sub-study 2 in Paper II. The single boxes were bedded with shavings and all lying halls with straw. Ten horses were housed in the active open barn during treatments 2, 3 and 4. Eight horses participated in all four treatments (including control).

3.3.4 Paper IV

The study described in Paper IV was conducted at Strömsholm and comprised in two parts: a prospective study (15 September 2018-24 May 2019) and a retrospective study of two years (2014, 2015). The housing systems studied were of three types: active open barn (designed for 24 horses); stabled in single boxes (3 m x 3.5 m) and in paddock in pairs; and stabled in single boxes and in paddock alone. Only geldings were kept in the active open barn, while both geldings and mares were kept in the single boxes but the sexes were not mixed in the paddock. The parameters documented were category of injury (wound from kick, self-inflicted wound, wound with unclear cause, lameness, colic), days lost from training (no days, <1 week, 1-3 weeks or >3 weeks) and location where the injury arose (in paddock/active open barn, in box, during riding or not documented).

The prospective study was based on data for a total of 66 individual horses (49 geldings and 17 mares), aged 3-20, with 87 occasions of injuries among the 66 horses over the one-year study period. An individual horse could be stabled in either the active open barn or a single box during different periods, or in only one housing system. The herd of school horses is dynamic, so each individual horse may not have been included in one housing system continuously throughout the study. Students in the equine studies programme were responsible for the horses and helped to collect the data, using a form.

The retrospective study was based on data for a total of 69 individual horses (52 geldings and 17 mares), aged 3-19 years, with 155 occasions of injuries among the 69 horses over the two-year study period. The horses were kept in the same housing system throughout, with the exception of two geldings that were relocated from the active open barn to the single boxes-paddock alone treatment. Data for each horse was collected from its individual veterinary records. The categories of injuries were defined based on the type and severity described in the veterinary records.

3.3.5 Other studies

Time-budget during acclimatisation to single boxes

In a starting-up study, lying time and time budget were recorded for eight horses (aged 3-18 years) during acclimatisation to single boxes after having been housed in an active open barn (Strömsholm). The horses spent 3-4 hours outside in a paddock and were exercised as usual. The behaviour of each horse was video-recorded for the first three days and compared with behaviour during three days after acclimatisation for seven days, giving a total period of 10 days. The behaviours recorded were sternal recumbency, lateral recumbency, standing resting, standing attentive, foraging, walk, other, and not in box. The study was conducted over two periods due to limited availability of single boxes. The video recording was continuous, but all observations were logged with scan sampling in 5-minute blocks. No video recording was done outside the box. The study took place in February 2016, when the temperature varied from -2 to +1 °C in daytime and from -5 to 0 °C at night.

Behaviours on pasture and in an active open barn

When comparing time budget on pasture and in active open barn, seven horses were observed on pasture during three days in July 2015 and in the open barn at Strömsholm during four days in September/October 2015. Observations were performed in two 3-hour sets per day (12-15 h and 17-20 h). Every 15 minutes each horse location was recorded, including activity and closeness to another horse (alone >5m from another horse, in pair, or in a group). The behaviours recorded were foraging, standing, walk, trot/canter, standing resting, insect repulsion, allogrooming, and play

Health and body condition

Twenty-seven Swedish Warmblood geldings (8-17 years) were inspected once a month in June 2014 and Sept 2014-May 2015. The experimental group consisted of 11 geldings housed in the active open barn at Strömsholm and the control group considered of 16 geldings housed in individual boxes. Aspects of horse management were scored in terms of: performance (according to their trained level and stamina), body score, muscle building (according to level of training), hoof status, basic coat condition (*e.g*. worn hair due to use of rug, hair loss or lesions due to bite marks) and coat cleanliness. A 10-point scale was used to rate all performance parameters except body score, for which a nine-point scale (1-9) according to Henneke *et al*. (1983) was used. Each parameter was scored by three experienced Level-3 instructors, one farrier, one veterinarian, two stable managers and two animal scientists. The horses had rugs to the same extent in both housing systems.

3.4 Statistical methods

3.4.1 Paper I

In sub-study 1 in Paper I, the two groups (older and younger horses) were compared with a Student's t-test for three parameters: total number of training sessions, number of training sessions per day and number of days to reach 90% of daily forage intake. In sub-study 2, descriptive statistics on forage intake rate for the 28 individual horses in sub-parts 2a and 2b were calculated. A non-parametric model was used for comparisons since the data were not normally distributed. Individual differences were compared using Kruskal-Wallis one-way analysis of variance (ANOVA) on ranks, where appropriate followed by Dunn's post hoc test.

A median was calculated for each horse and then the Mann-Whitney rank sum test was applied to compare differences in forage intake rate between: 1) housing systems (sub-part 2a), 2) Method 1 versus Method 2 (sub-part 2b) and 3) age group (2a, 2b). The Wilcoxon signed rank test was used for comparing forage intake rate between 0-10 minutes versus 11-20 minutes in sub-part 2a in sub-study 2. To establish the number of measurements needed to get a representative individual forage intake rate, an individual mean value for one to seven repetitions was first calculated and then the difference in mean value between seven and six repetitions (1-7 vs 1-6), seven and five repetitions (1-7 vs 1-5) and so on was determined. The mean value and standard deviation of the differences were then calculated for each set of repetitions. In combination, the correlation between seven repetitions and each set of sub-groups of repetitions (1, 1-2, 1-3, 1-4, 1-5, 1-6) was analysed. SigmaPlot version 13.0 (Systat Software Inc., Paolo Alto, USA) was used for statistical analyses, with the level of significance set to $p<0.05$. The results are presented as mean ± standard deviation and, when appropriate, the median.

3.4.2 Paper II

The data collected in sub-study 1 were compiled using Microsoft Excel. The mean, maximum and minimum values were calculated, as parameters for lying periods (Method 1) and the number of visits to the lying hall (Methods 1 and 2). The time budget was calculated for the five focal horses (Method 1). The proportions of observed horse locations (inside or outside the lying hall) were calculated for the entire 24-h period and for day or night time. The difference between day and night was analysed using a Student's t-test.

The results of sub-study 2 were based on mean values for observations which took place during 72 h of video recording in periods 1, 2 and 4. There were only 48 h of video recording in period 3, as the horses tore down the barriers to a closed lying hall on the last night. For treatment 4, there were no recordings of individuals, and it was therefore not included in the statistical analysis, so the mean values only represent mean of the group of horses. RStudio version 1.2.5033 (Boston, USA) was used for statistical analyses. The data were processed using a Poisson regression with horse as the variable factor and treatment as the fixed factor, using the model: glmer1<-glmer (LieS~beh + (1|Namn), data = horse, family = "poisson"). To ensure that the variance was not the same as the mean in the analysis, a negative-binomial distribution was made according to the model: glmer.nb1<-glmer.nb (LieS~beh + (1|Namn),data = horse). The significance level was set to $p<0.05$ for both sub-studies.

3.4.3 Paper III

The results from Paper III were mean values of all observations. Observations were made during the same treatment periods and the same limitations applied for treatment 4 as in sub-study 2 in Paper II. Observations of 'forced to stand up' and 'disturbed' were only recorded in treatments 2, 3 and 4, since these behaviours did not occur in period 1. Only eight horses participated in treatments 1, 2 and 3 and therefore only eight horses were included in the statistics. RStudio version 1.2.5033 (Boston, USA) was used for statistical analyses. The data were processed using Poisson regression, with horse as variable factor and treatment as fixed factor, using the model:

glmer1<-glmer (sternal~beh + (1|Namn), data = horse, family = "poisson"). To ensure that the variance was not the same as the mean in the analysis, a negative-binomial distribution was created according to the model: glmer.nb1<-glmer.nb (sternal~beh + (1|Namn),data = horse). The significance level was set to $p<0.05$.

3.4.4 Paper IV

The data in Paper IV were entered in spreadsheets (MicroSoftTM Excel for Microsoft 365 Version 2203) and the datasets from the retrospective and prospective studies were analysed separately. A Chi^2 test was performed (in Excel) to analyse for significant differences in proportion between the housing systems for the parameters: category of injury, time lost from training and where the injury arose (only in prospective study). In the retrospective study, the data came from two years and in the analysis the data from each year (2014 and 2015) were handled separately, so that the period for "number of injuries per horse" would be equivalent to that in the prospective study. Non-parametric statistics were used due to non-normally distributed data. Mann-Whitney rank sum test was used to analyse differences between two treatments (active open barn and single box) and ANOVA on ranks was used to analyse differences between three treatments (active open barn, stabled in single box-paddock in pairs (Box_pair), and stabled in single box in paddock alone (Box_ind)). The ANOVA was followed up with a post hoc test (Dunn's method) where appropriate. The ANOVA was performed in SigmaPlot 13 (Systat Software Inc., Paolo Alto, USA). The level of significance was set to $p<0.05$. The groups Box_pair and Box_ind did not show any significant differences and therefore the results for these were pooled for one group, named single box.

3.4.5 Other studies

Time-budget during acclimatisation to single boxes

The data obtained were analysed using Students T-test. SigmaPlot version 13.0 (Systat Software Inc., Paolo Alto, USA) was used for statistical analyses. The level of significance was set to $p<0.05$.

Time-budget on pasture and in an active open barn

Data were analysed using one-way ANOVA on Ranks. SigmaPlot version 13.0 (Systat Software Inc, Paolo Alto, USA) was used for statistical analyses. The level of significance was set to $p<0.05$.

Health and body condition

A mean value was calculated for each horse and a t-test was performed to detect differences between the groups. The analyses were carried out in SigmaPlot version 13.0 (Systat Software Inc., Paolo Alto, USA). The level of significance was set to $p<0.05$.

4. Main results

4.1 Paper I

After four days, 48% of the 22 horses in Paper I had reached the goal of 90% intake. After eight days, 71% of the horses had reached the goal, while at 16 days 95% had reached the goal. Younger horses needed significantly (p=0.01) fewer training sessions (11.8 ± 2.1) than older horses (23.5 ± 11.5). However, younger horses had significantly (p=0.036) more training sessions per day (5.9 ±1.0) than older horses (4.7 ± 1.5). There was no significant difference (p=0.91) in number of days taken to reach 90% of daily forage intake between the groups (younger horses: 7.3 ± 7.3 days, older horses: 7.8 ± 2.8 days).

The overall mean forage intake rate based on 314 observations was 22.4 ± 6.7 minutes per kg DM (range 11.5 to 61.1 min/kg DM). However, in the individual results there were significant inter-individual differences (p<0.001). There was still some fluctuation in intra-horse forage intake rate when the measurements were repeated seven times. It was found that 4-5 repetitions gave an acceptable difference in mean value and standard deviation, with a strong correlation (R2≥0.88) compared with the actual series (Figure 5).

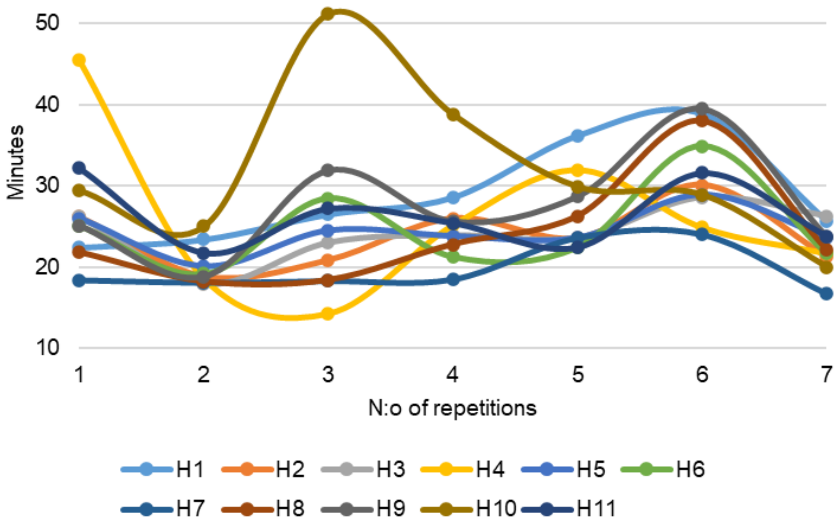

Figure 5. Intra-variation in forage feed intake rate in horses (H1- H11) as a function of number of repeated measurements in sub-study 2b in Paper I.

4.2 Paper II

At both Flyinge (lying area 15 m^2 per horse) and Strömsholm, the overall results showed that the horses used the lying halls (lying area 8, 18 and 28 m^2 per horse) for between 14% and 33% of each 24-hour-period (Figure 6). When the available lying area was increased from 8 m^2 to 18 m^2 per horse at Strömsholm, use of the lying halls by the horses increased significantly, from 14% to 33% (p<0.001). When the horses had access to two lying halls, with available lying area of 80 m^2 and 100 m^2, respectively, they were observed to spend more time (76%) in the larger lying hall.

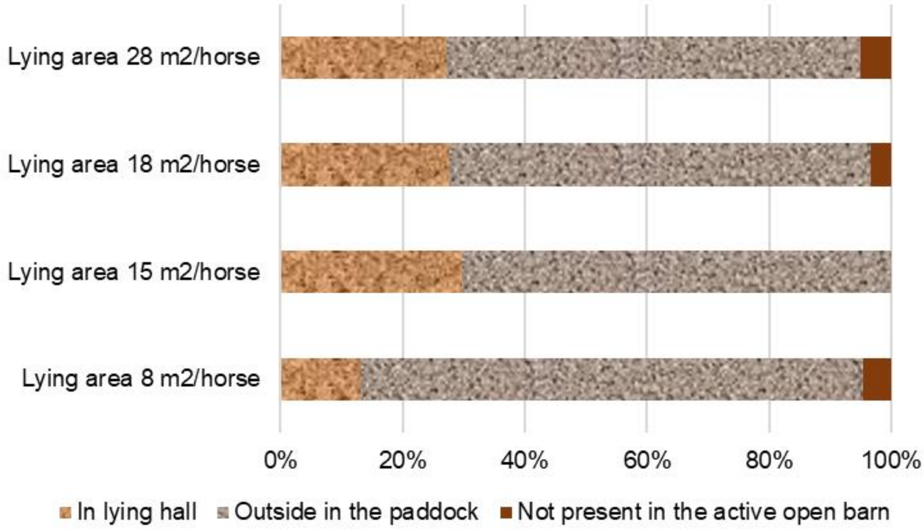

Figure 6. Horses' use of the lying halls as a percentage of each 24-h period. When the available lying area was increased from 8 m^2 to 18 m^2 per horse, use of the lying halls increased from 14% to 33%.

The five focal horses in the active barn in Flyinge exhibited recumbency, both sternal and lateral, in the lying hall of 15 m^2 per horse for 6% of the time spent in the active open barn (Figure 7). In the lying halls in Strömsholm the horses' lying times for both sternal and lateral recumbency were significantly lower in the smaller lying hall with an available lying area of 8 m^2 per horse versus 18 m^2 per horse (p=0.001 and 0.02, respectively) and the single boxes ($p \leq 0.001$ and ≤ 0.001, respectively). The horses also spent more time foraging from the bedding when they had access to a lying area of 18 m^2 per horse than when they had access to an area of 8 m^2 per horse ($p<0.001$). The horses also used the lying halls for urination and play.

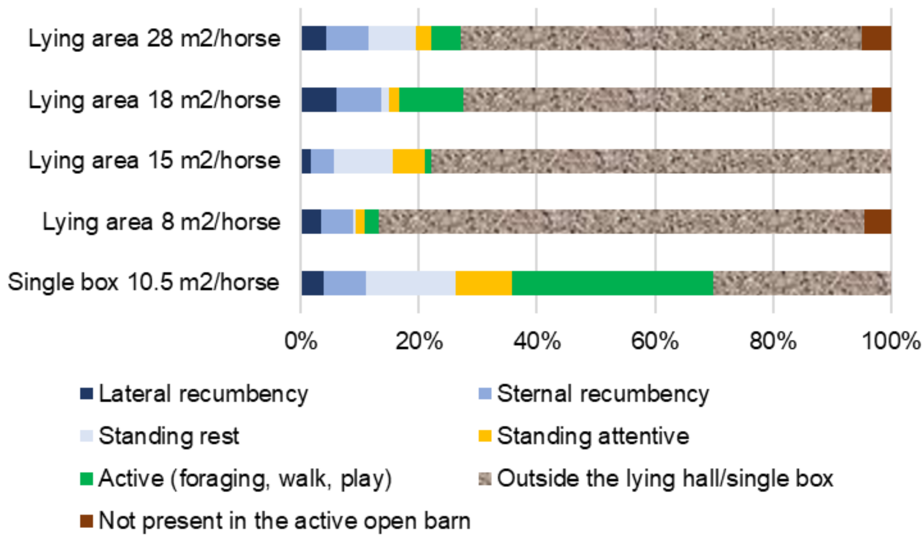

Figure 7. Time-budget for horses in the lying halls with different available lying area and the single boxes. The percentage of each 24-h period spent in sternal and lateral recumbency was smaller in the lying hall with available lying area 8 m^2 per horse than in the larger hall with 18 m^2 per horse (p=0.001 and 0.02, respectively) or the single boxes ($p \leq 0.0001$ and 0.0002, respectively).

4.3 Paper III

The horses lay down less when they had access to 8 m^2 lying area/horse compared with a single box ($p<0.001$) or lying halls with a total of 18 m^2 lying area/horse (p=0.001) (Table 1). The horses spent a longer time in sternal recumbency with 8 m^2 lying area per horse compared with single boxes ($p<0.001$) or with 18 m^2 lying area per horse ($p<0.001$). Lateral recumbency bouts were significantly longer in single boxes compared with 8 m^2 lying area per horse in halls (p=0.04). There was a tendency for shorter lateral recumbency with 8 m^2 lying area per horse compared with 18 m^2 lying area per horse (p=0.07). Minutes spent in sternal and lateral recumbency did not differ between single boxes and 18 m^2 lying area per horse. There were no differences in percentage distribution of sternal and lateral recumbency in treatments 1-4 in Paper III.

Table 1. Mean total lying time (minutes) and time spent in sternal and lateral recumbency (max-min) with different available lying area. No individual observations were made when the horses had access to a lying area of 28 m^2 per horse, and therefore no min-max range is presented for that treatment

Available lying area/horse	Sternal recumbency	Lateral recumbency	Total lying time
Single box, 10.5 m^2	94 (25-183)	52 (0-123)	145 (29-269)
Shelter, 8 m^2	47 (0-136)	22 (0-86)	69 (0-222)
Shelter, 18 m^2	82 (35-137)	48 (0-142)	130 (35-270)
Shelter, 28 m^2	82	51	132

The maximum number of horses lying down simultaneously in the lying hall was seven out of 10 in all treatments. However, this value was only observed once when the horses had access to 8 m^2 lying area per horse, four times with 18 m^2 lying area and 11 times with 28 m^2 lying area.

One of the younger horses was observed in sternal recumbency for only one minute, and not in lateral recumbency at all, during one 24-h period when it had access to a lying area of 8 m^2 per horse. This horse also had low sternal lying time during all three 24-h periods in the same treatment, with a range of 1-3 minutes. Lateral lying time varied between 0 and 24 minutes in horses given access to a lying area of 8 m^2, and between 1 and 66 minutes in horses given access to a lying area of 18 m^2. One of the older horses was not observed in lateral recumbency at all in the single box or with a lying area of 8 m^2 per horse. Another of the older horses was observed not to rest in lateral recumbency for two 24-h periods when it had access to a lying area of 8 m^2. That horse also preferred to lie down in the smaller lying hall when given access to two lying halls in treatment 3. Four horses always chose the larger lying hall for recumbency in treatment 3. Another young horse, which participated in treatments 2, 3 and 4, was observed to lie down twice on the hard surface outside the lying hall when only given access to 8 m^2 lying area per horse. This behaviour had not been observed previously by stable staff. None of the horses housed in single boxes was observed to lie down when in the paddock.

The horses had significantly fewer lying bouts/horse in the lying hall with 8 m^2 lying area (mean±standard error 2.1±0.3) compared with single boxes (3.5±0.3) (p=0.01) or the lying hall with 18 m^2 lying area (4.0±0.5) (p=0.001). There was no difference in number of lying bouts between the lying hall with 18 m^2 lying area and the single box. The horses remained for longer in both sternal and lateral recumbency in each bout when housed in single boxes and with 18 m^2 available lying area compared with 8 m^2 lying area (p=0.04 and 0.05, respectively).

Standing up without performing any form of prior rolling behaviour was the most common behaviour observed in the single box and in the lying halls with 8 m^2 and 28 m^2 lying area per horse (Table 2). The horses performed more full rolling behaviour when the lying area in the lying hall was increased from 8 m^2 to 18 m^2 per horse. Full rolling behaviour was only observed once in single boxes. There were no differences between single boxes and the lying hall with 18 m^2 lying area when comparing rolling behaviour prior to standing up. Horses were forced up by another horse in all lying halls and the frequency did not seem to differ with available lying area. All horses were forced to stand up by another horse at least once in the lying halls with 8 or 18 m^2 lying area. On analysing disturbances, there were no differences between 8 or 18 m^2 lying area per horse in relation to lying time. Forcing another horse to stand up was performed by all horses, but disturbances were only recorded for five horses. These behaviours were also noted when the horses had access to 28 m^2 lying area but, since the horses could not be identified, no individual comparisons were possible.

Table 2. Horses' behaviour when standing up in lying halls with different available lying area (presented as percentage of standing up events). No individual observations were made when the horses had access to 28 m^2 lying area, and therefore no standard error is presented for this treatment

Available lying area/horse	No rolling	Half roll	Full roll	Forced to stand up
Single box, 10.5 m^2	71%	29%	0%	----
Shelter, 8 m^2	33%	12%	29%	26%
Shelter, 18 m^2	22%	22%	33%	24%
Shelter, 28 m^2	64%	9%	5%	21%

4.4 Paper IV

The main and most interesting finding in Paper IV was that the proportion of lameness was lower in the active open barn (18%) than among the horses stabled in single boxes (26%) (Figure 8). Another notable finding was that only horses in single boxes suffered from colic (5%). These results were reflected in number of days lost from training (Figure 9), with lameness resulting in significantly more days lost from training than the other categories of injury (*p*<0.001). From a practical point of view, the overall number of days lost from training was lower in the active open barn (mean ± standard deviation 10 ± 15 days) than in single boxes (15 ± 34 days), even though the groups did not differ in the statistical analysis (*p*=0.36). The main types of wounds observed were wounds from kicks in the active open barn (51%) and self-inflicted wounds in single boxes (53%). This shows that horses can be hurt in social interactions or hurt themselves.

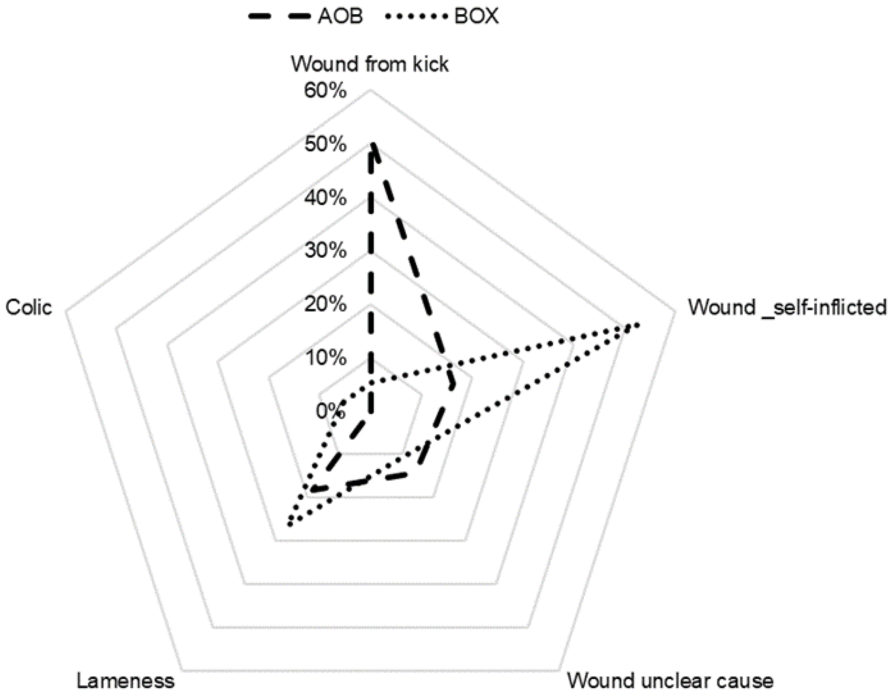

Figure 8. Percentage of different categories of injury in horses in the active open barn (AOB) and single-box (BOX) housing systems in the prospective study in Paper IV.

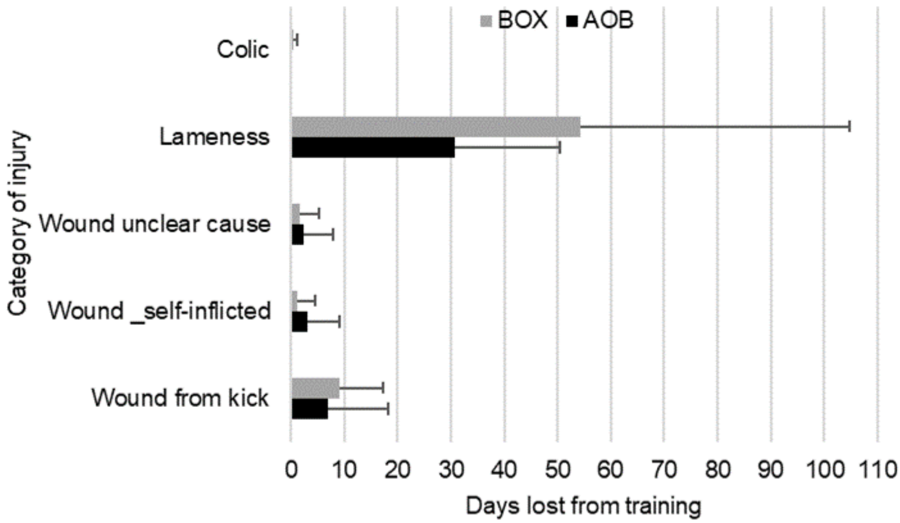

Figure 9. Number of days (mean ± standard deviation) lost from training due to different categories of injury in horses housed in the active open barn (AOB) respectively single boxes (BOX) in the prospective study in Paper IV.

The number of injuries per horse differed significantly between the active open barn (2.08 ± 2.02) and single-box (0.73 ± 0.99) (p<0.001) housing systems in the prospective study. Most of the horses had 0-3 injuries during the study period, three horses had 4-5 injuries and one horse (in the active open barn) suffered nine injuries. Of the three horses with 4-5 injuries, one was housed in a single box and kept alone outside, one was in the active open barn and one was first in the active open barn and later in single box-pair in paddock. The proportion of horses with an injury decreased gradually from the start of the observation period in September to reach a similar level between groups in mid-March (Figure 10). However, after regrouping in the active open barn in March (week 12), the proportion of injured horses rose again instantly and then decreased rather rapidly as the group re-stabilised.

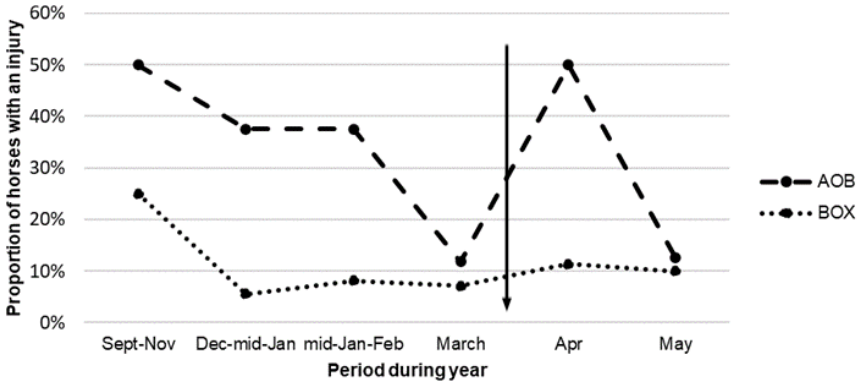

Figure 10. Proportions of horses injured in the active open barn (AOB) and single-box (BOX) housing systems during the prospective study. Regrouping was performed in the active open barn in mid-March.

In the retrospective study based on veterinary records, the results showed no significant difference for the parameters; proportion of injured individuals in the active open barn, categories of injuries (Figure 11). The overall distribution for categories of injuries was 12% wound from kick, 7% wound_self-inflicted, 29% wound_unclear cause, 51% lameness and 1% stable related. neither between the groups for number of injuries per horse; active open barn 1.54 ± 1.51 vs single boxes 1.14 ± 1.20.

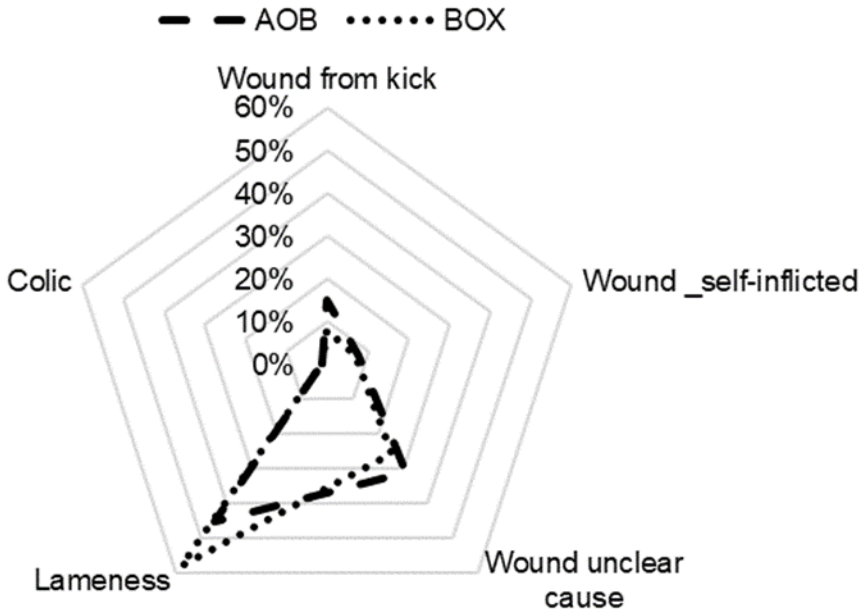

Figure 11. Percentage of different categories of injury in horses in the active open barn (AOB) and single-box (BOX) housing systems in the retrospective study in Paper IV.

There were no differences in median age of the horses in the different housing systems in either the prospective study (7.5 years for active open barn, 8.0 years for single boxes (p=0.720)) or the retrospective study (9.5 years for active open barn, 10.0 years for single boxes (p=0.137)). Considering the average number of horses in the active open barn, the available paddock area per horse was 218 m^2 in the prospective study and 175 m^2 in the retrospective study.

4.5 Other results

Time-budget during acclimatisation to single boxes

The time-budgets recorded for eight horses normally housed in an active open barn during acclimatisation to single boxes did not differ from the time budgets measured after acclimatisation (standing resting 14%, sternal recumbency 6%, lateral recumbency 4%, foraging 34%, standing attentive 10%, moving 2%, not in the single box (in paddock or training) 30%.

Behaviours on pasture and in active open barn

The horses foraged significantly more in the open barn (47% of observations) than on pasture (27%) (p=0.001). No behaviour related to insect repulsion was observed in the open barn, in contrast to on pasture, (Figure 12). The horses stayed close to the other horses for most of the time, both on pasture and in the open barn. Higher frequency of agonistic behaviour was noted when the horses were housed in the open barn, especially in the areas around the feeding stations.

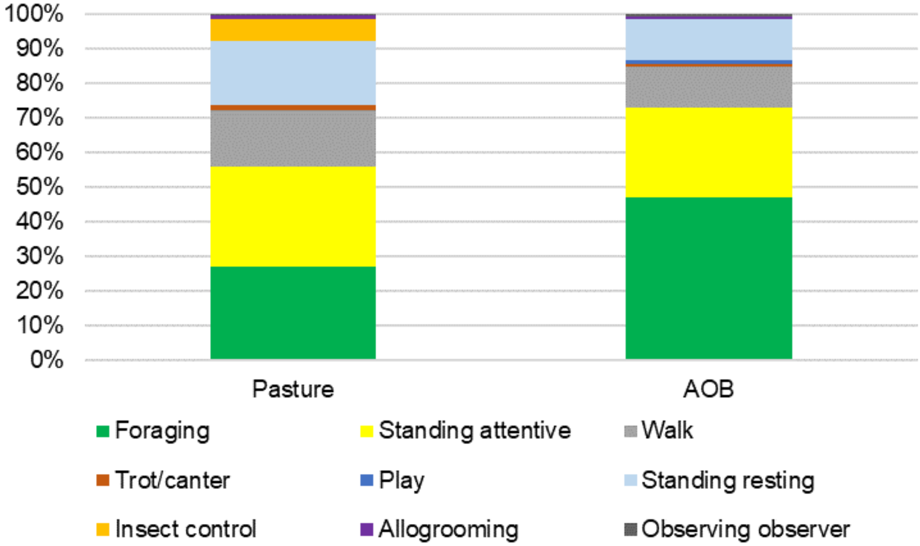

Figure 12. Time-budget for seven horses on pasture and in the active open barn (AOB) during afternoon and early evening. They foraged more in the active open than on pasture.

Health and body condition

A total of 155 health and body condition inspections were performed, 60 on horses in the active open barn and 95 on horses in single boxes. There were significant differences for basic coat condition (such as worn hair due to use of rug, hair loss or lesions due to bite marks) (active open barn 7.1 vs single box 7.7; p=0.01) and coat cleanliness (active open barn 6.9 vs single box 7.4; p=0.02) (Figure 13). No differences were found for performance, body score, muscle building or hoof status. However, horseshoes were worn down much faster in the open barn system and had to be changed every three weeks.

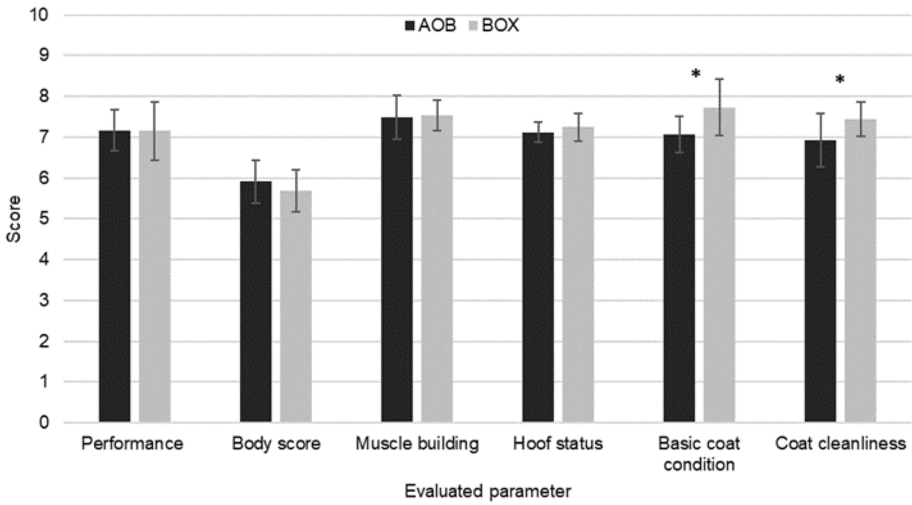

Figure 13. Differences in various parameters evaluated for horses kept in an active open barn (AOB) and horses kept in single boxes (BOX). Differences were significant (*) for basic coat condition (p=0.01) and coat cleanliness (p=0.02), but not for the other parameters. All parameters were rated from 0 to 10 (=excellent) except "body score", which was rated from 1 to 9 according to Henneke *et al.* (1983).

5. General discussion

5.1 Discussions of results

The results presented in this thesis show that there are large individual variations in feeding time, activity, resting behaviour and injuries between horses in active open barn housing systems. These individual variations must be considered when planning and managing such systems, to meet the welfare needs of the individual horse. There may also be variations within individuals in different situations, *e.g.* due to the social structure in the herd. Based on the Five Domains model, in this thesis the focus was primarily on welfare indicators concerning forage intake, use of lying halls, lying time, health in relation to body scores, injuries and lameness (as indicated in Figure 1).

When comparing the active open barn system with single boxes, it was found that the open barn approach seems to provide greater potential for better welfare for most horses if the areas provided for resting and movement are large enough. This is discussed in more detail below.

5.1.1 Management of feeding

In Paper I, a training programme to introduce the horses in an active open barn how to use a forage feeding station led to 50% of the horses learning to get enough feed within four days. According to Olczak *et al*. (2018), the degree of food motivation differs between individuals, which may affect how fast horses learn a new feeding routine. During the first week, one of the older horses, considered by staff to be a high-ranking horse, monopolised one stall in the automatic forage feeding station. This monopolising behaviour ceased as soon as the concentrate feeding station came into full operation, after a week. Hoffmann *et al*. (2012) also observed greater activity in active open barns with concentrate feeding stations compared with open barns without. Feeding a small amount of concentrate to all horses is therefore recommended to avoid blocking feeding stalls and encourage movement, which is an important part of the active open barn concept. This can be applied even for horses with small rations of concentrate, since the feeding station can be programmed to reduce number of portions over the day, as shown by Gülden *et al*. (2018).

Forage intake rate varied from 13.2 to 33.2 min/kg haylage DM, with an overall mean value of 22.4 ± 6.7 min/kg DM (min-max range 12-61 min/kg). This was a faster feed intake rate for haylage compared with other studies (Müller 2011; Abrahamsson 2012). An explanation for the differences between studies could be differences in fibre content, since the horses in these studies were of the same size and type.

The individual ration in forage stations for a horse in an active open barn system is set according to available feeding time in minutes. One important finding regarding feeding and welfare of the horses in this study was that forage intake rate varied between individuals and within individuals for the series of measurements. After four measurements, the variation in mean value was more consistent within each horse. Making only one measurement per horse could lead to forage intake of the individual horse varying from 5 to 25 kg DM per day, as the min-max values indicate. It is therefore recommended to measure forage intake rate at least four times for each horse, to establish individual adjusted daily ration for forage intake. It is also important that the caretaker monitors the body score of each horse over time and adjusts the feeding time when required.

5.1.2 Lying behaviour on different lying areas

Total mean lying time when the horses had access to 8 m^2 per horse was 1 hour and 9 minutes, which is comparable to values reported for feral horses of 0.5-2 hours (Kownacki *et al*. 1978; Duncan 1980; Duncan 1985; Sigurjonsdottir *et al*. 2012). Taking wild and feral horses as the norm, 8 m^2 lying area per horse might be sufficient, but wild horses face threatens from predators and therefore cannot lie down for long. Cerasoli *et al*. (2022) found higher cortisol levels in hair among free-ranging horses compared with stabled horse and Mazzola *et al*. (2021) found lower cortisol concentrations in horses that spent the night indoors. Physical activity also increases cortisol levels, so an explanation for the higher cortisol levels in free-ranging horses could be that these horses are more physically active. One can speculate over the difference for a horse between surviving and having a good life.

Resting time and especially duration of REM sleep are important for horse welfare, with a reported need for 30-70 minutes REM time per 24-h period (Fuchs *et al*. 2018; Greening *et al*. 2021). REM sleep can only be obtained in lateral or sternal recumbency if the muzzle is supported by the ground, and therefore lateral recumbency was used in this thesis as an approximation of time spent in REM sleep. The observed mean time spent in lateral recumbency in single boxes and in lying halls with lying area of 18 and 28 m^2 per horse was above the reported requirement in all three cases (52, 48 and 51 minutes, respectively), but was only 22 minutes when the horses had access to a lying area of 8 m^2 per horse. Still, there was only a tendency for longer lateral recumbency when the lying area increased from 8 m^2 to 18 m^2 per horse. With the smallest lying area tested, of 8 m^2 per horse, there was a wide max-min range (0-86 minutes) due to individual differences. Five of the horses studied spent on average only 17 minutes or less in lateral recumbency. One of these horses was not observed lying in lateral recumbency at all, either in the single box or when given access to 8 m^2 lying area per horse. Four horses only lay down in the larger of the two halls (100 m^2 versus 80 m^2), indicating that even a small increase in lying area could be important for horses. There could be several reasons for this choice, such as rank (Fader & Sambraus 2004), need for large individual spacing (Keiper & Sambraus 1986; Heleski & Murtazahvili 2010) or just that a larger lying area leads to more frequent lying down (Fader & Sambraus 2004; Raabymagle & Ladewig 2006). To fulfil the need for sleep and rest, 15-18 m^2 lying area per horse seemed to be sufficient, as 28 m^2 lying area/horse did not increase lateral recumbency.

Group housing leads to more social interactions (Hartmann *et al*. 2012a) and social interactions in the lying halls can lead to disturbances from another horse to horses lying down and interrupted lying bouts. The horses performed fewer and shorter lying bouts in the lying hall with 8 m^2 lying area per horse than in the other treatments, but there were no differences regarding frequency of disturbances between the different lying areas. Using straw in the lying halls could have led to shorter lying bouts for horses at both Flyinge and Strömsholm, since foraging from straw bedding has been observed to decrease lying time due to disturbances (Werhahn *et al*. 2010), leading to shorter lying bouts (Baumgartner *et al*. 2015). However, horses can also be disturbed during sleep and rest by sound and light (Greening *et al*. 2021), which can occur when horses are kept in single boxes. Therefore, there could have been disturbances in the single boxes that were not detected.

In this thesis, frequency of roll prior to rising behaviour varied from 14% to 55%, compared with around 30% in other studies (Pedersen et al. 2004; Raabymagle & Ladewig 2006; Hansen *et al*. 2007). When housed in single boxes or with access to the largest lying area (28 m^2 per horse) in lying halls, the horses generally stood up without any prior rolling behaviour. With the smallest available area in the lying hall (8 m^2 per horse), all horses except one showed a full roll prior standing up on at least one occasion. Previous studies have reported more rolling behaviour in small single boxes (Raabymagle & Ladewig 2006) and on pasture (Hansen *et al*. 2007). In this thesis, more rolling behaviour was found on 8 and 18 m2 available lying area and full rolling behaviour was not observed once in the single boxes. These results are therefore difficult to evaluate in relation to horse welfare and how rising behaviour varies between housing systems, and whether it is a potential indicator of welfare status, need to be studied in more detail in future investigations.

5.1.3 Use of different sizes of lying halls

The horses' use of the lying halls increased significantly, from 14% to 33%, when the available area was increased from 8 m^2 to 18 m^2 per horse. Extending the lying area to 28 m^2 per horse did not seem to increase the use of the lying halls. When the horses had access to two lying halls, the results showed that they preferred the larger lying hall (100 m^2) to the smaller one (80 m^2). Although most of the horses spent all or nearly all their time in the larger lying hall, some individuals preferred the smaller hall. As mentioned earlier, this could be explained by *e.g.* rank (Fader & Sambraus 2004) or individual spacing (Keiper & Sambraus 1986; Heleski & Murtazahvili 2010) encouraging some horses to choose the less crowded larger lying hall.

In the smaller herd at Strömsholm (10 horses), at most 80-90% of the horses occupied the lying halls (with available lying area of 8-28 m^2 per horse) at the same time. In the open barn at Flyinge, consisting of a larger herd (18 horses) and one lying hall with 15 m^2 available lying area per horse, at most 60% of the herd was present at the same time. However, the lying hall was never empty during the hourly observations. This indicates that a larger herd divides into subgroups and visits the lying hall in turns, as suggested previously by Nilsson (2006). Horses in groups prefer to forage, rest and move at the same time (Sweeting *et al*. 1985) and therefore it is important that the whole group can fit into a lying hall. One stable manager has reportedly observed that the group of 20 horses in an active open barn split into sub-groups and therefore prefer more than one lying hall (Johansson 2022). Another stable manager have in a conversation reported this behaviour of split into sub-groups also in a smaller herd (Jöngren 2022).

5.1.4 Occurrence and type of injuries

Overall, in the prospective study in Paper IV there was a significantly larger proportion of injured individuals in the active open barn (83%) compared with single boxes (52%). The distribution of days lost from training did not differ significantly between these two housing systems, but the distribution of categories of injuries differed significantly. Only horses in single boxes suffered from colic (5%), which is consistent with findings by Yngvesson *et al*. (2019).

Lameness occurred in both housing systems, but was less frequent among horses stabled in the active open barn (18%) compared with single boxes (26%). Lameness in horses usually led to more days lost from training than the other categories of injuries considered, which means a greater impact on both horse welfare and business finances. Penell *et al*. (2005) identified lameness not caused by trauma as the most common diagnosis in equine veterinary practice. Other studies have identified surface, training regime and age as risk factors for sport horses becoming lame (Murray *et al*. 2010; Lönell *et al*. 2013; Egenvall *et al*. 2013). Finding more factors to reduce lameness is therefore important. In this study, all horses had access to the same training arenas and horses training in dressage or showjumping were present in both housing systems. They were ridden by students with the same level of skill and trained by the same riding teachers, regardless of housing system. The primary difference between the two groups was the amount of free movement. Therefore, the possibility of moving freely could be a factor reducing lameness among horses. However, more studies are needed to determine how free movement affects sport horses.

The differences in number of injured individuals between the housing systems in the prospective study might be due to group composition (Majecka & Klawe 2018), regrouping (Knubben *et al*. 2008b; Christensen *et al*. 2011), restricted feeding (Benhajali *et al*. 2009; Jörgensen *et al*. 2011) or space in the paddock (Majecka & Klawe 2018; Flauger & Krueger 2013). The effect of regrouping on frequency of injured horses was clearly demonstrated in the prospective study. The herd had uniform composition from September to mid-March. There was then a regrouping due to a change of students and thereafter a notable increase in number of injured horses in the active open barn. Differences between individual horses may also explain why there was higher proportion of injuries in the active open barn, since most of the horses had 0-3 injuries during the study period but three horses had 4-5 injuries and one horse in the active open barn had nine injuries. Lexing & Östling (2016) noted that agonistic behaviour can be more frequent around feeding stations, which may explain the higher number of injured individuals in the active open barn compared with the single boxes. Majecka & Klawe (2018) observed differences in social interactions in different herds, indicating that the combination of specific individuals in each herd is important for the level of aggression.

The retrospective study showed no differences in proportion of injured individuals in the active open barn (60%) compared with single boxes (59%), or in categories of injuries or in days lost from training. The different results in these sub-studies might be due to the method of data collection, since veterinary records were used in the retrospective study and minor injuries not needing veterinary care were not recorded.

5.2 Discussions of other results

5.2.1 Acclimatisation from an active open barn to single boxes

On comparing lying times in the single boxes during and after acclimatisation, no differences were found between the periods. This indicates that the horses had fulfilled their need for sleep in the active open barn prior to the study. This observation supports choice of a 10-day treatment period, with seven days of acclimatisation and three days of observation, since no differences were found. However, the horses were accustomed to both housing systems prior to the study, which may have influenced the differences between measurements during and after acclimatisation.

5.2.2 Behaviours on pasture and in an active open barn

On comparing the daytime behaviour in a group of horses on pasture and later in the same horses in an active open barn, it was found that the horses foraged more in the open barn (47% of observations) than on pasture (27%). Nocturnal grazing in 55-70% of observations has been reported in several studies (Keiper & Keenan 1980; Houpt *et al*. 1986; Boyd *et al*. 1988), especially during sunrise and sunset (Keiper & Keenan 1980; Houpt *et al*. 1986). This is supported by the observations that the horses in this thesis spent more time around the water point during 12-15 PM and more time on grass during 17-20 PM. However, the behaviour of grazing was probably not observed to its full extent due to the observation periods. Another finding to consider is the higher frequency of agonistic behaviour around the automatic feeding stations for horses studied in the active open barn. Even though no injuries were recorded during the observations, this behaviour could lead to injuries for horses using this type of feeding system. Agonistic behaviour in relation to feeding (Benhajali *et al*. 2009) especially restricted feeding, has been reported in other studies (Jørgensen *et al*. 2011; Burla *et al*. 2016).

5.2.3 Health and body condition

Health and body condition were investigated in a field study in this thesis, which posed a risk that the groups were already pre-selected for each housing system due to their health status and social skills. In addition, the observers scoring the horses were aware of the system each horse was housed in, which may have affected the results. However, there were no differences in performance (dressage/show jumping) and muscle building, indicating that horses (on this level) in active open barns can perform as well as horses in individual boxes. There was also no significant difference in hoof status, but horseshoes were worn down much faster in the open barn and had to be changed every three weeks, which can affect hoof status depending on the farrier's skills. The faster wear of horseshoes was reduced in the following seasons, due to dulling of the gravel and a change of substrate in some places, and is now around five weeks (Johansson 2022). However, the same gravel was used in the paddocks for the horses in single boxes, indicating more movement overall for the horses in the active open barn than for those housed in single boxes, as also found by Gulbrandsen & Herlin (2015). The slightly lower condition scores obtained for basic coat condition and coat cleanliness in the active open barn indicate that more work effort will be needed to keep an open barn-housed competition horse in good appearance.

5.3 Strengths and weaknesses

The mean forage intake rate in Paper I was slightly lower than in other studies (Müller 2011; Abrahamsson 2012), although it was based on a quite a large sample of 314 observations. No prior inspection of the oral cavity was made before measuring forage feed intake rate, but all horses at the facility are checked at least once a year. It is thus possible, but unlikely, that oral problems influenced the forage intake rate in the horses, resulting in lower forage intake rate than in other studies,.

The observations regarding time budgets and lying behaviour made through video recordings in Paper II and III gave a good overview of the horses' behaviours, and the results were based on quite a large sample. The observations were made using either scan sampling in 5-minute blocks or continuous sampling. Both methods provided ample data suitable for investigating the research aims, as found by Altmann (1974). Scan sampling in 5-minute blocks gave a good overview concerning time budget and use of lying halls. However, it is possible that some behaviour or short visits to the lying halls were missed with this method. Therefore, the more time-consuming method of continuous sampling was used for observations regarding rising from lying, recumbency positions and disturbances in Paper III, in order to register more detail.

The data used for studying time budgets and use of lying halls in Paper II were based on observations from two herds of geldings with similar working intensity kept in two different active open barns with similar stable furnishings, such as lying halls with straw, gravel paddocks and individual computer-controlled feeding stations. Given the similarities in the active open barns and in the horses, the results are from equivalent systems. Fader & Sambraus (2004) found no correlation between number of lying halls and different lying times in their study of seven heterogeneous herds. This indicates that it is in fact differences in available lying area which affect lying time. Nevertheless, estimated average lying times when the horses only had access to a lying area of 8 m^2 per horse in Paper II were no shorter than the lying times observed among feral horses (Kownacki *et al*. 1978; Duncan 1985; Sigurjonsdottir *et al*. 2012). The five focal horses observed at Flyinge seemed to spend less time in lateral and sternal recumbency than the group of 10 horses observed at Strömsholm, even though these five horses were chosen randomly and were of representative age (10-16 years) and daily work levels. These five focal horses also spent less time in the lying hall compared with the mean value for the whole group at Flyinge. These findings are difficult to analyse, since lying time has been found to differ between individual horses (Baumgartner *et al*. 2015). Decreased lying time could be associated with rank (Fader & Sambraus 2004). However, no evaluation was made of the rank of the individual horses at Flyinge and using five other horses might have affected the results due to their rank or other individual differences.

Although it can be difficult to determine whether time and treatment co-vary, each horse in Paper III underwent several research periods in the same active open barn, thus acting as its own control, which lends credibility to the findings. In this thesis it was only possible to record lying behaviour in the horses, whereas Fuchs *et al.* (2018) used a polysomnograph and Keleman *et al*. (2021) a gyroscope to measure sleep. However, as lateral recumbency is a prerequisite for REM sleep, it was used in this thesis as an approximation of time spent in REM sleep. In the group of horses studied at Strömsholm, there were some changes in group composition during the four treatments in Paper III, which could have affected the social dynamics in the group, and therefore the observed lying time and behaviour of the horses (Fader & Sambraus 2004). However, it is also important to remember that this optimal lying area could differ in mixed-sex herds or herds comprising only mares, as they have different individual spacing needs (Keiper & Sambraus 1986).

In the retrospective study in Paper IV, only data from the veterinary notes were recorded, whereas in the prospective study all injuries were recorded even though they might not have needed veterinary attention. This probably led to a higher number of injuries, including less severe injuries not requiring veterinary attention, being recorded in the prospective study. This is supported by the finding that almost half of those injuries did not lead to days lost from training.

In the retrospective study, the proportion of horses in the active open barn was larger (45%) than in the prospective study (30%). The horses were cared for and ridden by students in a standardised way in both the retrospective and prospective study, which is a strength when comparing the housing systems and the two sub-studies. Horse median age in years did not differ between the active open barn and single boxes, even though the housing system of each horse was not randomised. Other factors that may have reduced the level of injuries could have been not mixing the sexes in the active open barn or in pairs in the paddock, or only keeping geldings in the active open barn.

5.4 Factors affecting welfare and management in open barns

Housing has a great influence on horse welfare (McGreevy *et al*. 2015) and many horse owners regard housing as important for their horses' welfare (Viksten 2016). Ensuring a horse's welfare does not only mean preventing suffering, but also promoting positive emotional states (Mellor & Burns 2020). Housing a horse in an open barn system may substantially improve its welfare, according to Yngvesson *et al*. (2019), providing that the horse's nutritional needs are met and that it is part of a suitable social group where competition for lying space is low. Young horses are believed by horse owners to benefit in particular from being housed in open barns (Häggmar & Svensson 2020). Factors affecting welfare are pointed out in the Five Domains model (Mellor & Beausoleil 2015). In this thesis, the focus was on factors concerning forage intake, area in the lying halls, lying behaviour, social contact in lying halls and injuries, and how these parameters relate to management, planning and welfare.

One important part of the active open barn concept is to ensure that each horse in the group receives an appropriate individual feed ration, using automatic feeding stations. Automated feeding is a way to improve working environment and to save time (Adolfsson & Geng 2010). Wild, feral and domesticated horses spend 60-80% of their time grazing (Boyd 1991; Berman 1993; Fleurance *et al*. 2001) and therefore manual feeding is usually performed up to four times a day (Fyhr & Pirooz 2022). Feeding in single boxes can lead to work-related pain in stable staff, due to more lifts and awkward postures (Löfqvist *et al*. 2009). However, stable managers have pointed out in interviews that automatic feeding stations still require refilling, daily monitoring and supervision of each horse's daily ration (Cederberg Ringmar 2022; Johansson 2022; Jöngren 2022).

The horses observed in this thesis used the lying halls mostly for resting and foraging, which are both important parameters for horse welfare (Mellor & Beausoleil 2015). When the available lying area was increased from 8 m^2

to 18 m^2 per horse, both lying time and foraging increased. Since no individual observations were possible when the horses had access to 28 m^2 per horse, there are no statistical comparisons for this lying area, but there are indications that the horses in this group did not increase their lying time when the lying area increased above 18 m^2 per horse. Comparing use of the lying hall between the groups of horses at Flyinge and Strömsholm revealed no differences between 15 and 18 m^2 per horse. This observation is important, since the construction of buildings is a cost to consider for stable owners. The straw bedding in the lying halls at both Flyinge and Strömsholm could have led to shorter lying bouts for the horses, due to disturbances caused by foraging, as seen in other studies (Werhahn *et al*. 2010; Baumgartner *et al*. 2015). At the same time, several studies have observed that lateral recumbency may be of longer duration on straw bedding (Pedersen *et al*. 2004; Ilvonen & Segander 2014; Kwiatkowska-Stenzel *et al*. 2016), which is positive for horse welfare. Therefore, if straw bedding is used in lying halls in an active open barn system, it might be important to offer a lying area larger than the minimum required area. It is important to establish the optimal area for a lying hall that fulfils the horses' requirements at a reasonable cost.

Another important observation is that the horses used the lying halls for purposes other than resting and foraging, such as standing attentive and urination, which must be considered when deciding on the optimal area. The work in this thesis was conducted during late autumn and early spring, when there was a drop in temperature overnight, and thus the horses might have been seeking shelter due to weather conditions (Tyler 1972; Michanek & Bentorp 1996; Mejdell & Bøe 2005; Heleski & Murtazahvili 2010). In the smaller herd at Strömsholm (10 horses), at most 80-90% of the horses occupied the lying halls (with available lying area of 8-28 m2) at the same time. In the open barn at Flyinge, consisting of a larger herd (18 horses) and one lying hall with 15 m2 available lying area per horse, at most 60% of the herd was recorded as present at the same time, but the lying hall was never empty at any observation time (every hour). This indicates that a larger herd divides into sub-groups and visits the lying hall in turns, as reported previously by Nilsson (2006). However, the fact that the lying hall was never empty also indicated that the horses may have had to wait their turn to enter the lying hall. If the horses had had access to more than one lying hall, they might not have had to wait to rest or forage in the straw in the lying hall.

Another major concern among horse owners about keeping horses in groups is the risk of injuries from other horses (Kemstedt 2010; Wallberg 2010; Hartmann *et al*. 2015). Agonistic behaviour can increase due to lack of space, restricted feeding and group composition (Benhajali et al. 2009; Christensen *et al*. 2011; Jørgensen *et al*. 2011; Flauger & Kreuger 2013; Burla *et al*. 2016). In a conversation reported by Jöngren (2022), a stable manager with experience of an active open barn highlighted the importance of consistent herd composition and new horses are only introduced during grazing season when there is plenty of space for all horses to interact which each other. The importance of consistent herd composition herd was evident in the study at Strömsholm, where the incidence of injuries increased at the end of the season (mid-March) due to regrouping. Christensen *et al*. (2011) found that regrouping led to more aggressive behaviour until a new hierarchy was established and that the horses did not seem to become accustomed to constant regrouping. Previous experience of social interaction may also be important for the risk of injuries as Christensen *et al*. (2002) found more aggressive behaviour among stallions stabled singly compared to stabled in groups.

As mentioned earlier, horseshoes were worn down quickly in the open barns at Strömsholm and Flyinge. According to Svensson (2022), after five years of use of these open barns, the interval for changing horseshoes has increased from three to five weeks, due to the surface (gravel and stones) losing their edge and therefore not wearing the shoes to the same extent. During the first years after barn construction, the farriers at Flyinge shod many horses with thicker shoes (10 mm) or shoes with pointed toes. The latter are still used on some horses. However, as indicated earlier, there was no difference in hoof status among the horses at Strömsholm, probably due to experienced farriers.

Restricted feeding has been noted to lead to more aggression (Benhajali *et al*. 2009; Jörgensen *et al*. 2011). In an active open barn, the horses are offered a restricted ration in automatic feeding stations and have access to straw in the lying halls, but that might not be enough to lower the aggression level. Agonistic behaviours also tend to be more frequent around feeding stations (Lexing & Östlund 2016). Horses housed in single boxes in this thesis were only offered feed in the boxes, which might have reduced aggression levels in the paddocks. Aggression is also influenced by paddock area (Flauger & Krueger 2013; Majecka & Klawe 2018). Flauger & Krueger

(2013) found that an available area of 106 m² per horse or less increased the level of aggression in the herd, while aggressions were unaffected by available area above 331 m² per horse. The horses observed in Paper IV had access to 218 m² per horse in the prospective study and 175 m² per horse in the retrospective study, which may have affected the rate of injuries. However, there had to be appropriate individuals and sufficient available area, as also found by Flauger & Krueger (2013) and Majecka & Klawe (2018). Paddock size has an impact on agonistic behaviour and must be considered in order to reduce injuries among horses. Depending on number of regroupings in the herd, the recommended area per horse may vary but should be at least 200 m^2 per horse to reduce the risk of injuries at a reasonable cost.

The positive impact of daily periods of free movement in a paddock on horse welfare, associated with an increase of oxytocin levels and a decrease in stereotypic behaviour, suggests a possible increase in positive emotions (Lesimple *et al*. 2020). Other studies have observed benefits in bone density from increased movement daily (Graham-Thiers *et al*. 2013) and fewer motion asymmetries after a long period on pasture (Jobusch 2022), which also points to the benefits for health of an open barn system. Thus, free movement is another important factor in several ways for increased welfare. Still, studies have found differences in daily movement between groups of horses kept in similar housing systems (Keller *et al*. 2022; Sassner *et al*. 2022). This suggest that there are more factors than only the housing system that influence physical activity among horses. An important factor when planning an active open barn might be to encourage the horses to move between different feeding and resting areas, to increase movement and improve health in the horses.

Human safety is another area to consider when keeping horses in groups, with injuries being more likely to occur to a person when removing one horse from a group (Hartmann *et al*. 2012b). Handling horses in general has been shown to carry a high risk of being kicked by a horse (Carmichael II *et al*. 2014) and for horses kept loose in groups this risk is likely to increase. Letting horses out into paddocks has been shown to lead to a high number of accidents and is therefore considered a high-risk task (Swanberg *et al*. 2015). However, keeping horses in groups has been shown to reduce working hours compared with keeping horses in single boxes (Adolfsson & Geng 2010; Söderman & Fransson 2018; Fyhr & Pirooz 2022). Therefore, operating costs in open barns can be expected to be lower and the reduced working hours can be spent on training or taking care of the horses instead

5.4.1 Horse stables in the future

Group housing of horses meets many of the horse's basic needs and provides good conditions for maintaining high welfare. This housing system provides a good working environment if the stable staff have good security routines. The conventional way of housing horses has long been in single boxes and tie-stalls, but there is a growing preference in Sweden for systems where the horses are allowed to move freely (Swedish Board of Agriculture 2018), and tie-stalls are not permitted in new constructions. Housing horses in tie-stalls is forbidden in some countries and restricted in others. Many horse owners today are keen to provide their horse/s with improved welfare conditions. At the same time, they have high demands on their own working environment and want their horse/s to be easily accessible for training. The likelihood is that future customers in riding schools and boarding stables will want access to a horse when they have the opportunity and not always on a regular basis. Keeping horses in an open barn with plenty of paddock area, automatic feeding and lying halls with adequate lying area would fulfil that demand. However, in group housing systems it is still important to check every animal daily and have the skill to notice immediately when a horse is not feeling well. Keeping horses in open barns thus places higher demands on staff knowledge and experience, since in these housing systems the horses must be observed in the paddocks, instead of inspections in the box for *e.g.* feed left-overs and consistency of the manure.

Due to hard-paving of paddocks to prevent surfaces being trampled by horses, it is easy to remove manure and thereby reduce nutrient losses from horse keeping. This kind of system could be appropriate for farmers with suitable buildings and machines and an ability to manage a herd of animals. However, installing hard surfaces, building lying halls and buying automatic feeding system are expensive, even if these features lower the labour costs in the housing system. Therefore, it is necessary to find optimal paddock and lying areas. Lower litter consumption in open barns contributes to lower cost and climate impacts (Fyhr & Pirooz 2022).

Some individual horses might not be suitable for group housing, particularly if they are not reared in a suitable social context. As shown in this thesis, some group-housed horses seem to suffer a higher frequency of injuries than others in the group. Therefore, as the stable manager at Strömsholm pointed out, there should always be alternative housing for horses not suited for keeping in an open barn (Johansson 2022). Riding school horses need to be able to work every day, for economic reasons. Of course, this is not only an economic issue, since most stable managers aim to ensure that every horse has a high level of welfare and protect them from injuries. In the active open barn at Strömsholm, horses that crib-bite have been seen to increase this stereotypic behaviour, triggered perhaps by up to 20 rations of forage and 10 rations of grain every 24-h period, while stereotypic locomotor behaviours such as box-walking and weaving decrease, or even cease, in horses released into the system. Another important factor to consider is the composition of the herd, which should be kept unchanged to achieve low agonistic behaviours. At the Swedish National Equine Centres at Flyinge and Strömsholm, only geldings are kept in the open barns due to some alterations in the herds during one season in combination with restricted paddock area, to maintain as low a level of agonistic behaviour as possible. However, there are examples of well-functioning mixed flocks, so with the right conditions this is a good alternative.

There will always be horse farms where group housing is not possible due to design or location. Single boxes that provide the opportunity to socialise with other horses in a paddock could then be a good alternative. For horses not suitable for group housing, stables with single boxes and time in a paddock in daytime will be needed in the future. On horse farms with group housing, there must be single boxes available for sick or injured horses or horses not fitting into the current herd. Well-managed single-box horse stables could maintain high welfare for these horses, but a well-managed open barn with automatic feeding stations has scope for providing better welfare conditions for horses, particularly due to increased freedom of movement and more social contact.

In all, an active open barn can provide several welfare benefits for the horse and for the caretaker. The trend in most countries is toward housing systems with more social contacts and movement for the horses, and higher mechanisation and safety for humans. Some more knowledge and experiences are now being gained to guide horse owners in promising re-development of horse housing systems for the 21st century.

6. Conclusions

- Horses quickly learned to use an automatic forage station, with two-thirds of the horses studied learning the system within a week.
- Forage intake rate in horses varies between and within individuals. Therefore, each horse's forage intake rate should be determined using at least four measurements for each horse, to establish a representative mean value for individual horses when setting the ration in timed automatic forage stations.
- Increasing the lying area in lying halls, or housing individuals in single boxes, increases horse lying time. Greater available area in lying halls results in horses lying for almost twice as many bouts, and for almost twice as long in each bout, compared with smaller lying area. Thus, it is likely that the space requirements to meet the need for rest in group-housed horses is larger, not smaller, than in individual boxes.
- Lameness seems to be less frequent in horses housed in active open barns compared with single boxes, possibly due to more free movement, but further studies are needed.
- The frequency of injuries in horses cannot only be explained by the fact that the horses are allowed in a group or kept alone in the paddock. Keeping horses in small groups or group-housing them, with correct management and sufficient available area in the paddock, can be recommended.

Overall, this thesis showed that housing horses in active open barns provides benefits in terms of frequent social contact, moving freely, good body condition, less lameness and colic, and sufficient sleep when the lying area exceeds the minimum requirement of 8-10 m2 per horse. Potential disadvantages are more frequent minor injuries due to kicks, greater wear on shoes and difficulty in maintaining excellent coat condition.

7. Future studies

Future studies should examine the following issues:

- ✓ Human safety and housing system: compare incidents and injuries among humans handling horses in different housing system and total number of incidents involving humans.
- ✓ Health in open barns
  - compare inflammation markers and motion asymmetries between horses in open barns and horses in single boxes.
  - compare occurrence of injury in open barns with different feeding regimes and management.
- ✓ The welfare impact on horses of providing one large lying hall or several smaller halls.
- ✓ How rising behaviour varies between housing systems and whether it is a potential indicator of welfare status.

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Popular science summary

Housing horses in groups in open barns is becoming increasingly popular, with at least 1300 active open barns in Europe. These new systems often have timed controlled automatic feedings stations and are designed to encourage movement and facilitate natural horse behaviour. However, the majority of horses are still kept in individual boxes that restrict social interaction and free movement, two behaviours that are very important for the horse since this species evolved to live in herds in steppe landscapes. Foraging for a major part of the day is also important behaviour for horses. Group housing in active open barns enables more social interactions and free movement for horses, which increases their welfare. There are other benefits with group housing, such as easier daily management of horses, better learning capacity in young horses, less stereotypic behaviour and better working environment for human caretakers.

There are always questions and concerns about horse welfare when a new system is introduced and some horse owners fear that allowing social interactions between horses may lead more injuries and insufficient rest for the horses. Risk of injuries, lack of rest (including essential REM sleep) and deficient feed ration for some horses are important welfare factors that could arise when housing horses in groups. Human safety is another important issue. This thesis evaluated aspects of management of an active open barn with automatic forage stations and effects on the behaviour and welfare of group-housed horses in terms of feeding, resting and health. The results obtained were used to draw up recommendations for horse owners.

The first issue investigated was how to introduce horses to the automatic forage station and manage the time-based forage feed ration. Almost all horses learned to eat in the forage station within eight days. The time needed to eat the roughage allowance varied greatly between horses, and between

measurements for the same horse. Based on analysis of the data, it was concluded that the eating speed of each horse needs to be measured individually at least four times, to make sure each horse eats the correct amount.

The second issue investigated was sleep, another important factor for well-being and basic performance. The size of the lying halls in active open barns was studied in relation to lying behaviour and disturbances by other horses. The results showed that total lying time increased when the available lying area was increased, with a lying area of 15-18 m^2 per horse giving rather similar lying time to an allowance of 10.5 m^2 in single boxes. The lying time was shorter when the statutory minimum lying area of 8 m^2 per horse was provided, even though it is similar to that found in feral horses. Greater available area in the lying hall increased use of the lying hall by horses from 14% to 33%. Providing a lying area of 28 m^2 per horse did not further increase resting and use of lying halls compared with a lying area of 15-18 m^2 per horse.

The third issue examined was horses' health when housed full-time in an active open barn and when housed in single boxes at night and released into paddocks alone or in pairs during daytime. The main and most interesting finding was that the incidence of lameness was lower among horses housed in the active open barn (18%) than among horses housed in single boxes (26%). Another interesting result was that only horses in single boxes suffered from colic (5%). Injuries were more frequent in horses in the active open barn (83%) compared with single boxes (52%), but around half of injuries in the active open barn did not lead to any days lost from training. The incidence of injuries in the active open barn decreased as the group stabilised, but increased temporarily following a regrouping.

Overall, the active open barn housing system has several welfare benefits for the horse and the caretaker. Offering high-welfare conditions for horses is a promising development for horse stables in the 21st century. Based on the findings in this thesis, the recommendations for horse owners keeping their horses in active open barns are to keep the groups as stable as possible, measure each horse's foraging time carefully and adjust feeding accordingly, and provide substantially more lying area per horse in the lying hall than the statutory requirement for single boxes.

Populärvetenskaplig sammanfattning

Att hålla hästar på lösdrift blir alltmer populärt och idag finns det i Europa minst 1300 lösdrifter med tidsstyrda automatiska utfodringsstationer och designade för att uppmuntra rörelse, så kallade, aktiva grupphästhållningar. Ändå hålls en stor del av hästarna i individuella boxar, vilket begränsar deras möjlighet till socialt beteende och fri rörlighet. Detta är två behov som är mycket viktiga för hästen, eftersom de är utvecklade för att leva i en flock på en stäpp. Detta innebär också att för en häst är möjligheten att få äta en stor del av dagen ett viktigt behov. Grupphästhållning ökar deras möjlighet till att få utöva sociala beteenden och att röra sig fritt under stor del av dygnet, vilket ökar deras välfärd.

Det finns även andra fördelar med att hålla hästar i grupp, såsom lättare att hantera hästar, bättre inlärningsförmåga hos unghästar, färre stereotypa beteenden och bättre arbetsmiljö för oss människor. Men det finns alltid frågor och farhågor kring hästens välbefinnande när ett nytt system införs och en del hästägare är oroliga för att grupphästhållning kan leda till fler skador och även otillräcklig vila för hästarna.

Ökad risk för skador, för lite vila, inklusive den nödvändiga REM-sömnen och för mycket eller för lite mycket foder till varje häst är viktiga punkter som kan äventyras när hästar hålls i grupp. Dessutom är människors säkerhet också viktig att utreda. Denna avhandling utvärderade hur skötseln av en aktiv grupphästhållning påverkade hästarnas välfärd i förhållande till utfodring, vila och hälsa och hur resultaten kan användas för att formulera rekommendationer till hästägare.

Till en början var det viktigt att ta reda på hur lång tid det tog att introducera hästarna till den automatiska foderstationen samt hur man säkerställde att hästarna fick lagom mycket hösilage då mängden grovfoder ställdes in i antal minuter. Nästan alla hästar hade lärt sig att äta i foderstationen efter åtta dagar. Hur mycket tid de behövde för att äta sitt grovfoder varierade mycket mellan varje häst och även mellan mätningarna på samma häst. Därför måste ättiden för varje häst mätas minst fyra gånger.

Då även sömn är en viktig faktor för hästvälfärd och grundläggande prestation filmades hästarna i ligghallar med olika storlek och deras liggtid mättes. Resultatet blev att den totala liggtiden ökade när den tillgängliga ligghallsytan ytan ökade. Hästarnas liggtid i box på 10,5 m^2 och i ligghallar med en yta på 15–18 m^2 per häst var ganska lika. Tiden när hästarna låg ner blev kortare när den av lagstiftningen föreskrivna minsta ytan på 8 m^2 per häst användes, även om dessa liggtider var som det som finns hos vilda hästar. Ökad yta i ligghallen gjorde också att hästarna ökade användningen av ligghallen från 14% till 33%. Vila och användning av ligghallar då hästarna hade tillgång till 28 m^2 per häst verkade ligga på samma nivå som 15-18 m^2 per häst.

I sista delen jämfördes hästarnas hälsa när de hölls i en aktiv grupphästhållning eller i box på natten och antingen ensamma eller i par i hagar under dagtid. Det mest intressanta resultatet var att hältan verkade vara lägre bland hästar som hölls i den aktiva grupphästhållningen (18%) än bland hästarna som hölls i boxar (26%). Ett annat intressant resultat var att endast hästar som hölls i box drabbades av koliktillfällen (5%). Även om hästarna i den aktiva grupphästhållningen fick fler skador (83%) jämfört med de i box (52%), resulterade nästan hälften av skadorna i den aktiva grupphästhållningen (45%) inte till någon sjukfrånvaro. I den aktiva grupphästhållningen ökade skadorna återigen efter en omgruppering efter att ha minskat när gruppen stabiliserades efter några månader.

Sammantaget så gynnar en aktiv grupphästhållning både hästens välfärd och skötaren på flera olika sätt och kan därmed anses erbjuda hästarna en hög djurvälfärd i denna typ av 2000-talets häststallar. Rekommendationen till hästägare som vill hålla sina hästar i en aktiv grupphästhållning är att hålla gruppen så stabil som möjligt, mäta varje hästs ättid flera gånger för att anpassa utfodringen och ge hästarna utrymme i ligghallen som är betydligt större än i en enda box.

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Introduction to automatic forage stations and measurement of forage intake rate in an active open barn for horses

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A B S T R A C T

Interest in the use of open barns on Swedish horse farms is increasing as an alternative to keeping horses in box stalls and as a 2007 law requires phasing out of tie stalls. To provide adequate forage to satisfy welfare requirements for nutrition, gut health and behavioural needs, the use of automated feeding is also increasing. Studies on forage intake rate report wide variation but provide little information on how to introduce horses to an automatic forage station and on how forage intake rate varies in individual horses fed using an automatic forage station. This study documented the process of training 22 horses to use a transponder-controlled automatic forage feeding station and measured forage intake rates. Observations on the learning period of horses for transponder-controlled automatic forage stations showed that after 4 days, 48% of the horses had reached the goal of 90% intake. After 8 days, learning was completed in 71% of horses and at 16 days in 95% of horses. Measurements of forage intake rate revealed significant differences between individual horses. Overall mean intake rate ± SD, based on 314 observations, was 22.4 ± 6.7 min/kg forage DM. Evaluation of the number of intake measurements required to set a representative average ration in the automatic station for an individual horse showed that the variation levelled off at four samples. In conclusion, horses quickly learned how to use an automatic forage station, with two-thirds of horses achieving this within 7 days. To ensure the correct ration in a timed transponder-controlled automatic forage station, each horse's forage intake rate must be measured at least four times to obtain a representative average.

Implications

This study showed that horses can quickly learn to use timed transponder-controlled automatic forage stations, with two-thirds of horses reaching the goal of 90% intake within a week of stepwise introduction. Measurements of forage intake rate revealed differences between individual horses, with an overall mean value of 22.4 min/kg DM haylage. Considering the variation within individual horse samples, when setting the ration in an automatic station, each horse's forage intake rate should be measured at least four times to obtain a representative individual mean value.

Introduction

Horse welfare has become a key issue in horsekeeping in Sweden. The Swedish Board of Agriculture (2018) estimates that the current housing system comprises 75% individual boxes, 20% open barns and 5% tie stalls. There is increasing interest in keeping horses in open barns, both for welfare reasons (Fors-Jadin and Wännman Kvantenå, 2017) and because of legislation banning tie stalls in new or renovated stables since 2007 (Swedish Animal Welfare Agency 2007 [Ch. 3, § 4 DFS 2007:6]). An open barn is defined as a loose-housing system with a paddock, a lying hall with bedding and *ad libitum* or restricted feeding. *Ad libitum* feeding of forage to leisure horses can result in obese horses, which can cause problems such as laminitis and equine metabolic syndrome (Chapman, 2014). To avoid these problems, automatic feeding stations that control access to individual feeding, using a time-based system, have been developed. The system is called active open barn, and there are currently 35 such facilities in Sweden.

Studies on forage intake rate show great variation between individual horses, with the time taken for intake of 1 kg of hay DM varying from 38 to 74 min in different studies (Dulphy et al., 1997; Harris et al., 2005; Brøkner et al., 2008). Intake of silage is reported to vary from 29 to 47

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min/kg DM in different studies (Müller, 2011; Abrahamsson, 2012). Müller (2011) also found that forage feed intake rate for haylage could also vary from time to time due to the harvest date. These results indicate that there is wide variation between individual horses, which must be considered in the management regime when allocating forage according to time.

There have been some previous studies on active open barns, concerning horse feeding behaviour around concentrate feeding stations (Hoffmann et al., 2012; Gülden and Büscher, 2017; Gülden et al., 2018). However, there is limited information on how to introduce horses to an automatic feeding station and how forage intake rate varies in horses using automatic individual forage stations. The aim of this study was to document the time needed to train the horses to autonomously manage a forage feeding station and to measure forage intake rates. The following research questions were addressed: How long does it take to train horses to use an automatic forage feeding station? How can individual forage intake rate be established for horses fed from an automatic forage feeding station?

Material and methods

Horses

The study was conducted at the Swedish National Equestrian Centre in Strömsholm, Sweden. All horses in the study were Swedish Warmblood geldings, aged 3–18 years. They are all used as school horses in the undergraduate programme in equine studies at the Swedish University of Agricultural Sciences. The horses were divided into two age groups, older (≥7 years) and younger (3–6 years). The older horses are trained to compete in dressage (advanced M-level) or showjumping (1.2–1.3 m). The younger horses are being trained in dressage or showjumping. All horses are exercised 5–6 times a week. The oral cavity of each horse is inspected and, if needed, corrected by a veterinarian once or twice a year.

Housing system

The horses were housed in either an active open barn system for 24 horses or in a single-box system (3 m × 3.5 m). Horses in boxes were fed manually four times a day (at 0630, 1130, 1600 and 2000 h) and spent 2–4 h in a paddock. The active open barn HIT Active Stable® (Weddingstedt, Germany) consisted of one paddock of at least 150 m^2 per horse and four lying halls with a total lying area of 23 m^2 per horse, mainly bedded with straw. For horses in the active open barn, haylage was served in a transponder-controlled automatic forage feeding station, HIT-double hay station type B, designed as double stations with a total number of six feeding stalls (Fig. 1). The individual feeding time of each horse was pre-programmed in a chip placed in a neck collar (Fig. 2). The horse enters the forage station via a rear gate that opens when the previous horse's feeding time is finished. When a horse enters the stall with feeding time left and has not been fed during the preceding 60 min, the rear gate closes and a partition wall is lowered in front of the horse. When feeding time for that session is used up, the partition wall is slowly raised, and the horse exits via a side-placed front gate. The horses were also offered straw *ad libitum*, in one hayrack, Horseking Safety HayRack. In addition, there were three automatic watering bowls, HIT-drinker Aqua, and one transponder-controlled automatic concentrate feeding station, HIT-concentrate feeder Kompakt.

Study 1: introduction of horses to an automatic feeding station

A total of 22 Swedish Warmblood geldings were introduced into the active open barn. These comprised a group of 14 older horses (aged 8–17 years) previously housed in a single-box system and a group of eight younger horses (aged 4–6 years) previously housed in a loose-housing system. All horses were fed haylage with 77% DM content and all had 300 min feeding time programmed each day, according to the manufacturer's recommendations and distributed into maximum 20 portions in each 24-hour period. When a horse left the housing system, a computer recalculated the remaining feeding times so the programmed feeding time was fulfilled during the remainder of the 24-hour period. During the first week of the study, only the automatic forage stations were in use, as installation of the automatic concentrate feeding station was delayed until the second week of the study.

One stable manager was responsible for the entire training period. Each horse was introduced to the automatic forage station with the assistance of a trainer in four steps: 1) approach the feeding stall (led initially), 2) learn how to find feed, 3) accept rear gate closing and 4) learn how to open the exit gate (Fig. 2). The stable manager decided when a horse was ready for the next step. The horses were trained by students under the supervision of the stable manager, so that up to six horses could be trained simultaneously. Each horse had the same student trainer for most of the time. The frequency of sessions per day depended on the number of available students. A protocol was established for each horse, recording how many training sessions were needed. A horse was considered ready to be released into the system when it had accepted the automatic forage feeding station and could perform the steps described above without assistance from the trainer. Recording of daily forage feeding time started as soon as the horse was released. A horse was considered to have learned the system when it reached 90% of its pre-programmed feeding time, calculated by the computer integrated in the system.

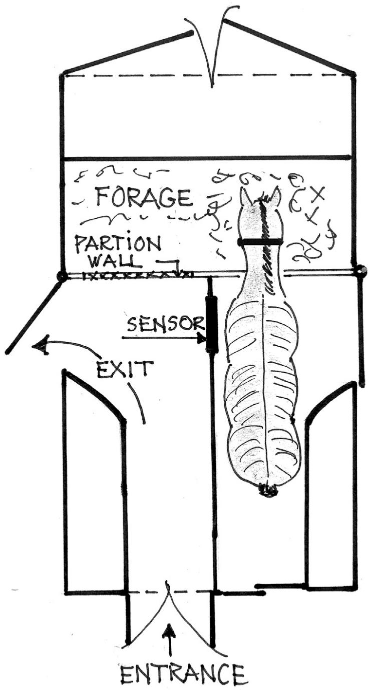

Fig. 1. An illustration of the transponder-controlled forage feeding stations, used in the study, displaying the horse's position and passage.

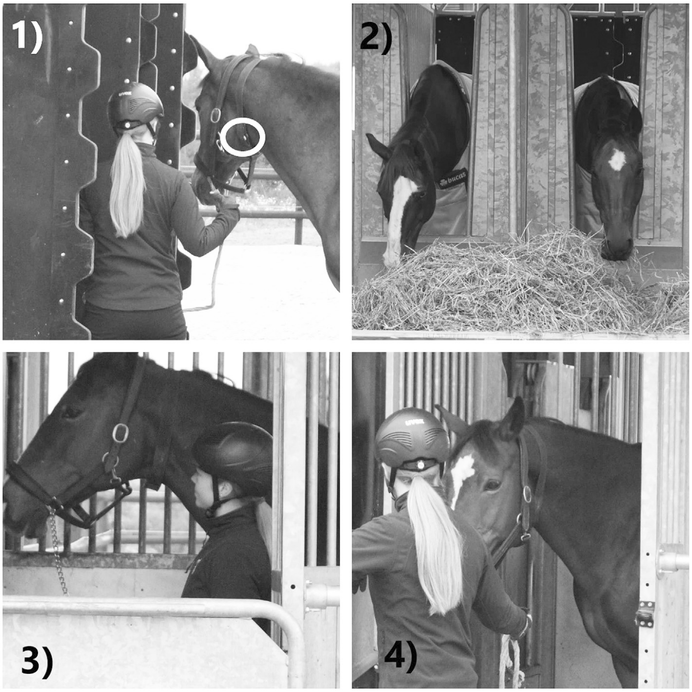

Fig. 2. The illustration visualizes the four steps of how to train a horse to use the automatic forage stations: 1) approach (led initially), 2) find feed, 3) accept closed doors behind, 4) open the exit gate. Photo 1 also shows the neck collar where the chip is placed (marked with a white circle).

Study 2: forage intake rate

Intake rate of haylage was measured in 28 Swedish Warmblood geldings in two consecutive sub-studies (2a, 2b). The BW of the horses varied between 510 and 700 kg, see Table 1. The horses were fed 110–145 MJ/day or 7.7–23.7 kg DM per day. All horses had been fasting for 2 h before measurement of forage intake rate began. They were all fed their usual haylage, the DM content of which was measured just before each sub-study by drying at 100 °C for 60 min in a TT Moisture tester from the company *Stallmästaren AB* (Lidköping, Sweden).

In study 2a, 20 horses were tested in pairs, 10 horses housed in an individual box system and 10 horses in an active open barn, to evaluate the effect of housing system due to different feeding regimes in individual boxes (4 times/day) and the active open barn (20 times/day). Measurements were performed in a series of eight tests, in a familiar room used for horse care. In each test, the horses were fed 3 kg of their usual haylage in a wide hay-bag for 20 min, divided into two 10-minute parts. After the first 10 min, the haylage in the hay-bag and waste from floor were weighed and then the horse was fed the remaining haylage in the same bag for another 10 min. After completing each feeding session, the remaining haylage including waste was weighed again and the forage intake rate for each horse was calculated in minutes per kg DM. Haylage DM was determined before each test (mean value $\pm$ SD of 79 $\pm$ 2%).

In study 2b, only horses housed in an active open barn were tested. Eleven geldings were tested in pairs in an automatic feeding station, in two series of seven tests comparing two methods to establish the most efficient way to measure the individual forage intake rate. In Method 1, the horses were fed 5 kg of their usual haylage for 15 min, and then the remaining haylage was weighed and the forage intake rate of each horse was calculated in minutes per kg DM. In Method 2, the horses were fed haylage corresponding to 1 kg DM and total feeding time to finish was measured. Seven repetitions were conducted for each method. Haylage DM was determined before each test and found to vary from 57 to 70% (mean 64 $\pm$ 3%).

Statistical analyses

In study 1, the two groups, older and younger horses, were compared with a Student's t-test for three parameters: total number of training sessions, number of training sessions per day and number of days to reach 90% of daily forage intake. For study 2, descriptive statistics on forage intake rate for the 28 individual horses in study 2a and 2b were calculated. A non-parametric model was used for comparisons since the data were not normally distributed, as shown in Fig. 3. Individual differences were compared using Kruskal–Wallis one-way ANOVA on ranks, followed by Dunn's test for post hoc test. A median was calculated for each horse before applying the Mann–Whitney rank sum test to compare differences in forage intake rate between 1) housing systems (2a), 2) Method 1 vs Method 2 (2b) and 3) age group (2ab). The Wilcoxon signed rank test was used for comparing forage intake rate between 0 and 10 min vs 11–20 min in study 2a. To establish the number of measurements needed to get a representative individual forage intake rate, an individual mean value for one to seven repetitions was first calculated. The difference in mean value between seven and six

Table 1
Characteristics (age, BW and daily forage ration) of the horses used in the study ($n = 28$) and individual forage intake rate (min/kg DM). There were significant differences between horse 1–11 vs horse 28, horse 1–5 vs 23–27 and horse 1–3 vs 21–22.

Horse no.	Age (years)	BW (kg)	Forage ration (kg DM)	Individual forage intake rate (min/kg DM)				No. of observations
				Mean ± SD	Median	Min – max	Range	
1	5	600	21.2	13.2 ± 0.4	13.3	12.6–13.7	1.1	$n = 5$
2	6	620	12.8	15.9 ± 3.7	15.4	11.5–23.6	12.1	$n = 8$
3	12	632	14.1	16.1 ± 5.7	13.9	12.6–29.8	17.2	$n = 8$
4	9	578	16.7	16.4 ± 4.0	14.9	13.7–26.0	12.3	$n = 8$
5	5	668	21.7	16.6 ± 3.1	15.7	13.6–23.2	9.5	$n = 8$
6	6	697	23.7	16.9 ± 1.8	16.6	14.5–19.5	5.0	$n = 8$
7	12	679	21.0	17.1 ± 5.9	15.3	12.7–31.1	18.4	$n = 8$
8	13	682	23.1	17.3 ± 2.7	18.2	14.1–20.5	6.4	$n = 8$
9	16	676	20.1	17.9 ± 4.5	16.5	14.7–28.3	13.6	$n = 8$
10	6	527	16.8	17.9 ± 2.6	18.1	14.1–22.0	7.9	$n = 8$
11	5	559	15.9	18.9 ± 3.2	18.3	16.0–26.4	10.4	$n = 8$
12	12	619	15.3	18.9 ± 5.4	17.7	14.2–30.3	16.0	$n = 8$
13	8	620	10.3	19.4 ± 2.4	18.4	16.7–24.0	7.3	$n = 14$
14	10	565	12.8	20.4 ± 3.7	19.6	15.3–26.9	11.6	$n = 8$
15	4	698	13.8	21.8 ± 6.9	19.8	16.8–37.2	20.4	$n = 8$
16	7.5	645	9.9	21.9 ± 5.0	21.3	14.6–34.9	20.3	$n = 22$
17	11	680	19.2	22.5 ± 2.3	22.3	19.5–27.1	7.6	$n = 8$
18	4	622	13.8	23.2 ± 3.2	22.4	18.9–30.1	11.2	$n = 14$
19	18	560	19.2	24.1 ± 5.5	24.3	17.6–31.8	14.3	$n = 8$
20	11	556	12.2	24.5 ± 5.0	23.7	18.2–38.0	19.8	$n = 14$
21	3	558	11.4	24.6 ± 2.9	24.7	17.9–28.6	10.7	$n = 14$
22	13.5	566	9.0	24.7 ± 5.2	24.0	17.2–38.9	21.7	$n = 22$
23	17	542	11.8	25.4 ± 3.4	24.3	21.7–32.2	10.5	$n = 14$
24	11	633	10.9	25.7 ± 6.5	24.6	18.6–45.4	26.8	$n = 14$
25	10	634	7.7	25.9 ± 5.2	25.1	18.8–39.5	20.6	$n = 14$
26	16	590	15.3	26.4 ± 9.3	23.3	20.7–48.7	28.0	$n = 8$
27	16.5	657	14.2	27.4 ± 9.5	25.2	17.6–61.2	43.6	$n = 22$
28	3	512	10.8	33.2 ± 7.7	32.8	20.0–51.2	31.2	$n = 14$

repetitions (1–7 vs 1–6), seven and five repetitions (1–7 vs 1–5) and so on was determined. The mean value and SD of the differences were then calculated for each set of repetitions. In combination, the correlation between seven repetitions and each set of sub-groups of repetitions (1, 1–2, 1–3, 1–4, 1–5, 1–6) was analysed.

SigmaPlot version 13.0 (Systat Software, 2014) was used for statistical analyses. The level of significance was set to $P < 0.05$. The results are presented as mean value ± SD and, when appropriate, the median.

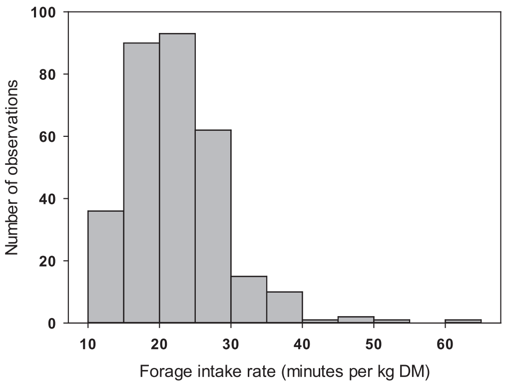

Fig. 3. The diagram shows the distribution of forage intake rates for the 28 horses in the two consecutive sub-studies (2a, 2b). There were in total 314 measurements where the number of samples from each individual varied ($n = 5$, 8, 14 or 22). The forage intake rate was measured either by recording the time to eat a fixed ration or by recording the eaten amount in a fixed time frame.

Results

Study 1: introduction to feeding station

After 4 days, 48% of the 22 horses in the study had reached the goal of 90% intake. After 8 days 71% of the horses had reached the goal, while at 16 days 95% had reached the goal. The younger horses needed a significantly ($P = 0.01$) fewer training sessions (11.8 ± 2.1) than the older horses (23.5 ± 11.5). However, it was noted that the younger horses trained for significantly ($P = 0.036$) more sessions per day (5.9 ± 1.0) than the older horses (4.7 ± 1.5). There was no significant difference ($P = 0.91$) in number of days taken to reach 90% of daily forage intake between the groups (younger horses: 7.3 ± 7.3 days, older horses: 7.8 ± 2.8 days).

Study 2: forage intake

The overall mean forage intake rate in both sub-studies (2ab, $n = 314$) was 22.4 ± 6.7 min/kg DM (ranging from 11.5 to 61.1). However, in the individual results, there were significant inter-individual differences ($P < 0.001$), see Table 1. No differences between groups were found for the parameters: 1) housing system ($P = 0.385$); active open barn (18.0 ± 4.3; median 17.4) vs the individual boxes (20.9 ± 7.9; median 18.8); 2) measuring method ($P = 0.948$); Method 1 (18.0 ± 4.3; median 24.4) vs Method 2 (20.9 ± 7.9; median 24.4); or 3) age group ($P = 0.331$); younger horses 3–6 years (21.7 ± 7.1; median 18.2) vs older horses 7–18 years (22.7 ± 6.5; median 22.3). In study 2a, the horses ate faster ($P < 0.001$) in the first period, 0–10 min of the test (17.8 ± 6.0; median 16.4) than in the remaining 10 min (22.2 ± 9.1; median 19.8).

There was some fluctuation in intra-horse forage intake rate when the measurements were repeated seven times. It was found that four to six repetitions gave an acceptable difference in mean value and SD in combination with a strong correlation ($R^2 \geq 0.88$) between seven

Table 2
Results of analysis to establish the number of measurements required to obtain a representative mean value of individual forage intake rate in horses. The mean value for seven measurements was compared with that for one up to six measurements. The values shown are mean ± SD of the difference compared with seven measurements, the correlation coefficient (R^2) and the equation.

Number of measurements compared	Difference mean ± SD	Correlation	
One (no. 1) vs all (no. 1–7)	−0.1 ± 4.2	$R^2 = 0.62$	y = 1.16x − 3.67
Two (no. 1–2) vs all (no. 1–7)	−1.5 ± 2.2	$R^2 = 0.79$	y = 0.92x + 0.17
Three (no. 1–3) vs all (no. 1–7)	−1.1 ± 1.9	$R^2 = 0.87$	y = 1.07x − 2.60
Four (no. 1–4) vs all (no. 1–7)	−0.6 ± 1.6	$R^2 = 0.88$	y = 0.92x + 1.21
Five (no. 1–5) vs all (no. 1–7)	−0.5 ± 1.4	$R^2 = 0.91$	y = 0.93x + 1.03
Six (no. 1–6) vs all (no. 1–7)	−0.1 ± 1.1	$R^2 = 0.94$	y = 0.99x + 0.10

measurements vs the actual series, see Table 2. Based on this analysis, we recommend at least four measurements to get a representative average for an individual horse.

Discussion

The first horses to learn to use the automatic forage station were horses considered to be easy feeders. This could be explained by findings by Olczak et al. (2018) that the degree of food motivation differs between individuals, which may affect how fast horses learn a new feeding routine. It was possible to release the younger horses into the system sooner than the older horses. This could possibly be due to more frequent training of the younger horses and the fact that they came from a loose-housing system and were accustomed to putting their head into a hayrack.

In the first week of the study, the concentrate feeding station was not in operation. This could have affected the time taken for the horses to learn how to use the feeding station. In the concentrate feeding station, the horse had to lower its head to be identified by its data chip and then rewarded by the ration of concentrate feed. When a horse had learned this, it made faster progress in learning to use the automatic forage feeding station. Palatable food, for example pelleted concentrate, has been shown to encourage quicker responses when horses are learning a new routine (Ninomiya et al., 2007). The concentrate feeding station seems to be important to encourage through-flow in the system (Hoffmann et al., 2012). An example of this was that during the first week, one of the older horses, considered by staff to be a high-ranking horse, monopolized one stall in the automatic forage feeding station. This behaviour ceased as soon as the concentrate feeding station was in full operation. Monopolizing time has been shown to decrease on reducing the number of portions to three per day (Gülden et al., 2018) and providing an acoustic signal followed by a compressed air stimulus (Gülden and Büscher, 2017).

The individual ration in forage stations for horses in an active open barn system is set according to available feeding time in minutes. Recommended feeding time when introducing a horse is fixed (300 min) and does not consider inter-horse differences in forage feed intake rate. In the present study (2a and 2b), the individual mean value varied from 13.2 to 33.2 min/kg haylage DM, see Table 1. It is therefore important to establish individual adjusted daily rations, since there are inter- and intra-individual differences in forage intake rate. According to previous studies, other factors may also affect the forage intake rate, such as harvesting method and harvest date. Haylage has been found to have a lower forage intake rate, for example, 29–47 min/kg DM (Müller, 2011; Abrahamsson, 2012), compared with hay, for example, 38–74 min/kg DM (Dulphy et al., 1997; Harris et al., 2005; Brøkner et al., 2008). Differences in forage intake rate between individuals were also found by Müller (2011), with ranges from 29 to 41, 34 to 65 and 35 to 64 min/kg DM for forages with different harvest dates. The overall mean value (22.4 ± 6.7 min/kg DM) in our study indicated lower forage intake rate for haylage compared with other studies (Müller, 2011; Abrahamsson, 2012). An explanation for the differences between studies could be differences in fibre content, since the horses in our study and those in Müller (2011) and Abrahamsson (2012) were of the same size and type. The highest value observed in this study, 61.2 min/kg DM, was recorded for a horse that was very distracted by the surroundings and had difficulty focusing on feeding, which prolonged the feeding time on the measurement occasion. This can happen when one individual is feeding in the forage feeding station and is a factor to consider when programming the feeding time. No prior inspection of the oral cavity was done in the present study, but all horses at the facility are checked regularly. It is thus possible, but unlikely, that oral problems influenced the forage intake rate in the studied horses.

We compared two different methods for measuring forage intake rate. The horses showed the same forage intake rate when fed *ad libitum* for 15 min (Method 1) or given 1 kg DM and allowed to finish (Method 2). Method 1 was more labour-intensive due to more steps, because the forage needed to be weighed twice (before starting and all leftovers), which also may create more sources of error. However, Method 1 was usually faster (15 min), especially if the horse ate slowly (>15 min). According to the results obtained, both methods were equally valid and showed the same measurement patterns. A common pattern with both methods was high variation within the series of measurements. Thus, making only one measurement for a horse and following the automatic station manufacturer's recommendation of 300 min feeding time per day could lead to forage intake of the individual horse varying from 5 to 25 kg DM per day. This means that several measurements are needed to get a relevant average for each horse. After four measurements, the variation in mean value was more consistent within a horse and can be used when introducing a horse to the system. However, it is important that the stable manager monitors the horse over time and adjusts the feeding time when required.

Conclusion

Horses quickly learned to use an automatic forage station, with two-thirds of the horses studied learning the system within a week. We recommend at least four measurements to establish a representative mean value for setting the correct ration in a timed automatic forage station for an individual horse.

Ethics approval

All experimental procedures involving animals were approved by the local ethics committee, according to Swedish legislation (SJVFS 2019:9), dnr C 80/15.

Data and model availability statement

None of the data have been deposited in an official repository.

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Author contributions

Kjellberg has written the manuscript with supervision of Morgan. The authors had joint responsibility for data collection and revision of the manuscript. Morgan performed the statistical analysis with statistical advice from von Brömssen. Morgan has drawn the illustration in Fig. 1.

Declaration of interest

The authors declare they have no conflicts of interest.

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Article

Horses' Use of Lying Halls and Time Budget in Relation to Available Lying Area

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Simple Summary: A safe and comfortable resting area to lie down and sleep in is an important factor in ensuring horse welfare. The lying times of stalled horses depend on factors such as bedding, housing, and lying area, while the sleeping behavior of group-housed horses may be influenced by such factors as social relations and competition for space. This study aimed to analyze time spent in, as well as activity taking place in, lying halls of various sizes. We compared single boxes and open barns with available lying areas of 8, 15, or 18 m^2/horse, on the basis that a lying area of 8 m^2 is the minimum requirement stipulated by Swedish legislation. We found that increasing lying area increased the horses' use of the lying hall and their total lying time, and that the lying time of a horse housed in a single box was equivalent to the lying time of a horse in group housing with access to a lying area of 18 m^2/horse. Hence, to ensure access to sufficient resting space for all horses in group housing, we recommend that the minimum requirement should be reassessed and increased.

Abstract: Sleep is crucial to horses' wellbeing, and their lying time can vary according to such factors as climate, exercise, bedding, and housing. This study aimed to analyze behavior and time spent in lying halls of various sizes. We examined the influence of housing systems on total lying time and behavior, and how changes to available lying area can affect lying time. Two open barns were used in this study, with lying areas of 8, 15, and 18 m^2/horse available in the lying halls. The horses' behavior was video recorded and logged using scan sampling and interval observations. Individual boxes were used as a control. The horses were found to spend longer time in sternal and lateral recumbency in the hall with a lying area of 18 m^2/horse than the hall with a lying area of 8 m^2/horse. Increasing the area of the lying hall also increased overall time spent there. Consequently, the hypothesis that increasing lying area will increase the horses' use of the lying hall, as well as their total lying time, was accepted.

Keywords: lying time; recumbency; group housing; lying behavior; shelter; open barn system; sleep; rest; welfare

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1. Introduction

Ensuring horse welfare is vital for riders and owners alike, both for ethical reasons and to ensure their health and happiness. From an ethical perspective, it may be argued that because we use horses for sport and leisure, we have a responsibility to protect their wellbeing, not only in preventing suffering, but also in promoting positive emotional states, as Mellor & Burns [1] concluded. The theoretical framework of animal welfare has been revised in 2015 by Mellor & Beausoleil [2] to include five domains (nutrition, environment, health, behavior, and mental state) and emphasize the importance of positive mental states. Furthermore, Mellor & Burns [1] have developed a practical assessment model for equine welfare, within which the present study is particularly concerned with the domains of Environment and Behavior. Housing horses in an open barn system may substantially benefit their welfare, as it gives them more choice, allows access to a larger space, and provides the opportunity to move around at all times. Yngvesson et al. [3] found that horses in Swedish riding schools were in better general health when kept in group housing then when they were housed individually and they had a lower incidence of respiratory problems and colic. Additionally, the open barn system is conducive to an improved working environment, as difficult and time-consuming tasks can be mechanized. The basic design consists of a lying hall, where the horses are provided with a dry and comfortable lying surface, and a paddock around the lying hall, with forage delivered ad lib or by computer-aided feeding stations. However, open barns can differ greatly in their planning and management. More research data are thus required to develop guidelines for suitable layouts, ensuring the sustainability of the horses' welfare.

An important factor in the welfare of horses is the opportunity to get enough sleep. Horses move through four stages of vigilance: wakefulness, drowsiness, slow wave sleep, and paradoxical sleep [4–6]. Even though horses can sleep while standing, they also need to lie down and rest their heads, which happens during paradoxical sleep. Monitoring the horses' lying time can be used to compare different housing systems from a welfare perspective [7]. It has been observed that feral horses tend to spend 0.5–2 h lying down during a 24 h period [8–11], and foals and young horses (2–3 years old) tend to spend even longer [9]. Individually stalled horses usually spend 3–5 h lying down during a 24 h period [4,5,12], while lying time for horses kept in open barns reportedly ranges from 1 to 2 h [13,14]. Raspa et al. [15] suggested that the longer lying times found in stalled young horses compared to feral young horses could be due to boredom and restricted space. Using an automatic concentrate station increased lying time from 84 ± 42 min to 115 ± 71 min per day [14]. In the same study, they found that the lying periods in this active open barn seemed to occur between the hay feeding times.

Total lying time can vary according to several factors. It tends to be shorter, for example, in hot climates [16], and longer with increased exercise [17]. Köster et al. [12] found that horses kept in open barns had shorter lying times than those kept in individual boxes, and horses kept in open barns were said to have similar lying times [13,14,18] to feral horses [8,10,11]. Studies also show that as many as one-third of horses kept in active open barns do not lie down every day [19]. Lower-ranked horses in open barns spend little to no time lying down when compared with higher-ranked horses [19–21], especially when the lying area is restricted [21]. Lower-ranked horses reportedly exhibit fewer lying bouts than higher-ranked horses [19] because their lying bouts are often disturbed or interrupted [20]. In comparing the activity levels of stabled horses and horses kept in open barns, Gansow [22] found a negative correlation between activity level and rank for the horses kept in open barns.

Fader & Sambraus [21] found that the size of the lying area influenced time spent lying down. Horses in open barns with a smaller lying area (4.6 m^2/horse, 59 ± 48 min) spent significantly less time lying down ($p < 0.01$) than horses with access to a larger lying area (10.0 m^2/horse, 103 ± 73 min, 17.3 m^2 per horse, 134 ± 37 min). In two of the open barns, the lying area was divided between two lying halls, and the lying time for those herds did not differ significantly from the other herds. Moreover, Raabymagle & Ladewig [23] found that lying time was shorter in smaller boxes ($(1.5 \times$ withers of the horse$)^2$ m^2) compared with larger boxes ((2.5 times withers' height of the horse$)^2$ m^2). In an open barn housed by broodmares, the proportion of the herd using the lying hall increased when the number of horses was reduced, which basically increased the available lying area from 7 to 17 m^2 [24]. The same study found that the mares used the lying hall in turns at a higher occupancy rate, suggesting that they divided themselves into subgroups. Swedish legislation for animal welfare stipulates that the minimum lying area in open barns must be 8 m^2/horse for large horses (determined by height of the withers over 1.71 m) when they are being fed outside the lying hall, and 10 m^2/horse when they are being fed inside [25]. Besides lying area, bedding material seems to be another factor that influences lying time, both in boxes and open barns. Extending the area covered by soft bedding materials, such as straw or wood shavings, increased both lying time and duration [20]. Lying times in an active open barn were found to be longest for shavings (74.3 $\pm$ 2.87 min), followed by rubber mats (62.3 $\pm$ 2.27 min), and then sand (43.0 $\pm$ 2.33 min) [19]. Using rubber mats instead of wood shavings in single boxes led to shorter lying times [26]. Werhahn et al. [27] found that foraging increased when straw bedding was used, indicating that this kind of bedding poses the risk of interrupting lying bouts.

Furthermore, horses' use of lying halls seems to be determined by the weather, and wet and windy conditions have been shown to increase the use of lying halls [28–30]. Feral horses also exhibit this behavior, seeking both shade and shelter from insect harassment [31], as well as protection from the wind and rain [32]. Individual spacing area is another factor that could influence the use of lying halls. Keiper & Sambraus [33] found that stallions spend most of their time with 1 m to 10 m between themselves and other horses. Mares tended to require less individual space, because they were broodmares with offspring nearby. Differences in individual spacing area, where foals were found to be more willing to share space than older horses [30], indicate that the adult horse's individual space requirements are likely to be >1 m.

On this basis, we believe there is demand for research into the "best practice" for planning and managing animal welfare in open barns, which should not be dictated solely by minimum requirements. Sleep is an important factor in the welfare of horses and lying time for stalled horses seems to vary according to such factors as climate, exercise, bedding, housing, and lying area. To ensure the wellbeing of the horses in this type of housing system, it is critical that lying areas provide the opportunity for adequate rest and sleep.

The aim of this study was to analyze time spent in, as well as activity taking place in, lying halls of varying sizes. The study had three research questions: How does the use of lying halls depend on available lying area? In what way does the lying time differ in individual boxes compared to shared lying area in an open barn? How do variations in total available lying area affect lying time? The hypothesis was that increasing available lying area would increase total lying time.

2. Materials and Methods

To answer the questions, we designed two different studies performed at two of the Swedish National Equestrian Centers: Flyinge (Study 1) and Strömsholm (Study 2). In both stables, the horses were housed in an open barn system for 24 horses and fed using the feeding technique from HIT Active Stable® (Weddingstadt, Germany). Within this system, haylage and concentrate were delivered by automatic computer-controlled feeding stations, as described by Kjellberg & Morgan [34]. The feeding stations were set to start a new feeding session at 8 AM in the active open barn at Flyinge and at 6 AM in the active open barn at Strömsholm. Straw was delivered ad lib in one hayrack, and the bedding in the lying halls was straw, so the horses were able to feed there as well. The system also made use of automatic watering balls.

2.1. Study 1—Open Barn at National Equestrian Center Flyinge

2.1.1. Horses

All 18 geldings, aged 6–21 years, including five focal horses, aged 10–16 years, were school horses at the equine center, used for riding or driving at the university equine bachelor program or the upper secondary school. They were all Swedish Warmblood, except for one horse which was a North Swedish draft horse. The horses were trained 5 days/week at an intensity dictated by their education, with 1 day/week spent hacking.

All horses were well accustomed to each housing system and had spent at least two months in the actual open barn before the study.

2.1.2. Facilities

The open barn system consisted of one paddock of 3500 m^2 and one lying hall with a lying area of 280 m^2 (Figure 1). Haylage was delivered by six automatic forage feeding stations, and concentrate by one automatic concentrate feeding station. The system also contained three automatic watering balls and one roller pit. The horses' use of, and behavior in, the lying hall were monitored using up to two IR night-and-day network cameras for outdoor use.

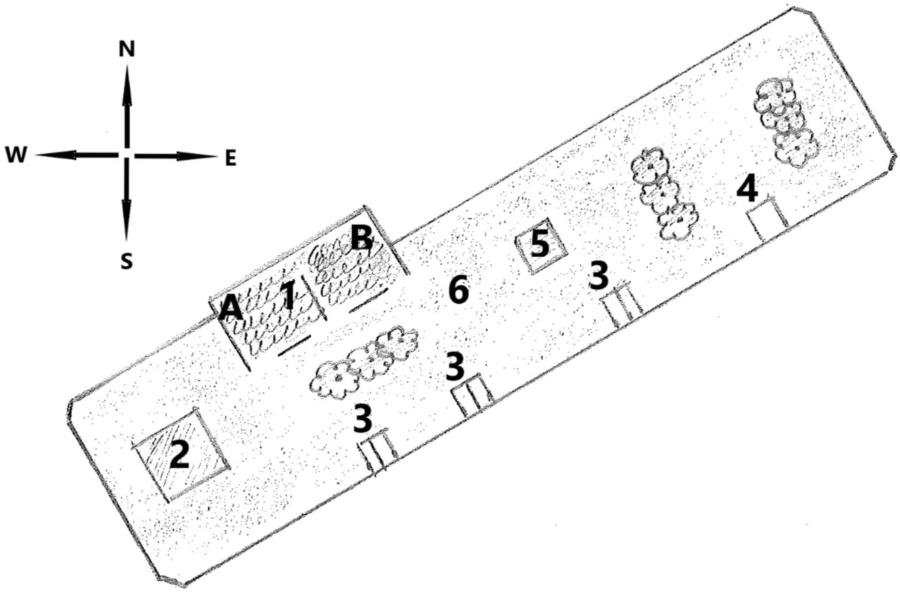

Figure 1. Detailed layout of the open barn at Flyinge in Study 1. 1: Lying hall, 2: roller pit, 3: automatic forage stations, 4: concentrate station, 5. hay bar, 6: paddock, A: camera 1, B: camera 2.

2.1.3. Data Collection

Two methods were used for data collection in the lying area (Figure 2). In method 1, the video recording was continuous, but all observations were logged as interval observations using an ethogram (Table 1), for each minute that the five randomly chosen focal horses spent in the lying hall. The horses used in method 1 were not allowed to leave the system during the two weekends when data were collected. Method 2 used scan sampling, recording the positions of all 18 horses in the lying hall every hour. No video recordings were conducted outside the lying hall. The video recording was performed over two weekends at the end of October and beginning of November. The temperature daytime shifted from +12 °C to +14 °C and from +2 °C to +8 °C at night. Data were collected in collaboration with students from the university equine bachelor program SLU and preliminary analysis was presented in Bengtsson & Eriksson [35].

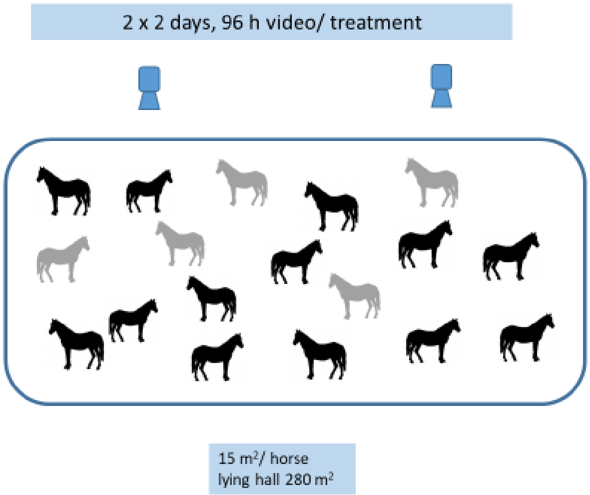

Figure 2. Illustration of the two methods used in the data collection for Study 1. The grey horses (n = 5) were used in method 1 (interval registrations each minute) and all horses (n = 18) were used in method 2 (scan sampling every hour).

Table 1. Ethogram of behaviors exhibited and recorded during video observation in Study 1. Most behaviors were the same in Study 2, but some were divided into two categories.

Behavior Exhibited	Study 1	Study 2
Sternal recumbency	Lying down on breast with head up or nose on bedding, legs under or next to the body	
Lateral recumbency	Lying down on side with body and head on bedding, legs stretched out	
Standing rest	Standing in relaxed state with head lowered/ relaxed ears/eyes closed/one rear foot slightly elevated	
Standing attentive	Standing with open eyes/ears pointed forward /head upright or eating	Standing with open eyes/ears pointed forward/head upright
Foraging		Standing with nose in bedding or eating in the single box or the lying hall
Active	In motion (including walking, playing, urinating)	
Walk		Walking
Other		Playing, urinating, human interaction (i.e., horse being tied up for mucking out)
Not in lying hall	Outside the lying hall with whole body or only the head	
Not in active open barn/box		Removed from active open barn or individual box

2.1.4. Statistical Analyses

The data collected in Study 1 were compiled using Microsoft Excel. We calculated the mean, maximum and minimum values, as parameters for lying periods (Method 1) and the number of visits to the lying hall (Method 1 and 2). The time budget was calculated for the five focal horses (Method 1). The proportion of observations of the horses' locations (inside or outside the lying hall) was calculated both for the entire day and for day or nighttime. The difference between day and night was analyzed using a Student's t-test. The significance level was set to $p < 0.05$.

2.2. Study 2—Open Barn at National Equestrian Center Strömsholm

2.2.1. Horses

All 11 geldings, aged 3–17 years, were Swedish Warmblood and were used as riding horses at the university equine bachelor program. The horses were trained 3–4 days/week at an intensity dictated by their education, with 2 days/week spent hacking, except for the 3-year-old. The horses were 1.62–1.74 m over the withers in height. All horses were well accustomed to each housing system and had spent at least two months in the actual open barn before the study.

2.2.2. Facilities

A stable with 25 single boxes, each with an area of 10.5 m^2 (3×3.5 m) was used as a control. This stable was situated immediately next to the active open barn. When the horses were housed in the single boxes, they were fed forage individually four times a day, and concentrate twice. They spent 4–6 h daily in a paddock. Each single box had an automatic watering ball and was permanently bedded with wood shavings. The horses could socialize with their neighboring horses through nose contact via grids.

The open barn system consisted of one paddock of 3600 m^2 and had a total indoor lying area of 460 m^2 divided into four lying halls, with the possibility of closing individual lying halls (Figure 3). Haylage was delivered by six automatic forage feeding stations, and concentrate by one automatic concentrate feeding station. The system also contained three automatic watering balls. The horses' use of, and behavior in, the lying halls were monitored during three periods, using up to four IR night-and-day network cameras for outdoor use.

2.2.3. Data Collection

Each period consisted of ten days, divided into seven days of acclimatization followed by three days of video recording (Figure 4). The first period was divided in two periods, 1a and 1b, due to limited access to single boxes. In this period the horses' lying and resting time in single boxes (10.5 m^2) was registered, before moving back to the open barn with its different available lying areas in the lying halls during periods 2 and 3. In period 2, the horses only had access to Lying hall 1 with an available lying area of 8 m^2/horse. In period 3, they had access to two lying halls (Lying hall 1 and Lying hall 2), with available lying areas of 18 m^2 per horse. In periods 2 and 3, there were always ten horses housed in the open barn. In total, eleven horses were recorded using video observation across all three periods, but only eight horses participated in all three periods. Consequently, these eight horses were included in the statistics. The video recording was continuous, but all observations were logged with scan sampling, in 5 min blocks based on the ethogram (Table 1). The same ethogram used in Study 1 was used in Study 2, with some activities divided into two; "Standing attentive" was divided into "Standing attentive" or "Foraging". "Active" was divided into "Walking" or "Other". The study took place from the beginning of February until the middle of April 2016. The temperature in daytime during period 2 shifted from +5 °C to +15 °C and from −2 °C to +4 °C at night. During period 3 the temperature shifted in daytime from +5 °C to +8 °C and from −1 °C to 0 °C at night.

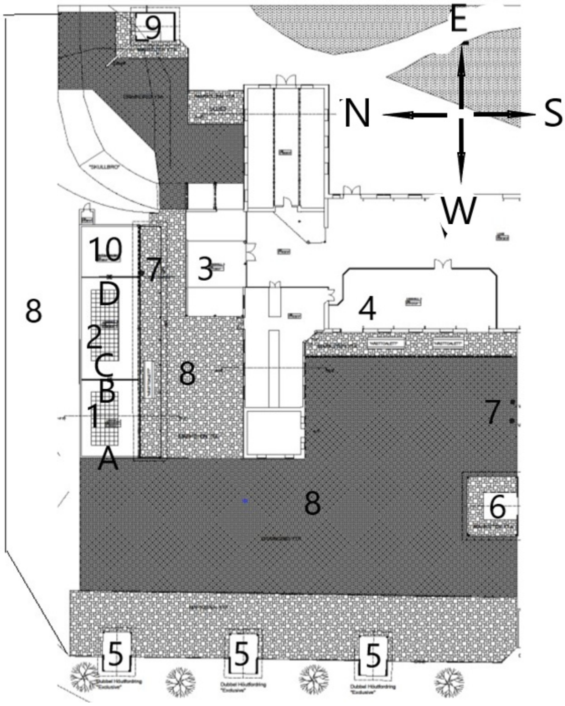

Figure 3. Detailed layout of the open barn. 1: Lying hall 1 (80 m^2, used in period 2 and 3), 2: Lying hall 2 (100 m^2, used in period 3), 3: Lying hall 3 (100 m^2, not in use during experimental study), 4: Lying hall 4 (280 m^2, not in use during experimental study), 5: automatic forage stations, 6: straw bar (not in use), 7: watering balls, 8: paddock, 9: concentrate station, 10: acclimatization box, A: camera 1, B: camera 2, C: camera 3, D: camera 4.

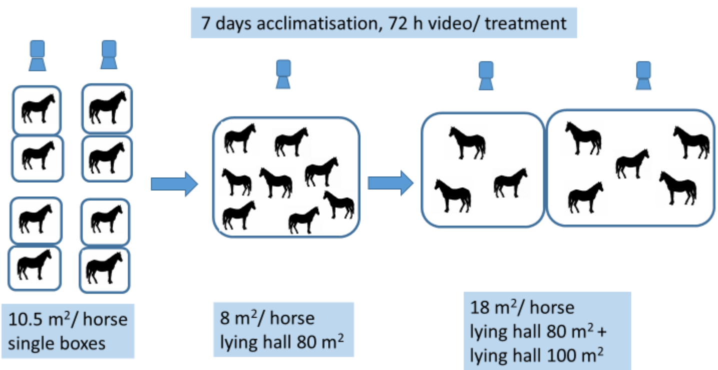

Figure 4. Flowchart illustrating the data collection during the three periods. Eight individuals participated in all three periods. These eight individuals were included in the herd of ten horses during period 2 and 3 in the open barn.

Activities in single boxes and in lying halls were monitored using up to four IR night-and-day network cameras for outdoor use (HIKVision, Hangzhou, China, model: DS 2CD4D26FWD-IZS). No video recordings were conducted in the paddock when the horses were housed in single boxes in period 1 or the lying halls in period 2 or 3. Four cameras were used during period 1a and 1b, with one camera filming each single box. Two cameras were used during period 2 for video recording Lying hall 1, and four cameras during period 3 for video recording Lying halls 1 and 2, two in each lying hall.

2.2.4. Statistical Analyses

The results of Study 2 are based on mean values, from observations which took place during 72 h of video recording in period 1 and 2. There were only 48 h of video recording in period 3, as the horses tore down the barriers to a closed lying hall on the last night. Statistical analyses were conducted using RStudio (Boston, MA, USA, version 1.2.5033). The data were processed using a Poisson regression with horse as the variable factor and treatment as the fixed factor, using model: glmer1<-glmer (LieS~beh + (1 | Namn), data = hast, family = "poisson"). To ensure that the variance was not the same as the mean and the analysis, a negative-binomial distribution was made according to the model: glmer.nb1<-glmer.nb (LieS~beh + (1 | Namn), data = hast).

3. Results

3.1. Study 1

3.1.1. Time Spent in Lying Hall

The five focal horses used in method 1 spent an average of 22% (ranging from 19.5 to 24.5%) of each 24 h period in the lying hall (Supplementary material Table S1: Rawdata Study 1—Rec. obs. focal horses). The highest recorded use of the lying hall for one horse during a 24 h period was 35.2%, and the lowest was 6.6%. The focal horses spent an average of 26% of their time in the lying hall during the night (18.00–07.59), compared with 16% during the day (08.00–17.59) ($p = 0.004$). The horses visited the lying hall an average of 5.7 (ranging from 3.6 to 7.0) times every 24 h.

Using hourly scan sampling for all 18 horses (method 2), the average number of horses in the lying hall was 4.1 ± 1.6 (Figure 5). The lying hall was least frequented in the morning, at 9 AM, and most frequented at night, at 2 AM, when 11 out of 18 horses spent time there. They visited the lying hall more frequently during the night than the day ($p < 0.001$). The lying hall was never empty (Supplementary material Table S1: Rawdata Study 1—No of horses in lying hall). It was always occupied by at least two horses.

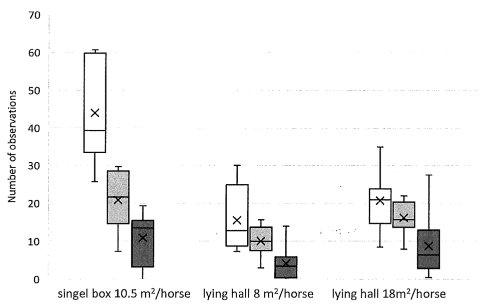

Figure 5. Median values for the resting observations of the horses in Study 2 ($n = 8$), for different housing systems and different available lying areas. White boxes show standing rest, light grey boxes show sternal recumbency, and dark grey boxes show lateral recumbency. The horses exhibited longer standing rest in single boxes than in the lying halls. They spent longer in both sternal and lateral recumbency in single boxes and in the lying hall with a lying area of 18 m^2/horse compared with the lying hall with a lying area of 8 m^2/horse.

3.1.2. Lying Time and Time Budget

The five focal horses exhibited the following behaviors: sternal recumbency (18%), lateral recumbency (8%), standing rest (45%), standing attentive (25%), and active (4%) during the time spent in the lying hall.

3.2. Study 2

3.2.1. Time Spent in Lying Hall

In Study 2, in 14% of observations the horses were found in the lying hall when the available lying area was 8 m^2/horse, compared to 33% of observations when the available lying area was 18 m^2/horse ($p < 0.0001$) (Supplementary material Table S2: Rawdata Study 2—Recorded. obs. per horse). In period 3, when the horses had access to two lying halls with available lying areas of 80 m^2 and 100 m^2, respectively, the horses were observed to spend more time (76%) in the larger lying hall (100 m^2).

When comparing the use of the lying halls, the results showed that the lying hall with the smallest available lying area (8 m^2/horse) was least frequented at 8 AM, 13–14 PM and 17–18 PM, and most frequented in the early morning, at 3 AM (Supplementary material Table S2: Rawdata Study 2—Use of lying hall). When the largest lying area of 18 m^2/horse was available, the two lying halls were least frequented at 9 AM, 13 PM, and 17 PM, and most frequented at 16 PM and 2 AM. The average number of horses in the smaller available lying area of 8 m^2/horse was 1.5 $\pm$ 1.1, and in the larger available lying area of 18 m^2/horse it was 2.9 $\pm$ 2.5. The highest number of horses observed in the lying halls was eight horses out of ten when the available lying area was 8 m^2/horse and nine horses out of ten when the available area was 18 m^2/horse.

3.2.2. Lying Time and Time Budget

The horses' lying times for both sternal and lateral recumbency were significantly lower in the smaller lying hall with an available lying area of 8 m^2/horse versus 18 m^2/horse (p = 0.001 and 0.02, respectively) and the single boxes ($p \leq 0.0001$ and 0.0002, respectively) (Figure 5). Standing rest was longer in single boxes than in the lying halls with available lying areas per horse of 8 m^2 and 18 m^2 ($p \leq 0.0001$). There was no difference in total resting time (sternal and lateral recumbency and standing rest) between the lying halls with different lying areas per horse (8 m^2 and 18 m^2). Moreover, none of the horses were seen lying down in the paddock during the period in which they were housed in single boxes.

In comparing activity in the lying halls, we can see that the horses spent more time foraging from the bedding when they had access to a lying area of 18 m^2/horse than when they had access to an area of 8 m^2/horse ($p < 0.0001$) (Figure 6). There were no differences in standing attentive or other behaviors between the lying halls with different available lying areas. They did exhibit other behaviors in the lying halls, as compared with the single boxes, such as play. The horses also used the lying halls for urination. They were also standing attentive, which included foraging, in 8% of the observations. In the single boxes, the behavior of the horse was restricted during some observations by human interaction, when the horse was tied up while their box was cleaned, or handled by the groom in other ways.

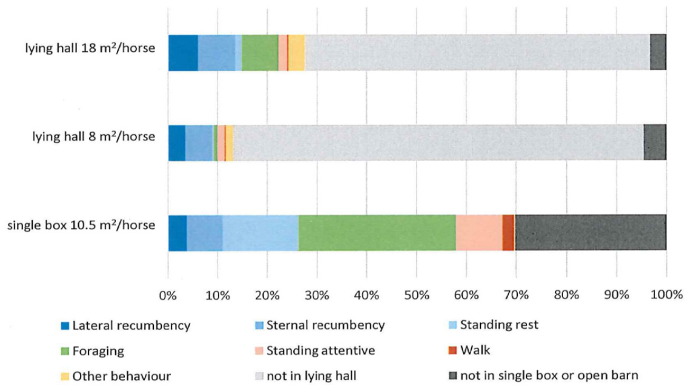

Figure 6. The chart shows the time budgets for single boxes and active open barn with lying areas of 8 m^2 and 18 m^2 in Study 2 in Strömsholm based on 10 horses.

4. Discussion

Housing horses in an open barn system may substantially improve their welfare, as Yngvesson et al. [3] found, provided that the horse's nutritional needs are also met and that they are part of a suitable social group where competition for lying space is low. Ensuring their welfare does not only mean preventing suffering, but also promoting positive emotional states [1]. The domains Environment & Behavior are particularly relevant in open barns when the horse has more choices [2]. The aim of this study was to analyze time spent, as well as activity taking place in, lying halls of various sizes. To answer the questions following the aim, we used two different studies. In the first study we received an answer for the use of and lying time in a lying hall. To follow up these findings we continued with the second study to analyze if the use of lying halls and lying time depended on available area. In the second study we also compared lying time in solitarity and shared spaces. The lying area of 8 m^2/horse in Study 2 was chosen based on the minimum requirement for a horse of a particular size stipulated by Swedish legislation [25]. The minimum requirement for a lying area in a lying hall is that it should be no less than 80% of the area of a single box which houses a horse of the same size, if the feeding area is placed outside the lying hall. The area requirement is calculated from the height of the withers, and does not consider the horse's behaviors or need for individual space.

The highest number of horses was found during the night (1–4 AM) in all lying halls, indicating that horses will seek shelter during nighttime whatever the available lying area, as seen in another study [27]. Since our studies were conducted during late autumn and early spring, there was a drop in temperature overnight, suggesting that the horses were seeking shelter due to weather conditions [28–30,32].

There was a wide range of time spent in the lying hall among the focal horses in Study 1, ranging from 6.6% to 35.2% of their time, during separate 24 h periods. This variation in use of lying halls is consistent with other studies and can vary due to weather or feed availability [30]. The lying halls were all facing either southeast (Study 1) or southwest (Study 2), meaning that the radiation of the sun was similar. Lying hall 1 in Study 2 (Figure 3) is less shaded by other buildings during afternoons compared to Lying hall 2 and some horses have been seen to stand there in on sunny days during the winter. The feeding stations restarted at 8 AM (Study 1) and 6 AM (Study 2) and this could explain the drop in horses each morning shortly before the restart. The same tendency for when lying periods occurred has been observed in other active open barns [13], meaning that the routines of the housing system could have influenced the lying periods. In Study 1, consisting of 18 horses and 1 lying hall, the lying hall was never empty. This finding indicated that a larger herd divides into subgroups and visits the lying hall in turns, as Nilsson [24] suggested.

In Study 2, the horses' use of the lying hall increased from 14% to 33% when the available area increased. In comparing time spent in the two lying halls during period 3, we find that the horses preferred the larger lying hall (100 m^2) to the smaller one (80 m^2). This indicated that even a small increase in the lying area had an impact on the time spent in the lying hall. Although most of the horses spent all or nearly all of their time in the larger lying hall, some individuals preferred the smaller hall. In opting for the smaller hall, these horses had access to a greater lying area for themselves, instead of being squeezed in with the other horses in the lying hall next door. There could be several reasons for this choice. Some studies have found that a larger lying area leads to more frequent lying down [21,23]. Other studies have found that low-ranked horses are more frequently disturbed [20], which might also have encouraged some horses to choose the less crowded larger lying hall. Individual spacing from other horses often depends on sex or age [30,33]. In Study 2, one horse was seen lying outside the lying hall during daytime when the horses had access only to the smallest available lying area (8 m^2). Consequently, we can speculate that this horse might have found it too crowded in the lying hall and required more individual space. Although neither individual spacing nor rank was measured in this study, when calculating the area per horse in relation to the number of horses in the lying hall, it was noted that in the smallest available area (8 m^2/horse) the horses used at least 19 m^2/horse. This indicates that it is important to take individual spacing into account when considering the minimum requirements for lying area.

In Study 2 we found that the horses demonstrated longer estimated sternal and lateral recumbency in the single boxes (10.5 m^2) and in the lying halls with a larger available lying area (18 m^2/horse), than they did in the lying halls with a smaller available lying area (8 m^2/horse). Still, the estimated average lying time in the single boxes was slightly lower (2 h and 40 min) than the length of 3 to 4 h reported in other studies [4,5,12]. The lying time in single boxes was still longer than the 30 min to 2 h reported for feral horses [8–11], suggesting that the horses in single boxes obtained more lying time than horses in more natural circumstances. The horses also performed more standing rest when housed in the single boxes than in the lying halls. Since the lying halls were the only area in the open barns to be video recorded, it is possible that the horses performed resting behaviors outside the lying halls. Some horses could have performed standing rest outside when they only had access to the smaller lying area of 8 m^2/horse, due to competition for space. In addition, they would have had a better environmental overview outside the lying hall. Another factor that could have increased the lying time in the single boxes was that the bedding in the single boxes was shavings, which may have led to increased lying time as the horses were not inclined to forage from their straw bedding as they were in the lying halls.

Both the sternal and the lateral recumbency in the lying halls increased when the horses were offered 18 m^2 available lying area instead of 8 m^2 available lying area. This result is consistent with Fader & Sambraus [21] and Raabymagle & Ladewig [23], who also observed longer lying times in larger lying areas than in smaller ones. Fader & Sambraus [21] found no correlation between number of lying halls and different lying times in their study of seven heterogeneous herds. This indicates that it is in fact the differences in available lying area which affect lying time, and not the separated lying areas when the lying area increased in Study 2 and could be due to the access to greater individual space afforded by larger lying areas. Nevertheless, estimated average lying times when the horses only had access to a lying area of 8 m^2/horse were no shorter than the lying times observed among feral horses [8,10,11]. The five focal horses in Study 1 seemed to spend less time in lateral and sternal recumbency when comparing the time budgets between the two studies. This finding is difficult to analyze, since lying time has been found to differ between individual horses [19]. Access to a comfortable and secure lying area might be a resource that horses compete for [19–21]. Decreased lying time could be associated with inappropriate environmental conditions [7], equating to a limited resource which could, in turn, impact their welfare. Total resting time, including sternal and lateral recumbency and standing rest, did not differ between different available lying areas in lying halls.

In both studies, the horses used the lying halls for purposes other than resting, such as standing attentive, which in Study 1 included foraging. Foraging was therefore separated from standing attentive in Study 2, where foraging from the straw bedding was shown to increase with increased lying area. Straw bedding in lying halls might decrease lying time when compared with other soft bedding due to disturbances caused by foraging [27]. Such disturbances could explain the decrease in lying time in the smaller available lying areas. One advantage of straw bedding is that the horse-keeper can see if the horse has been lying down without video recording, and another is that straw has a positive environmental impact, if it is to be included in an ecological cycle. Offering straw outside the lying hall could be a solution to satisfy the horses' eating requirements. In both the open barn systems, the horses were offered haylage from automatic, computer-controlled forage stations outside the lying halls, to meet the recommended requirement of 1.5 kg DM per 100 kg bodyweight. The forage feed intake rate is, on average, 22 min/kg DM [34], which means that their estimated daily forage intake time is 3.5 h and suggests that straw is required to meet their need for long feeding times.

The data from this study are based on observations from two different active open barns with similar stable furnishings, such as lying halls with straw, gravel paddocks, and individual computer-controlled feeding stations. The layouts did differ, however, between the open barns, which may have influenced the lying times that were observed. Furthermore, geographical differences affecting daylight and climate may also have influenced the horses' behavior, since the open barn used in Study 2 lies 600 km north of the open barn used in Study 1. The horses in both studies were all adult geldings and horses working on a medium level, which means that the horses in the two herds were comparable. Given the similarities between the barns and the horses, the results are equivalent and suggest that there is an optimal lying area per horse in the lying hall. However, it is also important to remember that this optimal lying area could differ in herds with mixed sexes, or herds comprising only mares, as they have different individual spacing needs [34]. In this study, we had no evaluation of the ranks of the individual horses, which has also been reported to influence lying time [20]. Using straw as the bedding material might have influenced the optimal lying area, since straw has been shown to decrease lying time, due to foraging [27]. Another factor pertaining to bedding that could influence lying time is the horses' prior experience with different bedding materials, which we had no record of.

The observations made through video recordings gave a good overview of the horses' behaviors, and our results are based on quite a large sample. Although it can be difficult to see if time and treatment covariate, each horse in Study 2 acted as their own control, which lends credibility to our findings. Only five focal horses were used for the interval observations of Study 1, and although these were chosen randomly and were of representative age (10–16 years) and daily work levels, using another five horses may have affected the result due to individual differences. When using scan sampling, there is a possibility of missing some details, such as the duration between the logging of each observation and behaviors exhibited in those intervals. It is hoped, however, that these disadvantages are compensated for by the ability to analyze more animals in less time. In Study 2 there is missing data for one 24 h period in which the horses had access to a lying area of 18 m^2/horse, due to a demolished fence between the lying hall and a second lying hall that was not in use. The statistics model used compensates for the missing data, meaning that the result is still valid.

The active barn system is suitable for urban horse-keeping and for riding schools with limited access to land for paddocks and grazing and meets all the horse's basic needs. Overall, however, our observations suggest that the current minimum lying area requirements (at least those stipulated by Swedish legislation) might be too small for the domesticated horse, and that the minimum requirement could be increased in order to better safeguard their welfare. Our recommendation, in order to improve the welfare of horses kept in open barns, is to increase the minimum requirement of the lying area by a factor of 20–100%. This recommendation is based on the finding that to offer a lying area extended by only 20% (Lying hall 2 in Study 2) encouraged the horses to prefer that specific lying hall. Furthermore, increasing the available lying area increased both the use of the lying area and the lying time. Since it is crucial to the welfare of horses that they have the opportunity to get enough sleep, the choice of bedding is an important factor to consider. However, further studies are needed to ascertain the optimal lying area per horse and bedding material in a lying hall, in order to maximize the sleeping comfort of each individual.

5. Conclusions

In this study conducted in Sweden in two active open barns, we found that the horses' lying time increased when they were given access to an individual space in a single box or a larger common space. Increasing the area in the lying hall also increased the use of the lying hall. The hypothesis that increasing the lying area will increase the horses' total lying time was accepted.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/ani11113214/s1, Table S1: Rawdata Study 1—Rec. obs. focal horses, No of horses in lying hall, Table S2: Rawdata Study 2—Recorded obs. per horse, No horses in lying hall.

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Institutional Review Board Statement: All experimental procedures involving animals were approved by the local ethics committee, according to Swedish legislation (SJVFS 2019:9), dnr C 80/15.

Data Availability Statement: Data is contained within the Supplementary Material. The data presented in this study are available in https://www.mdpi.com/article/10.3390/ani11113214/s1, Table S1: Rawdata Study 1—Rec. obs. focal horses, No of horses in lying hall, Table S2: Rawdata Study 2—Recorded obs. per horse, No horses in lying hall.

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Conflicts of Interest: The authors declare no conflict of interest.

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III

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Horses' resting behaviour in shelters of varying size compared with single boxes

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ABSTRACT

Lying behaviour in horses is affected by factors such as bedding, housing and available lying area. For group-housed horses, social factors may influence access to available lying area and affect their ability to meet their need for sleep, including essential REM sleep. REM sleep can only be achieved when the whole body, including the head, is supported by the ground, so lateral recumbency is important to meet horses' sleep requirements. This study investigated the effects of available lying area in shelters on horses' lying and rising behaviour, on disturbance behaviour by horses, and on lying bouts by individual horses. Lying and rising behaviour was video-recorded for eight horses in single boxes (control treatment) and in an open-barn with three available lying area of 8, 18 and 28 m^2/horse, respectively in the shelters. The results revealed significantly less lateral recumbency in the shelter with 8 m^2 lying area/horse (22 min, $p = 0.04$) compared with the single boxes (52 min), and a tendency for more lateral recumbency with 18 m^2 lying area/horse (48 min, $p = 0.07$) compared with 8 m^2 lying area/horse. Rising without prior rolling was the most common rising behaviour in the single boxes. Frequency of rolling prior to rising varied from 14% to 55% for all housing systems, compared with previous observations of ~30% irrespective of available lying area. This may be due to inter-individual differences, indicating a need for detailed studies of rising behaviour. Lying behaviour was affected by the behaviour of other horses and also significantly affected by available lying area. With more available area in the shelter, horses lay down for almost twice as many bouts ($p = 0.01$) and for almost twice as long as compared to a smaller area ($p = 0.001$). Number of lying bouts ($p = 0.001$) and behaviour during rising from the lying position were also affected by available lying area. It is therefore likely that the space requirement to meet horses' need for rest will be larger in group-housed horses than for horses in individual boxes.

1. Introduction

Measuring the lying behaviour of horses (*Equus caballus*) could be a way to assess horse welfare (Auer et al., 2021). The Five Domains model developed by Mellor et al. (2020) considers nutrition, environment, health and behavioural interactions, all of which influence mental state. Sleep and rest are important for all domains of horse welfare. Open barn systems, housing horses in groups, may have benefits over tied stalls and boxes (Yngvesson et al., 2019), e.g. group housing allows horses to perform more goal-directed behaviours, improving welfare (Mellor et al., 2020). However, group housing may pose other welfare risks related to social competition for limited resources such as lying area. Feral horses have been observed lying for 1–2 h/day (Duncan, 1980; Kownacki et al., 1978), while stalled horses lie for 3–5 h/day (Dallaire, 1986; Dallaire and Ruckebusch,1974). Horses perform four stages of sleep: wakefulness, drowsiness, slow-wave sleep and paradoxical (REM) sleep (Dallaire, 1986). Most sleeping time is spent standing, but during REM sleep horses need to rest their head on the ground. REM sleep can be achieved in lateral or sternal recumbency if the muzzle is in contact with the ground (Williams et al., 2008). Mean REM sleep duration is reported to be 30–70 min/day (Fuchs et al., 2018; Greening et al., 2021).

Horses can manage without lying down for several days, but eventually they must lie down (Dallaire, 1986). The horse's need for sleep, and especially for REM sleep, is not fully established, but several studies

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indicate that sleep deficiency impairs horse welfare (Fuchs et al., 2018; Greening et al., 2021; Keleman et al., 2021). Horses with reduced REM sleep have been found to collapse (Fuchs et al., 2018), sometimes repeatedly (Lyle et al., 2010). Hence sleep is considered crucial for animal welfare (Horne, 1985).

A study by Fader and Sambraus (2004) found that group structure is important for lying, with low-ranking horses in open barns having a shorter lying time than high-ranking horses. In addition, rest is affected by housing, e.g. Raabymagle and Ladewig (2006) found that sternal recumbency time and number of lying bouts increased with space in single boxes, while Kjellberg and Rundgren (2010) showed that horses kept in tied stalls had more, but shorter, lying bouts than when kept in single boxes. Group-housed horses are reported to show more lateral recumbency with increasing lying area (Burla et al., 2017; Kjellberg et al., 2021a) and lying behaviour in open barn systems is reported to be affected by multiple factors (Hoffmann et al., 2012; Kjellberg et al., 2021a). Lying behaviour can also differ depending on type of pasture. Sassner et al. (2022) observed longer lateral recumbency among young horses on cultural pasture than in a nature reserve (103 and 42 min, respectively). Rolling by horses prior to rising has been observed to decrease with increasing space (Raabymagle and Ladewig, 2006), and in tied stalls compared with single boxes (Kjellberg and Rundgren, 2010), although Hansen et al. (2007) observed more rolling prior to rising on pasture than in stables.

Bedding type and thickness are important, e.g. Burla et al. (2017) found that increasing amounts of soft bedding, such as straw and wood shavings, increased lying time among group-housed horses compared with soft rubber mats, while Greening et al. (2021) found that horses spent less time in lateral REM sleep when the bedding was thin. Studies comparing different bedding materials have shown that straw sometimes increases lateral recumbency (Pedersen et al., 2004; Kwiatkowska-Stenzel et al., 2016), but not always (Ninomiya et al., 2008; Werhahn, 2010; Koster et al., 2017). These conflicting results may be due to individual preferences in horses. Edible bedding (e.g. straw) in shelters can lead to group members interrupting lying bouts (Baumgartner et al., 2015), possibly due to increased foraging in the bedding (Werhahn et al., 2009).

In summary, lying behaviour in horses is influenced by bedding, health, age and available lying area, while group-housed horses can also disturb each other. Therefore the lying area in shelters could be an important factor for horses' possibilities to meet their need for sleep. The aims of this study were to investigate horses' lying behaviour in shelters with different available lying area, starting at lowest minimum area of 8 m^2 required by the Swedish Board of Agriculture, and to formulate appropriate recommendations for horse owners. Research questions were:

- How does available lying area in shelters affect horses' lying and rising behaviour compared with boxes?
- How does available lying area affect disturbance behaviour in horses and lying bouts by individual horses?

2. Material and methods

2.1. Horses

All horses were gelded Swedish Warmblood (SWB) school horses, aged 3–17 years, kept at Swedish National Equine Centre Strömsholm and used for riding by students in the Equine Science programme at the Swedish University of Agricultural Sciences. All horses were trained 3–4 days/week at an intensity dictated by their education level, with 2 days/week spent hacking, except for the 3-year-old. Horse height was 1.62–1.74 m over the withers. All horses were well-accustomed to each housing system and had spent at least two months with access to all four shelters in the open barn facility before starting the study. The horses were also accustomed to each other, since they had spent 6–8 weeks together on pasture and time together in the open barn during autumn prior to the study. No horse displayed any stereotypic behaviour.

2.2. Data collection

The study comprised four treatments, in four 10-day periods (Fig. 1). Each period was divided into seven days of acclimatisation, followed by three days of video recording. All horses were exposed to all treatments in a cross-over design. During treatment 1 (control), the horses were kept in single boxes (10.5 m^2/horse) at night, and in a paddock during daytime (when not being ridden). This stable was insulated but not heated, meaning that the outside weather had an impact on temperature at nights. Due to limited number of boxes, these horses were divided into two treatment groups, period 1a and 1b, starting with four horses in period 1a and followed by another group of four horses in period 1b. Only the four horses being filmed were housed in the single boxes, while the other four remained in the active open barn with the other horses during the period. The horses participating in period 1a and 1b spent daytime together in the paddock with the other horses participating in the same treatment period. The same four single boxes, bedded with shavings, were used during the two periods in treatment 1. In treatment 2, the horses only had access to one shelter with available lying area of 8 m^2/horse. In treatment 3, the horses had access to two shelters, with total available lying area of 18 m^2/horse. In treatment 4, the horses had access to a shelter with total available lying area of 28 m^2/horse. All shelters were bedded with straw. In total, 12 horses were included in video-recorded observations across all four treatment periods, but only 10 horses were housed in the active open barn during treatments 2–4. Eight horses were observed during treatments 1–3 and participated in all four treatments. The horses were identified using symbols and letters on their rugs. The study ran from mid-February 2016 to early May 2016. Average daytime and night temperature was, respectively: − 1 °C and − 2 °C during treatment 1; + 9 °C and 0 °C during treatment 2; + 6 °C and − 1 °C during treatment 3; and + 15 °C and + 3 °C during treatment 4. All horses in treatments 1–3 wore rugs. Due to the warm weather during treatment 4, several horses no longer wore rugs, which led to difficulties in identifying some horses at night, so individual recordings were not possible in treatment 4.

Activities in single boxes and shelters were monitored using up to four infrared (IR) night-and-day network cameras for outdoor use (HIKVision model: DS 2CD4D26FWD-IZS). Data for the same set-up and horses were used previously in Kjellberg et al. (2021b). No video recordings were made when the horses were outside in the paddock during treatment 1, while four cameras were used when they were housed in the single boxes. Two cameras were used during treatment 2. Four cameras were used during treatment 3 for video-recording (two in each shelter) and two cameras during treatment 4. Observations were carried out as continual focal sampling for treatments 1–3 and continuous group sampling for treatment 4, and recorded as listed in Table 1.

2.3. Facilities

Treatment 1: A stable with 25 single boxes (3 × 3.5 m) was used in the control (treatment 1), where the horses were housed prior to the treatments in the active open barn. This stable was situated immediately next to the active open barn. In treatment 1, the horses were fed haylage according to their individual needs (1.3–1.8 kg DM per 100 kg bodyweight) four times a day, and concentrate twice. They spent 4–6 h daily in a paddock measuring 12,000 m^2. Each single box had an automatic watering bowl and had deep littering consisting of wood shavings. The bedding was mucked out every 8 weeks. The horses were able to socialise with neighbouring horses through nose contact via grids.

Treatments 2, 3 and 4: In all these treatments, the horses were housed in an open barn system for 24 horses at Swedish National Equestrian Centre Strömsholm. The open barn system consisted of one paddock of 3600 m^2 and had a total indoor lying area of 460 m^2 divided

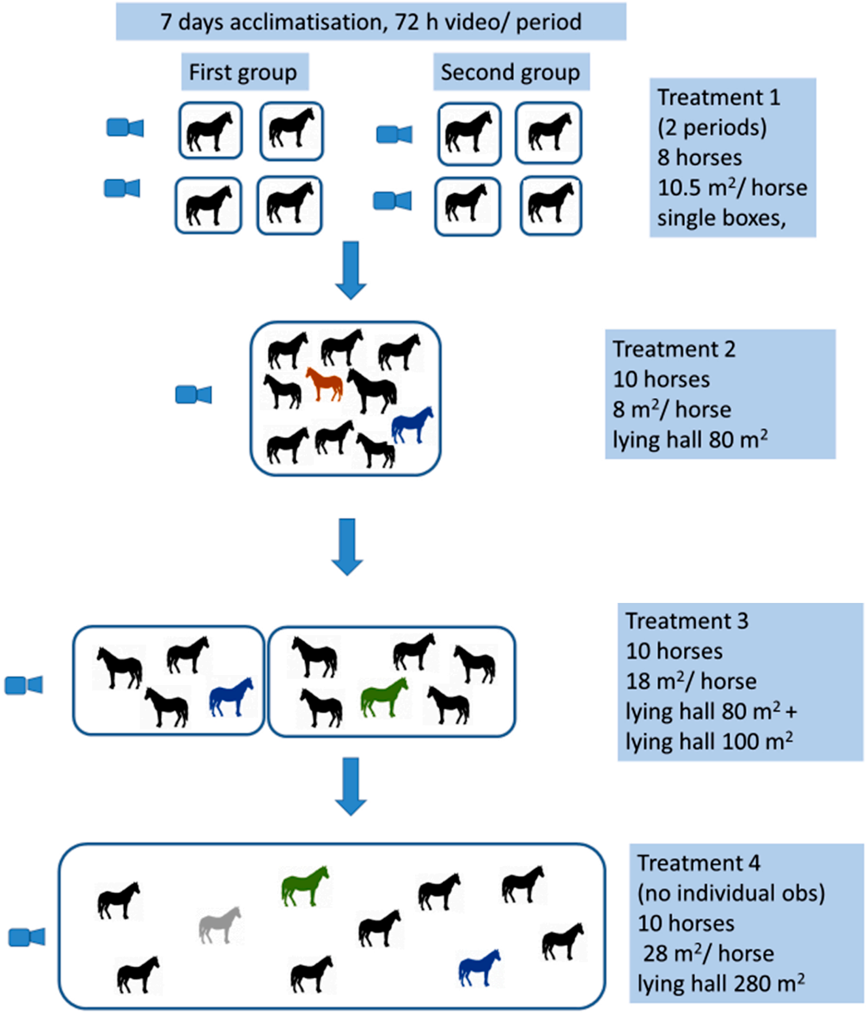

Fig. 1. Flow chart showing treatments 1–4. In treatment 1 (control), the horses spent the night in single boxes and daytime together in a paddock. The eight horses in treatment 1 were divided in two periods due to limited number of available cameras, with the four being filmed housed in the single boxes and others remaining in the active open barn. Horses in treatment 2 had access to one shelter. Horses in treatment 3 had access to two shelters (one of which was that used in treatment 2). Horses in treatment 4 had access to a large shelter. Horses in black participated in all four treatments, those in blue in treatments 2–4, those in green in treatments 3 and 4, the red horse in treatment 2, and the grey horse in treatment 4.

into four shelters, with the possibility of closing individual shelters (Fig. 2). The shelters used in the study were different. Those in treatment 2 and 3 had open fronts, designed as sheds, while the shelter in treatment 4 had enclosing three entries. The horses were housed and fed using the HIT Active Stable® (Weddingstadt, Germany) feeding system, which delivered haylage and concentrate at automatic computer-controlled feeding stations, as described by Kjellberg and Morgan (2021b). The bedding in the shelters was straw, on a concrete floor, so the horses were also able to feed there. The straw, with a depth of around 30 cm, was topped up once a week and removed once a year when the horses left for pasture. The system had automatic watering bowls. The horses' use of the shelters during treatments 2–4 and their behaviour in these were monitored using up to four IR night-and-day network cameras for outdoor use.

2.4. Statistical analysis

The results shown are mean values of all observations. Observations during treatments 1, 2 and 4 were based on 72 h of video recording, but there were only 48 h of video recording in treatment 3, as the horses

Table 1
Ethogram of behaviours exhibited and recorded during video observations. Ethogram based on Raabymagle and Ladewig (2006), further modified with added details.

Behaviour exhibited	Behaviour explained
Sternal recumbency	Lying down on sternum with hindquarters touching the ground and with head up or nose touching the ground and legs not stretched out
Lateral recumbency	Lying down on side with head and neck touching the ground, legs stretched out
Standing up with no rolling behaviour	Standing up, front legs stretching first, sitting, and then stretching also the hindlegs, without performing rolling behaviour just before standing up
Standing up after a half roll	Standing up after performing a half roll, defined as the horse first lying in sternal or lateral recumbency and then rolling with the back touching the ground, without rolling over to the other side, just before standing up (45–90° roll)
Standing up after a full roll	Standing up just after performing a full roll, defined as the horse first lying in sternal or lateral recumbency and then rolling from one side to another over the back (180° roll)
Disturbance	A horse lying down is approached or touched by another horse and remains lying down, but changes position (e.g. lateral to sternal recumbency). This behaviour could not be recorded when horses were in single boxes
Forced to stand up	The horse is forced to stand up by another horse using physical contact or close physical approach, e.g. threat. This behaviour could not be recorded when horses were in single boxes.

broke through the barrier to a closed-off shelter on the last night. Observations of ‘forced to stand up’ and ‘disturbed’ were only recorded in treatments 2, 3 and 4, since these behaviours did not occur in period 1. For treatment 4, there were no individual recordings and this treatment was therefore not included in the statistical analysis, so the mean values only represent mean of the group of horses. Only eight horses participated in treatments 1, 2 and 3, and therefore only eight horses were included in the statistics. Statistical analyses were conducted using RStudio (Boston, USA, version 1.2.5033). The data were processed using Poisson regression, with horse as variable factor and treatment as fixed factor, using the model: glmer1 < -glmer (sternal~beh + (1|Namn), data = hast, family = “poisson”). To ensure that the variance was not the same as the mean in the analysis, a negative-binomial distribution was created according to the model: glmer.nb1 < -glmer.nb (sternal~-beh + (1|Namn),data = hast).

3. Results

3.1. Lying behaviour

Significantly less total time lying down was displayed when horses were housed in a shelter with 8 m^2 available lying area compared with 18 m^2 available lying area ($Z = 3.557$, $p = 0.001$) or single boxes ($Z = -4.299$, $p = 0.0001$) (Table 2). With 8 m^2 available, the horses spent less time in sternal recumbency compared with single boxes ($Z = -4.349$, $p < 0.001$) or 18 m^2 available lying area ($Z = 3.461$, $p = 0.002$). Significantly less time was spent in lateral recumbency with 8 m^2 available lying area compared with single boxes ($Z = -2.423$, $p = 0.004$). There was a tendency for shorter lateral recumbency with 8 m^2 lying area compared with 18 m^2 ($Z = 2.231$, $p = 0.07$). Minutes spent in sternal and lateral recumbency did not differ between single boxes and 18 m^2 available lying area per horse. There were no differences in percentage distribution between sternal or lateral recumbency in treatments 1, 2, 3 and 4. Lateral recumbency varied from 34% to 39% of the total lying time.

The highest number of horses lying down simultaneously was seven in all shelters during the whole study. This was observed once when the horses had access to 8 m^2/horse, four times when they had access to 18 m^2 (only in the larger shelter, Shelter 2, 100 m^2) and 11 times when they had access to 28 m^2. In treatment 3, where the horses had access to two shelters, when they were lying down they spent on average more time lying down in the larger (Shelter 2, 100 m^2) than the smaller (Shelter 1, 80 m^2) shelter, measured both as sternal recumbency (17% and 83%, respectively) and lateral recumbency (8 % and 92 %, respectively) in each 24-h period.

Three horses were not observed in lateral recumbency at all when housed in the shelter with 8 m^2/horse and one of these was not observed in lateral recumbency in the single box either (Table 3). One young horse was observed to lie down twice on the hard surface outside the shelter when only given access to 8 m^2 lying area/horse. During the control treatment, none of the horses was observed to lie down in the paddock.

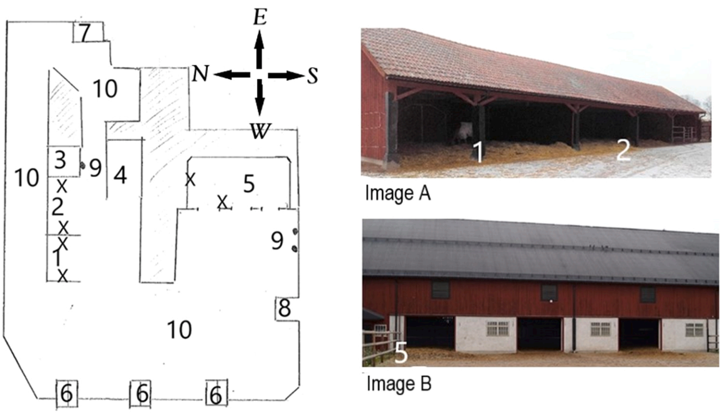

Fig. 2. Detailed design of the open barn and the shelters used in the study. 1) Shelter 1 (Image A: open front, 80 m_2) used in treatments 2 and 3). 2) Shelter 2 (Image A: open front, 100 m^2) used in treatment 3). 3) Acclimatisation box. 4) Shelter not used in the study. 5) Shelter 3 (Image B: four sides with three openings, 280 m^2) used in treatment 4). 6) Automatic forage stations. 7) Automatic concentrate station. 8) Hay bar (not used during the study). 9) Watering bowls. 10) Paddock. X) Cameras.

Table 2
Mean total lying time and time spent in sternal and lateral recumbency (max-min) in minutes, calculated for eight horses with different available lying area. There were significant differences in sternal recumbency and total lying time for available lying area of 8 m^2/horse compared with 18 m^2 lying area/horse ($Z = 3.461$, $p = 0.002$ and $Z = 3.557$, $p = 0.001$, resp.) and single box (control) ($Z = -4.349$, $p < 0.001$ and $Z = -4.299$, $p = 0.0001$, resp.) but no differences between available lying area of 18 m^2 and single box. Lying time in lateral recumbency showed significant differences between available lying area of 8 m^2/horse and single box ($Z = -2.423$, $p = 0.004$), and a tendency for differences between available lying area of 8 m^2/horse and 18 m^2/horse ($Z = {}^2.231$, $p = 0.07$). No individual observations were made when the horses had access to a lying area of 28 m^2/horse, and therefore no min-max range is presented for that treatment.

Available lying area/ horse	Sternal recumbency	Lateral recumbency	Total lying time
single box, 10.5 m^2	94(25–183)	52(0–123)	145(29–269)
shelter, 8 m^2	47(0–136)	22(0–86)	69(0–222)
shelter, 18 m2	82(35–137)	48(0–142)	130(35–270)
shelter, 28 m^2	82	51	132

3.2. Lying bouts and standing up behaviour

The horses had significantly fewer lying bouts/horse in the shelter with 8 m^2 available lying area compared with the single boxes ($Z = -2.910$, $p = 0.01$) or the shelter with 18 m^2 available lying area ($Z = 3.564$, $p = 0.001$) (Table 4). There were no differences in number of lying bouts between the shelter with 18 m^2 available lying area and the single boxes. Number of lying bouts during a 24-h period was 1–6 in the single boxes, 0–5 with 8 m^2 lying area and 2–10 with 18 m^2 lying area. Comparing total lying time per bout, the horses lay down in significantly longer bouts in the single boxes and with 18 m^2 available lying area compared with 8 m^2 lying area ($Z = 2.478$, $p = 0.04$ and $Z = -2.345$, $p = 0.05$, respectively). Standing up without performing any form of prior rolling behaviour was the most common behaviour in the single boxes and in the shelters with available area per horse of 8 m^2 and 28 m^2 (Table 4). The horses performed more full rolling behaviour when the available lying area in the shelter increased from 8 m^2 to 18 m^2/horse. Full rolling behaviour was only observed once in the single boxes. Standing up after a half roll was observed in all four treatments, but more often in the single boxes and in the shelter with access to 18 m^2 available lying area per horse (treatment 3) compared with 8 m^2 and 28 m^2 per horse (treatments 2 and 4). There were no differences between single boxes and the shelter with 18 m^2 available lying area when comparing rolling behaviour prior to standing up. About a quarter of all lying bouts were ended by the horse being forced up by another horse in all shelters and the frequency of this, on average every 10 min, did not seem to differ with available lying area. All horses were forced to stand up by another horse at least once in the shelters with 8 or 18 m^2 available lying area. No horse rolled before being forced to stand up. The horses were disturbed on average every 9 min in the shelters. Analysis of disturbances revealed no differences between 8 and 18 m^2 available lying area/horse in relation to lying time. Analysis of individual observations revealed that all horses except one were disturbed once or twice during one of the 24-h periods. Forcing another horse to stand up was performed by all horses, but disturbances were only recorded for five horses. These behaviours were also noted when the horses had access to 28 m^2 available lying area but since the horses could not be identified, no individual comparisons were possible.

4. Discussion

4.1. Effect of available lying area in the shelter on horses' lying behaviour

This study recorded horses' lying behaviour in shelters with varying available lying area and compared this with the lying behaviour of horses kept in single boxes. Resting time, and especially duration of REM sleep, is important for horse welfare, with a reported need for 30–70 min REM time per 24-h period (Fuchs et al., 2018; Greening et al., 2021).

Lateral recumbency, a prerequisite for REM sleep, was used in the present study as an approximation of time spent in REM sleep. The horses were found to have mean lateral recumbency of 22 min/24-h period when given access to 8 m^2 lying area. Of course, their REM sleep

Table 4
Number and duration of lying bouts by horses (mean±standard error) and behaviour when standing up for shelters with different available lying area (presented as percentage of standing up events). There were significant differences in number of lying bouts between 8 m^2 available lying area and single boxes ($Z = -2.910$, $p = 0.01$) and 18 m^2 available lying area ($Z = 3.564$, $p = 0.001$) and in lying duration between 8 m^2 available lying area and single boxes ($Z = 2.478$, $p = 0.04$) and 18 m^2 available lying area ($Z = -2.345$, $p = 0.05$). No individual observations were made when the horses had access to 28 m^2 lying area, and therefore no standard error is presented for this treatment.

Available lying area/ horse	Mean no. Of lying bouts	Mean lying duration, min/bout	No rolling	Half roll	Full roll	Forced to stand up
single box, 10.5 m^2	3.5 ± 0.3	40.8 ± 2.7	71 %	29 %	0 %	–
shelter, 8 m^2	2.1 ± 0.3	30.6 ± 3.4	33 %	12 %	29 %	26 %
shelter, 18 m^2	4.0 ± 0.5	40.0 ± 2.7	22 %	22 %	33 %	24 %
shelter, 28 m^2	3.6	37.1	64 %	9 %	5 %	21 %

Table 3
Time (minutes) spent in different lying positions (mean±standard deviation) by the eight horses participating in treatments 1 (control), 2 and 3. Horses 1–4 were aged 8–17 years, horses 5–8 were aged 3–4 years.

Treatment	Behaviour	Horse 1	2	3	4	5	6	7	8
1: Single box 10.5 m^2	*Sternal recumbency*	71 ± 27	71 ± 54	35 ± 8	47 ± 19	117 ± 31	147 ± 54	130 ± 15	81 ± 11
	Lateral recumbency	0	41 ± 38	17 ± 17	20 ± 24	91 ± 17	76 ± 12	79 ± 16	77 ± 48
	Total lying time	71 ± 27	113 ± 89	52 ± 25	68 ± 39	208 ± 43	223 ± 66	209 ± 7	157 ± 37
2: Shelter 1 8 m^2/horse	*Sternal recumbency*	20 ± 8	39 ± 16	41 ± 31	28 ± 8	53 ± 9	68 ± 10	100 ± 33	2 ± 1
	Lateral recumbency	0	9 ± 16	17 ± 10	48 ± 15	45 ± 32	10 ± 5	63 ± 20	11 ± 12
	Total lying time	20 ± 8	48 ± 31	58 ± 26	77 ± 14	98 ± 35	78 ± 15	163 ± 52	13 ± 13
3: Shelter 1 + 2, 18 m^2/ horse	*Sternal recumbency Shelter 1*	0	0	39 ± 5	0	3 ± 4	75 ± 38	0	9 ± 13
	Sternal recumbency Shelter 2	97 ± 15	73 ± 5	0	56 ± 27	69 ± 33	45 ± 63	109 ± 26	55 ± 35
	Total sternal recumbency	97 ± 15	73 ± 5	39 ± 5	56 ± 27	71 ± 30	120 ± 25	109 ± 26	64 ± 22
	Lateral recumbency Shelter 1	0	0	9 ± 12	0	6 ± 8	22 ± 31	0	1 ± 1
	Lateral recumbency Shelter 2	22 ± 0	23 ± 6	0	43 ± 4	71 ± 64	27 ± 38	132 ± 14	33 ± 47
	Total lateral recumbency	22 ± 0	23 ± 6	9 ± 12	43 ± 4	76 ± 57	49 ± 16	132 ± 14	34 ± 46
	Total lying time	119 ± 15	95 ± 2	47 ± 17	99 ± 31	147 ± 86	169 ± 32	241 ± 40	97 ± 68

may have been slightly longer than 22 min, since horses can also achieve REM sleep in sternal recumbency if the head is supported by the ground (Williams et al., 2008), a position that could not be specifically analysed in this study. On adding the time spent in sternal recumbency, the total lying time increased to 69 min/24-h period, indicating a greater likelihood of satisfying the horses' need for rest and sleep. However, duration of lateral recumbency was halved in the shelter with 8 m^2 available lying area per horse compared with shelters with larger available area and individual boxes, raising concerns about the welfare of group-housed horses with limited lying area. The observed reduction in lying behaviour in small spaces is consistent with findings in other studies (Raabymagle and Ladewig, 2006; Burla et al., 2017; Kjellberg et al., 2021a).

Mean lying time of the horse group was not alarmingly low in the treatment with 8 m^2 lying area/horse, but five horses spent on average a mere 17 min or less in lateral recumbency. One of these horses was not observed lying in lateral recumbency at all, either in the single box (10.5 m^2) or when given access to 8 m^2 lying area/horse, meaning that this individual may have been at risk of sleep deprivation. In treatments 1, 2 and 4, mean duration of lateral recumbency was well above 30 min and the horses' need for sleep was likely better fulfilled. When the horses had access to two shelters in treatment 3 (total 18 m^2 lying area/horse), four of the horses only lay down in the larger of these shelters (100 m^2 versus 80 m^2), which indicates that even a small increase in lying area could be important for horses. To fulfil the need for sleep and rest, 18 m^2 lying area/horse seemed to be sufficient, as 28 m^2 lying area/horse did not significantly increase lateral recumbency. Dividing the lying area in treatment 3 between two shelters clearly affected the behaviour of the horses, e.g. four horses always chose the larger shelter for lying down and three others only spent up to 10 min lying down in the smaller shelter. The difference between one large shelter and several smaller shelters needs to be studied further to determine the welfare impact on horses.

4.2. Effect of lying area on disturbance behaviour and lying bouts

The horses performed fewer and shorter lying bouts in the shelter with 8 m^2 lying area/horse than in the other treatments. No statistical analysis was possible using data for the largest available lying area (28 m^2/horse), but the number of lying bouts (3.6/24-h) appeared to be at the same level as with a lying area of 18 m^2 (4.0 lying bouts/24-h). Bouts ended voluntarily or following interference. When rising from the lying position in single boxes, the horses generally did so without any prior rolling behaviour and they never showed a full roll, which is consistent with findings in other studies (Pedersen et al., 2004; Raabymagle and Ladewig, 2006). However, in a study by Chung et al. (2018), horses kept in larger single boxes (10.2–16.2 m^2) than in this study (10.5 m^2) exhibited rolling behaviour before rising from lateral recumbency, indicating that our result was due to the smaller boxes. Likewise, when the horses had access to the largest lying area (28 m^2/horse), standing up without prior rolling behaviour was the most common way of getting up. With the smallest available area in the shelter (8 m^2/horse), all horses except one showed a full roll prior to getting up on at least one occasion. Full rolling prior to rising has been observed in horses on pasture (Hansen et al., 2007), indicating that a full roll may be a comfort behaviour when there is enough space. In this study, frequency of rolling prior to rising behaviour varied from 14% to 55%, compared with around 30% in other studies (Pedersen et al., 2004; Raabymagle and Ladewig, 2006; Hansen et al., 2007). How rising behaviour varies between housing systems and whether it is a potential indicator of welfare status need to be studied in more detail.

Horses housed in groups inevitably affect each other, with one impact being that they may disrupt each other's rest. Disturbances in this study were defined as physical contact and were recorded only in the shelters, as the horses were housed alone in the single boxes. On comparing the different treatments in the shelters, the level of disturbance did not vary when corrected for lying time, but longer lying time involved numerically more disturbances. One horse was forced to get up three times during the three observation days in the hall with 18 m^2 lying area/horse, but that horse had total lying time of over 100 min so its welfare was likely not compromised. To our knowledge, disturbances during sleep in group-housed horses have not been studied previously. This study indicated that inter-horse variation in need for sleep and rest may be large, so disturbed sleep should be studied further.

4.3. Strengths and weaknesses

Using wood shavings in the single boxes and straw in the shelters could have affected the results, since lateral recumbency may be longer on straw (Pedersen et al., 2004; Kwiatkowska-Stenzel et al., 2016). However, straw has also been observed to decrease total lying time in shelters, due to disturbances between horses due to foraging in the straw bedding (Werhahn et al., 2009), leading to shorter lying bouts (Baumgartner et al., 2015). In an earlier study using the same horses, we found that foraging behaviour increased with larger lying area (Kjellberg et al., 2021a). Another consideration is that we only recorded lying behaviour in the horses, whereas Fuchs et al. (2018) used a polysomnograph and Keleman et al. (2021) used a gyroscope to measure sleep.

As previous housing conditions may influence sleep profile, to avoid carry-over effects we allowed an acclimatisation period of seven days before starting observations of a new treatment. The design of the shelters, and individuals within the social group affecting each other, likely also influenced the results. All shelters had openings on one side but the design varied, and to our knowledge there are no systematic studies of impacts of shelter design. There were some changes in group composition during the four treatments, which could have affected the social dynamics in the group and therefore the observed lying time and behaviour of the horses (Fader and Sambraus, 2004). Three horses included only in treatments 2 and 3 and three included in treatments 3 and 4 were all familiar with the other horses in the group and had been together on pasture and in the open barn prior to the study.

Disturbances were defined here as physical contact or close approach by a horse to a lying horse. However, horses can be disturbed during sleep and rest by sound and light, which can occur also when horses are kept in single boxes. Therefore, the horses kept in single boxes (control) could have had interrupted lying bouts. Disturbances were sometimes difficult to detect and could have been missed, e.g. threats and physical approaches farther away than 1 m away were difficult to see in the videos, but could have affected the behaviour of horses lying down.

4.4. Practical implications

This study revealed the importance of available lying area when housing horses in groups. If horses' need for sleep is not met, this can cause short- and long-term welfare issues, including episodic collapses (Fuchs et al., 2018). Building a shelter can be a major financial commitment for horse owners, so it is important to identify the optimal lying area. Based on findings in this study, the optimal lying area is between 8 and 18 m^2/horse, at least for shelters with one open side. The size of the horses may matter, as well as their personalities and social dynamics. A horse with height 175 cm (at the withers) would occupy an area of around 8 m^2 when lying and, depending on the social structure of the group, the individual distance between horses may be several metres. There may also be other advantages with larger shelters, such as better hygiene, possibilities for foraging and room for social and comfort behaviours. Our results need to be confirmed in systems without automatic feeding stations.

5. Conclusions

Available lying area and the behaviour of other horses affected lying behaviour in several ways. Greater available area in the shelter meant that horses lay down for almost twice as many bouts and for almost twice as long as with a smaller lying area. Number of lying bouts and behaviour while rising from the lying position were also affected by available lying area. Thus it is likely that the space requirement to meet the need for rest in group-housed horses is larger, not smaller, than for horses in individual boxes.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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This thesis evaluated the effects of housing horses an active open barn on behaviour and welfare in terms of health, rest and feeding. Lameness and colic were found to be lower for horses housed in the active open barn than in single boxes, probably due to moving freely in the active open barn. Comparisons of lying halls with different lying areas revealed that smaller lying halls led to shorter lying times compared with larger lying halls and single boxes.

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