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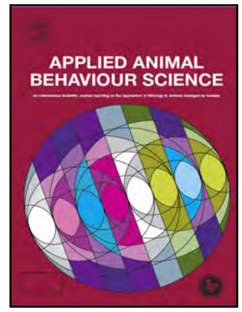

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Influence of mild feed restriction and mild reduction in dietary amino acid content on feeding behaviour of group-housed growing pigs

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Highlights

- Pigs were exposed to an *ad libitum* (AL) or a mild restricted feeding (RF) regime.
- Feeds with high (CAA) or low (LAA) indispensable amino acid (AA) contents were used.
- Feed restriction reduced feed intake, but increased the speed of eating.
- The AA reduction increased feed intake, and tended to increase the speed of eating.
- The feeding patterns were changed to accommodate for nutritional deficiencies.

Abstract

This study investigates changes in the feeding behaviour of pigs as a result of a restriction in their feed allowance and a reduction in dietary indispensable amino acid (AA) content. Ninety-six Topig Talent × PIC barrows were housed in 8 pens and individually fed either *ad libitum* (AL) or a restricted diet (RF) from 47 to 145 kg body weight (BW). The amount of feed given to RF pigs was close to their expected voluntary intake, but it was limited to proportions of 0.33, 0.66 and 1.00 of the estimated daily amount of feed in 3 time intervals, 00:01 to 8:00, 8:01 to 16:00 and 16:01 to 24:00 h, respectively. From 86 kg BW, the pigs in 4 of the pens were fed diets with conventional standardized ileal digestible AA content (CAA), while the pigs in the other pens received diets (LAA) in which the proportions of dietary indispensable AA were lowered with respect to CAA by 0.91 from 86 to 118 kg BW and by 0.82 from 118 to 145 kg BW. Automated feeders monitored individual feeding behaviour. Data were analysed by pig and feeding phase with a 2×2 factorial design. Over the whole experimental period, feed restriction resulted in a decrease in daily feed intake (7%, $P < 0.001$), the number of visits (27%, $P < 0.001$) and the time spent feeding (14%, $P < 0.001$), but an increase in feed consumption per visit (20%, $P = 0.001$) and feeding rate (10%, $P = 0.032$). The reduction in AA increased daily feed intake (7%, $P = 0.031$), tended to increase feeding rate (14%, $P = 0.07$) and interacted with feeding regime with respect to the number and duration of feeding visits. During growing and finishing, we observed high, negative, non-linear relationships between feed consumption per visit and visit frequency ($R^2 = 0.989$ to 0.876), between visit duration and visit frequency ($R^2 = 0.648$ to 0.695), and between feeding rate and time spent feeding in a day ($R^2 = 0.802$ to 0.707), and positive linear relationships between visit duration and feed consumption per visit ($R^2 = 0.614$ to 0.570). The individual feeding rate during growing was positively correlated with that during finishing ($R^2 = 0.458$). We conclude that pigs try to adapt their feeding pattern to compensate for a reduction in feed allowance or nutrient restriction by, for example, increasing their feeding rate, which may reflect increased feeding motivation.

Abbreviations

AA, amino acids; AL, *ad libitum* feeding; aNDF, neutral detergent fibre with amylase treatment and including the residual ash; BF, back fat depth; BW, body weight; CAA, conventional crude protein and amino acid diet; CP, crude protein; CV, coefficient of variation; DM, dry matter; EE, ether extract; FR, feeding regime; LAA, low-crude protein and amino acid diet; Lys, lysine; N, nitrogen; NE, net energy; RF, restricted feeding; SID, standardized ileal digestible; SD, standard deviation.

Keywords: growing pigs; feeding behaviour; feeding phase; feed restriction; dietary AA reduction

1. Introduction

Feeding behaviour may be thought of as the strategy pigs adopt to achieve their desired feed intake (Emmans and Kyriazakis, 2001) and can basically be described in terms of the number, size and duration of feeding visits to the manger (Nielsen, 1999). The feeding behaviour of individual pigs, usually measured by automated single- or multi-space feeding stations (Young and Lawrence, 1994) is influenced by the number of animals, environmental and social factors related to the feed, and the production environment (Boumans et al., 2015; Maselyne et al., 2015). Studying animal feeding behaviour allows us to identify the effects of treatments and conditions in order to predict illness, and to understand the causes of variations in feed efficiency (De Haer and De Vries, 1993) and animals' feeding motivations (Boumans et al., 2015; Maselyne et al., 2015). In the case of feed or nutrient restriction, we would expect pigs to modify their feeding behaviour to compensate for the restriction, for example by increasing feeding speed or the time spent feeding. We recently investigated the effects of mild feed restriction alone or in combination with a reduction in the dietary indispensable amino acid (AA) content on the growth performance of pigs (Schiavon et al., 2017). Feed restriction caused reductions in feed intake and average daily gain, but increased feed efficiency, whereas AA reduction increased feed intake and average daily gain but had no influence on feed efficiency. Although various studies have been carried out on the effects of feed restrictions and reductions in AA allowances on performance and carcass traits, few have looked at their influence on pig feeding behaviour. Our aim was to study the feeding behaviour of group-housed pigs fed individually from single-space feeders and subjected to feed restriction alone or in combination with a reduction in the dietary indispensable AA content.

2. Material and methods

2.1. Pigs and experimental design

Readers are referred to Schiavon et al. (2017) for details regarding the pigs and their diet, growth performance, and estimated N and energy balance. All experimental procedures were reviewed and approved by the University of Padua's Ethical Committee for the Care and Use of Experimental Animals.

Briefly, the experiment involved 96 Topigs Talent × PIC barrows of the same age, with an average body weight of 35.8 ± 2.8 kg. On arrival at the farm, the pigs were allotted to 8 pens (5.8 m × 3.8 m) at a density of 12 pigs/pen and were subjected to an acclimation period until about 47 kg BW. Each pen was equipped with an automated feeding station (Compident Pig – MLP, Schauer Agrotronic, Austria). From 47 to 145 kg BW, 6 pigs in each pen were fed *ad libitum* (AL), while the others were placed on the restricted feeding regime (RF). The RF allowance was established on a weekly basis in accordance with the feeding guidelines for TOPIGS Talent barrows (Topigs, 2012). Restriction was mild, with the planned feed allowances close to the expected voluntary feed intake to prevent excessive feed consumption by some pigs in this group, although we set a threshold quantity of feed to be consumed during the 3 daily feeding periods. From 86 kg BW onwards, the pigs in 4 pens were given feeds with conventional indispensable AA contents (CAA) close to the requirements estimated by NRC (2012), while the others were given feeds low in indispensable AA (LAA).

2.2. Feed formulation and chemical analysis

During the growing period (47-86 kg BW), all the pigs received the same commercial feed, which had a CP content of 161 g/kg with SID lysine, methionine, threonine, and tryptophan contents of 56, 20, 37 and 10 g/kg CP, respectively. In the early (86 to 118 kg BW) and late (118 to 145 kg BW) finishing periods, the LAA feeds were formulated from the corresponding CAA feeds by replacing soybean meal with corn and wheat grain, and by adding a very small amount of crystalline AA so that the contents of the various AAs per unit of CP were similar.

During early finishing, the barrows of 4 pens were fed either a CAA diet with 158 g/kg of CP or an LAA diet with 143 g/kg of CP; both diets contained 51 g/kg CP of SID lysine, 17 of SID methionine, 34 of SID threonine and 10 of SID tryptophan. During late finishing, the CAA feed contained 155 g/kg of CP and the LAA 126 g/kg of CP, both containing 47 g/kg CP of SID lysine, 17 of SID methionine, 34 of SID threonine and 10 of SID tryptophan. The average net energy content of the various feeds, calculated according to NRC (2012), was in the order of 10.4 MJ/kg.

The CAA and LAA feeds were composed from the same batches of ingredients. Feeds were sampled as described by Schiavon et al. (2017) and analysed in triplicate for DM (# 934.01; AOAC, 2012), N (# 976.05; AOAC, 2012), EE (# 920.29; AOAC, 2012), ash (# 942.05, AOAC, 2012), and neutral detergent fibre (aNDF), including residual ash, determined with amylase treatment (Van Soest et al., 1991). Starch was determined by liquid chromatography after hydrolysis to glucose (Bouchard et al., 2005). The AA content of the feed samples (0.5 g/sample) was determined in accordance with the Council of Europe (2005; chapter ♯ 2.2.56). The chemical and nutritional characteristics of the diets are given in the supplementary material as Table S1.

2.3. Feed distribution and behaviour control

The feeding stations allowed the animals access to the feed throughout the whole day, while lateral barriers limited competition among the pigs during feeding. In each pen, 6 pigs were fed AL, and the other 6 were fed RF. The AL pigs were able to access the station and eat all day. The RF pigs had access to the station 24 h, but were allowed to eat only a portion of the feed ration for that day during specific periods of time: 0.33 from 00:01 to 08:00 h, 0.66 from 08:01 to 16:00 h and 1.00 from 16:01 to 24:00 h. When a pig visited the manger, the feeding station identified the ear transponder, opened the automatic gate placed in front of the trough and released the feed. The date and time of feeding, the time spent feeding and the weights of the feed consumed and left over were recorded. The leftovers were automatically weighed and assigned to the next pig visiting the station. Once the RF pig had consumed its ration for a given 8 h period, no further feed was provided until the next 8 h period. Since the feed was released by the station in doses of 200 g, it was possible for some RF pigs to consume more feed than their ration for that day. Nonetheless, the RF pigs always consumed less than their ration. All the pigs had free access to a nipple drinker placed in each pen. All feeding stations were calibrated at the start of the study and weekly thereafter using a 1-kg test weight.

2.4. Data editing

The dataset consisted of 107 249 records reporting animal identity code, date, entering and exiting times, and feed consumption per visit, which were collected throughout the experiment from the 8 feeding stations. The data were edited using the R software (R Development Core Team, 2011). During the experiment, 4 pigs (one pig in the AL-LAA group, two in RF-CAA, and one in RF-LAA) died or were discarded due to illness or injury and their data were removed from the database. The final dataset was compiled from 92 pigs.

The day, and not the single visit, was considered the proper temporal basis to describe the feeding behaviour traits of the pigs during growing and finishing, and thus problems of consistency due to not normal distributions of variables were partially avoided. Therefore, daily feed intake was computed as the sum of the feed consumed during all the visits in a given day by each pig. Visits to the feeding stations were counted and distinguished as feeding or sham visits, in other words, visits with or without feed consumption. Daily feeding time was calculated as the total duration of all feeding visits by a given pig in one day. The feeding rate of each pig was computed from its average feed intake per visit and the average duration of its feeding visits.

Secondarily, we also explored the within-day feeding behaviour of the pigs, but only the data regarding the finishing period were considered. In this case the temporal basis for the calculation of the various feeding behavioural traits, i.e. feed intake, number of feeding visits, time spent feeding, and feeding rate, was the within day time-interval.

2.5. *Statistical analysis*

Feeding behaviour data computed on daily basis were averaged by pig and by period, i.e. growing, finishing and overall, and each trait was analysed for deviation from normality. Descriptive statistics analyses were carried out with SAS software (SAS Inst. Inc., Cary, NC). The MIXED procedure of SAS was used to analyse the daily-based feeding behavioural traits according to the following linear model:

$$y_{ijkl} = \mu + FR_i + AA_j + FR \times AA_{ij} + pen(AA)_{k:i} + e_{ijkl};$$

where y_{ijkl} is the observed trait, μ is the overall intercept of the model, FR_i is the fixed effect of the i_{th} feeding regime (I = 1, 2), AA_j is the fixed effect of the j_{th} kind of feed with differing amino acid contents (j = 1, 2), $pen_{k:j}$ is the random effect of the $k{:}j_{th}$ pen (k = 1, …, 8) within AA, FR × AA is the effect of the interaction between feeding regime and type of feed, and e_{ijkl} is the random residual. Pen within AA and residuals were independently and normally distributed with a mean of zero and variances of σ_k^2 and σ_e^2, respectively. In accordance with the experimental design, the effect of AA was tested using pen within AA as the error line, where the effect of FR was tested on the residual (animal), given that each pen housed pigs of both FRs. Those variables that did not have a normal distribution, such as the numbers of feeding and sham visits, were log transformed. Because the experimental design was balanced, only one standard error of the least-squares means (SEM) is reported for each source of variation. The growing and the finishing periods were analysed separately as during the growing only the feed restriction, and not the amino acid restriction, was applied. The same model was used to analyse the feeding behavioural data computed on the within–day time interval basis, for the finishing period only.

The individual means obtained for the following pairs of variables, number of visits (x_i) vs. feed intake per visit (y_i), or the number of visits (x_i) vs. visit duration (y_i), or daily feeding time (x_i) vs. feeding rate (y_i), were plotted against each other to reveal mutual relationships, separately for the growing and finishing periods. For each of these comparisons the products $x_i \times y_i$ were computed with a spreadsheet. These values were averaged, and the resulting mean value "a" was used to compute a third variable "z_i" as a/x_i. The resulting z_i values of the isoline, representing all the combinations of x_i and z_i in the theoretical case of no influence of the dietary treatments, were plotted in each graph. The proportion of the y variance explained by each isoline (R^2) was computed.

Lastly, the R^2 of the linear relationship between visit duration and feed intake per visit was computed.

3. Results

3.1. Descriptive statistics of feeding behaviour

Average feed intake was 2409 g/d with a coefficient of variation (CV) of 8.22 % during the growing stage, and 2730 g/d with a CV of 13.02% during finishing (Table 1). The pigs spent just over 60 minutes per day feeding at the growing stage and just under 60 minutes during finishing, with CVs ranging from 18.3 to 21.2%. The average number of individual feeding visits per day was 8.25 during growing and 7.06 during finishing, while the average number of sham visits per day was 1.13 at growing and 1.34 at finishing. The CVs for these traits ranged from 35 to 144%, but the kurtosis and skewness values showed that the frequencies did not have a normal distribution. The number of feeding visits decreased from 5.90 to 4.28 with advancing stage of growth, with CVs for this trait ranging from 29.8 to 38.0%.

The average amount of feed consumed per feeding visit increased from 299 to 377 g with advancing growth, CVs ranging from 29.5 to 35.5%. The average individual feeding visit duration was 7.3 minutes over the entire trial, CV in the order of 30%. The average individual speed of feeding increased from 39 to 53 g/min with advancing stage of growth, CVs ranging from 18.5 to 27.9%.

The within-pig standard deviations for the various feeding behaviour traits were similar in magnitude to the among-pigs SDs; while those during growing were weakly correlated with those during finishing (data not shown).

3.2. Relationships among feeding behaviour traits.

The average individual feed intakes per visit during growing and finishing were highly negatively related (R^2 = 0.989 and 0.876, respectively) to the number of feeding visits (Figure 1a,b). The curved isolines denote all the combinations of feeding visits and feed intakes per feeding visit, resulting in mean daily feed intakes of 2409 g/d during growing and 2730 g/d during finishing. These curves explained large proportions of the total variance of feed intake per feeding visit. Similarly, the mean individual duration of feeding visits was negatively and non-linearly related to the number of feeding visits, and the proportion of variance explained by the isolines ranged from 0.648 to 0.695 (Figure 1c,d). Consequently, the mean individual feed intake per visit was positively (and linearly) related to the average duration of the feeding visits (Figure 2a,b), and the strength of the relationships decreased from growing (R^2 = 0.614) to finishing (R^2 = 0.570). The slopes of these regressions, which represent the average rates of feeding in the two periods, were 37.7 g/min during growing and 48.9 g/min during finishing.

There were also high, non-linear negative relationships between the average individual feeding rate and the time spent feeding (Figure 3a,b). The isolines, representing all the combinations between the y and the x axes, which revealed daily feed intake to be 2409 min/d during growing and 2730 min/d during finishing, absorbed a large part of the total variance in the feeding rate.

Finally, a linear relationship between the average individual feeding rates during growing and finishing. The overall relationship had a value of $R^2 = 0.45$ (data not shown). However, the strength of these relationships was greater for the two groups of pigs fed AL (R^2 ranging from 0.625 to 0.682) than for the pigs fed restrictively (R^2 ranging from 0.386 to 0.304).

3.3. Influence of dietary variations on feeding behaviour during growing and finishing

The RF diet had many significant effects on the pigs' feeding behaviour (Table 2). It resulted in a 7% reduction in feed intake, a 14% reduction in the time spent feeding per day, halved the number of sham visits, and reduced by 27% the number of feeding visits. It also caused a 20% increase in the amount of feed consumed per feeding visit, a 10 % increase in feed intake per visit, and a 10% increase in the rate of feeding.

Reducing the dietary AA content only during the finishing period resulted in a 7.4% increase in feed intake, along with a tendency to shorten the visit duration by 14% ($P = 0.09$) and a corresponding 14% increase in the speed of feeding ($P = 0.07$). The effects of this dietary reduction on the various feeding behaviour traits were often non- significant. However, during finishing there was a tendency towards an FR×AA interaction with respect to the number of feeding visits ($P = 0.07$), as the LAA diet increased the number of feeding visits under AL conditions by 35%, compared with an 8% decrease under RF conditions. The FR×AA interaction, therefore, also tended to influence the mean quantity of feed consumed per feeding visit ($P = 0.09$), which was 7.5% lower under dietary AA reduction and AL conditions, compared with an increase of 14.4% under AA reduction and RF conditions.

During the finishing period (Table 3), feed restriction increased feed intake by 41% during the first part of the day, and lowered it by 23% during the middle part and by 15% during the last part of the day. During the first 8 h of the day, feed restriction increased the time spent feeding (by 23%), the feed intake per feeding visit (by 35%) and the feeding rate (by 16%), but not the number of feeding visits. During the rest of the day, on the other hand, feed restriction caused a reduction in the time spent feeding and the number of feeding visits, but some increase in the feeding rate, so that there was a weak or no influence on feed intake per feeding visit.

The reduction in dietary AA content during the finishing period had little influence on feeding behaviour during the various daily time intervals. The most important change was that the feeding rate increased by about 14% in all three time intervals, and the FR×AA interaction was sometimes significant for the number of feeding visits.

4. Discussion

4.1. General pattern

The magnitude and trends of the results regarding feeding behaviour are in general agreement with those reported in previous studies conducted with group-housed pigs fed individually from single-spaced automated feed dispensers (De Haer, 1992; Young and Lawrence, 1994).

In the present experiment, feeding activity was predominantly diurnal. The proportions of feed consumed during the 0.01-8.00, 8.01-16.00, and 16.01-24.00 periods were 0.19, 0.42 and 0.39 of total daily intake, respectively, reflecting the influence of the circadian rhythm (Andretta et al., 2016). On average, each pig spent 57.8 min/d feeding, so that the mean individual daily occupation of the feeder was in the order of 0.48 (57.8 min/60 min × 12 pigs/24 h). However, taking the circadian distribution into account, average feeder occupancies were 0.36, 0.60, and 0.49 during the three consecutive daily time intervals, respectively.

4.2. Individual feeding behaviour

Few studies have reported data on the feeding behaviour of individual pigs. In the present experiment, feeding behaviour varied greatly, among and within animals. The individual mean number of feeding visits, feed intakes per visit and visit durations are the major factors influencing flexibility in feeding behaviour patterns and we found negative relationships between them. Variation in the actual or desired feed intake could, therefore, be achieved by a combination of modifications, even small ones, to these three variables. The within-animal standard deviation for the various traits confirms the existence of strict relationships between behavioural traits, as the pigs with high variation for one trait tended also to have high variation for the other traits. As previously noticed by Nielsen et al. (1995), the average individual feeding rate was negatively and non-linearly related to the time spent feeding, although this result might be an artefact of the calculation method as the feeding rate was calculated from feed intake per visit and visit duration. Nonetheless, there was a good correlation between the individual feeding rates of the pigs at growing and at finishing. This supports the view that feeding rate might be an intrinsic characteristic of the pig and its previous feeding experience, for example, its feeding motivation, since faster rates would suggest greater feeding motivation (Nielsen, 1999; Colpoys et al., 2016). Labroue et al. (1997) found that among the feeding behaviour criteria of Large White growing pigs, the rate of feed intake had a high genetic correlation with daily feed intake (around 0.5) and average daily gain (around 0.4), while Young and Lawrence (1994) found an increase in the feeding rate and number of visits, and a consequent decrease in consumption per visit, when there was high competition among the animals. In our experiment, the strongest correlation between feeding rate at growing and at finishing was found with the pigs fed AL, the weakest by the pigs fed restrictively. This suggests that the feed restriction interfered with feeding motivation and altered the pigs' feeding patterns. Nielsen (1999) provided evidence to suggest that a period of environmental constraint may have long term consequences on feeding rate due to the increased feeding rate of pigs previously subjected to feed restriction.

4.3. Influence of feed restriction on feeding patterns

Most studies on the feeding behaviour of pigs have been carried out under *ad libitum* conditions, so there is very little literature on the effects of feed restriction on feeding patterns (Maselyne et al., 2015). In the present study, feed restriction altered the feeding pattern, in that there was a reduction in the number and duration of feeding visits, but an increase in feed intake per visit and feeding rate.

Feed restriction also resulted in increased consumption during the night, with a consequent reduction in intake during the rest of the day. The magnitude and trend of these results are in agreement with previous studies showing the flexibility of pigs in being able to modify their feeding patterns when under limiting conditions. In Nielsen et al.'s (1995) study, pigs kept in groups of 20 per pen made fewer visits to the trough but increased their feed intake per visit and feeding rate compared with pigs raised in smaller groups. Bornett et al. (2000a,b) found similar changes in feeding behaviour when individually-housed pigs were switched from AL conditions to a regime restricting the amount of time they had access to the trough, or were switched from individual to group housings. In our experiment, the RF pigs' feed allowance was almost identical to the average actual feed consumption of the AL-CAA fed pigs (2620 g/d). The RF-CAA pigs consumed about 6.4% less feed than their allowance, and the actual feed consumption of the RF-LAA pigs was only 2% less than the planned feed amounts (data not shown). This would suggest that the RF pigs were reluctant to consume feed during the night, generally preferring to maintain their feed intake during the diurnal period through a better combination of visit frequency, feeding rate and time spent per visit (De Haer, 1992; Young and Lawrence, 1994; Andretta el al., 2016), but the inadequate nutrient provision forced them to increase their feed consumption during the night.

However, in the present study the feed restriction was mild and close to the expected voluntary feed intake as we wanted to prevent excessive feed consumption by some pigs in the group. The pigs on restricted feed did not consume more than the established threshold throughout the growing and finishing periods. This regime caused a reduction in feed intake and growth rate, but an increase in average feed efficiency (2%) and carcass leanness (2%), as reported in detail by Schiavon et al (2017). The observed 10% increase in feeding speed may reflect an increase in the feeding motivation of those RF pigs that were more severely underfed in comparison with their desired feed intake. That restricted feeding of pigs alters their feeding motivation is also suggested by the greater CV in the feeding rate of the RF-fed pigs (11.8%) compared with AL-fed pigs (8.5%). The lower correlation between the feeding rates of growing and finishing RF pigs (R^2=0.304-0.386) compared with that of *ad libitum* fed pigs (R^2 = 0.625-0.682) is also indicative of the effect of feed restriction on the pigs' feeding motivation.

4.4. *Influence of dietary amino acid reduction on feed intake and feeding behaviour*

Short- and long-term regulation of feed intake is under physiological control, although the underlying mechanisms are not fully understood (Nyachoti et al., 2004). A useful working hypothesis is that feed intake reflects the pig's desire for nutrients and may be constrained by animal, diet and environmental factors (Whittemore et al., 2001). Conceptually, "this implies that pigs eat because they desire to grow, not that pigs grow because they eat" (Nyachoti et al., 2004). Numerous studies have shown the effects of dietary energy concentration and AA level on pigs' voluntary feed intake (Li and Patience, 2016). It is commonly accepted that a reduction in dietary net energy (NE) content leads to an increase in feed intake to keep the NE intake constant (Cámara et al., 2016), although the influence of nutrient deficiencies, particularly of indispensable AA, is controversial. Some authors found that voluntary feed intake decreased when pigs were placed on diets that were deficient in protein or indispensable AA (Gallo et al., 2015; Schiavon et al., 2015; Suárez-Belloch et al., 2015), especially tryptophan (Henry et al., 1992;). Other studies found that mild deficiencies in protein, lysine or threonine resulted in increased feed intake (Ferguson and Gous, 1997; Henry, 1995; Chiba et al., 2002). Moreover, Kyriazakis et al. (1991) showed that pigs were able to control their protein intake when they had free access to feeds with differing protein contents. In this regard, reduced levels of tryptophan in the diet increased the feeding activities of pigs under AL conditions (Dalcin Castilha et al., 2016), and a similar effect was observed by Jensen et al. (1993) as a consequence of dietary CP restriction. However, Andretta et al. (2016) found that dietary crude protein and SID lysine contents had no correlation with various feeding behavior variables, and Montgomery et al. (1978) found total feed intake and feeding rate decreased when dietary tryptophan was reduced. Some of the above inconsistencies may be explained by assuming that a pig always tries to eat enough to meet its nutrient requirements, but may be hampered by social and environmental factors related to diet, climate, disease or housing (Black, 2009; Emmans, 1988; Ferguson et al., 2000).

In the present experiment, reduction in the dietary indispensable AA content during finishing increased feed intake, body weight at slaughter, and carcass weight and fat content (Schiavon et al., 2017). The feeding pattern of pigs was altered, and the most evident effect, though only in terms of a tendency, was an increase in the feeding rate in both feeding regimes. This supports Nielsen's (1999) suggestion that the feeding rate may be considered an index that reflects the pig's feeding motivation. This might be useful in identifying sub-optimal dietary nutrient allowances, even in conditions where there can be no compensatory increase in daily feed intake because this is constrained.

5. Conclusion

We conclude that pigs try to adapt their feeding pattern to compensate for a reduced feed allowance or nutrient restriction, for example by increasing their feeding rate, which may reflect the pigs' increased feeding motivation. However, the results of present experiment show that a change of feeding rate is not the only strategy that pigs adopt to reach their desired feed intake. Depending on the context, they may also modify the number of visits and the time spent feeding per visit, so we can expect considerable variation in feeding patterns among individual pigs and across experiments. This suggests we should be cautious in generalising the results obtained across experimental conditions, or even individuals.

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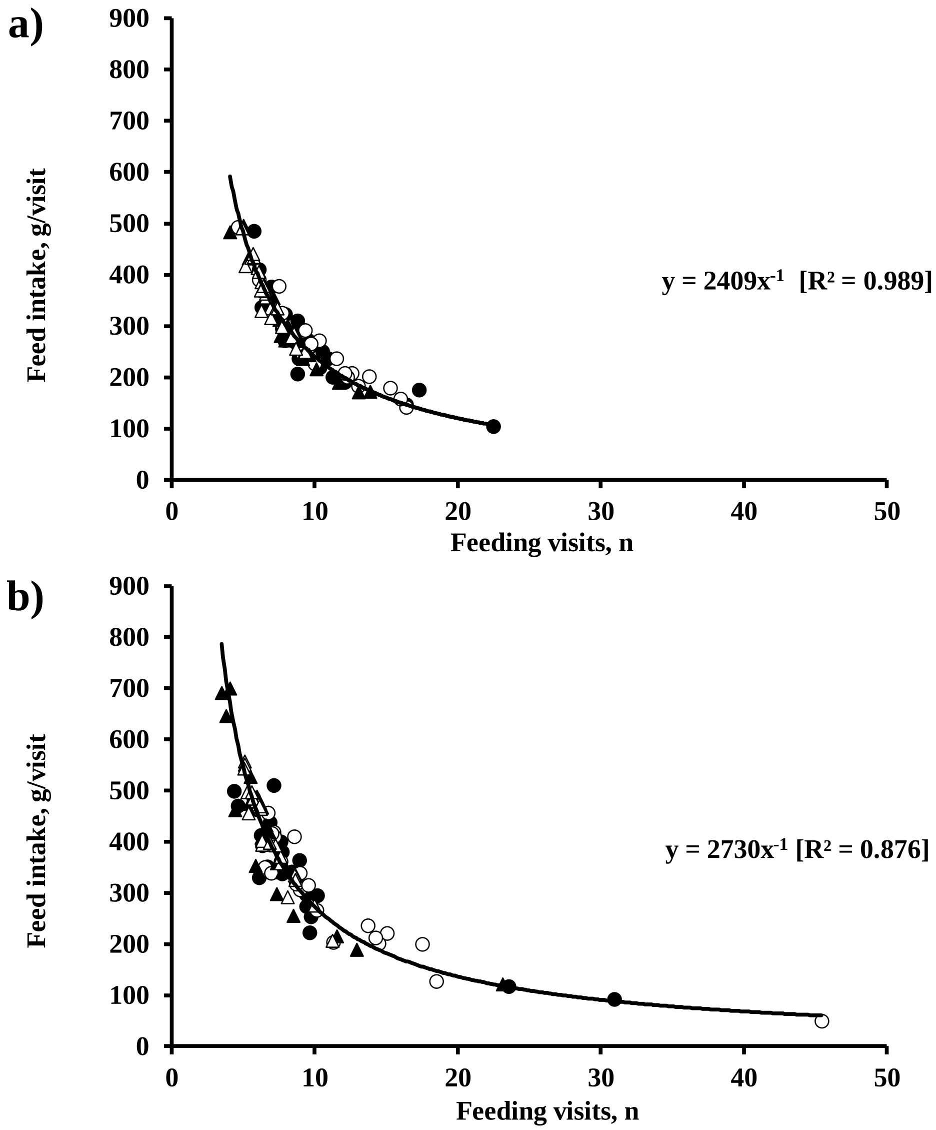
Figure 1. Relationships of feeding visits with feed intake per visit or occupation time per visit of pigs fed, *ad libitum* or restrictively, conventional (CAA) or low (LAA) amino acids feed, during growing (a, c), and finishing (b, d). The isolines denote all combinations of feeding visits and feed intake per visit resulting in 2409 and 2730 g/d mean daily feed intake and all combinations of feeding visits and occupation time per visit resulting in 64.0 and 54.6 min/d mean daily feeding times, during growing and finishing, respectively [each single point represents a pig, n = 92].



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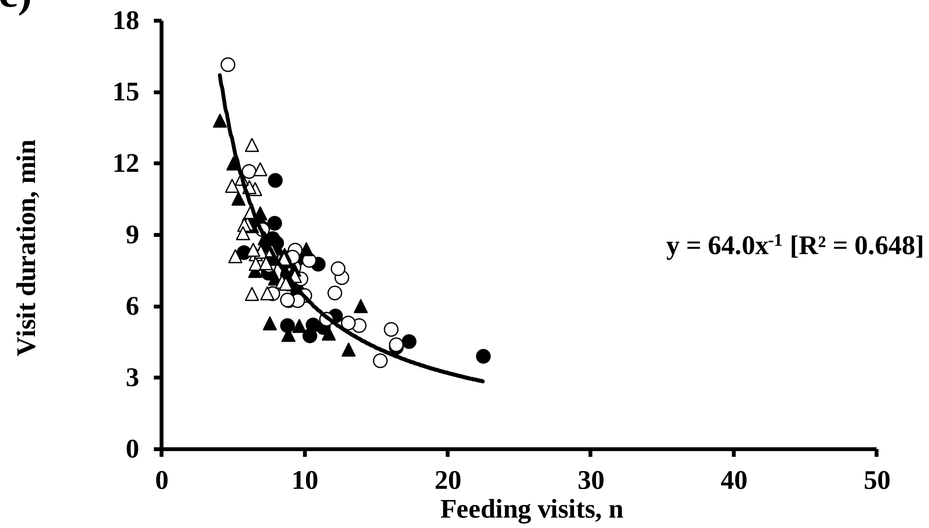

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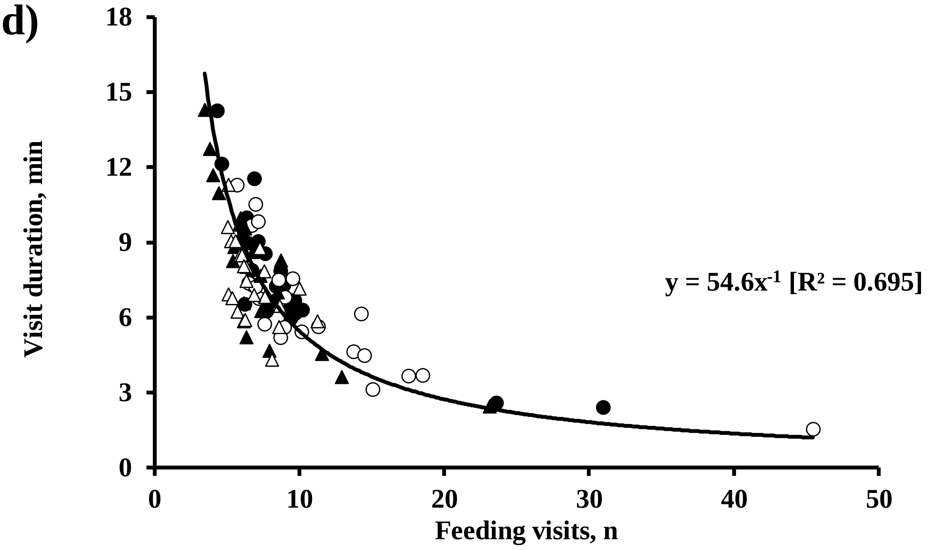

Ad libitum CAA● Ad libitum LAA○ Restricted CAA▲ Restricted LAA △

Figure 2. Relationship between individual visit duration and feed intake per visit of pigs fed *ad libitum* or restrictively, conventional (CAA) or low (LAA) amino acids feed, during a growing (a), and a finishing (b) periods [each single point represents a pig, n = 92].

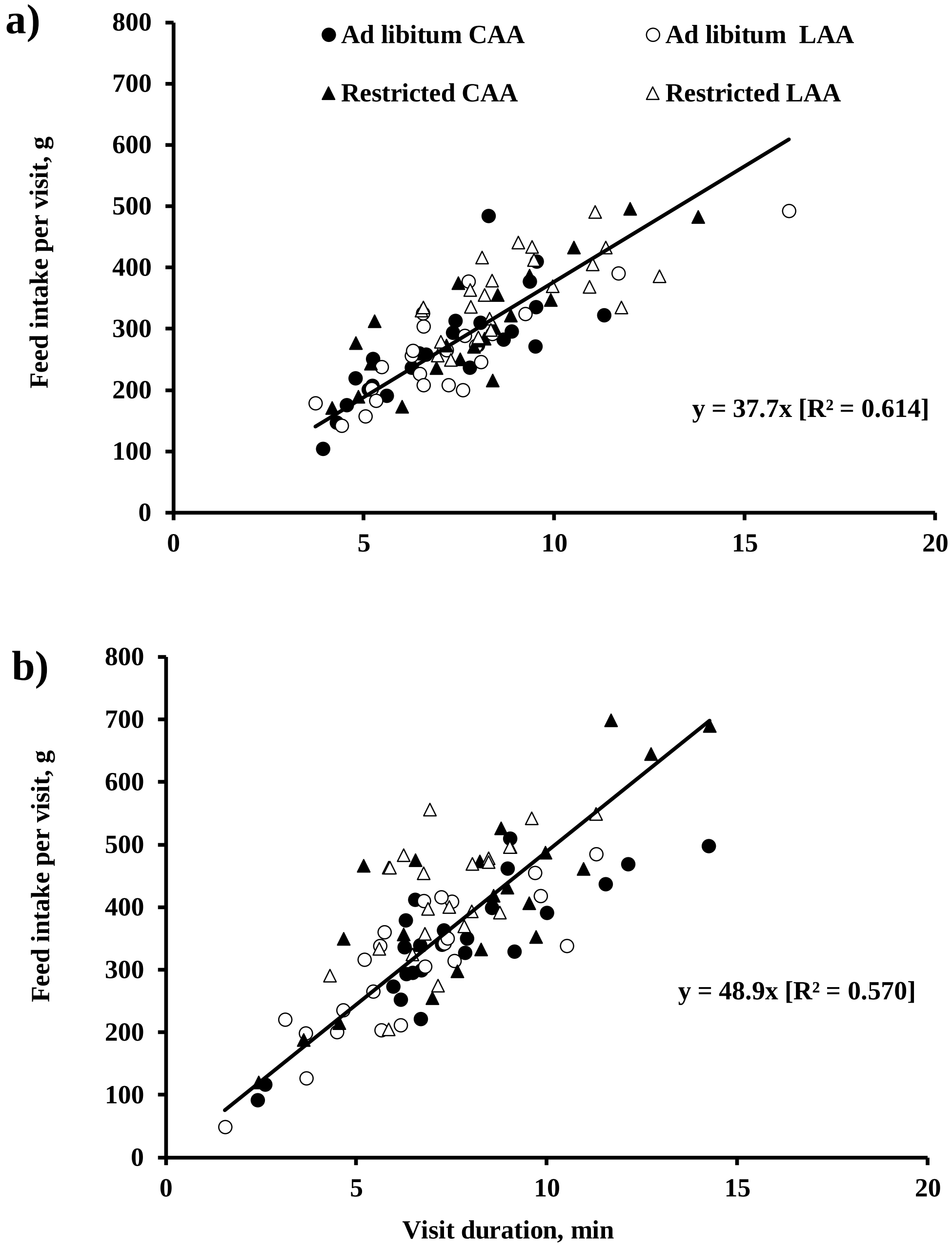

Figure 3. Relationship between individual daily feeding time and feeding rate of pigs fed, *ad libitum* or restrictively, conventional (CAA) or low (LAA) amino acids feed, during a growing (a) and a finishing (b) period. The isolines denote all combinations of daily feeding time and feeding rate which result in the actual mean daily intakes of 2409 and 2730 g/d for growing and finishing, respectively [each single point represents a pig, n = 92].

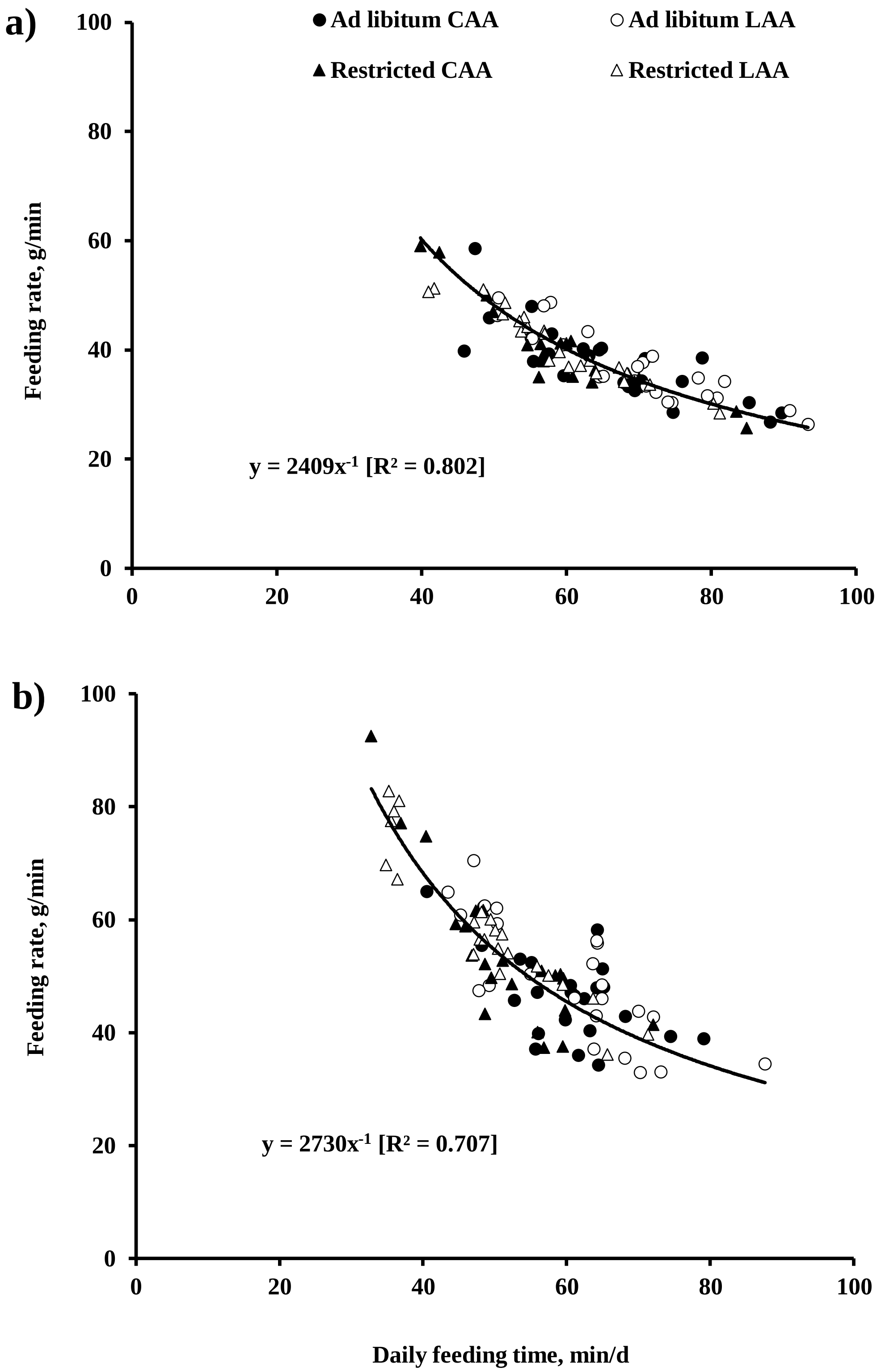

Table 1. Statistical descriptive of growth performance and behavioral traits[1].

	Mean	Median	SD	CV	Min	Max	kurtosis	skewness
Feed intake								
growing (47 -86 kg BW)	2409	2405	198	8.22	1825	3041	0.987	0.265
finishing (86-145 kg BW)	2730	2749	356	13.02	1750	3623	0.672	-0.183
Overall	2621	2633	255	9.74	1966	3427	0.938	0.095
Feeding time, min/d								
growing (47 -86 kg BW)	64.0	63.2	11.84	18.5	39.8	93.3	-0.231	0.3245
finishing (86-145 kg BW)	54.6	54.6	11.56	21.2	29.2	83.5	-0.233	-0.007
Overall	57.8	57.5	10.60	18.3	32.8	86.9	-0.134	0.033
Sham visits, n								
growing (47 -86 kg BW)	1.13	0.50	1.62	144	0.00	10.0	12.59	3.124
finishing (86-145 kg BW)	1.34	1.01	1.35	101	0.00	7.13	3.565	1.726
Overall	1.27	0.88	1.13	89.2	0.00	4.75	1.253	1.156
Feeding visit, n								
growing (47 -86 kg BW)	8.87	8.25	3.16	35.6	4.07	22.5	3.410	1.554
finishing (86-145 kg BW)	8.80	7.06	5.80	65.9	3.77	47.0	20.638	3.839
Overall	8.83	7.56	4.40	49.9	4.18	35.3	15.041	3.266
Feed intake per feeding visit, g								
growing (47-86 kg BW)	299	288	88.0	29.5	105	496	-0.333	0.316
finishing (86-145 kg BW)	378	384	134	35.5	53.0	612	-0.674	-0.364
Overall	338	337	102	30.3	71.9	536	-0.412	-0.313
Feeding visit duration, min								
growing (47-86 kg BW)	7.81	7.79	2.29	29.4	3.72	16.2	1.208	0.758
finishing (86-145 kg BW)	7.36	7.20	2.59	35.2	1.33	14.7	-0.028	0.150
Overall	7.32	7.21	2.18	29.7	2.04	13.6	0.054	0.111
Feeding rate, g/min								
growing (47-86 kg BW)	38.8	38.0	7.15	18.5	25.7	59.1	0.671	0.375
finishing (86-145 kg BW)	52.5	51.8	14.8	27.9	26.8	100.7	0.856	1.033
Overall	46.9	45.7	10.42	22.2	29.6	83.6	0.854	0.768

[1] Data were computed from the means of 92 pigs (n=92).

Table 2. Feeding behaviour of pigs over growing[1], finishing[1] and overall period as influenced by the feeding regime [FR, *ad libitum* (AL-) or restricted (RF-)], and by the indispensable amino acid content of the diets [AA, conventional (CAA) or low (LAA) contents][2].

	Feeding treatment					P values[3]		
	AL- CAA	AL-LAA	RF -CAA	RF-LAA	SEM	FR	AA	FR×AA
Feed intake, kg/d								
growing (47 -86 kg BW)	2.429	2.513	2.329	2.361	0.052	< 0.001	0.41	0.48
finishing (86-145 kg BW)	2.719	2.962	2.541	2.689	0.069	0.002	0.031	0.49
Overall	2.620	2.810	2.470	2.579	0.048	< 0.001	0.020	0.40
Feeding time, min/d								
growing (47 -86 kg BW)	65.7	69.6	61.1	59.4	2.37	0.003	0.66	0.24
finishing (86-145 kg BW)	59.4	59.3	52.2	47.4	2.20	<0.001	0.31	0.29
Overall	61.6	62.8	55.2	51.5	2.02	<0.001	0.56	0.22
Sham visits[2], n								
growing (47 -86 kg BW)	2.00	0.92	1.15	0.33	0.49	0.002	0.16	0.81
finishing (86-145 kg BW)	2.06	1.58	0.89	0.75	0.32	<0.001	0.26	0.47
Overall	2.04	1.35	0.98	0.60	0.29	<0.001	0.15	0.80
Feeding visits[2], n								
growing (47 -86 kg BW)	9.96	10.40	8.31	6.74	0.74	<0.001	0.48	0.043
finishing (86-145 kg BW)	8.66	11.71	7.68	7.08	1.29	0.001	0.45	0.07
Overall	9.10	11.27	7.89	6.96	0.95	<0.001	0.74	0.043
Feed intake per feeding visit, g								
growing (47-86 kg BW)	270	264	304	360	19.6	<0.001	0.31	0.06
finishing (86-145 kg BW)	369	324	389	433	32.9	0.016	1.00	0.09
Overall	320	296	346	396	26.5	0.001	0.70	0.06
Feeding visit duration, min								
growing (47-86 kg BW)	7.16	7.26	7.89	8.97	0.51	0.009	0.33	0.29
finishing (86-145 kg BW)	8.00	6.34	7.89	7.24	0.61	0.45	0.14	0.33
Overall	7.45	6.49	7.69	7.71	0.53	0.10	0.47	0.26
Feeding rate, g/min								
growing (47-86 kg BW)	37.9	37.1	39.3	40.8	1.49	0.09	0.85	0.43
finishing (86-145 kg BW)	46.7	51.5	51.9	60.8	2.99	0.016	0.07	0.50
Overall	43.5	46.0	46.6	52.1	2.12	0.032	0.11	0.49

[1] During the growing period all pigs received feeds with the same amino acids content, so that a P-value > 0.05 was expected for the AA treatment. In the finishing period pigs were subjected to different FR and fed diets with different amino acid content.

[2] Data were computed from the means of 92 pigs (n=92).

[3] *P*-values computed on logarithm transformed values.

Table 3. The within-day feeding behaviour of pigs during finishing as influenced by the feeding regime [FR, *ad libitum* (AL-) or restricted (RF-)] and by the dietary indispensable amino acid contents [AA, conventional (CAA) or low (LAA) contents]. [1]

	Feeding treatment						P values[2]		
	AL- CAA	AL-LAA	RF-CAA	RF-LAA	SEM		FR	AA	FR×AA
Feed intake, kg/d									
00:00-08:00 h	509	573	718	809	45.7		<0.001	0.14	0.77
08:01-16:00 h	1161	1336	953	972	49.2		<0.001	0.10	0.12
16:01-23:59 h	1047	1046	874	909	49.1		0.002	0.75	0.71
Feeding time, min/d									
00:00-08:00 h	11.73	12.00	14.60	14.58	0.93		0.004	0.90	0.87
08:01-16:00 h	25.97	26.98	19.91	17.40	1.40		<0.001	0.61	0.21
16:01-23:59 h	21.72	20.36	17.66	15.40	1.09		<0.001	0.15	0.68
Sham visits[2], n									
00:00-08:00 h	0.42	0.33	0.21	0.15	0.07		<0.001	0.30	0.74
08:01-16:00 h	1.18	0.84	0.43	0.43	0.18		<0.001	0.31	0.20
16:01-23:59 h	0.46	0.41	0.25	0.17	0.09		0.005	0.32	0.95
Feeding visits[2], n									
00:00-08:00 h	1.78	2.37	2.12	1.89	0.26		0.96	0.22	0.11
08:01-16:00 h	4.15	5.92	3.12	3.02	0.78		<0.001	0.39	0.10
16:01-23:59 h	2.73	3.43	2.45	2.17	0.33		0.013	0.59	0.09
Feed intake per feeding visit, g									
00:00-08:00 h	342	301	399	467	33.9		0.001	0.71	0.10
08:01-16:00 h	335	296	358	390	33.1		<0.001	0.72	0.030
16:01-23:59 h	441	384	415	464	35.6		0.010	0.45	0.20
Feeding visit duration, min									
00:00-08:00 h	7.83	6.15	8.31	8.08	0.64		0.054	0.20	0.25
08:01-16:00 h	7.35	5.84	7.29	6.49	0.60		0.53	0.15	0.44
16:01-23:59 h	9.23	7.29	8.20	7.54	0.65		0.39	0.92	0.54
Feeding rate, g/min									
00:00-08:00 h	43.8	49.1	49.9	58.5	2.87		0.008	0.053	0.56
08:01-16:00 h	46.4	50.9	51.8	60.6	3.02		0.011	0.07	0.47
16:01-23:59 h	48.3	53.3	53.7	63.0	3.27		0.017	0.08	0.48

[1] Data were computed from the means of 92 pigs (n=92).
[2] *P*-values computed on log values.