Applied Animal Behaviour Science 133 (2011) 40–53

Contents lists available at ScienceDirect

Applied Animal Behaviour Science

journal homepage: www.elsevier.com/locate/applanim

Feed barrier design affects behaviour and physiology in goats

Eva Nordmann[a,*], Nina Maria Keil[b], Claudia Schmied-Wagner[a], Christine Graml[a], Jan Langbein[c], Janine Aschwanden[b], Jessica von Hof[a], Kristina Maschat[a], Rupert Palme[d], Susanne Waiblinger[a]

[a] Institute of Animal Husbandry and Welfare, University of Veterinary Medicine, Veterinärplatz 1, A – 1210 Vienna, Austria
[b] Federal Veterinary Office, Center for Proper Housing of Ruminants and Pigs, Agroscope Reckenholz-Tänikon ART, Research Station, CH – 8356 Ettenhausen, Switzerland
[c] Research Unit Behavioural Physiology, Leibniz Institute for Farm Animal Biology, Wilhelm-Stahl-Allee 2, D – 18196 Dummerstorf, Germany
[d] Department of Biomedical Sciences/Biochemistry, University of Veterinary Medicine, Veterinärplatz 1, A – 1210 Vienna, Austria

ARTICLE INFO

Article history:
Accepted 27 April 2011
Available online 26 May 2011

Keywords:
Social behaviour
Stress
Heart rate variability
Faecal cortisol metabolites
Goats
Feed barrier

ABSTRACT

Among other things, feed barrier design for goats can differ with regard to ease of leaving, backward view, and presence of physical separation. The aim of our study was to investigate whether the type of feed barrier influences agonistic behaviour and stress. The study involved 55 adult non-lactating female goats of several Swiss dairy breeds. Three groups of 14 and one group of 13 goats (2 horned, 2 hornless) were rotated between four pens with different types of feed barriers (neck rail, metal palisade, wooden palisade, diagonal fence). Each group stayed four weeks with each feed barrier type. Social interactions in the feeding area were recorded for 12 h per group and feed barrier type (1.5 h on 8 days each group) and corrected by the average number of feeding animals. Heart rate and heart rate variability were measured in lying and undisturbed goats to evaluate chronic stress independently of actual levels of motor activity and agonistic interactions. Individual faecal samples were taken for analysis of the concentration of cortisol metabolites. Data were analysed by linear mixed-effect models taking into account interactions between the type of feed barrier and presence of horns.

Hornless goats displayed the most agonistic behaviour with physical contact in the feeding area of the neck rail and diagonal fence and least in the feeding area of the metal palisade, whereas goats with horns showed much fewer interactions of this behaviour; thus, only slight differences depending on the type of feed barrier were found ($p < 0.0001$). Hornless goats also displayed the most agonistic behaviour leading to displacements from the feeding place with the neck rail, whereas for horned goats the effect of the type of feed barrier was less distinctive ($p = 0.0009$). The duration of leaving the feed barrier was longest with the diagonal fence for both horned and hornless goats, while the horned goats also took longer to leave the neck rail compared to the palisades ($p = 0.0194$). The interaction of type of feed barrier and presence of horns showed an effect on heart rate variability in the parameters root mean square of successive interbeat interval differences (RMSSD; $p = 0.0355$), RMSSD in relation to the standard deviation of all interbeat intervals (RMSSD/SDNN; $p = 0.0215$) and determinism ($p = 0.0364$). The metal palisade distinctly differed from the diagonal fence as well as from the neck rail in hornless goats, with highest heart rate variability (HRV) and thus lowest levels of chronic stress in the pen with the metal palisade. Independently of horn status, the concentration of faecal cortisol metabolites tended to be lowest for goats in the pen with the metal palisade ($p = 0.0600$). In summary, the metal palisade showed

* Corresponding author. Tel.: +43 1250774911; fax: +43 1250774990.
E-mail address: eva.nordmann@vetmeduni.ac.at (E. Nordmann).

0168-1591/$ – see front matter
doi:10.1016/j.applanim.2011.04.016

the most beneficial effects, especially on hornless goats. In contrast to the neck rail and the diagonal fence, both types of palisades seem to be recommendable for feeding goats in loose housing.

1. Introduction

The feeding area in indoor housing systems is a location of high competition where agonistic social interactions are displayed at an increased level (Baxter, 1983; Preston and Mulder, 1989; Miller and Wood-Gush, 1991) to assure the individual's access (Miranda-de la Lama and Mattiello, 2010). Restricted feeding and insufficient space at the feeding place enhance competition by further limiting access (Olofsson, 1999, 2000; Mülleder et al., 2003; Jørgensen et al., 2007). In general, feeding space offered for goats on farms rarely exceeds 40 cm per animal and often is much lower (Gall, 2001; Anonymous, 2006; Jørgensen et al., 2007; Waiblinger et al., 2010). This frequently leads to the inability of the goats to maintain individual distances during feeding (Aschwanden et al., 2008b). The individual distance is the critical distance at which further proximity of two animals would trigger active displacement behaviour by the higher-ranking animal or passive avoidance behaviour by the lower-ranking one (Hediger, 1940). Consequently low feeding space contributes to social tension and increased levels of agonistic behaviour.

In addition to aspects of space and availability of food, the actual design of the feeding place also impacts on social behaviour. In dairy cows, headlock feed barriers (some type of physical separation between feeding animals) as compared to a post-and-rail barrier (no physical separation) reduced displacements and aggression (Konggaard, 1983; Huzzey et al., 2006). In goats, no such comparison exists, but similar effects can be expected, as partitions between feeding places did reduce agonistic interactions (Aschwanden et al., 2009b). Other aspects of the feed barrier design can also affect the ease of entering and leaving the feeding place, and presence or absence of horns can be relevant. For instance, in horned dairy cows, the duration of pulling the head out of the feed barrier in order to exit was longer for headlock feed barriers with a rail above the head compared to a feed barrier type with the locking mechanism at the bottom, thus with an open space, i.e., no restriction above the necks of feeding animals (Waiblinger et al., 2001).

The greatest stressors for captive animals are considered to be those over which they have no control and from which escape is not possible (Morgan and Tromborg, 2007). In terms of the feed barrier design, controllability might be influenced by backward view of approaching goats, ease of leaving, and protection by physical separation between single feeding places. These factors may contribute (i) to the distance and speed at which a lower-ranking goat is able to recognise a higher-ranking goat, (ii) and, then, to its ability to leave the feed barrier easily, as well as to (iii) the feeling of security or protection at the feeding place.

In our study, we compared four different designs of feed barriers (neck rail, metal palisade, wooden palisade, diagonal fence) with respect to effects on social agonistic behaviour, on ease of leaving (duration of leaving), as well as on physiological parameters of stress (concentration of faecal cortisol metabolites and heart rate variability) in goats with and without horns. The feed barrier types were chosen to differ in the three abovementioned characteristics. In principle, we expected the least level of stress in feed barrier types allowing animals to have a good backward view, to leave easily, and providing physical separation between single feeding places. The metal palisade seems to fulfil all the abovementioned characteristics, whereas the other feed barrier types were regarded as unfavourable in one or more of these characteristics. For example, according to results from comparing feed barrier types with or without physical separation in other animals (see above), we expected higher levels of agonistic behaviour with the neck rail, as it is the only one of the four feed barrier types tested without physical separation. Consequently, we expected to find best results in terms of decreased agonistic behaviour, low leaving duration, and least stress when the goats are fed at the metal palisade feed barrier.

2. Animals, materials, and methods

2.1. Animals and housing conditions

The experiment involved 55 non-lactating female goats of different Swiss dairy breeds and their crossbreeds at the Center of Proper Housing of Ruminants and Pigs, Agroscope Reckenholz-Tänikon Research Station ART, Tänikon in Switzerland (May to August 2008). The goats were kept in four groups (a–d). Three groups consisted of 14 (b–d) and one group of 13 (a) animals because one goat had died shortly before the experiment started. We decided against replacement of the goat to avoid conflicts in the course of establishing new rank positions.

Five weeks prior to the experiment, the four groups had been formed by joining two groups of seven animals each. At the time of the study, the goats were 3–8 years old. Two of the groups consisted of horned goats (a and d), whereas the other two groups were composed of hornless goats (b and c; not distinguished between genetically hornless or dehorned goats). Since the presence of horns is a characteristic which is either strongly desired (e.g. Grison striped) or completely undesired (e.g. Appenzeller) by breeders for certain breeds, it was not possible to include horned and hornless animals of every breed in this study. However, the distribution of the different breeds such as Appenzeller, Saanen, Chamois Coloured, Grisons Striped, Toggenburger, St. Gallen Booted, and Valais Blackneck was balanced over the groups as much as possible with at least four different breeds per group.

All four groups were kept in a loose-housing system (Fig. 1). The four pens had similar equipment, and each pen had a total dimension of 30.4 m^2 (5.8 m × 5.4 m), subdivided in a deep-bedded straw area of 23.2 m^2

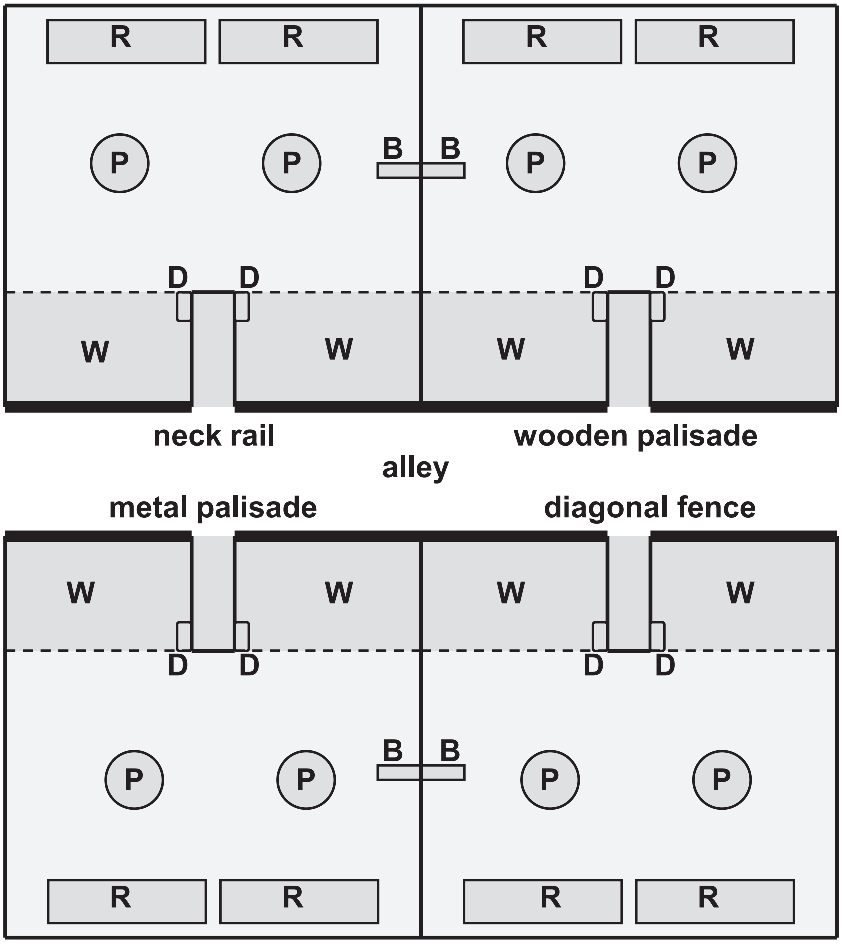

Fig. 1. Overview of the stable with the four identical pens: B = brush, D = drinker, P = wooden partition, R = resting place, W = elevated wooden feeding platform.

(5.8 m × 4.0 m) and a wooden feeding platform elevated 0.5 m over ground level. The feeding platform was separated by two gates into two parts of 3.6 m^2 each. Providing entry into the pen, the two gates were located in the middle of the feeding platform of each pen, so that it was divided into two parts without direct connection, i.e., goats had to change from one part to the other via the straw-bedded area. All pens were identically equipped with two drinkers and one lick stone for vitamins and minerals. Non-electronic brushes (0.67 m high) for grooming were installed in each pen at the fences which separated the groups. Each pen was structured by two wooden resting places (0.55 m high, 2.5 m × 0.65 m), where the goats could lie beneath or stand upon, as well as two freestanding wooden partitions (0.80 m high, diameter of round resting place: 1 m).

The goats were fed hay ad libitum twice a day (8:30 h and 17:00 h). Every morning before feeding, one group (regular rotation of the groups) was sent into an outside runout zone for approximately half an hour. Before the experiment started, all goats had been marked individually with symbols painted with hair dye and a numbered collar.

2.2. Types of feed barriers and experimental design

The entire experiment lasted 16 weeks. The four groups of goats rotated between the four pens, each of which had a different type of feed barrier installed (Fig. 2). The groups remained in the same pen for a four-week period before changing to the next pen. Each four-week period consisted of 12 days of familiarisation and, thereafter, a 16-day period of data collection. The two neighbouring groups stayed as neighbours during the whole experiment to avoid as much disconcertment as possible and keep conditions comparable.

The length of all feed barriers was two times 2.5 m (total length: 5 m, i.e., 35 cm per goat). As one group consisted only of 13 goats instead of 14, one feeding place (or 35 cm at the neck rail) was blocked at each feed barrier type for this particular group. We tested four types of feed barriers with different characteristics in terms of ease of leaving, backward view, and presence of physical separation between single feeding places (Fig. 2). Our experimental set up was not designed for an investigation of the relative meaning of the three abovementioned characteristics of the different feed barrier types. However, it allowed an overall evalua-

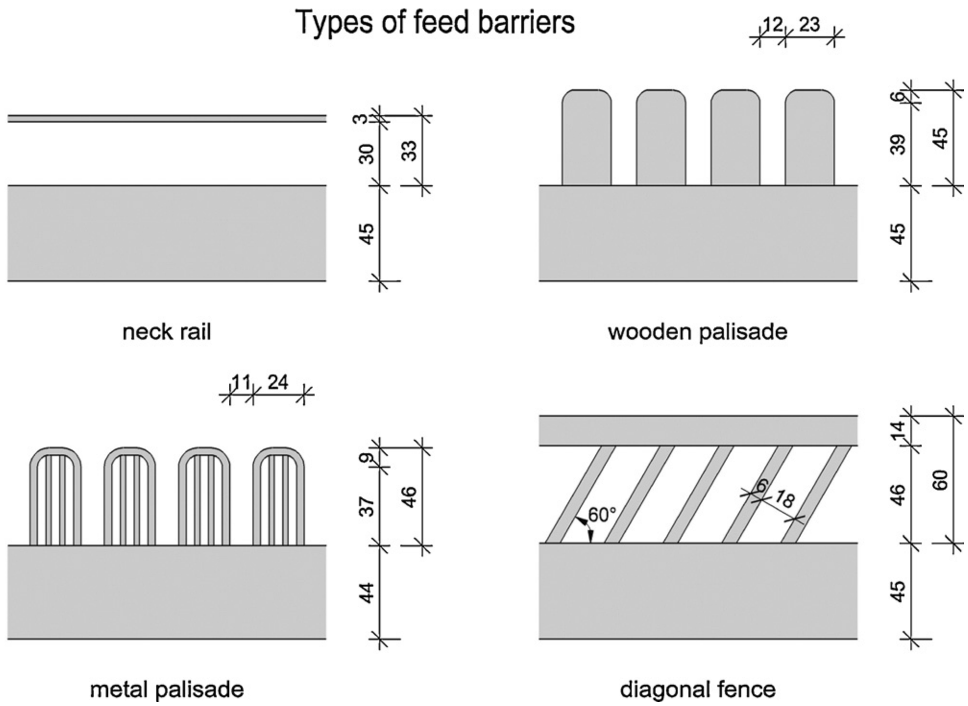

Fig. 2. Design of the four types of feed barriers tested in this study (measurements in cm).

tion of those feed barrier types that are all commonly used on farms.

The design of the feed barrier types differed as follows: Both types of palisades had no rails or anything what restricted feeding goats from above, thus providing an open space above the necks (Fig. 2). This enabled the goats to leave the feed barrier by raising the head and stepping backwards what might be the easiest way to leave a feed barrier. Contrastingly, the two other feed barrier types provided restrictions above the necks of feeding goats what might require more effort of leaving. Backward view was supposed to be best with the metal palisade and the neck rail, as there were no wooden planks restricting the goats' view. Lastly, the neck rail was the only one of the four feed barrier types tested without any physical separation between single feeding places. Physical separation was, however, more distinct in the palisades, offering at least 23 cm between adjacent feeding goats (23 cm in wooden and 24 cm in metal palisade), than in the diagonal fence, where the separating wooden planks were only 7 cm wide (measured horizontally). The three feed barriers with physical separation also differed with respect to the number of animals that were potentially able to feed at the same time (number of feeding places in case of physical separation). The palisades offered 14 fixed feeding places (ratio of feeding place/animal = 1:1), as compared to 16 fixed feeding places with the diagonal fence. Each feed barrier was stanchioned at the top to prevent the goats from jumping over it. Additionally, the diagonal fence had a bar on the top of the distant board of the trough, which did not disturb feeding but prevented the goats from breaking out straight through the feed barrier.

2.3. Measurements

2.3.1. Social behaviour

Social agonistic behaviour was observed on 8 days at each feed barrier (day 14–17 and day 21–24 since moving into the pen), 1.5 h per group and day, resulting in 12 h per group and feed barrier type. The goats were observed for 6 h a day around main feeding times (8:30–11:50 h and 16:20–19:00 h) by the same single observer. The observations were made from a raised platform in the middle of the stable. Since only one group of goats could be observed at the same time, the observer rotated between groups in a balanced order. Each group was observed for a period of 10 min, then the observer switched to the next group. Before and after each 10-min period of observation of a group, we recorded the number of feeding animals by scan sampling. "Feeding" was defined as a goat fully inserting its head into the feed barrier, so that the head and both ears were in front of the feed barrier and above the feed trough.

Agonistic interactions in the entire pen were recorded by continuous behaviour sampling (Martin and Bateson, 1993). We recorded the identities of the initiator (actor) and the receiver of an interaction, as well as their locations during the interaction. One part of the observed area was the "feeding area", which was defined as the area on the wooden feeding platform (W in Fig. 1) and in the feed barrier, but not in the straw-bedded area. With regard to the "feeding area", it was differentiated if actor and receiver of an interaction were (a) "in(side) the feed barrier" (the goat in the "feeding" position had its head fully put through the feed barrier), and (b) "outside the feed barrier" (the goat was standing on the wooden feeding platform, but had its head not put through the feed barrier). With regard to the observed agonistic interactions, we categorised the behaviours according to intensity (with or without physical contact) and their consequences (resulting in displacement or not).

Interactions with physical contact were butts, horn kicks, levering outs, hits, pushes, and bites. Interactions without physical contact consisted of threats and avoiding behaviour. Avoiding describes a goat leaving its place (receiver) in response to another goat (actor), but no threatening sign from the actor was recognisable to the observer.

For the comparison of the feed barrier types, only interactions recorded in the "feeding area" were included. All data for the comparison of the feed barrier types were designed in relation to the receiver. The following outcome variables were calculated:

(1) Agonistic interactions without physical contact (Ago_nonPhys): All agonistic interactions without physical contact received in the feeding area with and without displacement.
(2) Agonistic interactions with physical contact (Ago_Phys): All agonistic interactions with physical contact received in the feeding area with and without displacement.
(3) All displacements from feeding place in the feed barrier (Displace_Total): This variable sums up all agonistic behaviour leading to displacement of the receiver from the feeding place, i.e., the receiver was standing in the feed barrier and left its place in response to an interaction. In case of the palisades and the diagonal fence, displacement from the feed barrier implied that the receiver took the head fully out of the feed barrier and vacated the feeding place. In case of the neck rail, it also implied stepping to the side, making room for the actor.

Displacements were further differentiated whether the actor stood in the feed barrier or acted from outside the feed barrier:

(a) Displacement from feeding place by an actor in the feed barrier, without physical contact (ActorIN_nonPhys): All interactions resulting in displacement of the receiver without physical contact, both receiver and actor standing in the feed barrier.
(b) Displacement from feeding place by an actor in the feed barrier, with physical contact (ActorIN_Phys): All interactions resulting in displacement of the receiver with physical contact, both receiver and actor standing in the feed barrier.
(c) Displacement from feeding place by an actor outside the feed barrier, without physical contact (ActorOUT_nonPhys): All interactions resulting in displacement of the receiver without physical contact, the receiver standing in the feed barrier and the actor interacting from outside the feed barrier.
(d) Displacement from feeding place by an actor outside the feed barrier, with physical contact (ActorOUT_Phys): All interactions resulting in displacement of the receiver without physical contact, the receiver standing in the feed barrier and the actor interacting from outside the feed barrier.

For all these outcome variables, the number of interactions experienced by a receiver was calculated for each individual goat. Data were corrected with respect to the number of feeding animals by dividing the number of interactions by the average number of simultaneously feeding animals in their group.

All interactions resulting in displacements in the entire pen were used to calculate the dominance values of each individual within its group. The dominance value (DV) of each goat was calculated following Sambraus (1975) by dividing the number of animals dominated by a goat by the total number of "known" dominance relationships of this goat (DV = Number of animals dominated by goat A/Number of animals dominated by goat A + number of animals dominating goat A). With regard to the outcome of displacements of a goat pair, a dominance relationship was considered as "known" if one goat displaced another goat at least twice as frequently as the other way around. Only 12 out of 351 observed dominance relationships were based on less than 4 observations, all being without contradictory observations. Only for 11 pairs of goats the dominance relationship had to be classified as "unknown" because of contradictory observations (at least 5 interactions per pair were observed).

2.3.2. *Duration of leaving the feed barriers*

Eight cameras, two per group, were installed in the stable to videotape each group at each feed barrier type. More than 2×3 h per group and feed barrier type were videotaped continuously. In total, 16 videotapes (four groups × four feed barrier types) were digitised and stored on computer. The videos were observed using the programme VirtualDub-MPEG 1.6.19., which allowed measuring the duration of leaving the feed barrier of a goat. Due to the accuracy of the programme, the images could be displayed at a standard frame rate of 25 pictures per second.

By definition, "feeding" described a goat standing inside the feed barrier with the head fully put through and both ears behind the feed barrier. The behaviour "leaving the feed barrier" was detected as one continuous motion that was necessary to leave the feed barrier. The characteristic motion for leaving the palisades used to be an initial lifting of the head, followed by a backward movement to take the head over the feed barrier and leave. With the neck rail, especially the horned goats had to lower their head (also sometimes a turn of the head was necessary) and then move backwards out of the feed barrier. For leaving the diagonal fence, the head had to be inclined; the horned goats had to find the exact angle between the wooden planks for the horns and then get out by stepping backwards.

The variable "duration of leaving the feed barrier" describes the duration taken by the goats to leave the feed barriers. It began when a goat started to move its head with the intention to leave the feed barrier and finished just when the complete head of the goat (including nose) had left the feed barrier. In general, at least ten events of each goat leaving each feed barrier type were observed and included into the statistical analysis. Few animals were observed less in one or more feed barrier types or did not put their head through the feed barrier during observation times (neck rail: $n = 28/23$ for hornless/horned goats, metal palisade: $n = 27/25$, wooden palisade: $n = 28/27$, diagonal fence: $n = 28/24$; number of observations: mean = 13.4, min = 2, max = 17).

2.3.3. Heart rate and heart rate variability (HRV)

Measurements were carried out between 10:00 h and 15:00 h on 2 days during the 16-day period of data collection at each pen. Heart rate was recorded in 40 goats, 10 per group and feed barrier type (five goats per group were measured in the first week, the other five in the second week of the 16-day period of data collection). For the recording of heart rate, we used a commercial monitoring test system (horse trainer transmitters and S810 monitors from Polar Elektro Oy, Helsinki, Finland). The transmitter was connected with cables to two electrodes. One electrode was positioned at the heart region on the left side of the thorax, the other one on the right side straight behind the scapula (bladebone). Electrode gel was applied to ensure electrode contact. A horse's girth fastened the electrodes and the transmitter to the body of the goats. On top, an elastic girth held the transmitter in position and protected it from the goats as well as carried the polar watch/monitor safely in an integrated pocket. Interbeat interval (IBI) data were recorded and downloaded on computer. The recorded IBIs were analysed for quality and artefacts by use of the software Polar 3.0. As parameters of HRV are very sensible to measurement errors (Marchant-Forde et al., 2004), the following correction criteria were applied: the measurements had to have an error rate of less than 5% to be corrected by the software within its standard settings and had to be tested for plausibility; otherwise measurements were discarded.

As we were interested particularly in chronic effects on the parameters of heart rate variability, disturbances of the measurements due to activity of the goats were excluded by taking into account only IBIs during undisturbed lying periods (Langbein et al., 2004). For the selection of these lying periods, the entire area of each pen was recorded on videotape simultaneously with heart rate measurement. To be included into analysis, a lying period had to last at least 7.5 min. Finally, 215 measured valid lying periods of 30 goats (average weight of the goats was 63.6 kg) fulfilled the correction criteria and were used for statistical analysis. Although the number of measurements was equal in hornless and horned goats, more errors were found in measurements in hornless goats and therefore had to be discarded (neck rail: $n = 9/13$ for hornless/horned goats, metal palisade: $n = 4/10$, wooden palisade: $n = 4/12$, diagonal fence: $n = 6/9$).

Using the programme Multidat (©by Mohr, 1997), we calculated the mean heart rate (HR), root mean square of successive interbeat interval differences (RMSSD), and RMSSD in relation to the standard deviation of all interbeat intervals (RMSSD/SDNN) as parameters of the heart rate variability in the time domain. The percentage of recurrent points that appeared in sequence, forming diagonal lines in the recurrence plot (determinism), was calculated as a parameter in the non-linear domain (von Borell et al., 2007).

2.3.4. Adrenocortical activity

We collected faecal samples to analyse cortisol metabolites as another measure of stress. At the end of each four-week period, at each pen with a different type of feed barrier undischarged faeces were sampled rectally from each goat on two consecutive days during the morning hours (8:30–10:30 h). In goats, concentrations of faecal cortisol metabolites (FCM) reflect cortisol production around 13 h before faecal sampling (Kleinsasser et al., 2010). Thus, in our experiment this was the evening before, being a period undisturbed by humans. All samples were firstly cooled in a cool box and, after the collection of samples from all goats was finished, stored at −20° C until analysis. An aliquot (0.5 g) of each faecal sample was extracted with 5 ml of methanol (80%). A group of cortisol metabolites (with a 5β-3α-hydroxy-11-oxo-structure) was determined by an 11-oxoaetiocholanolone enzyme immunoassay (Möstl et al., 2002). The used method has been successfully validated for the evaluation of adrenocortical activity in goats (Kleinsasser et al., 2010). One goat was ill during collecting times in one four-week period, so that n was only 27 for the hornless goats in the wooden palisade (neck rail, metal palisade, and diagonal fence: $n = 28/27$ for hornless/horned goats, wooden palisade: $n = 27/27$ for hornless/horned goats).

2.4. Statistical analysis

For statistical analysis, we used a linear mixed-effect model for all outcome variables calculated with the statistical package R 2.6.1. (R Development Core Team, 2007). Fixed effects were the type of feed barrier, presence of horns (yes/no), and the interaction of both (type of feed barrier × presence of horns). Dominance value was included as covariate to control for effects of social status in all models except the model for "duration of leaving the feed barrier". Random effect was the individual nested within its group. To verify the assumptions of the models, residuals were checked for normal distribution and homogeneity of variance. All outcome variables had to be transformed (log- or square root-transformed) to fulfil the model assumptions. The experimental design was chosen in such a way that the investigation focused on the influence of the feed barriers depending on the presence of horns (type of feed barrier × presence of horns). So, in case of a significant effect of this interaction, its result would be presented. If the interaction type of feed barrier and presence of horns did not reach significance ($p > 0.05$), it was taken out of the model, and the result of the effect of the feed barrier itself would be shown. The effect of horns was included in the model due to technical reasons of the model building process, but because of the small sample size ($n = 2$), the estimates of the models were not able to form substantiated propositions about the difference in the behaviour of horned and hornless goats and therefore were excluded from presentation.

Table 1
Mean and standard deviation (s.d.) of simultaneously feeding animals per group and feed barrier type with regard to the total observation period of the study (8 × 4 days) and splitted into morning and afternoon observations. Both observations include main feeding times while the afternoon observations include one 10-min observation period of each group prior to feed supply. Group a and d had horns, group b and c were hornless.

	Group a		Group b		Group c		Group d	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
Total observation period								
Neck rail	2.87	0.93	5.72	2.05	4.49	1.70	3.48	1.12
Metal palisade	2.92	1.02	5.73	2.58	5.81	1.79	3.12	1.18
Wooden palisade	2.95	0.88	6.36	2.50	5.00	1.54	3.35	0.98
Diagonal fence	2.84	0.98	5.37	2.60	4.90	1.70	3.02	0.85
Morning observation hours (08:30–11:50 h)								
Neck rail	3.10	0.87	6.11	1.55	4.68	1.69	3.61	1.03
Metal palisade	3.08	1.00	6.23	2.27	6.23	1.57	3.39	1.16
Wooden palisade	2.94	0.86	6.89	2.22	5.19	1.39	3.43	1.11
Diagonal fence	2.95	0.95	5.41	2.31	5.24	1.43	3.16	0.87
Afternoon observation hours (16:20–19:00 h)								
Neck rail	2.58	0.94	5.22	2.49	4.25	1.71	3.31	1.22
Metal palisade	2.73	1.03	5.11	2.84	5.30	1.94	2.78	1.14
Wooden palisade	2.97	0.91	5.70	2.70	4.77	1.70	3.25	0.80
Diagonal fence	2.70	1.01	5.31	2.96	4.47	1.92	2.84	0.81

3. Results

3.1. Social behaviour

The number of simultaneously feeding animals was about half as large for horned as for hornless goats. The number of animals feeding on average in the different groups and feed barrier types is shown in Table 1. It was differentiated between morning and afternoon observations because in the afternoon one 10-min observation period of each group prior to feed supply was included. Differences between morning and afternoon observation periods were only marginal.

There was no effect of the interaction of type of feed barrier and presence of horns or the type of feed barrier itself on the total number of agonistic interactions without physical contact (Ago_nonPhys: hornless: neck rail: median (min–max): 8.7 (2.7–45.4), metal palisade: 7.8 (1.6–45.6), wooden palisade: 9.1 (1.8–61.0), diagonal fence: 10.3 (1.7–39.4); horned: neck rail: 6.3 (0.0–15.8), metal palisade: 5.8 (0.0–24.3), wooden palisade: 7.5 (0.0–15.8), diagonal fence: 6.3 (0.0–16.2). In four of the seven outcome variables of agonistic behaviour, the interaction of type of feed barrier and presence of horns had a significant effect (Ago_Phys, Displace_Total, ActorIN_Phys, ActorOUT_nonPhys). In ActorIN_nonPhys and ActorOUT_Phys, the effect of the type of feed barrier itself, independently of the presence of horns, was significant (Table 2).

In hornless goats, the number of agonistic interactions with physical contact (Ago_Phys) observed in the feeding area was highest with the neck rail (median: 5.8 interactions/goat × 12 h) and, with respect to the median, about half as high with the palisades (median: metal palisade: 2.8, wooden palisade: 3.4), with the diagonal fence ranking at an intermediate level. Horned goats rarely showed this behaviour, and only marginal differences between the different types of feed barriers were seen. Median values were between 0.7 and 1.5 with the different feed barriers (Ago_Phys; Fig. 3a).

In hornless goats, displacements from the feeding place (Displace_Total) were seen most often with the neck rail (median: 4.2) compared to the three other feed barrier types where again only around half as many interactions were observed (median levels ranging from 2.1 to 2.7). In horned goats no effect of type of feed barrier was obvious (Displace_Total; Fig. 3b).

Displacements from feeding place were analysed in more detail by differentiating the behaviour with regard to intensity (with or without physical contact) and the location of the actor, leading to four additional parameters (Fig. 3c–f): Overall, the occurrence of an actor standing inside the feed barrier and displacing another goat from its feeding place without physical contact (ActorIN_nonPhys) was much more frequent than the three other forms of displacements (ActorIN_Phys, ActorOUT_nonPhys, ActorOUT_Phys). The average number of interactions per goat of ActorIN_nonPhys over all feed barrier types and all goats was 1.8, whereas the average of the three other forms of displacements ranged from 0.3 to 0.9. Both horned and hornless goats displayed ActorIN_nonPhys most often with the neck rail (median: 2.0) and half of it with the metal palisade (ActorIN_nonPhys; Fig. 3c). Displacements of a goat in the feed barrier by an actor inside the feed barrier with physical contact (ActorIN_Phys) were shown by hornless goats most often with the neck rail (median: 1.1 interactions/goat × 12 h) and least often with the metal palisade, where only a fifth of such displacements was observed (median: 0.2). In total, such agonistic interactions were at a very low level among horned goats (all medians: 0.0), so that no differences between the feed barrier types could be seen (ActorIN_Phys; Fig. 3d).

Generally, displacements from feeding place without physical contact by an actor outside the feed barrier (ActorOUT_nonPhys) occurred at a low level. In hornless goats, feed barrier types differed only marginally, with most interactions with the metal palisade (median: 0.6). In horned goats, it more often happened with the palisades (metal or wooden) than with the neck rail or diagonal

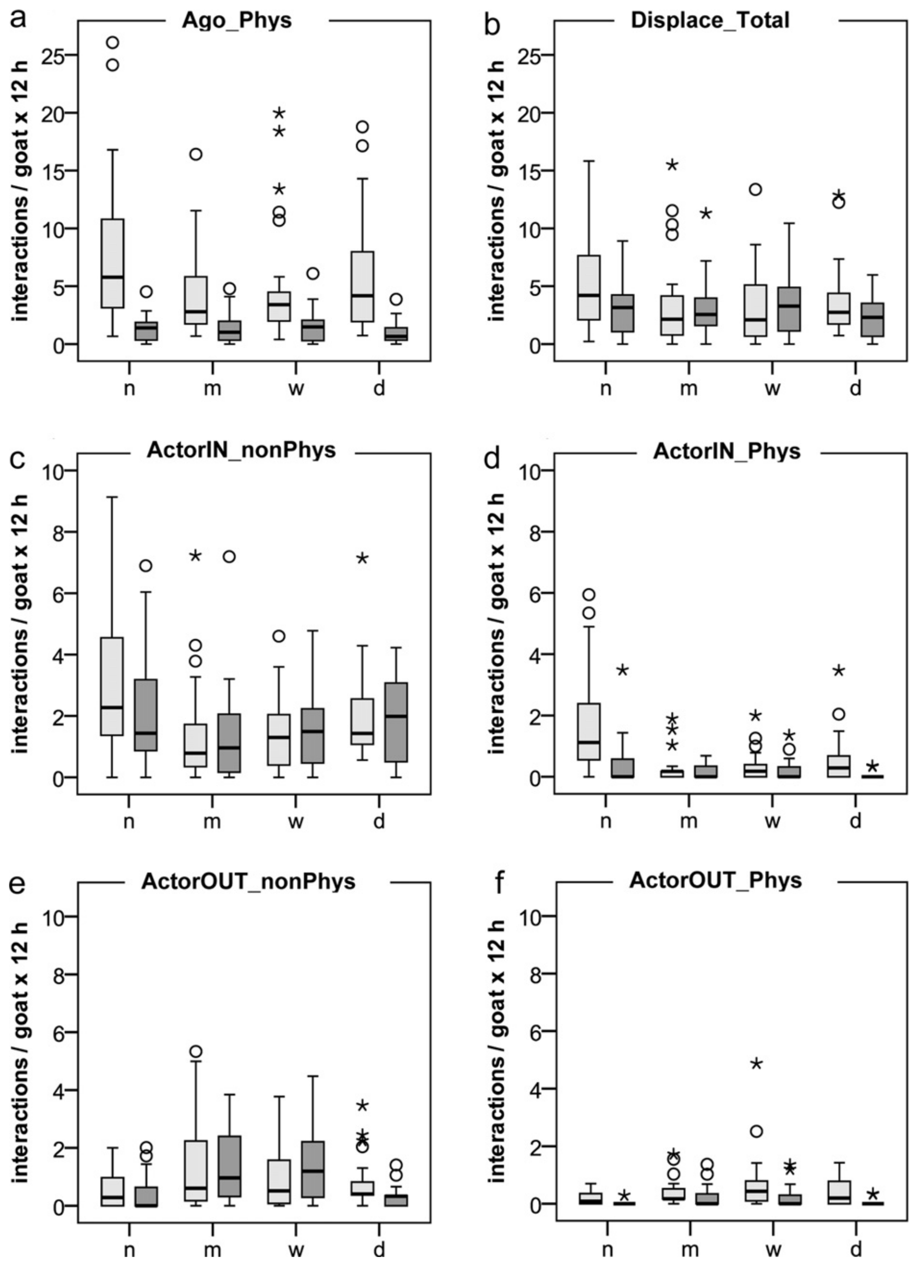

Fig. 3. Agonistic interactions in the feeding area of the pens with the four different types of feed barriers (n = neck rail, m = metal palisade, w = wooden palisade, d = diagonal fence) within 12 h of observation, in relation to the presence of horns (light grey = hornless ($n = 28$), dark grey = horned ($n = 27$)). (a) Total number of agonistic interactions with physical contact (Ago_Phys), (b) total number of agonistic interactions resulting in a displacement from feeding place (Displace_Total). Displacements from feeding place by an actor standing in the feed barrier next to the receiver: (c) without physical contact (ActorIN_nonPhys), (d) with physical contact (ActorIN_Phys). Displacements from feeding place by an actor standing outside the feed barrier: (e) without physical contact (ActorOUT_nonPhys), (f) with physical contact (ActorOUT_Phys). Interaction of type of feed barrier and presence of horns had a significant effect ($p < 0.05$) on the variables (a, b, d, and e), but not on (c and f). On (c and f) the type of feed barrier itself had a significant effect ($p < 0.05$). Please note the different scales between (a, b) and (c–f). Data are presented as box-and-whiskers plots with boxes (25% and 75% percentiles, central bar = median), whiskers (range from minimum to maximum excluding outliers and extremes), dots (° = outliers), and stars (* = extremes).

fence (ActorOUT_nonPhys; Fig. 3e). Displacements from feeding place with physical contact by an actor outside the feed barrier (ActorOUT_Phys) did not depend on the presence of horns. The goats showed such interactions at a very low level, with slightly higher levels and a median of 0.2 interactions/goat $\times$ 12 h with the two types of palisades and almost none with the neck rail (ActorOUT_Phys; Fig. 3f).

In all outcome variables, a highly significant influence of the dominance value was shown, suggesting that the lower the dominance value of goats, the more often goats were receivers of agonistic behaviour.

Table 2
Results (*p*- and *F*-value of significant explanatory variables) of the linear mixed-effect models of the outcome variables in social behaviour, leaving duration, heart rate and heart rate variability, and faecal cortisol metabolites. The main fixed effect "type of feed barrier" is only presented if the interaction "type of feed barrier × presence of horns" was not significant and taken out of the model.

Outcome variable	Fixed effect	*p*-value	numDF[a]	denDF[b]	*F*-value
Social behaviour					
Ago_nonPhys	Type of feed barrier	n.s.[c]			
	Dominance value	< 0.0001	1	50	25.6
Ago_Phys	Type of feed barrier × presence of horns	< 0.0001	3	159	7.6
	Dominance value	0.0008	1	50	12.8
Displace_Total	Type of feed barrier × presence of horns	0.0009	3	159	5.8
	Dominance value	0.0025	1	50	10.2
ActorIN_nonPhys	Type of feed barrier	< 0.0001	3	162	14.4
	Dominance value	0.0065	1	50	8.1
ActorIN_Phys	Type of feed barrier × presence of horns	< 0.0001	3	159	15.5
	Dominance value	0.0108	1	50	7.0
ActorOUT_nonPhys	Type of feed barrier × presence of horns	0.0039	3	159	4.6
	Dominance value	0.0047	1	50	8.8
ActorOUT_Phys	Type of feed barrier	0.0002	3	162	7.0
	Dominance value	0.0065	1	50	8.1
Leaving duration					
Duration of leaving the feed barrier	Type of feed barrier × presence of horns	0.0194	3	149	3.4
Heart rate and heart rate variability					
RMSSD	Type of feed barrier × presence of horns	0.0355	3	31	3.2
	Dominance value	0.0770	1	25	3.4
RMSSD/SDNN	Type of feed barrier × presence of horns	0.0215	3	31	3.7
	Dominance value	0.0879	1	25	3.2
Determinism	Type of feed barrier × presence of horns	0.0364	3	31	3.2
	Dominance value	n.s.[c]			
Heart rate	Type of feed barrier × presence of horns	0.0106	3	31	4.4
	Dominance value	n.s.[c]			
Adrenocortical activity					
5β-3α-hydroxy-11-oxo-FCM[d]	Type of feed barrier	0.0600	3	161	2.5
	Dominance value	0.0924	1	50	2.9

[a] numDF = numerator of degree of freedom.
[b] denDF = denominator of degree of freedom.
[c] n.s. = not significant.
[d] FCM = faecal cortisol metabolites.

3.2. Duration of leaving the feed barriers

In general, the duration of leaving the feed barrier was short, and in most cases the goats needed less than 2 s (Fig. 4). The percentiles of the duration of leaving the feed barrier over all animals (both horned and hornless) and feed barrier types were 1.1 s (25% percentile), 1.2 s (50%) and 1.4 s (75%). The interaction type of feed barrier and presence of horns significantly influenced the duration of leaving the feed barrier of a goat (Table 2). Goats both with and without horns showed the longest leaving duration with the diagonal fence. Median values of 1.3 s for hornless and 1.5 s for horned goats were analysed with this type of feed barrier. Accordingly, the percentage of animals needing more than 1.4 s to leave the feed barrier was highest with the diagonal fence (hornless goats: 47%; horned goats: 63%). In hornless goats, only slight differences were found between the other three feed barriers types and the percentage of animals which needed more than 1.4 s to leave the feed barrier ranged from 11% (neck rail) to 18% (both palisades). In horned goats, the percentage of animals with leaving durations longer than 1.4 s were lower for both types of palisades (metal palisade: 8%, wooden palisade: 15%) than for the neck rail (48%).

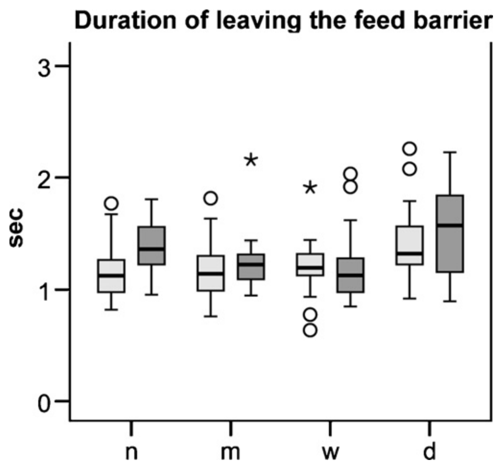

Fig. 4. Mean duration of leaving the four different types of feed barriers, n = neck rail (*n* = 28/23 for hornless/horned goats), m = metal palisade (*n* = 27/25), w = wooden palisade (*n* = 28/27), d = diagonal fence (*n* = 28/24) in relation to the presence of horns (light grey = hornless, dark grey = horned). The interaction type of feed barrier and presence of horns had a significant effect ($p < 0.05$) on the duration of leaving the feed barrier. Data are presented as box-and-whiskers plots with boxes (25% and 75% percentiles, central bar = median), whiskers (range from minimum to maximum excluding outliers and extremes), dots (° = outliers), and stars (* = extremes).

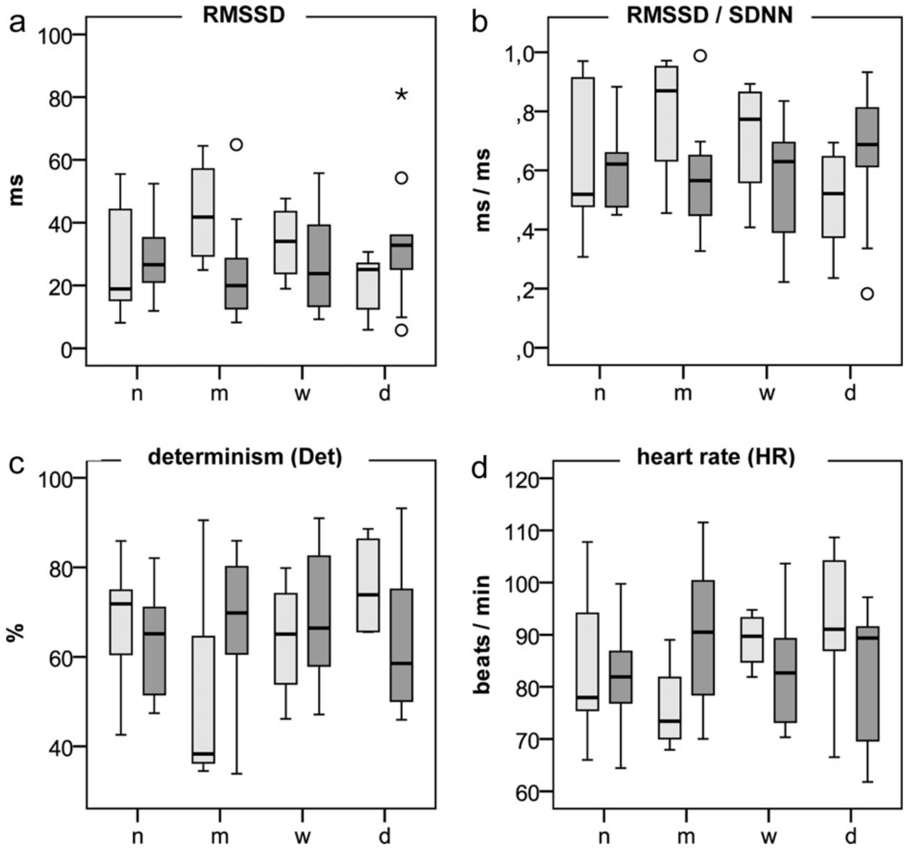

Fig. 5. Parameters of heart rate variability, (a) RMSSD, (b) RMSSD/SDNN, (c) determinism, and heart rate, (d) heart rate, of the goats with the different types of feed barriers: n = neck rail (n = 9/13 for hornless/horned goats), m = metal palisade (n = 4/10), w = wooden palisade (n = 4/12), d = diagonal fence (n = 6/9) in relation to the presence of horns (light grey = hornless, dark grey = horned). The interaction of type of feed barrier and presence of horns had a significant effect on (a–d). Data are presented as box-and-whiskers plots with boxes (25% and 75% percentiles, central bar = median), whiskers (range from minimum to maximum excluding outliers and extremes), dots (◦ = outliers), and stars (* = extremes).

3.3. Heart rate and heart rate variability

For all four outcome variables, the interaction of type of feed barrier and presence of horns was significant (Table 2), with clear effects of the feed barrier type only in hornless goats (Fig. 5). In hornless goats, the metal palisade differed from the other feed barrier types in all four parameters, with the highest values for RMSSD (Fig. 5a) and RMSSD/SDNN (Fig. 5b) and the lowest values for determinism (Fig. 5c) and heart rate (Fig. 5d). Compared to both types of palisades, hornless goats in pens with the diagonal fence had lower RMSSD and RMSSD/SDNN and higher values of determinism and heart rate. For hornless goats in pens with the neck rail, similar values of RMSSD, RMSSD/SDNN and determinism could be measured as in pens with the diagonal fence. For horned goats, consistent effects of the parameters of heart rate variability and heart rate were not obvious, and differences between the four different feed barrier types were much smaller than in hornless goats.

Dominance value did not seem to have a strong impact on these parameters of stress. RMSSD and RMSSD/SDNN tended to be higher for goats with a higher DV.

3.4. Adrenocortical activity

The interaction of type of feed barrier and presence of horns did not reach significance and therefore was taken out of the model. The type of feed barrier tended to influence the concentration of faecal cortisol metabolites (Table 2 and Fig. 6). Lowest concentrations were measured in the pen with the metal palisade (median: 145.7 ng/g) for both horned and hornless goats, while concentrations with the three other feed barrier types were higher and median levels ranged between 165.1 and 170.8 ng/g. A higher dominance value tended to be associated with higher concentrations of faecal cortisol metabolites.

4. Discussion

The present study gives evidence that feed barrier design does affect social behaviour, the duration of leaving the feed barrier, and stress parameters in goats. However, most effects were much more pronounced or only present in hornless than in horned goats.

We hypothesised that goats would experience least stress, shortest leaving duration, and lowest level of

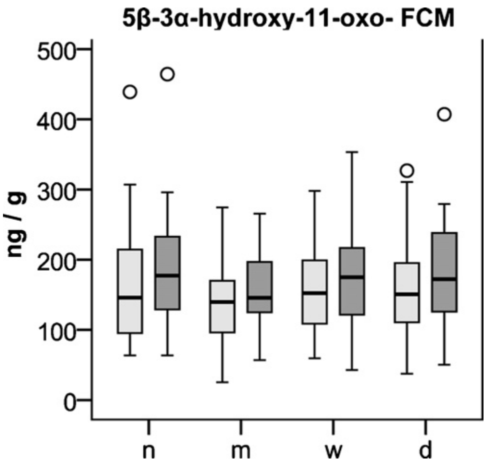

Fig. 6. Faecal cortisol metabolites (FCM) measured in samples from goats from the pens with different types of feed barriers: n = neck rail, m = metal palisade, w = wooden palisade, d = diagonal fence in relation to the presence of horns (light grey = hornless, dark grey = horned). Neck rail, metal palisade, and diagonal fence: $n = 28/27$ for hornless/horned goats, wooden palisade: $n = 27/27$ for hornless/horned goats. The interaction of type of feed barrier and presence of horns was not significant ($p > 0.05$) but the type of feed barrier itself tended to have an influence on the concentration of faecal cortisol metabolites ($p < 0.1$). Data are presented as box-and-whiskers plots with boxes (25% and 75% percentiles, central bar = median), whiskers (range from minimum to maximum excluding outliers and extremes), dots (° = outliers), and stars (* = extremes).

aggression with feed barrier types that fulfil certain characteristics, i.e., when goats have a good backward view, can leave the feeding place easily, and when there are physical separations between single feeding places. Our results confirm these hypotheses: The metal palisade fulfilled all the abovementioned characteristics and generally – but especially in hornless goats – had the most favourable effects in relation to the outcome variables tested compared to the other feed barriers tested. The wooden palisade differed from the metal palisade with respect to limited backward view, but seemed to be better than the diagonal fence or the neck rail. This might be explained by the characteristics of the diagonal fence and the neck rail, which, though allowing backward view, offered only limited or no physical separation and seemed to cause difficulties in leaving the feed barrier (the diagonal fence for both horned and hornless goats and the neck rail for horned goats). Longer durations of leaving the feed barrier may also impact on welfare via the risk of injuries, which merits further research.

In line with our hypothesis, the lack of physical separation seemed to have an unfavourable impact due to the fact that direct physical contact between feeding goats is easily possible. This is confirmed by the highest number of agonistic behaviour with physical contact and displacements from feeding place in the neck rail in hornless goats. Higher levels of displacements and agonistic behaviour in a feed barrier type without physical separation (neck rail) as compared to feed barriers with physical separation were also found in several studies in dairy cows (Bouissou, 1970; Endres et al., 2005; Huzzey et al., 2006) and in sows (Andersen et al., 1999). Similarly, in goats, results from an experimental setting in which a pair of goats was tested as well as from a study on goats kept in small groups showed that partitions separating feeding places reduced initiated agonistic interactions and displacements during feeding (Aschwanden et al., 2009a,b). Physical separation between adjacent goats, as, for example, by fixed arcs in the construction of the palisades tested, provided a certain amount of feeding space for each goat. The lack of physical separation between single feeding places at the neck rail may enhance the possibility of goats intruding into another goat's individual distance and thus elicit agonistic interactions (Aschwanden et al., 2008b). In contrast, the palisades do not allow goats to push aside each other and protect the area around the goats' head from direct aggression to some extent. Apart from that, the motivation to change feeding places might vary in the different types of feed barrier due to different costs (of energy and time) to do so. If a goat wants to change feeding places in a feed barrier with physical separation, it has to pull out its head, step back and step forward again: This results in higher costs of energy than just stepping aside as it could do in the neck rail. According to optimal foraging theory, changing feeding places might be less preferable, as suggested by Metz (1983) and supported by Aschwanden et al. (2009b). A dominant goat may accept a subordinate animal feeding in close proximity for a longer period, because increasing the intensity of aggression to establish adequate distance by physical contact (e.g. bite, horn butt) may often require leaving the feed barrier with abovementioned consequences regarding motivation. Furthermore, it can be assumed that threatening by a dominant animal in a feed barrier with physical separation, such as the palisades, is less effective because subordinate goats are aware of being protected by the physical separation from further consequences as long as the other goat is still in the feed barrier. The consequence of these combined effects is reflected in the lower occurrence of displacements in palisades compared to the neck rail, at least in hornless goats. Additionally, the difference in the location of a goat displacing another one supports the notion of lower effectiveness of threatening inside the palisades: While in pens with the neck rail (and the diagonal fence) displacements by an actor outside the feed barrier happened rarely compared to displacements by an actor in the feed barrier, such displacements were observed more often in pens with the palisades. Thus, goats adapted their tactics of displacement to the type of feed barrier.

Results for the diagonal fence regarding social behaviour ranged between the neck rail and the palisades, maybe due to the complexity of its characteristics. In hornless goats, the diagonal fence caused more agonistic behaviour compared to the palisades. This could possibly be explained by the small physical separation between the necks of feeding goats, which were only 7 cm wide (measured horizontally), leading to a lower effect of protection than the physical separation at the palisades (measuring at least 23 cm between adjacent goats). Furthermore, the diagonal fence hindered the leaving of the feed barrier in the horned as well as in the hornless goats, because spaces between the diagonal wooden planks were only 18 cm wide, and they had to find the exact angle for their head and, especially, for their horns to get out of the feeding place, which prolonged the duration of leaving this feed barrier in comparison to the others. A diagonal fence is difficult to construct in such a way that it, on the one hand, offers enough space for the goats to put their head through to feed, and, on the other hand, prevents the goats from breaking out straight through it into the trough by limiting the space between the diagonal wooden planks.

Differences between types of feed barriers were much more pronounced in hornless goats. This might be related to the fact that about twice as many hornless goats were feeding at the same time as compared to the horned goats. While on average around 40% of the animals of a group were feeding simultaneously in the hornless groups, only roughly a quarter did so in the horned groups. The freely chosen distance of pairs of goats during feeding was shown to range from 0.44 m to 4.75 m, being less than 1 m in only 7% of the pairs and more than 2 m in more than 40%, independently from horns (Aschwanden et al., 2008b). In accordance with these freely chosen distances, two pairs, or even one pair only, would be able to feed at the feed barrier, as in the pens we used one side of the feed barrier was 2.5 m long – and the horned goats acted likewise in our study. This could be ascribed to the greater respect for social distances in horned compared to hornless goats (Aschwanden et al., 2008b) and thus to larger space requirements of horned animals at the feed barrier (Loretz et al., 2004) – where subordinate goats avoid violating the individual distance to a dominant goat. Horned goats might just avoid potential situations of conflict beforehand (Fournier and Festa-Bianchet, 1995), which is in agreement with the present study and an experimental setting (Aschwanden et al., 2008b) in terms of a lower frequency of agonistic interactions with physical contact observed in horned goats compared to hornless goats. The differences in social behaviour that were reflected in feeding behaviour might explain why we found much less obvious effects of the feed barrier types in horned goats compared to hornless goats. But all in all, the results in horned goats do not contradict the findings in hornless goats. Recent observations in larger groups of horned and hornless goats suggest that such distinct differences in feeding place occupancy are more pronounced in small groups due to the overall small pen dimensions (Waiblinger et al., 2010).

Dominance relationships are thought to serve the function of avoiding frequent fights and conflicts in competitive situations by clearly regulated access to resources (Fraser and Broom, 1997; Lindberg, 2001). This seems to be achieved to a higher degree in the horned animals, as they generally had lower levels of agonistic interactions and agonistic interactions with physical contact. However, effects of social status on agonistic behaviour generally existed as expected. Goats with a high dominance value rarely became receivers of agonistic interactions and were seldom displaced, which gives them priority access to the vital resource food (Brouns and Edwards, 1994; Barroso et al., 2000). Interestingly, no significant effects of social status on stress were detected, while it clearly affected agonistic behaviour. Only a tendency of low RMSSD and RMSSD/SDNN in lower-ranking goats, which was proved to exist by Aschwanden et al. (2008a), was found. Counterintuitively, lower-ranking goats tended to have lower concentrations of faecal cortisol metabolites.

The effects of the physiological indicators of stress, i.e., RMSSD, RMSSD/SDNN, and determinism as measures of heart rate variability (HRV) and faecal cortisol metabolites as an indicator of adrenocortical activity, are in line with the effects of the behavioural parameters. Earlier research indicates that a combination of linear and non-linear parameters of HRV can be used as a sensitive indicator of stress (von Borell et al., 2007). Using periods of undisturbed lying and thus of minimal physical activity for analysis of interbeat intervals enabled us to measure chronic changes (Langbein et al., 2004; Hagen et al., 2005). A lower short-term variability (lower RMSSD) indicated a decreased vagal tone and an increased level of stress (Porges, 1995; von Borell et al., 2007) in hornless goats in the pens with the neck rail or the diagonal fence. This is also shown in RMSSD/SDNN, which mirrors the relation of short-term to long-term variability. Overall, a higher influence of the short-term variability and therefore a stronger parasympathetic than sympathetic influence was found. Higher deterministic non-linear shares of the HRV indicated a higher challenge to the organism. Higher HRV (RMSSD, RMSSD/SDNN, determinism) and lower HR indicate lower levels of stress in the pen with the metal palisade than with the wooden palisade in hornless goats. Although, due to the limited sample size, the data regarding HRV in the hornless goats have to be interpreted with caution, this might reflect the importance of a good backward view.

Again, almost no differences between feed barrier types could be confirmed for the horned goats in relation to the stress parameters. This could possibly be explained by the limited housing space in the small groups. As it could be challenging enough for the goats to keep the preferred social distances in those small groups, which was also recognisable by the small number of animals feeding simultaneously, the situation at the feed barrier might not have had any further impact on the level of social stress. However, adrenocortical activity was lowest in goats in the pen with the metal palisade and highest with the neck rail, independently from the presence of horns. This suggests a slightly lower stress level of horned and hornless animals in the pen with the metal palisade (Morméde et al., 2007) and supports the results regarding agonistic behaviour and heart rate variability in hornless goats.

In summary, our results for the metal palisade suggest an advantage of a good backward view, combined with easy leaving and physical separation. It possibly enables goats to predict and control their social environment best: it lets the goats see and recognise an approaching dominant goat early, gives them the chance to escape in time, and may allow them to feed beside a dominant goat protected from direct attacks. High predictability and controllability of the environment are prerequisites for low levels of stress (Wiepkema and Koolhaas, 1993). The differences between feed barrier types seem to be largely explained by differences in these basic requirements.

5. Conclusions

In hornless goats, the metal palisade clearly caused least chronic stress and fewest displacements from feeding place and facilitated easy leaving. This is why it can be recommended in contrast to the diagonal fence and the neck rail. The wooden palisade can be an acceptable alternative. For horned goats, these effects were not as strong, probably due to their different feeding behaviour, but results of agonistic behaviour, duration of leaving the feed barrier, and adrenocortical activity tend to support these recommendations.

Acknowledgements

Our special thanks go to Marc Wymann, Gallus Jöhl, and Vid Vidovic for caring for the goats, to Hans-Rudolf Ott for constructing the wooden feed barriers and fixing all feed barriers in time, to Daniel Herzog for drawing the figure of the feed barrier types, to the company “DeLaval Switzerland” for donating us the metal palisade feed barrier, and to Urs Marolf for his excellent technical support. Many special thanks also go to Alexandra Ettinger, Jennifer Schweiger, and to everybody who provided support in collecting data and samples. Moreover, we thank Marc Orel for reviewing the English language of this paper. This project (project-number 100191) was financed by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW, Austria) and the Federal Ministry of Health (BMG, Austria).

References

Andersen, I.L., Bøe, K.E., Kristiansen, A.L., 1999. The influence of different feeding arrangements and food type on competition at feeding in pregnant sows. Appl. Anim. Behav. Sci. 65, 91–104.

Anonymous, 2006, Verordnung der Bundesministerin für Gesundheit und Frauen über die Mindestanforderungen für die Haltung von Pferden und Pferdeartigen, Schweinen, Rindern, Schafen, Ziegen, Schalenwild, Lamas, Kaninchen, Hausgeflügel, Straußen und Nutzfischen (1.Tierhaltungsverordnung), BGBI. II Nr.485/2004 vom 17.12.2004 idF BGBI. II Nr. 25/2006 vom 27.01.2006.

Aschwanden, J., Gygax, L., Wechsler, B., Keil, N.M., 2008a. Cardiac activity in dairy goats whilst feeding side-by-side at two different distances and during social separation. Physiol. Behav. 95, 641–648.

Aschwanden, J., Gygax, L., Wechsler, B., Keil, N.M., 2008b. Social distances of goats at the feeding rack: influence of the quality of social bonds, rank differences, grouping age and presence of horns. Appl. Anim. Behav. Sci. 114, 116–131.

Aschwanden, J., Gygax, L., Wechsler, B., Keil, N.M., 2009a. Loose housing of small goat groups: influence of visual cover and elevated levels on feeding, resting and agonistic behaviour. Appl. Anim. Behav. Sci. 119, 171–179.

Aschwanden, J., Gygax, L., Wechsler, B., Keil, N.M., 2009b. Structural modifications at the feeding place: effects of partitions and platforms on feeding and social behaviour of goats. Appl. Anim. Behav. Sci. 119, 180–192.

Barroso, F.G., Alados, C.L., Boza, J., 2000. Social hierarchy in the domestic goat: effect on food habits and production. Appl. Anim. Behav. Sci. 69, 35–53.

Baxter, M.R., 1983. Feeding and aggression in pigs. Appl. Anim. Ethol. 11, 74–75.

Bouissou, M.-F., 1970. Role du contact physique dans la manifestation des relations hierarchiques chez les bovines, Consequences pratiques. Ann. Zootech. 19, 279–285.

Brouns, F., Edwards, S.A., 1994. Social rank and feeding behaviour of group-housed sows fed competitively or ad libitum. Appl. Anim. Behav. Sci. 39, 225–235.

Endres, M.I., DeVries, T.J., von Keyserlingk, M.A.G., Weary, D.M., 2005. Short communication: effect of feed barrier design on the behavior of loose-housed lactating dairy cows. J. Dairy Sci. 88, 2377–2380.

Fournier, F., Festa-Bianchet, M., 1995. Social dominance in adult female mountain goats. Anim. Behav. 49, 1449–1459.

Fraser, A.F., Broom, D.M., 1997. Farm Animal Behaviour and Welfare, third ed. Cab International, Oxon.

Gall, C., 2001. Ziegenzucht, second ed. Ulmer, Stuttgart.

Hagen, K., Langbein, J., Schmied, C., Lexer, D., Waiblinger, S., 2005. Heart rate variability in dairy cows – influences of breed and milking system. Physiol. Behav. 85, 195–204.

Hediger, H., 1940. Biologische Gesetzmässigkeiten im Verhalten von Wirbeltieren. Mitteilungen der Naturforschenden Gesellschaft in Bern 1941, 39–55.

Huzzey, J.M., DeVries, T.J., Valois, P., von Keyserlingk, M.A.G., 2006. Stocking density and feed barrier design affect the feeding and social behavior of dairy cattle. J. Dairy Sci. 89, 126–133.

Jørgensen, G.H.M., Andersen, I.L., Bøe, K.E., 2007. Feed intake and social interactions in dairy goats – the effects of feeding space and type of roughage. Appl. Anim. Behav. Sci. 107, 239–251.

Kleinsasser, C., Graml, C., Klobetz-Rassam, E., Barth, K., Waiblinger, S., Palme, R., 2010. Physiological validation of a non-invasive method for measuring adrenocortical activity in goats. Wien. Tierärztl. Monat. 97, 259–262.

Konggaard, S.P., 1983. Feeding conditions in relation to welfare for dairy cows in loose-housing systems. In: Baxter, S.H., Baxter, M.R., MacCormack, J.A.D. (Eds.), Farm Animal Housing and Welfare. Martinus Nijhoff Publishers, Dordrecht, pp. 272–280.

Langbein, J., Nürnberg, G., Manteuffel, G., 2004. Visual discrimination learning in dwarf goats and associated changes in heart rate and heart rate variability. Physiol. Behav. 82, 601–609.

Lindberg, A.C., 2001. Group Life. In: Keeling, L.J., Gonyou, H.W. (Eds.), Social Behaviour in Farm Animals. CAB International, Oxon, pp. 37–58.

Loretz, C., Wechsler, B., Hauser, R., Rüsch, P., 2004. A comparison of space requirements of horned and hornless goats at the feed barrier and in the lying area. Appl. Anim. Behav. Sci. 87, 275–283.

Marchant-Forde, R.M., Marlin, D.J., Marchant-Forde, J.N., 2004. Validation of a cardiac monitor for measuring heart rate variability in adult female pigs: accuracy, artefacts and editing. Physiol. Behav. 80, 449–458.

Martin, P., Bateson, P., 1993. Measuring behaviour – an introductory guide, second ed. Cambridge University Press, Cambridge.

Metz, J.H.M., 1983. Food competition in cattle. In: Baxter, S.H., Baxter, M.R., MacCormack, J.A.C. (Eds.), Farm Animal Housing and Welfare. Martinus Nijhoff Publishers, Dordrecht, pp. 164–170.

Miller, K., Wood-Gush, D.G.M., 1991. Some effects of housing on the social behaviour of dairy cows. Anim. Prod. 53, 271–278.

Miranda-de la Lama, G.C., Mattiello, S., 2010. The importance of social behaviour for goat welfare in livestock farming. Small Ruminant Res. 90, 1–10.

Morgan, K.N., Tromborg, C.T., 2007. Sources of stress in captivity. Appl. Anim. Behav. Sci. 102, 262–302.

Morméde, P., Andanson, S., Aupérin, B., Beerda, B., Guémené, D., Malmkvist, J., Manteca, X., Manteuffel, G., Prunet, P., van Reenen, C.G., Richard, S., Veissier, I., 2007. Exploration of the hypothalamic–pituitary–adrenal function as a tool to evaluate animal welfare. Physiol. Behav. 92, 317–339.

Möstl, E., Maggs, J.L., Schroetter, G., Besenfelder, U., Palme, R., 2002. Measurement of cortisol metabolites in faeces of ruminants. Vet. Res. Commun. 26, 127–139.

Mülleder, C., Palme, R., Menke, C., Waiblinger, S., 2003. Individual differences in behaviour and in adrenocortical activity in beef-suckler cows. Appl. Anim. Behav. Sci. 84, 167–183.

Olofsson, J., 2000. Feed availability and its effects on intake, production and behaviour in dairy cows. Acta Universitatis Agriculturae Sueciae Agraria 221, 45.

Olofsson, J., 1999. Competition for total mixed diets fed ad libitum intake using one or four cows per feeding station. J. Dairy Sci. 82, 69–79.

Porges, S.W., 1995. Cardiac vagal tone: a physiological index of stress. Neurosci. Biobehav. R. 19, 225–233.

Preston, A.P., Mulder, J., 1989. Effect of vertical food-trough dividers on the feeding and agonistic behaviour of layer hens. Brit. Poultry Sci. 30, 489–496.

R Development Core Team, 2007. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: http://www.R-project.org/.

Sambraus, H.H., 1975. Beobachtungen und Überlegungen zur Sozialordnung von Rindern. Züchtungskunde 47, 8–14.

von Borell, E., Langbein, J., Després, G., Hansen, S., Leterrier, C., Marchant-Forde, J., Marchant-Forde, R., Minero, M., Mohr, E., Prunier, A., Valance, D., Veissier, I., 2007. Heart rate variability as a measure of autonomic regulation of cardiac activity for assessing stress and welfare in farm animals – a review. Physiol. Behav. 92, 293–316.

Waiblinger, S., Reichmann, V., Troxler, J., Dreiseitl, H., Haller, J., Windischbauer, G., 2001. Einfluß eines Vorrückfressgitters auf Druckbelastungen und Schäden an den Schultern von Milchkühen. In: Bau, Technik und Umwelt in der landwirtschaftlichen Nutztierhaltung.

Institut für Agrartechnik der Universität Hohenheim, Hohenheim, pp. 462–465.
Waiblinger, S., Schmied-Wagner, C., Nordmann, E., Mersmann, D., Szabo, S., Graml, C., von Hof, J., Maschat, K., Grubmüller, T., Winckler, C., 2010. Haltung von behornten und unbehornten Milchziegen in Großgruppen. Endbericht zum Forschungsprojekt 100191. Eigenverlag, Vienna.
Wiepkema, P.R., Koolhaas, J.M., 1993. Stress and animal welfare. Anim. Welfare 2, 195–218.