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Structural modifications at the feeding place: Effects of partitions and platforms on feeding and social behaviour of goats

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ABSTRACT

In goat housing, agonistic interactions elicited by close distances at the feeding place can have a negative impact on feed access and performance of low-ranking group members. The aim of this study was to investigate experimentally how structural modifications at the feeding place affect the feeding and social behaviour of goats. In two experiments, dyads of goats were observed feeding side-by-side at feeding places with and without partitions and platforms.

In the partition experiment, 6 dyads from eight groups each (48 dyads in total) were fed at two adjacent hayracks which were either separated by a partition varying in length (short, 50 cm; long, 110 cm) and visibility afforded (wire mesh, solid wood), or were not provided with a partition (control). In the platform experiment, goats of a dyad had to share one hayrack accessible either via an elevated platform of varying height (25 cm, 50 cm or 80 cm above ground level) or without a platform (control). The dyads stemmed from groups differing in terms of grouping age and presence of horns. In both experiments, each dyad was tested in all experimental conditions and at all feeding times, and agonistic interactions were recorded by direct observations. Data were analysed using linear mixed-effects models with experimental situation, presence of horns, grouping age, rank-index difference within a dyad, and quality of social bond (based on observations made in the home pens of the groups) as explanatory variables. Compared to the experimental situation without a partition, all types of partitions had marked effects on goat behaviour. Where there was a partition, the two individuals of a dyad spent more time feeding simultaneously (all $p < 0.001$), the first bout of simultaneous feeding lasted longer (all $p < 0.001$), the first feeding-place change occurred later (all $p < 0.001$), and the rates of agonistic interactions (all $p < 0.001$) and feeding-place changes (all $p < 0.001$) were lower. These effects were more pronounced with long and solid partitions than with short partitions or those made of wire mesh, especially for horned goats, for goats grouped as adults, and for dyads characterised by a large difference in rank index. In the platform experiment, strongest effects were found when a platform at a height of 80 cm was provided. In conclusion, our results show that both partitions and platforms at the feeding place are effective in reducing agonistic interactions and increasing feeding time in goats feeding at near distances.

1. Introduction

When two goats feed side-by-side, the lower ranking individual must observe a minimum distance (termed the "individual distance" by Hediger, 1940) to the higher ranking one to avoid an aggressive reaction from the latter

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(Aschwanden et al., 2008a). Consequently, low-ranking goats often avoid approaching a feeding place where the minimum distance to higher ranking individuals cannot be kept. In an experimental study with goats feeding at a hayrack (Aschwanden et al., 2008a), this individual distance was 0.5–1.30 m for most of the dyads, but could reach up to 4.0 m. By contrast, the usual feeding-space allowance in dairy-goat farming is 35–45 cm per goat (Cull, 1988; Mottram, 1991; Gall, 2001), which does not allow goats to feed at a distance to each other that they would freely choose. High-ranking goats may also defend several feeding places at once, compelling lower ranking animals to wait (Loretz et al., 2004). It is therefore not surprising that aggressive interactions occur frequently among loose-housed goats during feeding, and that the time spent feeding varies greatly among the individuals of a group (Jørgensen et al., 2007). Moreover, a high rate of aggressive interactions at the feeding place may result in reduced performance (Barroso et al., 2000) and should thus be prevented. A low space allowance at the feed manger, however, appeals to farmers wishing to reduce building costs. Ideally, therefore, it is aimed to make structural modifications at the feeding place that are effective in reducing the rate of agonistic interactions whilst increasing the time goats at close distances spend feeding simultaneously.

For both cattle (Bouissou, 1970; Metz, 1983; DeVries and von Keyserlingk, 2006) and horses (Holmes et al., 1987), physical partitions at the feeding place were found to improve the feeding times of lower ranking animals. Such partitions also reduce the number of agonistic interactions at the feeding place for cattle (Metz, 1983; DeVries and von Keyserlingk, 2006) and sows (Andersen et al., 1999). With calves, a physical partition between the teat buckets of pair-housed milk-fed calves was found to reduce the number of switches between teat buckets and to increase the latency for such a switch (Jensen et al., 2008). It is likely that physical partitions would also have similar effects for domestic goats. To our knowledge, however, this has not been tested previously.

The effectiveness of a physical partition is likely to depend on its dimensions and material. The size of a partition, i.e. its length, was investigated by Andersen et al. (1999) for pigs and by Bouissou (1970) and Jensen et al. (2008) for cattle. Bouissou (1970) reported that a short partition was equally effective to a long partition. By contrast, Andersen et al. (1999) and Jensen et al. (2008) found a stronger positive effect for long as opposed to short partitions. The fact that Bouissou (1970) used partitions which allowed the two cows to see one another (horizontal bars), whilst the partitions were opaque (solid plywood) in both of the other studies might account for these differing results. Since many signals of rank (e.g. body size, horn length) and agonistic behaviours (e.g. threats) are conveyed visually, visibility is an important factor in determining the effect of partitions. To our knowledge, only Holmes et al. (1987) has to date investigated the effects of visibility. In all other studies, the partitions either permitted visibility (Bouissou, 1970; Metz, 1983; DeVries and von Keyserlingk, 2006) or did not (Andersen et al., 1999; Jensen et al., 2008). Since goats are good at climbing, it might also be possible to separate them vertically in space. The feeding place could thus be modified to allow the goats to feed at different heights, e.g. by providing elevated platforms for every second animal at the feed barrier. Compared to a non-modified situation, any modification of the feeding place may be deemed effective if it allows low-ranking goats to approach the feeding place more readily in the presence of higher ranking individuals, and if it encourages high-ranking goats to tolerate simultaneous feeding of lower ranking individuals despite their proximity. Thus, indicators for the effectiveness of such modifications are an increase in the time two goats spend feeding simultaneously side by side and a decrease in the rate of agonistic interactions.

The aim of this study was to investigate experimentally how different types of modifications at the feeding place affect the behaviour of goats whilst feeding. In two experiments, dyads of goats were observed feeding side-by-side at feeding places with or without partitions and platforms. In the partition experiment, we tested partitions differing in length and material. In the platform experiment, one of the two goats was able to use a platform of varying height to gain better access to the feeding place. We hypothesised that the provision of both partitions and platforms at the feeding place would reduce the rate of agonistic interactions and increase the time the goats spent feeding simultaneously, compared to control situations without such modifications. Since goats' behaviour whilst feeding can be influenced by presence or absence of horns, rank relationships or quality of social bonds, and can also differ according to whether or not the goats grew up together (Aschwanden et al., 2008a,b), the presumed effects of partitions and platforms might be modified according to these factors. For instance, partitions and platforms may be especially effective with categories of goat dyads likely to have difficulties in feeding simultaneously side-by-side, such as horned goats, goats with a large rank difference, goats with an antagonistic social relationship, or goats that did not grow up together. These factors were therefore included in our analyses.

2. Methods

2.1. Animals and housing conditions

The experiments were conducted with non-lactating female goats from eight groups (six groups of nine and two groups of eight animals at the time of the experiment: originally there were nine goats in each group; two goats had to be put down and were not replaced). The animals had been purchased on different Swiss farms and grouped in May 2005. The experiments took place between May and August 2007. Four of the eight groups were grouped as juveniles at an age of about three months, whilst the other four groups were grouped as adults (average age per group at time of grouping: 2–3 years). Two each of the four juvenile and adult groups consisted of horned goats, whilst the other two consisted of hornless goats (unknown whether naturally hornless or dehorned), according to a 2×2 factorial design. The goats, which belonged to various Swiss milking breeds (Saanen, Toggenburger, Appenzeller,

Chamois Coloured, St Gallen Booted, Grisons Striped, Valais Blackneck) and their crossbreeds, were allocated to the groups such that breed composition was as similar as possible for all groups, especially with respect to grouping age. Since the presence of horns is a characteristic that is either strongly desirable (e.g. for Grison Striped) or completely undesirable (e.g. for Appenzeller) in certain breeds, it was not possible to create groups of horned and hornless animals with identical breed combinations.

The groups were kept in eight identically equipped loose-housing pens. The total area of each pen was 15.3 m^2 (approx. 3 m × 5 m), consisting of a deep-bedded straw area of 11.7 m^2 (approx. 3 m × 4 m) and a feeding place (3.6 m^2, 0.5 m high) divided by a solid-wood partition into two compartments of equal size (1.2 m × 1.5 m). Hay was fed ad libitum in a 2.6-m-long hayrack at the feeding place and in an additional 1-m-long hayrack in the straw area. The animal/feeding-place ratio in the pens was 1:1 with a calculated space of 40–45 cm per goat. Each pen was equipped with one water source, a lick stone for minerals and vitamins, and a broom. Further structures in the straw area were a 55-cm-high wooden platform (2.5 m × 65 cm) and a freestanding partition (80 cm in height) in the centre of the pen which goats could stand on or lie beneath.

2.2. Quality of social bonds and rank-index differences

From previous experiments, we knew that the quality of socials bonds and/or rank within a group could affect feeding behaviour in a social context (Aschwanden et al., 2008a,b). We therefore collected data on these aspects of the social relationships in the home pens of the groups. So that the information on social relationships would be up-to-date, data were recorded shortly before and during the period in which the experiments described below (Sections 2.4 and 2.5) took place. Spatial distribution whilst lying was used to characterise the quality of social bonds between goats. Each group was observed and videorecorded for 24 consecutive hours on two different days, with a gap of at least three days between the two observation days. The videotapes were analysed by the one observer (JA) by painting a grid on the video monitor to virtually divide the area of a pen into 0.8-m squares. A square was roughly equivalent to the space occupied by a lying goat. The position (i.e. number of the square) in which the heads of all simultaneously lying goats were to be found was noted using scan-sampling at 10-min intervals. Based on these data, each dyad was assigned to one of three social-bond qualities (according to Aschwanden et al., 2008a): (a) antagonistic—dyads in which the individuals never lay close to one another; (b) neutral—dyads in which the individuals lay close to each other in at least one sampling scan but never with bodily contact; and (c) amicable—dyads in which the individuals were observed lying with bodily contact in at least one sampling scan.

Using the methods described by Aschwanden et al. (2008a), the dominance relationships of the goats in each group were evaluated by direct observation during the morning and evening feeding times in the barn. Based on these data, a rank index was calculated for each goat, and a difference in rank index for each dyad. Greater differences indicated goats further apart in the hierarchy of their group. Group hierarchies were checked for linearity using the number of circular triads according to Kendall (1962). As the Kendall indices were 1.00 in two, >0.9 in three, >0.8 in one and ≥0.7 in two groups (0 = absence of linearity, 1 = linear hierarchy), the hierarchies in the groups were all close-to-linear or linear. We therefore considered the rank index to be a meaningful parameter for describing a goat's position in the group hierarchy. The rank-index difference of the dyads did not depend on the quality of their social bond, as rank indices varied in the same range for all categories of social bonds.

2.3. Experimental room, experimental procedure and animal selection

The experiments described in 2.4 and 2.5 were carried out in a separate room away from the building with the home pens. The entire group of goats was always brought to the experimental room, in order to prevent individuals becoming separated from their group. The room consisted of a waiting area (2.7 m × 8 m) where all the goats were tethered to prevent agonistic interactions in the group, and a test area (4 m × 8 m) where goat dyads were exposed to the experimental situation. The waiting and test areas were separated by wooden panels and metal barriers so that goats involved in the experiments still had visual and acoustic contact with their group.

For an experiment, a dyad was taken from the waiting into the test area to feed in a given test situation for 4 min, after which it was brought directly back to its group in the waiting area. To prevent unnecessary agonistic interactions, the higher ranking goat of a dyad was released first, followed by the lower ranking animal. To enhance feeding motivation, goats were fed straw only on the evening before and morning of a test day. Because the goats had taken part in previous experiments, they were all familiar with the experimental room and the procedure of being tested in pairs.

For the experiments, we selected six goat dyads from each of the eight groups, i.e. 48 dyads in total. Goat dyads were selected according to three criteria. Firstly, in order to show a distinct effect of a modification, the lower ranking goat of a pair had to avoid feeding in the presence of the higher ranking goat, or had to stop feeding within 30 s owing to an agonistic interaction in the unmodified situation. Secondly, all types of social bonds (antagonistic, neutral or amicable) had to be represented in the dyads. Thirdly, in order to maintain high feeding motivation throughout the experiment, a goat was not included in more than three dyads. In total, 26 goats were involved in one dyad, 29 in two dyads, and 3 in three dyads. The dyads were subjected to the test situations in a sequence preventing any given goat from being exposed to the same situation twice in a row.

Goats which were involved in more than one dyad (32 goats) had rank indices between 0.0 and 1.0 spanning the complete range in hierarchy. Since there is no scientific evidence that goats' social behaviour differs among the Swiss breeds used in our study, we mixed goats of different

breeds in the dyads; moreover, breed was not a selection criteria for composing the dyads.

2.4. Partition experiment

In the first experiment, we investigated the effect of four different types of partitions on the feeding and social behaviour of two goats feeding simultaneously side-by-side. Two small hayracks with a narrow gap (5 cm) through which to take the hay were set up on one side wall in the test area of the experimental room (Fig. 1a). The distance between the narrow gaps of the two hayracks was 25 cm. This was less than the minimum distance at which all the selected dyads fed without agonistic interactions (Aschwanden et al., 2008a)—a distance which was also re-checked before the current experiments. The two hayracks were first presented to the dyads without a partition (control), and subsequently with 120-cm-high partitions varying in length (50 cm or 110 cm, see Fig. 1a) and material (wire mesh or solid wood) mounted between the two hayracks (five test situations per dyad in total). All four combinations of length and material were presented to the dyads in a balanced sequence, which was the same for two dyads of each group (e.g. dyads 1 and 2 had sequence A (long/wire mesh, short/wood, short/wire mesh, long/wood); dyads 3 and 4, sequence B (short/wood, long/wire mesh, long/wood, short/wire mesh etc.). In addition, these types of sequences (A, B, etc.) were balanced over the groups, i.e. dyads 1 and 2 had different types of sequences in different groups. The six dyads of a group were exposed once to each test situation over a two-day period between the hours of 8.00 am and 6.30 pm The types of sequences were also balanced over the two days.

Although the goats were already accustomed from their home pens to both solid-wood partitions and partitions through which another goat could be seen (i.e. metal barriers dividing neighbouring home pens), they were habituated to each test situation on both days by being allowed on several occasions to feed in dyads (other than the ones tested with the different types of partitions), until both animals approached the hayracks in under 5 s. Consequently, the partitions were familiar to the goats, but the experimental dyads had never fed together in the test situation before.

Owing to the animal-selection criteria (see Section 2.3), qualities of social bonds could not be completely balanced. Of the 48 dyads selected, 25 were characterised by an antagonistic social bond (median = 3 per group), 12 by a neutral social bond (median = 1.5 per group) and 11 by an amicable social bond (median = 1 per group).

2.5. Platform experiment

In the second experiment, we investigated whether the feeding and social behaviour of goats feeding side-by-side altered when one of the two goats stood on a platform above ground level. In this experiment, the goats were fed on one vertically elongated hayrack (30 cm wide × 200 cm high) having one 5-cm gap through which to take the hay (Fig. 1b), and located on one side wall in the test area of the experimental room. The hayrack was first presented to the dyads without a platform (control), after which a platform (60 cm × 120 cm) was offered on the left side of the hayrack. Thus, one of the goats of a dyad could jump onto the platform to reach the hay, whilst the other goat could feed at ground level. Three different heights of platform (25 cm, 50 cm and 80 cm) were provided to each dyad in a sequence as described above (four test situations per dyad in total). The six dyads of a group were tested in all the situations within a one-day period between the hours of 8.00 am and 6.30 pm.

Though goats were accustomed to 50- and 80-cm-high platforms from their home pens, an habituation phase was conducted as with the partition experiment. With the exception of five of the dyads, the same dyads were used as in the partition experiment, resulting in 25 antagonistic (median = 3 per group), 11 neutral (median = 1.5 per group) and 12 amicable (median = 1 per group) dyads.

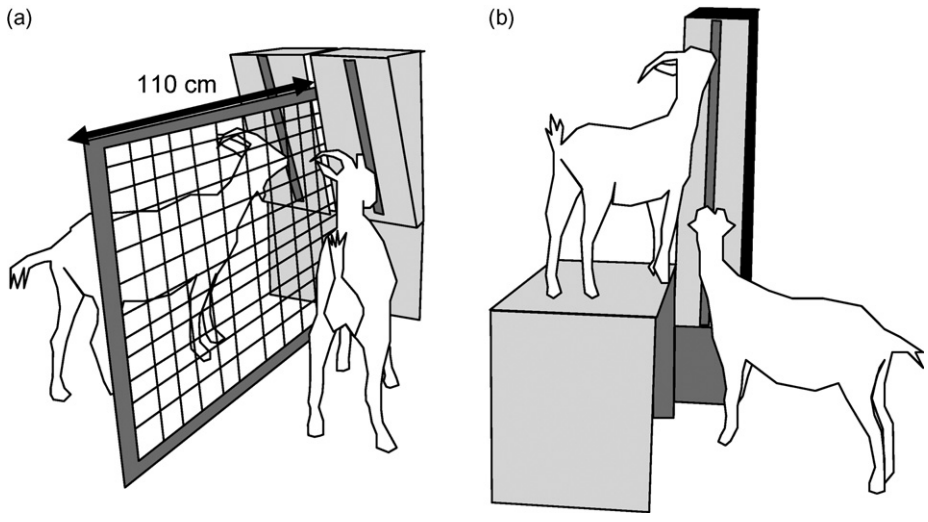

Fig. 1. Examples of experimental conditions: (a) shows the long wire-mesh partition in the partition experiment and (b) the 80-cm platform situation in the platform experiment.

The five dyads had to be replaced by others because two goats refused to jump onto the platforms in the habituation phase, despite them being lured with food.

2.6. Behavioural observations, definition of variables and missing values

During the two experiments, the behaviour of both goats was observed directly, always by the same observer (JA), and continuously recorded using the non-commercial software ETHO. In the partition experiment, the behavioural elements were feeding, not feeding, agonistic interactions (subdivided into threats, attacks and fights), and feeding-place changes. In the platform experiment, feeding was additionally subdivided into 'feeding standing on the platform' and 'feeding standing on the ground'. A *feeding* goat was defined as one standing with her head within a radius of approximately 30 cm of the hayrack and chewing hay taken out of the hayrack. A *threat* was defined as an interaction without physical contact where one goat presented her horns/head, ears erect, towards the other goat, sometimes combined with taking a maximum of one step towards the other animal. An *attack* involved physical contact, with one goat butting and/or chasing the other goat with head/horns. In a fight – as described by Shank (1972) – two goats stood opposite one another with heads raised. From a distance of 1–2 m, possibly rearing up, the two goats clashed their heads together. An attack always took place prior to a fight and was counted separately. A *feeding-place change* was noted when a goat stopped feeding at the hayrack at which she currently stood, moved to the other hayrack, and started pulling hay from that other hayrack. Based on these data, the following outcome variables were calculated:

(1) Feeding simultaneously—the percentage of time both goats spent feeding simultaneously at the hayrack/s.
(2) Duration of the first simultaneous feeding bout—how much time elapsed before the first bout of simultaneous feeding after the start of the test in a given situation was terminated by a social interaction, i.e. a threat, an attack, avoidance behaviour, or a feeding-place change.
(3) Rate of agonistic interactions—number of threats, attacks and fights per minute.
(4) Latency to first feeding-place change—how much time elapsed before the first feeding-place change occurred after the start of the test in a given situation.
(5) Rate of feeding-place changes—number of changes occurring per minute.

The percentage of time goats spent feeding simultaneously was calculated by dividing the length of time during which both goats were effectively feeding simultaneously by the potential simultaneous feeding time of a specific dyad. The potential simultaneous feeding time was [240 s minus the duration of a *fight* minus the length of time in which the higher and/or lower ranking goat did not feed for reasons not attributable to the social interactions between the goats]. The latter consisted of outside circumstances (e.g. interruption due to noise) or goats having no motivation to feed, but instead displaying other behaviour, such as exploring parts of the experimental set-up. Where the lower ranking goat did not feed right from the outset until the end of the 4 min' feeding time, it was unclear whether her behaviour should be attributed to the presence of the higher ranking goat, or to a lack of motivation to feed. To differentiate between these possibilities, the higher ranking goat was taken away from the hayrack after the 4 min. If the lower ranking goat then immediately approached the hayrack and started feeding, her behaviour in the experiment was attributed to the presence of the higher ranking goat at the feeding place. In some situations, no social interaction and no feeding-place change occurred at all during the 4 min when both goats were feeding. In such cases the total time of 240 s was used to calculate the value of the outcome variables 2) and 4). Since it was not possible for the goats to change feeding place in the control situation of the platform experiment (one hayrack only), and as there were only two feeding-place changes in total in the situation with the platform, the outcome variables (4) and (5) used in the partition experiment were omitted.

In the partition experiment, data was successfully collected in all situations (48 dyads $\times$ 5 test situations = 240); in the platform experiment, data was successfully collected in 177 (=92.2%) out a total of 192 test situations (48 dyads $\times$ 4 test situations). Again in the platform experiment, one goat of an amicable dyad did not feed in any of the four situations (reason unknown). In four dyads (two antagonistic, one neutral and one amicable) from two groups, no data could be collected for the 50- and 80-cm platforms (8 test situations). In another three dyads (one antagonistic and two amicable) from three groups (3 test situations), the data for the 80-cm platform had to be discounted, because none of the goats jumped onto the platform in any of these test situations.

2.7. Statistical analysis

The analysis of dyadic data poses a special problem, in that individuals occur repeatedly in the dyads with other group members (Hemelrijk, 1990). Here, an approach was needed that allowed us to include data from several groups and several explanatory variables. A data structure of this type may be viewed as a special case of a linear mixed-effects model with crossed random effects (Gill and Swartz, 2001; Li and Loken, 2002).

Each of the outcome variables of the two experiments were analysed for their dependence on the modifications at the feeding place by separate linear mixed-effects models using the "lmer" method (Bates and Sarkar, 2006) in R 2.5.1 (R Development Core Team, 2007). Residuals were checked graphically for normal distribution, homoscedasticity and outliers. In order to satisfy these assumptions, most outcome variables needed to be transformed (Table 1).

In both experiments, we first tested whether the situations with a modification differed in general from the control situation for each outcome variable. Here, the only fixed effect in each of the two models was the modification (Partition experiment: partition type represented by dummy variables with two levels each: wire

Table 1
Outcome variables with measurement unit and type of transformation for the partition and platform experiments, the fixed effects, their interactions, and the crossed random effects.

Partition experiment	Platform experiment
Outcome variables with unit and type of transformation	
Feeding simultaneously [%, logit: log $(X/(1-X))$]	Feeding simultaneously [%, logit: log$(X/(1-X))$]
Duration of first simultaneous feeding bout [s, log]	Duration of first simultaneous feeding bout [s, log]
Rate of agonistic interactions [number/60 s, log]	Rate of agonistic interactions [number/60 s, log]
Latency to first feeding-place change [s, log]	Not available
Rate of feeding-place changes [number/60 s, log]	Not available
Fixed effects	
Length (factor with levels short/long)	Height (ordered factor with levels 0/25/50/80)
Material (factor with levels wire mesh/wood)	
Grouping age (factor with levels juvenile/adult)	Grouping age (factor with levels juvenile/adult)
Presence of horns (factor with levels no/yes)	Presence of horns (factor with levels no/yes)
Quality of social bonds (ordered factor with levels antagonistic/neutral/amicable)	Quality of social bonds (ordered factor with levels antagonistic/neutral/amicable)
Rank-index difference (continuous)	Rank-index difference (continuous)
Interactions	
Length with	Situation with
All other fixed effects	All other fixed effects
Material with	
All other fixed effects	
Grouping age with	Grouping age with
Presence of horns	Presence of horns
Quality of social bonds	Quality of social bonds
Presence of horns with	Presence of horns with
Quality of social bonds	Quality of social bonds
Crossed random effects	
Group, individual, dyad partner, dyad	Group, individual, dyad partner, dyad

mesh/short (no/yes), wire mesh/long (no/yes), wood/short (no/yes), wood/long (no/yes); Platform experiment: platform height as dummy variables with two levels each: 25 cm (no/yes), 50 cm (no/yes), 80 cm (no/yes)).

To analyse the effect of the partitions in greater detail, the outcome variables were compared across the four situations with partitions only using separate linear mixed-effects models. For an overview of the outcome variables together with the explanatory variables of the full models, see Table 1. We structured the model as a two-by-two crossed factorial design with the variables length (factor with levels short/long) and material (factor with levels wire mesh/wood). In addition, we included the grouping age (factor with levels juvenile/adult), the presence of horns (factor with levels no/yes), the dyads' rank-index difference (continuous), and the dyads' quality of social bond (ordered factor with levels antagonistic, neutral, amicable). To allow for simplification of the curvature modelled by the ordered factor "quality of a social bond", we explicitly included the quality of a social bond coded as values 1, 2, 3 linearly and squared.

Data of the platform experiment were analysed by integrating the control situation and treating it as a height of 0 cm. The height of the platform was included in the models as an ordered factor with levels 0, 25, 50, 80, coded by their numerical values and represented by a linear, squared and cubed term. All other explanatory variables included in the models were the same as in the partition experiment (Table 1).

The models were set up as full models, then reduced by a stepwise backwards method (threshold $p < 0.05$). Interactions were excluded first and main effects only in later steps. In interactions where a square and a cubic term of a given variable were used, the interaction with the cubic term was excluded before the interaction with the square and the linear term of the same variable, which was dropped from the model last.

The crossed random effects of the row individual of a dyad (in a social-interaction matrix), the column individual within the same dyad, and the dyad nested within group were included in every model. The crossed random effects reflected the variability attributed to the general sociability of the row individual, the general effect of the column individual on her dyadic partner, and the repeated measuring of the dyads (each dyad in every situation).

The calculated p-values of a model of this type are non-trivial (Bates, 2006), and we followed the recommendations of Bates (2006) and Bates et al. (2006) and used a Markov Chain Monte Carlo method to resample the posterior distribution of the parameter estimates (a method borrowed from Bayesian statistics, e.g. Gelman et al., 2004) to provide confidence intervals for the model parameters. By calculating the percentile X at which the confidence interval borders on the value zero (e.g. the 99% confidence interval), we attributed a p-value to the parameter as $p = 1 - (X/100)$ (e.g. $1 - (99/100) = 0.01$).

3. Results

3.1. Descriptive results

In the control situations of both experiments, all higher ranking goats of the dyads fed for 100% of their potential

feeding time. In the same situations, the lower ranking goats of the pairs fed for 6.8% (median; range 0–31.7%) of the feeding time in the partition experiment and for 0.0% (median; range 0–12%) in the platform experiment.

Considering all test situations of the partition experiment, the first simultaneous feeding bout proceeded without interruption for the entire observation period of 4 min in 75 out of 240 test situations (31%). In the other 165 test situations, the bout was terminated by a feeding-place change in 48%, a threat in 26%, an attack in 15%, and avoidance behaviour in 11% of the test situations. Ninety-seven per cent of the total number of feeding-place changes (430 out of 443) were initiated by the higher ranking goat.

In the platform experiment, the first simultaneous feeding bout proceeded without interruption for the entire observation period of 4 min in 28 out of 177 test situations (16%). In the remaining 149 test situations, the feeding bout was terminated by a threat in 22%, an attack in 43%, and avoidance behaviour in 35% of the test situations. In 99.1% of all test situations, it was the lower ranking goat of a dyad who fed on the platform.

3.2. General effects of partitions and platforms

When the two feeding places were separated by a partition of whatever sort, the goats spent a significantly larger percentage of time feeding simultaneously ($p < 0.001$ for each type of partition, Fig. 2a), the duration of the first simultaneous feeding bout was significantly longer ($p < 0.001$ for each type of partition, Fig. 2c) and the rate of agonistic interactions was significantly lower ($p < 0.001$ for each type of partition, Fig. 2e) than in the control situation. Furthermore, in all situations with a

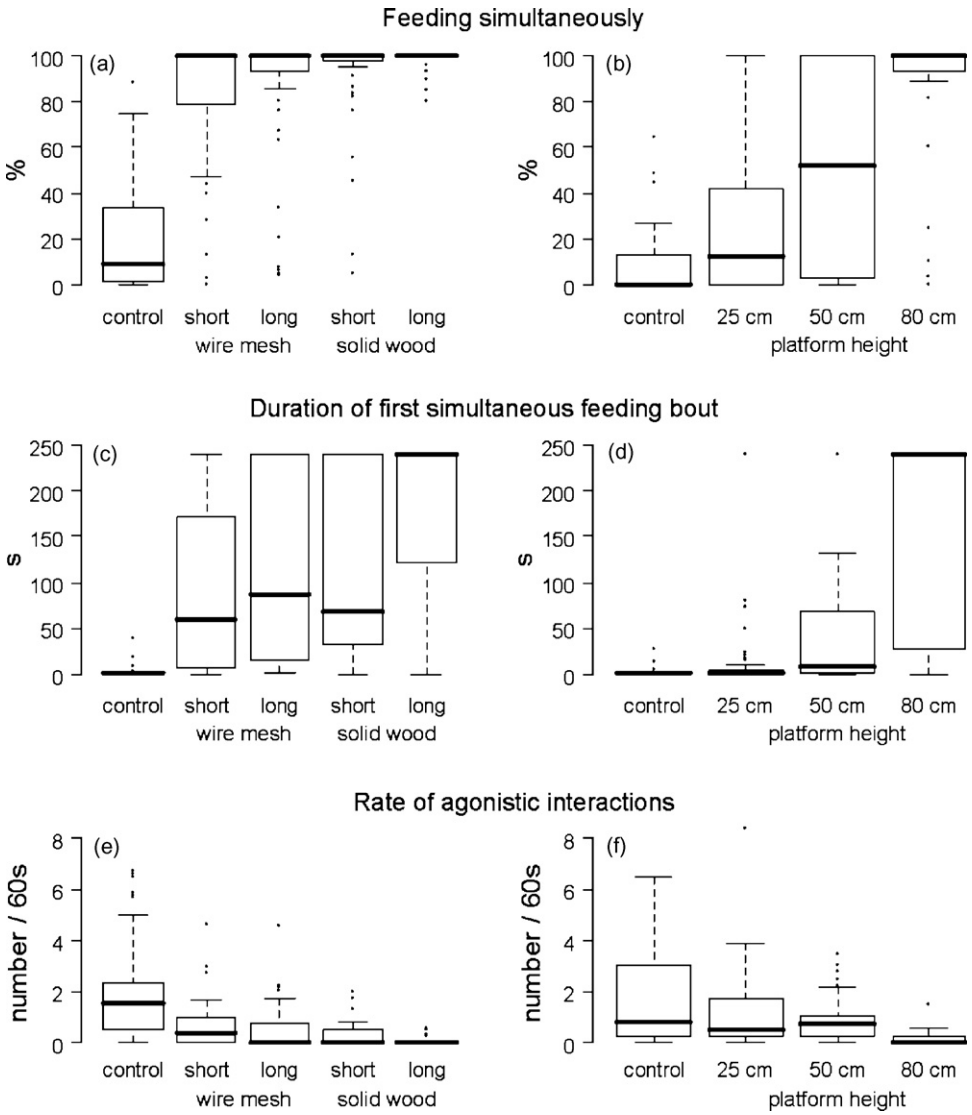

Fig. 2. Percentage of time the goats spent feeding simultaneously (a, b), duration of the first simultaneous feeding bout (c, d) and rate of agonistic interactions per minute (e, f) for the control situation versus the situations with either different types of partitions (a, c, e) or different platform heights (b, d, f).

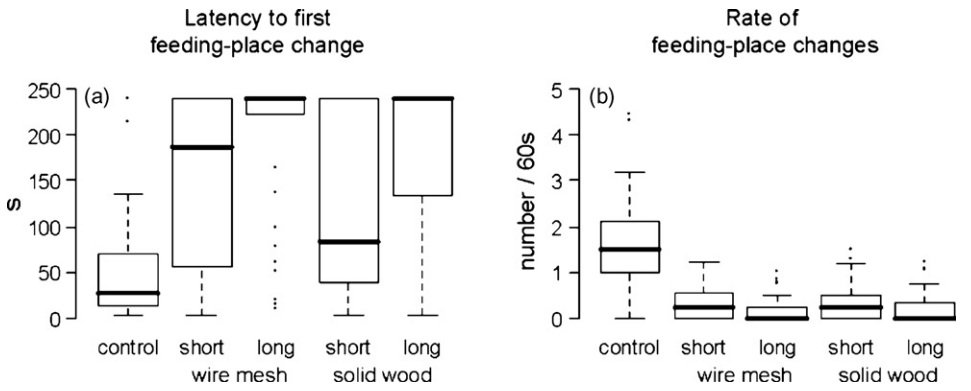

Fig. 3. Latency to first feeding-place change (a) and rate of feeding-place changes (b) for the control situation versus the four types of partitions.

partition, the latency to the first feeding-place change was significantly longer ($p < 0.001$ for each type of partition, Fig. 3a) and the rate of feeding-place changes significantly lower (all $p < 0.001$, Fig. 3b) than in the control situation.

In the platform experiment, the percentage of time feeding simultaneously was significantly higher ($p < 0.001$ for each height of a platform, Fig. 2b) and the duration of the first simultaneous feeding bout significantly longer (25 cm: $p = 0.01$, 50 cm and 80 cm: $p < 0.001$, Fig. 2d) when a platform was provided than in the control situation. The rate of agonistic interactions was significantly lower with a 50 cm ($p = 0.01$) and an 80-cm platform ($p < 0.001$), but not with a 25-cm platform ($p = 0.12$, Fig. 2f), than with the control.

3.3. Effects of partition length and platform height

In the partition experiment, comparison of the four experimental situations with a partition showed that all outcome variables were affected by the length of the partition (Table 2). The latency to the first feeding-place change was longer with a long partition than with a short one ($p = 0.001$).

There were interactions of length with grouping age for the time spent feeding simultaneously ($p = 0.05$), for the rates of agonistic interactions ($p = 0.01$) and for feeding-place changes ($p = 0.05$). The odds ratios of feeding simultaneously were higher and the rates of agonistic interactions lower with long partitions than with short ones. For the time spent feeding simultaneously the effect of length was stronger for goats grouped as adults than for those grouped as juveniles, whilst for the rate of agonistic interactions the effect was less pronounced for goats grouped as adults than for those grouped as juveniles. The rate of feeding-place changes did not differ between the experimental situations with short and long partitions for goats grouped as juveniles, but was higher with long partitions for goats grouped as adults.

Interactions of partition length with the presence of horns were found for the duration of the first simultaneous feeding bout ($p = 0.05$) and for the rate of feeding-place changes ($p = 0.01$). With both horned and hornless goats, the duration of the first simultaneous feeding bout was shorter with short partitions than with long ones, but the effect of a long partition was stronger for hornless than for horned goats. Furthermore, hornless goats changed feeding places at the same rate with long and short partitions, whilst the rate increased with short partitions for horned goats.

In the platform experiment, all outcome variables were influenced by the height of the platform interacting with at least two other variables (Table 3).

There were interactions of platform height with grouping age for feeding simultaneously ($p = 0.01$) and the duration of the first simultaneous feeding bout

Table 2
Significant effects of partition length and interactions with partition length on the outcome variables found in the partition experiment when comparing the different characteristics of partitions (second step of the statistical analysis, without control-situation data): odds ratios for the outcome variable 'feeding simultaneously' and estimated values for the other outcome variables are shown. An asterisk (*) denotes interactions between variables.

Explanatory variables	Outcome variables	Levels	Estimated values	
			Short	Long
Length	Latency to first feeding-place change (s)		78.26	151.41
Length * grouping age	Feeding simultaneously (odds ratios)	Juvenile	1	1.38
		Adult	0.5	1.43
	Rate of agonistic interactions (number/60 s)	Juvenile	0.19	0.1
		Adult	0.22	0.17
	Rate of feeding-place changes (number/60 s)	Juvenile	0.55	0.55
		Adult	0.46	0.54
Length * presence of horns	Duration of first simultaneous feeding bout (s)	Hornless	78.26	190.57
		Horned	59.15	84.77
	Rate of feeding-place changes (number/60 s)	Hornless	0.55	0.55
		Horned	0.63	0.52

Table 3
Significant effects of interactions with platform height on the outcome variables found in the platform experiment. Odds ratios for the outcome variable 'feeding simultaneously' and estimated values for the other outcome variables are shown.

Explanatory variables interacting with height	Outcome variables	Levels	Estimated values/situation			
			Control	25 cm	50 cm	80 cm
Grouping age	Feeding simultaneously (odds ratios)	Juvenile	1	17.12	578.25	>10,000
		Adult	0.5	8.85	244.69	>10,000
	Duration of first simultaneous feeding bout (s)	Juvenile	1.6	4.22	11.13	29.4
		Adult	1.45	2.72	5.1	9.6
Presence of horns	Feeding simultaneously (odds ratios)	Hornless	1	13.87	107.77	132.95
		Horned	0.28	5.47	5.16	129.02
	Duration of first simultaneous feeding bout (s)	Hornless	1.6	5.31	27.93	232.76
		Horned	1.21	1.25	5.87	126.47
	Rate of agonistic interactions (number/60 s)	Hornless	2.16	0.34	0.17	0.38
		Horned	0.35	0.16	0.26	0.18
Quality of social bonds	Duration of first simultaneous feeding bout (s)	Antagonistic	1.6	5.31	27.94	232.76
		Neutral	1.67	8.58	28.5	60.95
		Amicable	2.2	10.07	2.44	459.44
	Rate of agonistic interactions (number/60 s)	Antagonistic	2.16	0.32	0.1	0.08
		Neutral	9.6	1.48	0.38	0.16
		Amicable	42.52	1.01	0.07	0.01
Rank-index difference	Rate of agonistic interactions (number/60 s)	0	2.16	0.32	0.1	0.08
		1	1.11	8.76	7.54	0.7

($p = 0.05$). The odds ratios of the percentage of time spent feeding simultaneously and the duration of the first simultaneous feeding bout increased with platform height, with this increase being more pronounced for goats grouped as juveniles than for those grouped as adults.

Depending on the presence of horns, height had an influence on feeding simultaneously ($p = 0.05$), duration of the first simultaneous feeding bout ($p = 0.001$) and rate of agonistic interactions ($p = 0.01$). The odds ratios of feeding simultaneously for horned goats were lower than for hornless goats in the control situation and with platforms 25 cm and 50 cm high, but reached the same level as those for hornless goats with an 80-cm platform. The duration of the first simultaneous feeding bout increased along with platform height, with this effect being more pronounced for hornless than for horned goats. For hornless goats, the rate of agonistic interactions was similar with platforms of 25 and 80 cm, but lowest with a 50-cm platform. With horned goats, the lowest levels occurred with 25- and 80-cm platforms.

Height also interacted with the quality of social bonds for duration of the first simultaneous feeding bout ($p = 0.05$) and rate of agonistic interactions ($p = 0.05$). Duration of the first simultaneous feeding bout in the control situation was similar for all three qualities of social bonds. For antagonistic and neutral social bonds, duration increased along with platform height. With amicable social bonds, duration in the 50-cm platform situation was similar to that of the control situation, but was longer in the 25-cm situation and increased sharply in the 80-cm platform situation. For all three qualities of social bonds, the rate of agonistic interactions decreased with increasing platform height, and was also influenced by the interaction of height with the rank-index difference ($p = 0.001$). The highest rate of agonistic interactions in the control situation occurred in dyads with a small rank-index difference. The frequency of these interactions was lower when platforms were present, and decreased with the increasing height of a platform. In dyads with a large rank-index difference, the rate of agonistic interactions increased from the control to the 25-cm platform situation, decreasing thereafter with increasing platform height.

3.4. Effects of partition material

In the partition experiment, comparison of the four experimental situations with a partition showed that all outcome variables were affected by the partition material (Table 4), which interacted with at least one other explanatory variable for all outcome variables.

For duration of first simultaneous feeding bout ($p = 0.01$) and rate of agonistic interactions ($p = 0.01$), the material interacted with grouping age. The duration of the first simultaneous feeding bout was longer for goats grouped as juveniles than for those grouped as adults, and longer with wooden partitions than with wire-mesh ones, but the effect of the partition material was more pronounced for goats grouped as adults than for those grouped as juveniles. Goats grouped as adults displayed higher rates of agonistic interactions with wire-mesh partitions than with wooden ones, whilst the converse was true for goats grouped as juveniles.

Time spent feeding simultaneously ($p = 0.001$) and rate of agonistic interactions ($p = 0.001$) were influenced by interactions of the material with presence of horns. The odds ratios of feeding simultaneously in hornless goats were similar for both wire-mesh and wooden partitions, whilst horned goats had higher odds ratios with solid-wood than with wire-mesh partitions. Horned goats displayed higher rates of agonistic interactions with wire-mesh partitions than with wooden ones, whilst the converse was true for hornless goats.

Type of material interacted with quality of social bonds for feeding simultaneously ($p = 0.01$) and latency to first

Table 4
Significant effects of interactions with partition material on the outcome variables found in the partition experiment when comparing the different characteristics of partitions (second step of the statistical analysis, without control-situation data): Odds ratios for the outcome variable 'feeding simultaneously' and estimated values for the other outcome variables are shown.

Explanatory variables interacting with material	Outcome variables	Levels	Estimated values	
			Wire mesh	Wood
Grouping age	Duration of first simultaneous feeding bout (s)	Juvenile	78.26	106.7
		Adult	19.9	56.26
	Rate of agonistic interactions (number/60 s)	Juvenile	0.19	0.26
		Adult	0.22	0.18
Presence of horns	Feeding simultaneously (odds ratios)	Hornless	1	1.01
		Horned	0.17	0.73
	Rate of agonistic interactions (number/60 s)	Hornless	0.19	0.27
		Horned	0.29	0.22
Quality of social bonds	Feeding simultaneously (odds ratios)	Antagonistic	1	1.01
		Neutral	1.01	0.58
		Amicable	1.01	0.33
	Latency to first feeding-place change (s)	Antagonistic	78.26	51.94
		Neutral	132.95	60.34
		Amicable	66.69	55.14
Rank-index difference	Feeding simultaneously (odds ratios)	0	1	0.87
		1	1.01	6.69
	Rate of agonistic interactions (number/60 s)	0	0.19	0.26
		1	0.55	0.14
	Latency to first feeding-place change (s)	0	78.26	51.42
		1	35.87	102.51
	Rate of feeding-place changes (number/60 s)	0	0.55	0.47
		1	0.47	0.73

feeding-place change ($p = 0.05$). Odds ratios in all the experimental situations with wire-mesh partitions were largely the same irrespective of quality of social bond, whilst in the situations with a wooden partition the odds ratios were lower for goats with neutral or amicable social bonds. Latency to the first feeding-place change was longer with wire-mesh partitions than with wooden ones for all three 'quality of social bond' categories, but this difference was markedly greater with neutral dyads.

Finally, material interacted with rank-index difference for feeding simultaneously ($p = 0.05$), rate of agonistic interactions ($p = 0.01$), latency to first feeding-place change ($p = 0.05$) and rate of feeding-place changes ($p = 0.05$). In the experimental situations with wire-mesh partitions, the odds ratios of feeding simultaneously were largely the same irrespective of rank-index difference, whilst they were markedly higher for dyads with a large rank-index difference in situations with a wooden partition. Goat pairs with a large rank-index difference showed higher rates of agonistic interactions with wire-mesh partitions than with wooden ones, whilst the converse was true for dyads with a small rank-index difference. Whereas latency to the first feeding-place change was longer and the rate of feeding-place changes higher with wooden than with wire-mesh partitions for goats with a large rank-index difference, the opposite was observed to be true for goats with a small rank-index difference.

4. Discussion

In two experiments with goats, we investigated the effect of structural modifications aimed at spatially separating the animals at the feeding place on the goats' feeding and social behaviour. Compared to the non-modified situation, both partitions and platforms at the feeding place exerted an obvious and positive influence on these behaviours. The percentage of time spent feeding simultaneously, the duration of the first simultaneous feeding bout and the latency to the first feeding-place change increased, whilst the rate of agonistic interactions and feeding-place changes decreased.

4.1. General effects of partitions and platforms

In the control situations of both experiments, lower ranking goats fed during only a small percentage of the total potential feeding time, and simultaneous feeding bouts were often terminated by agonistic interactions. The changes in behaviour observed by us in the situations with partitions and platforms indicate that these modifications were effective in enabling low-ranking goats to approach and feed despite the presence of a higher ranking animal, and in inducing higher ranking goats to more easily tolerate a lower ranking animal feeding at a close distance. Our results tally with those of previous studies on cattle (Bouissou, 1970; Metz, 1983; DeVries and von Keyserlingk, 2006), sows (Andersen et al., 1999) and horses (Holmes et al., 1987), thereby demonstrating that physical partitions between animals feeding side-by-side increase the time lower ranking animals spend feeding. This effect can be explained by both proximate and ultimate reasoning. Bouissou (1970) and Metz (1983) argued that low-ranking animals may somehow "feel" protected behind a physical partition. Possibly, they have learned that there are no direct consequences of a threat from a dominant animal if they are separated from that animal by an obstacle. Not

being able to reach the subordinate animal directly may also reduce the tendency of the higher ranking animal to show aggressive behaviour. In a reference to optimal foraging theory, Metz (1983) also ultimately argued that chasing away a herd member at a feeding place might require more effort if both animals are separated by a physical partition, making it energetically less preferable to change feeding places. This view is supported by Jensen et al. (2008) in the case of pair-housed milk-fed calves, as well as by the data from the current study, since the latency of the goats until a feeding-place change was longer and the rate of feeding-place changes was lower in a situation with a partition than in the control situation.

The provision of platforms had similar effects to the provision of partitions. Again, this might be explained by the theory of a balanced cost-/benefit ratio, since jumping onto a platform is likely to be as much of an effort as bypassing a partition. A proximate explanation might be that the effect of a platform was simply to increase the distance between the goats in the vertical dimension. This would mean that a higher ranking goat would tolerate the lower ranking one when they were further apart than the individual distance of the two goats (Aschwanden et al., 2008a).

The effects observed in the platform experiment, however, were somewhat less pronounced than those of the partition experiment. To give an example, a small vertical distance in the situation with a platform 50 cm above ground level had a smaller effect than a short wire-mesh partition. It is thus reasonable to assume that the platforms did not separate the two goats as rigorously as the physical partitions. In general, we may state that a feeding-place modification separating the animals via partitions or different height levels has a positive influence on the feeding and social behaviour of two goats feeding side-by-side.

4.2. Effects of partition length and platform height

In the partition experiment, all five outcome variables investigated were influenced by the length of a partition. This tallies with the results of Andersen et al. (1999), who reported that a long partition reduced the occurrence of agonistic behaviour in sows during feeding more effectively than a short partition, and Jensen et al. (2008), who observed that a long partition increased the latency period before milk-fed calves switched between teat buckets. In the platform experiment, the most pronounced effects on all three investigated outcome variables occurred in the 80-cm platform situation. Assuming that the effort involved in walking around a long partition is greater than that of walking around a short one, and that the effort of chasing away a goat from a platform increases with the platform's height, these results are in accordance with the theory of a balanced cost-/benefit ratio of a behaviour.

In both experiments, the explanatory variables were mainly influenced by interactions of partition length and platform height with grouping age and/or the presence of horns. It would appear that the modifications need to be more rigorous for horned goats and goats grouped as adults to achieve similar values to hornless goats and goats grouped as juveniles. In terms of platform height, for example, the values for horned goats and goats grouped as adults were not similar to those of hornless goats and goats grouped as juveniles until the 80-cm platform was used. For hornless goats and goats grouped as juveniles, the effect was already pronounced with a 50-cm platform, possibly because horned goats and goats grouped as adults respect rank relationships more strictly than do hornless goats and goats grouped as juveniles. Among horned goats and goats grouped as adults, lower ranking animals are more likely to avoid social conflicts with higher ranking ones through avoidance behaviour than is the case among hornless goats and in goats grouped as juveniles. Moreover, with horned goats and goats grouped as adults, the mere threat of a higher ranking animal towards a lower ranking one induces avoidance behaviour in the latter, whilst for hornless goats and goats grouped as juveniles, higher ranking goats more often displace lower ranking ones with physical contact (Aschwanden et al., 2008a).

In summary, our results indicate that long partitions have a stronger positive effect on the feeding and social behaviour of goats feeding side-by-side than short ones. Moreover, an 80-cm platform produces more consistent positive effects than a 25- or 50-cm platform. Hence, the more effort required to overcome the obstacle, the more effective the separation.

4.3. Effects of partition material

In our experiment, we also varied the partition material. The solid-wood partitions prevented the two animals from seeing each other, whilst the wire-mesh partitions did not. In summary, our results show that both short and long wooden partitions had a stronger effect on several behavioural parameters than wire-mesh partitions of identical length. Vision (Baldwin, 1978; Buchenauer and Fritsch, 1980; Langbein et al., 2004), and since signals of rank such as body mass, horn size and threatening behaviour are visual stimuli, seems to be an important sense for goats. A proximate cause of the effects of solid partitions might therefore be that in not seeing the lower ranking goat, the higher ranking goat possibly 'feels less provoked', and the lower ranking goat is accordingly not forced to respect a certain distance and/or show submissive behaviour (e.g. avoidance). In accordance with our results, Whittington and Chamove (1995) reported that in a paddock, reduced visibility owing to freestanding visual barriers lowered aggression in farmed red deer, whilst Chamove and Grimmer (1993) reported reduced aggression among Friesian bulls where trees served as the visual barriers.

The influence of partition material on feeding and agonistic behaviour interacted with grouping age, presence of horns, quality of the dyad's social bond and rank-index difference. On the one hand, the main overall pattern in our findings was that, among horned goats, goats grouped as adults and goats with a large rank-index difference, the wooden partitions were more effective in increasing the time spent feeding simultaneously, the length of the first feeding bout and the latency to feeding-place change, and in reducing agonistic interactions, than

the wire-mesh partition. The wooden partitions also represented a more rigorous barrier than the wire-mesh ones, and the same factors responsible for the effects of length and height of a modification as those described above might also be responsible for the effects of the wooden partitions.

On the other hand, our findings concerning the effects of partition material in relation to hornless goats, goats grouped as juveniles, goats with a small rank-index difference, and quality of social bonds in the dyad might imply that preventing the goats from seeing one another is not necessarily advantageous for all types of dyads. Given that the wooden partition had a negative influence on the majority of the variables in these cases, mutual visibility during feeding would appear to be beneficial. In a study of horses, Holmes et al. (1987) found that the time subordinate mares spent feeding was higher with a wire head partition than with a solid partition, and concluded that it is important for the lower ranking animal that the higher ranking can be seen to be able to react quickly. In this study, however, no data are provided on the actual rank differences, nor on whether the social relationships of the horses were positive or negative.

In conclusion, having visual cover whilst feeding would appear to be a major factor in reducing aggressive interactions in goat dyads in which rank relationships are strongly respected, i.e. in the case of horned goats, goats that have not grown up together, and goats with a large rank-index difference. By preventing the goats in a dyad from seeing each other, visual cover reduces stimuli which elicit interactions for maintaining rank relationships.

4.4. Discussion of experimental design and conclusions

Unlike other studies dealing with the separation of animals at the feeding place, our study combined the two possible aspects of partitions, namely their length (variable effort to walk around) and material (visual contact possible or not). Furthermore, we included the new aspect of vertical separation in space, which made use of the goats' ability to jump and climb. With our approach of testing animals in dyads and allowing them to feed for a few minutes only from a small rack, we were able to compel the goat dyads which would otherwise not do so to feed simultaneously and in close proximity to one other, as well as being able to exercise close control over the goats' motivation to feed. Testing the effects of partitions and platforms on the variables chosen in this study within a group situation would have been much more difficult. Due to ad libitum feeding, these dyads would not necessarily feed simultaneously side-by-side, and their feeding motivation would therefore be different. Nevertheless, although it is reasonable to assume that separating the animals in space during feeding within a group might be generally advantageous for the goats, a further experiment with full groups is needed.

The results of the present study show that both partitions and platforms have a positive effect on the feeding and social behaviour of goats at the feeding place. Long partitions made of wood or high platforms might be especially suitable for horned goats, goats that have not grown up together (i.e. those grouped as adults), and goats with a large rank-index difference, since the positive influence of such modifications was more pronounced than that of less rigorous ones (i.e. short, wire-mesh, or low-level partitions).

For hornless goats, goats that have grown up together (i.e. those grouped as juveniles) and goats with a small rank-index difference, less rigorous modifications already exert a positive influence on feeding and social behaviour, and would seem to be more advantageous than rigorous ones. Our data show, for example, that a rigorous modification preventing goats with an amicable relationship from making visual contact might even have a negative impact on their feeding and social behaviour. It might therefore be beneficial for a group of goats in a feeding area to be able to choose between feeding places that have been modified to different extents. With such an approach, all of the goats in a herd could simultaneously satisfy their differing social needs whilst feeding.

In conclusion, the structural modifications implemented in this study should be considered in order to achieve optimised feeding-place design in goat housing. Although high platforms are similarly effective to partitions, the latter's construction might be more feasible.

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